12 HAZARDS TO LIFE

12.1 INTRODUCTION

This section of the EIA Study Report presents the risk assessment for the power station component of HEC's proposed Lamma Extension development.

The responsible authorities within Government for the risk assessment aspects of the project are the Gas Standards Office (GSO) and the Environmental Protection Department (EPD). The GSO is concerned with the subsea gas supply pipeline and the fuel gas facilities at the power station, while EPD deals with the hazards associated with the transport, storage and use of all other Dangerous Goods (DG) at the power station.

In respect of the fuel gas-related hazards, the objective of the risk assessment is to determine whether there are any insurmountable risk issues. GSO has advised that, as the project is only at the feasibility stage, a detailed quantitative risk assessment is not required. Therefore, only a "high level" risk assessment has been undertaken, making reference to established codes of practice and standards for gas-fired power stations and subsea gas pipelines. A detailed risk assessment will, however, be required at a later stage to demonstrate compliance with Government Risk Guidelines and a brief for this has already been issued by GSO.

In respect of the other hazards, EPD has advised that a quantitative risk assessment is required to demonstrate compliance with the Government Risk Guidelines. The scope of the risk assessment is set down in the EIA Study Brief as follows:

- identification of all hazardous scenarios associated with the transport, storage and processing of dangerous goods;
- execution of a quantitative risk assessment expressing population risks in both individual and societal terms;
- comparison of individual and societal risks with the Criteria for Evaluating Hazard to Life stipulated in *Annex 4* of the *EIAO Technical Memorandum*; and
- identification and assessment of practicable and cost-effective risk mitigation measures.

The scope for this study excludes the existing power station at Lamma, but includes all new facilities associated with the Lamma Extension, whether located on the new reclamation or not.

The risk assessments for both the fuel gas-related and other hazards are concerned with the risk of fatal injury to the public, namely any incident which could have fatal effects at the site boundary of the power station. The risk to power station workers is excluded.

12.2 *Assessment Methodology*

In this section of the EIA the risk assessments for the fuel gas and non-fuel gas hazards are reported separately. However, the potential for hazardous interactions or "domino" events is considered, including incidents which may arise at the existing HEC power station on Lamma Island.

Although the risk assessments for the fuel gas and non-fuel gas hazards are being conducted at two levels, each nevertheless follows a logical approach in:

- identifying the hazards associated with each aspect of the design/operation of the power station;
- assessing potential impacts on the public;
- assessing the likelihood of occurrence of events;
- determining the risks; and
- recommending mitigation measures.

The assessment of the fuel gas hazards is qualitative in nature, focusing on identifying any new or unusual features of this project, in relation to other similar facilities operating elsewhere. This approach recognises that the hazards associated with gas-fired power plant and subsea pipelines are generally well-understood and that safeguards exist to ensure that risks are as low as reasonably practicable.

The assessment of the non-fuel gas hazards is quantitative in nature (as far as is needed) and addresses all hazards at the power station (other than those associated with the fuel gas facilities) where fatal injury to the public could arise.

It should be noted that, at the time of writing this report, the design of the power station is at an early stage with only preliminary design information being available.

12.3 *Detailed Description of the Project*

12.3.1 *Site Location and Layout*

The proposed gas-fired power station will be located on an area of new reclamation to the south of the existing Lamma power station on the western coast of Lamma island. The location of the site is shown in *Figure 12.3a*.

Six 300 MW gas-fired combined cycle units will be constructed on the Lamma Extension. The layout of the gas-fired power station (see *Figure 12.3b*) will comprise:

- power block units, including gas turbines, heat recovery steam generators (HRSGs), steam turbines, generators, pipe racks and chimneys;
- a gas receiving station (see Process Flow Diagram, *Annex D7-2);*
- construction site/laydown areas; and

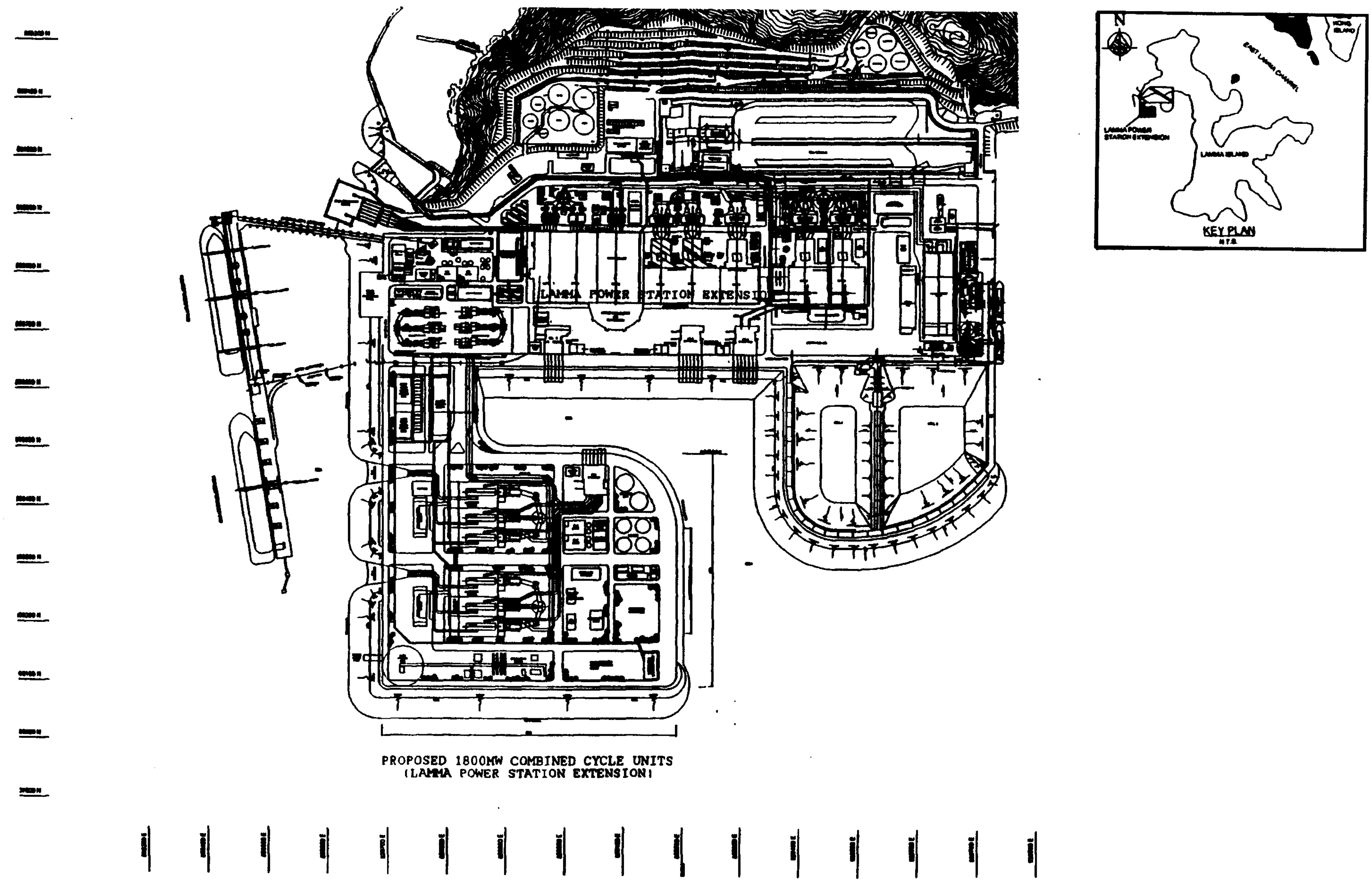


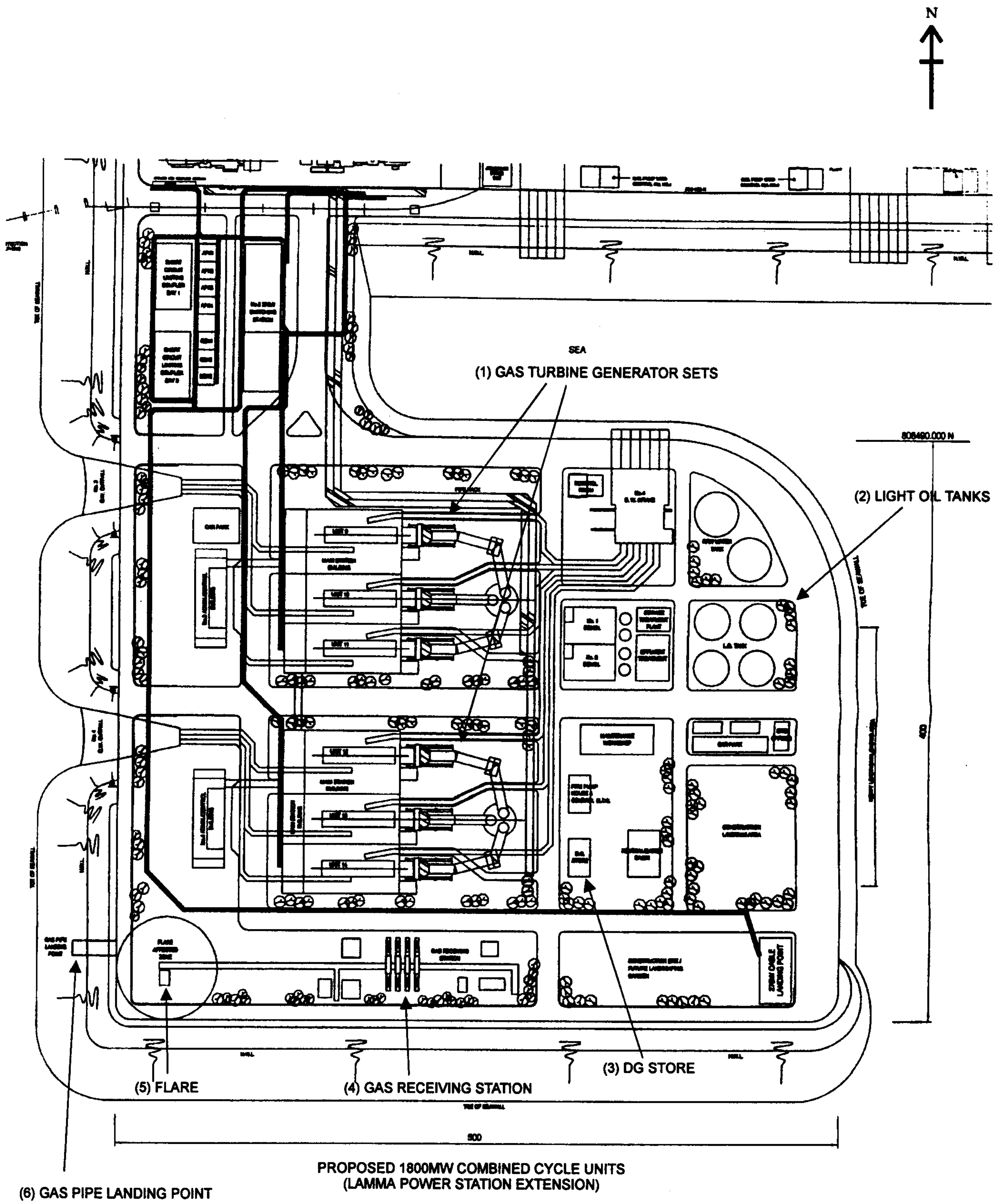
FIGURE 12.3a

LAMMA POWER STATION AND PROPOSED EXTENSION

FILE: C1830/C1830o
DATE: 07/12/98

Environmental Resources Management

ERM



PROPOSED 1800MW COMBINED CYCLE UNITS
(LAMMA POWER STATION EXTENSION)

FIGURE 12.3b

LAYOUT OF LAMMA POWER STATION EXTENSION

FILE: C1830/C1830o1
DATE: 07/12/98

Environmental
Resources
Management

ERM

- ancillary facilities including the sewage and effluent treatment plants, liquid fuel storage tanks, raw water tanks, cooling water facilities, administration and control buildings, a DG store, maintenance facilities, a flare stack and a switching station.

The nearest residential population on Lamma is over 900 m away to the north-east of the Lamma Extension site, although there is a typhoon shelter about 600 m to the north. A bathing beach also lies about 1 km to the northeast of the new reclamation area and it is assumed that there would be regular traffic of small boats around the south of the reclamation area.

12.3.2 *Station Operation*

Gas from a receiving station will be combusted in the gas turbine, which in turn will drive a generator to produce electricity. The waste heat energy from the hot exhaust gases discharged from the gas turbine will be utilised by passing these gases through a HRSG to produce steam for driving a steam turbine for secondary electricity generation. The exhaust gas will then be discharged to the atmosphere through the stack. A once-through cooling water system will be adopted to condense steam exhaust from the steam turbine. Sea water will be extracted from the east side of the site and discharged at a higher temperature to the west side after passing through a condenser.

For receiving the natural gas from the subsea pipeline a gas receiving station is provided. This comprises three parallel trains of gas metering and pressure reduction equipment. Each train comprises a process shutdown valve, filter, pressure reduction/control valve, a check valve and an isolation valve.

The gas receiving station also incorporates an emergency blowdown and depressurising system with connections from the gas pipeline and each train of the gas metering and pressure reduction equipment. The emergency blowdown lines connect to a flare scrubber, the top outlet of which passes to the flare. A natural gas purge/pilot system is provided for the flare.

12.3.3 *Storage and Handling of Other Dangerous Goods At the Power Station*

Light Gas Oil

In line with restrictions imposed by the Environmental Protection Department on existing generating units at the Lamma Power Station, light gas oil with sulphur content of less than 0.5% and viscosity of not greater than 6 centistokes at 40°C will be used as an alternative fuel in cases of interruption of natural gas supply. A light gas oil supply system with a storage capacity of about 43,000 m^3 to cater for seven days of full oil-firing will be established.

The light gas oil (LGO) will be transported to the power station by marine vessel and will be unloaded using the existing jetty facilities, which can accommodate vessels of up to 1000 dwt. A piping system of carbon steel will be installed to transport the LGO to the storage tanks at the Lamma Extension. It is possible that a cross-connection may be made to the existing fuel oil system in order to provide an additional reserve in the event of a loss of the natural gas supply at the Lamma Extension. The capacity of the LGO storage will be 43,000 m^3 in four 25 metre diameter, 22 metre high tanks, which will cater for 7 days of operation of 1800 MW units.

Hydrogen

Hydrogen gas is used for generator cooling which circulates within a sealed system. Make-up hydrogen for the new generators will be supplied from the hydrogen cylinder pallet store at the existing Lamma power station. No additional hydrogen store is required at the Lamma Extension and there will be no additional hydrogen storage at the existing pallet store. The hydrogen cylinder pressure is 200 bar, but this is regulated to 10 bar at the pallet store and maintained at 4 bar at the generators. Stainless steel (SUS 316) will be used for the additional piping, which will be fully welded.

DG Store

It is proposed to store various packaged DGs in a DG store at Lamma Extension. The DGs will be similar in nature and quantity to the existing power station. The DGs comprise acids, alkalis, compressed gases, solvents etc in quantities of typically a few tonnes or more. A full list of the chemicals and the anticipated storage quantities is provided in *Section 12.5* below.

Chlorine

Cooling water extracted from the sea will be used to condense steam exhaust from the steam turbine of the combined cycle unit. In line with the practise adopted in the existing Lamma Power Station, sodium hypochlorite solution will be dosed at the sea water intake to prevent the growth of marine organism in the cooling water system. The sodium hypochlorite solution will be produced through electrolysis of sea water. This is a continuous process in which sea water is passed through electrochlorinator cells and electrolysed at the anode plates to generate sodium hypochlorite for continuous chlorination of the cooling water system. There will be no storage of chlorine gas or hypochlorite solution and hence assessment of chlorine hazards is not required.

12.4 *RISK ASSESSMENT FOR POWER STATION (FUEL GAS HAZARDS)*

12.4.1 ***Hazard Identification***

The hazards which have been identified for the fuel gas facilities at the power station are outlined in the following sections.

Loss of Containment

This category of hazards concerns escapes of gas which may subsequently ignite leading to a fire or explosion. The potential causes of an accidental gas leakage include:

- mechanical failure (eg material defects, construction defects including weld defects);
- operational/maintenance error (eg failure to isolate plant prior to maintenance, or error during recovery of scraper at scraper receiver);
- external events (eg dropped object due to nearby construction activities);

- domino events (eg an explosion or fire on other parts of the Lamma Extension or at the existing power station); and

- environmental factors (eg subsidence or lightning strike).

Internal Explosion

This category of hazard concerns explosions within items of equipment which may lead to catastrophic failure of the equipment and the associated hazards of blast, projectiles and fire. The possible sources of internal explosion are as follows:

- internal explosion in flare stack due to ingress of air and subsequent ignition (eg due to contraction of the unburnt gas in the stack following flaring or system leakage);

- internal explosion in combustor of gas turbine due to incorrect start-up procedures (eg due to a fuel leak and failure to purge before attempting ignition);

- internal explosion in other parts of plant due to ingress of air (eg following maintenance) and subsequent ignition; and

- explosion within acoustic enclosure of gas turbines due to fuel leak.

From the above it is apparent that two of the important underlying causes of internal explosions are mechanical failure of equipment and operational/maintenance errors.

Explosions in gas turbine enclosures are a particular hazard identified in a recent UK HSE Interim Advice Note on Health and Safety at CCGT and CHP Plant. Acoustic enclosures have become the norm in this type of plant and this creates a hazard whereby gas leakages can accumulate and therefore present an explosion hazard. Indeed such leakages are common due to the large number of joints typically present in the gas supply pipework. The likelihood of ignition in the enclosure should be assumed to be high due to the presence of hot surfaces (which may be above the auto-ignition temperature of the gas) and other potential sources such as combustion gas backflow and static discharge.

Catastrophic Failure of Rotating Machinery

The UK HSE Interim Advice Note referred to above identifies mechanical failure of rotating machinery as a hazard for gas-fired power plant. The most common failure in traditional power plant was failure of a steam turbine blade. Gas turbines contain a much larger number of blades and have been known to suffer from blade and rotor vibration problems due to poor design or maintenance. Combined cycle gas turbine plant contain both gas and steam turbines.

12.4.2 *Consequence Modelling*

Loss of Containment

The effects of a release of gas at high pressure are likely to be severe to anyone caught within the impact zone. The size and duration of the release will depend on a number of factors including the nature of the incident, the release location, the pipework/vessel dimensions and locations of shut-off valves. When high pressure pipework fails, immediate and rapid depressurisation occurs, followed by a relatively stable flow as the supply pipeline "unpacks" and the pumping of gas into the pipeline continues. A release may be subject to immediate ignition, delayed ignition or no ignition at all. Ignition of a release will result in serious effects and may involve little opportunity to escape. People indoors may be shielded from the effects of thermal radiation, but the severity of the radiation may be sufficient to cause buildings to catch fire.

If a release of gas is not immediately ignited it will form a cloud which will disperse in the atmosphere. As it disperses it will be diluted with air and the concentration will eventually fall below the lower flammable limit. The dispersion distance depends on a variety of factors including the weather conditions, the nature of the release and the influence of obstacles and terrain.

For delayed ignition the cloud may burn as a flash fire back to the point of failure. If a release is ignited immediately it will burn as a jet flame. Delayed ignition of the cloud, in particular clouds which envelope confined or congested areas on the plant, have an associated risk of explosion. However, evidence (Lees, 1996) suggests that explosions involving natural gas releases in the open are unlikely.

Internal explosions within gas turbine enclosures are covered separately below.

Internal Explosion

Ignition of flammable atmospheres inside equipment can lead to severe damage to the equipment unless it has been specifically designed to withstand the resultant overpressure. The hazards associated with internal explosions are catastrophic failure of the equipment leading to blast, projectiles and fire. The overpressure generated by the explosion can be up to eight times the initial pressure inside the equipment depending on a number of factors including, the concentration of the flammable mixture and the paths available for relief of the explosion overpressure.

Related hazards associated with the ignition of flammable atmospheres inside equipment are:

- *detonation* (as opposed to the more usual *deflagration*), which is a considerably more destructive phenomenon, occurring under particular conditions associated with the concentration of the flammable mixture, the geometry of the equipment, the strength of the ignition source and the degree of turbulence; and

- pressure piling, which also has more serious effects, and can arise where a flammable atmosphere exists in two or more interconnected vessels.

It is unlikely that either of these phenomena will be of particular significance in this context, however they underline the hazards associated with the ignition of flammable atmospheres inside equipment.

Catastrophic Failure of Rotating Machinery

Catastrophic failure of steam turbine blades has, in the past, resulted in major injury due to the missile damage. For gas turbines the problem is likely to be significant only in respect of "aero-derivative" type turbines which have thin walls. Heavy duty industrial turbines usually have adequate wall thickness to prevent danger from this source.

12.4.3 *Risk Assessment*

Loss of Containment

Various causes of loss of integrity of high pressure gas systems including mechanical failure, operational/maintenance error, external events, domino events and environmental factors have been identified above. The underlying causes of pressure system failure are nowadays much better understood and numerous standards and codes of practice have been developed which address most of the generic issues. These standards provide essential guidance for all stages of the project lifecycle, including the design, construction, installation, testing, commissioning, operation and maintenance of pressure systems.

The relevant standards for this project are published by organisations such as the American National Standards Institute (ANSI), the American Petroleum Institute (API), the American Society of Testing and Materials (ASTM), the American Society of Mechanical Engineers (ASME), the American Gas Association (AGA), the US National Fire Protection Association (NFPA), the British Standards Institute (BSI), the UK Health and Safety Executive, the UK Institution of Gas Engineers (IGasE), the UK Institute of Petroleum, British Gas etc. These standards cover both the hardware aspects of the project (eg materials of construction, pipework design) and the software aspects (eg safety management, emergency planning etc) which are of at least equal significance in determining the overall risk from the power station. Examples of the latter type of standard are the UK HSE's *Guidance on the Safe Isolation of Plant and Equipment* (providing specific guidance on isolation requirements for intrusive maintenance of pressurised systems) and HSE's *Guidance on Successful Health and Safety Management* (which is the umbrella guidance on safety management of hazardous facilities).

Adherence to codes such as those published by these organisations should enable the Lamma Extension project to take full advantage of experience gained with similar plant already in operation elsewhere in the world. However, there will remain a number of specific issues which may need to be considered further in the detailed risk assessment for the project (*Section 1.2* above).

At the time of writing this report the preliminary design of the gas receiving station (and other gas facilities at the powers station) is in still progress. However, from discussions with the designers, it is apparent that the intention is that the gas receiving station (and the other gas facilities) will follow established practice as closely as possible.

Internal Explosion: Within Flare System

The hazard of explosions within flare systems is well known and various design solutions have been developed for countering air ingress, the ignition of flammable vapours in the flare system and the effects of explosion overpressure. These include measures such as:

- use of purge gas;
- elimination of leaks;
- monitoring of oxygen ingress;
- use of molecular seals or seal drums;
- use of flame arresters; and
- design of equipment to withstand explosion overpressure.

Flare system design is covered by the American Petroleum Institute (API) Recommended Practice (RP) 521: 1990.

Internal Explosion: Within Combustor of Gas Turbine

Explosions in combustors are a well-recognised hazard and guidance is available (eg the British Gas Burner Code) on the safe design and operation of such equipment.

Many explosions in the firing space take place during start-up when an attempt is made to light a burner. The fuel leaks and forms a flammable atmosphere in the firing space while the burner is not in operation and an explosion occurs when an attempt is made to light the burner. The most important thing is to eliminate the admission of unburnt fuel into the firing chamber. This is principally a matter achieving a positive isolation on the main fuel feed line to the burner. Usually, for gas-fired burners, double block and bleed valves should be used and for oil fuel either double block and bleed valves or slip plates should be used. In the case of oil, the configuration between the shut-off valve and burner should be such that oil does not flow from this section of the pipe to the firing space after the valve has been shut. Also, before starting up the burner the firing space should be purged with air.

Internal Explosion: Within Other Plant

This hazard arises typically following maintenance activities. The UK HSE's Oil Advisory Committee document *The Safe Isolation of Plant and Equipment* gives general guidance on the safe re-instatement of items of equipment after maintenance, namely that it should be carried out by competent staff under the Permit-to-Work system.

Internal Explosion: Within Gas Turbine Enclosure

The hazard of a gas leakage followed by an explosion has arisen from the requirement to provide enclosures for the gas turbines for environmental reasons. Various standards have been developed to cover the safe design of the enclosures including those by the NFPA, API, ANSI, British Gas and the IP. These standards refer to various requirements, including measures to minimise the chance of a fuel leakage (eg by minimising the number of joints), provision of adequate ventilation of the enclosure, gas detection and explosion relief.

The recent UK HSE *Advice Note on Health and Safety at CCGT and CHP Plant* addresses the issue of explosion gas turbine enclosures at some length. This Advice Note refers to evidence that, despite provision of dilution ventilation systems for gas turbine enclosures, many such systems have been found to be inadequate (providing poor air distribution). Furthermore, ventilation rates are sometimes so high as to preclude the effective operation of the gas detection system. This creates a situation, therefore, in which gas could accumulate in "dead" spaces in the enclosure but the plant operators would be unaware of any danger.

To counter the above deficiencies HSE suggests the following approach:

- avoid the need for acoustic enclosures, wherever reasonably practicable (eg by installation within acoustically-sealed turbine halls);
- implement a Permit-to-Work system for any entry into an acoustic enclosure;
- provide safe systems of work for investigation of fuel leaks within the enclosure (recognising that typical plant designs make off-load pressure testing or use of tracer gases difficult);
- ensure adequate dilution ventilation, through competent design and verification by techniques such as smoke testing, air flow measurement, and use of Computational Fluid Dynamics (CFD);
- minimise the chance of a fuel leak through minimisation of the number of joints, adherence to relevant standards for pipework, provision of fuel safety shut-off and vent valves with valve proving systems;
- provide explosion relief/suppression systems where dilution ventilation is inadequate; and
- conduct an engineering risk assessment to verify that the chosen means of control are effective.

For the Lamma Extension project it is likely that HEC will follow CLP's Black Point Power Station with regard to the design of the acoustic enclosures for the gas turbines.

12.5 *Risk Assessment For Power Station (Non-Fuel Gas Hazards)*

12.5.1 *Introduction*

The non-fuel gas DGs at the power station comprise light gas oil (the alternate fuel), hydrogen gas (used for generator cooling) and various packaged DGs stored at the DG store on the Lamma Extension.

12.5.2 *Hazard Identification*

General

The hazard identification exercise for the non-fuel gas hazards at the power station comprises:

- a high level Hazard and Operability (HAZOP) study for the light gas oil system and hydrogen system;
- a review of past incidents involving bulk fuel oil storage and handling; and
- a review of the hazards associated with the various packaged DG in the new DG store.

The results of the hazard identification exercise for each of the non-fuel gas DGs is presented below.

Light Gas Oil System: Overview of Hazards

Light gas oil is a petroleum product, similar in nature to diesel oil with a carbon chain length in the range C_{13}- C_{17}. The hazardous properties of LGO are summarised in *Table 12.5a* below.

Table 12.5a ***Hazardous Properties of Light Gas Oil***

Property	Value
Flash point	43°C
Autoignition temperature	257°C
Flammable limits (v/v)	1.3 (lower) 5 (upper)
Normal boiling point	127°C
Liquid specific gravity	0.84

Light Gas Oil System: HAZOP Study

A high level HAZOP study of the light gas oil system for the Lamma Extension was carried out (*Annex D7-3*) to provide a systematic identification of the hazards associated with transport, storage and handling of LGO. The focus of this study was on possible causes of fire and/or explosion incidents involving light gas oil. The reference information for the HAZOP study was the preliminary layout plan for the Lamma Extension, together with outline design details of the light gas oil system provided on request by HEC.

The results of the HAZOP study are summarised in *Table 12.5b*.

Table 12.5b ***Results of HAZOP Study for Light Gas Oil System***

Plant area	Hazard		Causes
	Ref	Description	
Jetty and pipeline to LGO storage area	J1	Pool fire at jetty	Barge strikes berth Fire/explosion on-board barge Ranging Improper connection of unloading hose Leak from hose or flanged joints on barge Dropped object Premature disconnection of unloading hose Barge breaks away from berth Leak from pipework/fittings between jetty and LGO storage area
	J2	Explosion in fuel compartment on barge	Ignition of flammable atmosphere in ullage (eg due to prior use of barge for light products)
LGO storage area	S1	Fire on tank	Unauthorized hotwork Lightning strike Impact arising from construction activities for future units.
	S2	Fire in bund	Fuel spillage from tank or tank connections Overfilling

Plant area	Hazard		Causes
	Ref	Description	
	S3	Fire spreading outside bunded area	Fuel spillage and bund overtopping, e.g. due to drain valve left open, damage to bund. failure of other tanks in bund, rocketing of tanks etc
	S4	Explosion in tank	Ignition/heating of flammable vapour during tank maintenance/cleanout
LGO delivery system to gas turbines	D1	Pool fire around LGO pump area	Pump leakage
	D2	Fire in gas turbine enclosure	Ignition of an LGO leak due to hot surface of the gas turbine
	D3	Explosion in gas turbine enclosure	Fuel leakage and buildup of flammable vapour Release of fuel as flammable mist

From *Table 12.5b* it is apparent that there is the possibility of either a major fire or explosion involving the LGO. Fire could arise at the unloading jetty, along the transfer line to the LGO storage area, at the LGO storage area or along the delivery lines to the gas turbines.

An explosion hazard is identified for particular circumstances where other light products may be present (eg in the DG barge), where the LGO is inadvertently heated and ignited (eg poorly-controlled maintenance activities at the LGO storage area or releases of LGO in the gas turbine enclosure, where hot surfaces are present) or where the LGO could be released as a mist (eg the LGO pump delivery lines).

Light Gas Oil System: Review of Past Incidents

The MHIDAS accident database was consulted to provide further information on the types of incidents which could occur at bulk liquid fuel storage and handling facilities.

A selection of 9 incidents occurring in the last 20 years is presented in *Table 12.5c* below. Four of these incidents concern bulk fuel storage at power stations and three resulted in fatal injury to site workers. Two of the incidents at power station were explosions of fuel tanks relating to maintenance activities.

Further information on fuel oil hazards at gas turbine plant is provided in the HSE Interim Advice Note on Health and Safety at CCGT and CHP plant. This notes that over 60 fires have occurred at this type of facility worldwide over the past 20 years, most due to liquid fuel leaks. The significant factor is the presence of hot surfaces in the gas turbine enclosure which presents an immediate ignition source for any fuel spillage.

Table 12.5c Past Incidents for Bulk Fuel Storage and Handling Facilities (from MHIDAS)

Date of incident	Location	Material Name	Incident type	General cause	No. of people affected	Abstract
7/8/92	Hereford, Worcs, UK	Fuel oil	Fire	Human factor	1 killed 10 evacuated	Explosion killed workman as he welded fuel tank at power plant. Smaller tank hurled 50ft into air and carried 150ft over warehouse landing on fire service turntable appliance. Crew had just left vehicle to try and contain burning fuel oil. Workers evacuated.
3/6/89	Puerto, Ayacucho, Venezuela	Fuel oil	Tank fire	Human factor	No info.	Fire began at a fuel storage tank in a power plant. Fire extinguished after 4hours. 70% of the plant was destroyed.
26/5/87	Tokyo, Japan	Fuel oil	Explosion	Not known	3 killed 6 injured 1000 evacuated	Fuel oil tank belonging to Tokyo Denryoku OHI Electric power plant was ready for maintenance check when it exploded at 9:00am. Fire under control 40 minutes later.
12/2/92	Guernsey, UK	Heavy Fuel oil	Explosion Tank fire	Not known	10 evacuated	Explosion in 1500te heavy fuel oil tank. Evacuation from offices and factories. Fire out in 20 mins.
2/12/91	Altona, Australia	Fuel oil	Tank fire	No info.	No info.	Small fire broke out in 650te fuel oil tank. Fire was brought under control, but subsequently re-ignited.
5/12/80	Immingham, South Humberside, UK	Heavy fuel oil	Explosion Tank fire	No. info.	3 killed 4 evacuated	A team were cleaning out a heavy fuel oil tank owned by Immingham Storage Co Ltd. when it exploded killing 3 men and injuring 4. The resulting fire lasted for several hours.
5/8/80	Sandwich, MA, USA	Fuel oil	Explosion Fire	Human factor	2 injured	Explosion/fire at large oil storage complex occurred as workmen installed insulation on nearly full fuel oil tank ($7.7x10^6$ gal). Smaller tank blew up and another deteriorated due to heat. Possible oil spillage in canal due to location of tanks
22/9/93	Souk, Lebanon	Fuel oil	Fire	No info.	No info.	Tanker was discharging fuel oil at electrical power station when it was arrested by authorities for causing pollution of 30m on sea surface. Fine of Leb. currency 6 million was imposed. Power station claimed $150,000 fine for alleged damage to sea lines
27/10/87	Dhanbad, India	Petrol	Fire	No info.	No info.	1.5 km stretch of river Damodar on fire following ignition of 11000 klitres of petrol released into river from power station.

Hydrogen System: Overview of Hydrogen Hazards

Hydrogen is a flammable gas which is easily ignited over a wide range of concentrations in air. Since hydrogen does not contain any carbon it burns with a non-luminous flame which is near invisible in daylight.

The hazardous properties of hydrogen are summarised in *Table 12.5d* below.

Table 12.5d ***Hazardous Properties of Hydrogen***

Property	Value
Autoignition temperature	400 - 600 °C
Flammable limits	4.0 - 75.0 v/v
Vapour density	0.07 (air = 1)

Hydrogen System: HAZOP Study

Hydrogen gas will be used at the Lamma Extension for generator cooling. The hydrogen will be supplied via a pipeline connecting to the existing hydrogen system at the Lamma Power Station, which is fed from a pallet store near to the existing gas turbines. There will be no storage of hydrogen at the Lamma Extension and no additional storage of cylinders at the existing pallet store.

A high level HAZOP study of the additional hydrogen piping for the Lamma Extension was conducted (*Annex D7-3*), and the results are summarised in *Table 12.5e* below.

Table 12.5e ***Results of HAZOP Study for Hydrogen System***

Plant area	Hazard		Causes
	Ref	Description	
Additional hydrogen pipework	H1	Jet fire	Leak from pipeline (immediate ignition)
	H2	Flash fire	Leak from pipeline (delayed ignition)
	H3	Explosion due to accumulation of hydrogen in confined space	Leak from pipeline and accumulation in confined space
	H4	Internal explosion in hydrogen pipework	Air ingress into pipeline, eg following maintenance

In August 1992 an incident occurred at Castle Peak Power Station in which two hydrogen receivers in the hydrogen generation plant at the power station exploded killing two workers and injuring 19. The incident took place whilst staff were switching from the temporary hydrogen to the permanent supply after maintenance.

Following this incident, HEC switched to bottled hydrogen for generator cooling and a risk assessment (HEC, 1994) was undertaken to confirm that the risks associated with the new facility were acceptable.

Packaged Dangerous Goods

HEC propose to store a variety of packaged DGs at a new store on the Lamma Extension. The DGs stored will be similar in quantity and nature to DGs stored at the existing power station.

Table 12.5f lists the anticipated types and quantities of DGs to be stored in the new store and gives a profile of the hazards associated with each chemical. The information in the hazards profile is drawn from various references, including *Dangerous Properties of Industrial Materials*, Sax and Lewis (1989), *The Handbook of Reactive Chemical Hazards*, Bretherick (1989), the *Hazardous Chemicals Desk Reference*, Lewis (1990) and the *Fire Protection Guide to Hazardous Materials*, US NFPA (1994). The hazards information presented includes the primary hazards associated with the chemical itself, hazardous interactions with other chemicals stored and possible toxic products of combustion or decomposition.

From *Table 12.5f* it can be seen that the DGs to be stored fall into DG categories 2 (compressed gases), 3 (corrosive substances), 4 (poisonous substances) and 5 (substances giving off inflammable vapour).

The hazardous interactions identified in *Table 12.5f* include:

- hydrochloric acid - sulphuric acid (giving off toxic HCl gas);
- reactions between acids (HCl, H_2SO_4) and alkalis (Na OH, NH_4OH);
- hydrazine - sodium hydroxide (explosive reaction); and
- hydrocarbon (eg solvent) - oxidiser reactions (eg sodium hypochlorite).

Various hazardous products of decomposition or combustion have been identified including chlorides, SO_x, Na_2O, ammonia, NO_x and fluorides.

In addition to the above hazards, there are hazards associated with rocketing of drums and cylinders in a fire affecting the DG store (or other areas where the chemicals are used). This could lead either to direct injury or injury through secondary fires.

Table 12.5f ***DGs to be Stored at Lamma Extension***

Item	DG category	Anticipated quantity	Profile of hazards
Hydrochloric acid	3	200 x 25 kg & 10 x 200 litres	1) Potentially dangerous reaction with sulphuric acid releases hydrogen chloride gas. 2) Violent reactions with sulphuric acid, sodium hydroxide and ammonium hydroxide. 3) Emits toxic fumes of Cl^- when heated to decomposition.
Sulphuric acid	3	56 x 240 kg	1) Potentially dangerous reaction with hydrochloric acid releases hydrogen chloride gas. 2) Can ignite or explode on contact with ammonium hydroxide, chlorates, sodium hydroxide, water, and steel. 3) Reacts with water to produce heat. 4) Can react with oxidizing materials. 5) Emits toxic fumes of SO_x when heated to decomposition.
Liquid sodium hydroxide	3	56 x 200 litres	1) When heated to decomposition, it emits toxic fumes of Na_2O.
Solid sodium hydroxide	3	400 x 25 kg	1) Can react violently with hydrochloric acid and sulphuric acid. 2) When heated to decomposition, it emits toxic fumes of Na_2O.
Ammonium hydroxide solution (25% concentration)	4	30 x 20 litres	1) Emits toxic fumes of NH_3 and NO_x when exposed to heat.
Hydrazine	4	10 x 200 litres	1) Flammable liquid and a very dangerous fire hazard when exposed to heat, flame or oxidizing agents. 2) Severe explosion when exposed to heat or flame or by chemical reaction. 3) Explodes on contact with sodium hydroxide. 4) Forms sensitive, explosive mixtures with air. 5) Ignites spontaneously in air when absorbed on earth, cloth, wood. 6) Vapour burns in absence of air. 7) Confined carcinogen.
Sodium hypochlorite	4	100 x 20 litres	1) Emits toxic fumes of Na_2O and Cl^- when heated to decomposition.
Immiscible organic solvent (hexane, heptane, petroleum ether, toluene)	5	300 litres	1) Dangerous fire and explosion hazard when exposed to heat, flame or spark. 2) Reacts vigorously with oxidizing materials.

Item	DG category	Anticipated quantity	Profile of hazards
Miscible organic solvent: (i) acetone (ii) isopropyl alcohol (iii) glycerol	5	300 litres	1) Items (i) and (iii) - Very dangerous fire and explosion hazard when exposed to heat, flame or oxidizers. 2) Item (ii) - Reacts vigorously with oxidizing materials. 3) Item (ii) - Reacts with air to form dangerous peroxides.
Carbon dioxide	2	2,880 kg	1) Cylinders may rocket if exposed to heat.
Nitrogen	2	558 m^3	1) Cylinders may rocket if exposed to heat.
Paint & Thinner	5	5000 litres	1) Thinner is typically a mixture of paraffins, monocycloparaffins, condensed cycloparaffins, benzene, toluene and C8 alkyl benzenes. 2) Fire hazard for both paint and thinner.
Acetylene	2	297.6 m^3	1) Very dangerous fire hazard when exposed to heat or flame or oxidizers. 2) Moderate explosion hazard when exposed to heat or flame or by spontaneous chemical reaction. 3) Reacts vigorously with oxidizing materials. 4) Decomposes explosively in the absence of air at high temperature and moderate pressure.
Kerosene	5	7000 litres	1) Can react with oxidizing materials. 2) Combustible when exposed to heat or flame. 3) Moderately explosive in the form of vapour when exposed to heat or flame.
Cleaning solvent	--	340 litres	Hazards assumed to be covered by immiscible and miscible organic solvents (as above).
Freon	2	148.8 m^3	1) Cylinders may rocket if exposed to heat. 2) Freon 113 - Combustible when exposed to heat or flame. 3) Freon 114 - non-flammable gas.
Oxygen	2	310 m^3	1) Cylinders may rocket if exposed to heat. 2) Fire hazards associated with enhanced oxygen atmospheres.
SF_6	2	120 m^3	1) Emits highly toxic fumes of F^- and SO_x when heated to decomposition.
FM200	2	980 kg	1) Chemically known as heptafluoropropane. 2) Used as a fire extinguishant for flammable liquids, gases and in electrical equipment. 3) Commonly adopted as an extinguishant in areas where water is discouraged. 4) Gas cylinder may rocket if exposed to heat.
Water solvent	5	30 x 200 litres	Hazards assumed to be covered by miscible organic solvent (as above).

12.5.3 *Risk Assessment*

Light Gas Oil System

To illustrate the hazards associated with major liquid fuel fires three of the most severe cases have been modelled: fire on top of storage tank *(Scenario S1)*, fire in bund (*Scenario S2*) and a fire which overtops the bund (*Scenario S3*). These have been modelled using the Society of Fire Protection Engineers (SFPE) pool fire model.

Table 12.5g ***Downward Distances for Different Intensities of Thermal Radiation***

Scenario	Downward distance* (m) at 5 kW/m²	10 kW/m²
Fire on tank	31	27
Fire in bund	88	57
Fire spreading outside bunded area	128	86

*measured from centre of flame

The results tabulated above are evaluated against the criteria presented in *Table 12.5h* below (after Cassidy and Pantony, 1995).

Table 12.5h ***Effects of Thermal Radiation***

Intensity (kW/m²)	Time to pain (s)	Time to blister (s)	Time to react (s)
22	2	3	2
18	2.5	4	1.5
11	5	8.5	3.5
8	8	13.5	5.5
5	16	25	9
2.5	40	65	25

From *Tables 12.5g and 12.5h* it is concluded that the impact on the nearest residential population on Lamma (over 900 metres away) will be negligible, whilst only injury levels of thermal radiation could be experienced at the site boundary of the power station.

With regard to explosions involving LGO, two scenarios need to be covered: explosions in the LGO tanks and explosions in the gas turbine enclosure. Explosions in tanks (due to inadequately-controlled maintenance activities) is a foreseeable occurrence, but it is considered that the effects of such an explosion would be limited to the site of the Lamma Extension.

With regard to an explosion in the gas turbine enclosure, this is considered much less likely for a liquid fuel leak than a gas fuel leak. Despite the presence of hot surfaces (which could generate a localised fuel vapour/air mixture) and the fact that the liquid fuel may be released as an aerosol, the more likely outcome of a fuel leak in the enclosure is considered to be fire.

Hydrogen System

Various hazards have been identified for the hydrogen system, including jet fires (due to immediate ignition of a leak from the pipework), flash fires (due to delayed ignition of a leak from the pipework) and explosion (due to formation of flammable atmospheres within the hydrogen pipework or, following leakage, within confined spaces through which the hydrogen pipework may pass) .

The effects of such incidents, however, would confined to the site itself, because the hydrogen pipework is small bore, operating at low pressure (4 to 10 barg) and is likely to be routed away from the site boundary.

This conclusion is supported by HEC's own risk assessment for the hydrogen pallet store which shows maximum effect distances of the order of 55 metres and off-site individual risks below 10^{-8} per year. The increase in hydrogen usage due to the Lamma Extension (approximately double) would be expected to increase off-site individual risk levels proportionately but this will still be negligible in relation to the Government Risk Guidelines (10^{-5} per year).

Packaged Dangerous Goods

The hazards identified for the packaged DGs which will be present at the Lamma Extension site include fire, explosion, toxic gas release (either through fire or inadvertent reaction between chemicals) and rocketing of drums and cylinders.

These are significant hazards to the staff of the power station involved in the transport, handling and use of these chemicals but, as for the hydrogen hazards above, it is not considered that any accident involving these chemicals could have fatal off-site effects. This is because the DG store is situated away from the site boundary (100m from the southern edge of the reclamation) and there is no potential off-site impact.

To provide further justification for this conclusion each of the hazards identified above may be considered in turn, ie thermal radiation due to fire, blast effects due to an explosion within the store, toxic gas release and missile effects.

In respect of *fire*, the worse scenario which could be envisaged would be a unconfined pool fire involving the entire flammable inventory of the DG store (ie around $10m^3$). Even assuming unconfined spreading to a depth of around 1cm this gives a pool radius of around 17 metres. Based on the data presented in *Table 12.5g* it can be seen that thermal radiation levels at the site boundary will amount to no more than injury levels.

In respect of *explosion*, the worst scenario which could be envisaged would be a build-up of flammable gas or vapour within the DG store (eg due to a leak of acetylene and failure of the store ventilation). Upon ignition the blast from the explosion would be expected to cause severe damage to the store resulting in the effects of thermal radiation, blast and missiles to those in the immediate vicinity. It is not considered that such effects could extend to the nearest off-site population (ie the transient marine population which may pass within approximately 120 metres to the south of the DG store).

With respect to the *toxic gas hazard*, this may arise in one of two ways, ie uncontrolled mixing of chemicals or a fire at the DG store. Uncontrolled mixing of chemicals may result from leaks or spills in the DG store or during use of the various DGs elsewhere on the site. Such mixing may result in emission of toxic gases such as HCl, however it is considered that the hazardous effects of such releases would be confined to the vicinity of the incident, rather than affect off-site areas. With respect to the fire hazard there has been growing attention in recent years on warehouse/DG store fires due to a number of well-publicised incidents in which toxic combustion products were emitted in large quantities. This focus has mainly been on sites storing chemicals such as pesticides in which small fractions of unburnt chemical released in the fire can have significant off-site effects (dangerous toxic loads for pesticides may be as low as 10 -100 ppm.min compared to chlorine which is 100,000 ppm^2.min).

The nature of the toxic combustion products which could arise for the proposed DG store at the Lamma Extension is significantly less severe than this. The most hazardous are likely to be gases such as NO_2 (severely irritant at 80 ppm, threshold levels of fatality at around 150-200 ppm over 5 minutes), ammonia (threshold levels of fatality at around 4500 ppm over 5 minutes) and CO (can cause incapacitation at around 1% or 10,000 ppm in a few minutes). It is not considered that the presence of such gases could cause fatal injury at distances of the order of 120 metres from the source of the fire. This is due to the following:

- such gases would only be expected to be present as a small fraction of the overall emissions from the fire;
- the thermal uplift from the fire would provide significant further dilution of the gases in the atmosphere; and
- one would expect a high likelihood of escape due to the slow build-up typical of such incidents.

In respect of the hazard of *missiles* due to a major fire at the DG store, there is a possibility that compressed gas cylinders may rocket and affect people beyond the site boundary. Such an occurrence would be expected to be rare however due to the adoption of suitable fire prevention and protection measures in the design and operation of the DG store and the low likelihood of members of the public being present near the site boundary on the southern side of the reclamation.

12.5.4 *Hazardous Interactions*

General

A brief overview is given here of possible hazardous interactions between the non-fuel gas facilities at the Lamma Extension (also including the existing Lamma Power Station) and the fuel gas facilities.

This is to determine to what extent the risk associated with the fuel gas facilities (which represents the main off-site risk) could be affected by other activities at the Lamma Extension and on-going operation of the existing power station.

In general terms, the gas receiving station and high pressure gas pipework are well located with respect to any incidents which could arise elsewhere at the Lamma facility. In the preliminary layout for the Lamma Extension, the gas receiving station is located in the south-east corner of the new reclamation, separated from the other DG facilities and over 400 metres away from the existing power station.

Possible incidents which could affect the fuel gas facilities at the Lamma Extension are identified in *Table 12.5i* below:

Table 12.5i ***Possible 'Knock-on' Incidents to Fuel Gas Facilities at Lamma Extension***

Source of incident		Type of incident
Non-fuel gas facilities at Lamma Extension	DG Store	Fire/explosion
	Hydrogen generator cooling system	Fire/explosion
	Alternate fuel system	Fire/explosion
	HRSGs/steam turbines	Pressure vessel failure Failure of rotating machinery Fire (lubricating oil)
Existing Lamma Power Station	Coal storage and handling	Fire/explosion
	Boiler-furnaces	Fire/explosion
	Steam turbines	Pressure vessel failure Failure of rotating machinery

The nature of these incidents is either fire/explosion or mechanical failure of high pressure equipment or rotating machinery. These could impact the fuel gas facilities by causing failure of equipment through fire engulfment, blast damage or missile damage.

The various sources of hazard are considered in further detail below.

Incidents Arising At the Lamma Extension

As noted above, the fuel gas facilities at the Lamma Extension are generally well-separated from other DG activities at the site. The gas receiving station lies over 100 metres from the DG store and over 250 metres from the LGO storage area. The main gas supply pipeline is buried over the short distance (80 metres) between the landing point and the gas receiving station.

It is feasible that a major fire/explosion at the DG store could impact the fuel gas facilities through missile damage. Such a situation could arise due to accumulation of flammable gas/vapour inside the store (followed by ignition) or due to fire engulfment of drums and cylinders leading to rocketing. It is likely that the main threat would be to the smaller bore pipework at the gas receiving station rather than the main gas lines. Typical safeguards which would be incorporated into the design of the DG store to minimise this hazard would include the provision of adequate ventilation, segregation of incompatible DGs, and provisioning of appropriate fire-fighting equipment.

The hydrogen generator cooling system does not present a major threat to the fuel gas facilities at the Lamma Extension as it comprises only small bore pipework operating at relatively low pressure. No hydrogen gas bottles will be stored in the gas turbine enclosures.

Large fires at the LGO storage area would not threaten the fuel gas facilities. The only possible interaction would be at the gas turbines where a major liquid fuel fire could impact engulf high pressure gas lines. It would be expected that the liquid fuel lines would include automatic emergency shut-off facilities which would limit the size/duration of any fire which could arise at the gas turbines.

The other potential source of hazard to the fuel gas facilities is the high pressure equipment and rotating machinery associated with heat recovery system for the gas turbines, ie the HRSGs and steam turbines. Major failure of this equipment would be expected to be a rare occurrence and is addressed through adherence to relevant standards for the design, fabrication, installation and operation of such equipment.

Incidents Arising At the Existing Lamma Power Station: Coal Fires

Coal is a commonly used fuel in electricity generating plants. It consists largely of carbon with varying amount of hydrogen, oxygen, nitrogen, sulphur and mineral ash. The risk associated with handling coal is its susceptibility to spontaneous combustion which would generate hot spots or even fire within the coal storage pile.

Spontaneous combustion results from oxidation of the coal under conditions in which the rate of heat generated exceeds the rate of heat dissipated. The rate of heating depends on many factors such as rank, moisture content, sulphur content, particle size, friability, etc.

It is important that operations managers and plant designers understand the factors which contribute to spontaneous combustion so that problems can be minimised and effectively dealt with when they occurred. During the period from January 1992 to October 1998, there were only 28 incidents recorded of "warm" coal at the Lamma Power Station, 8 of which were reported as "fires". All of these incidents occurred in the coal storage yard, except one which occurred outside this area being smoke observed emitting from inside a coal bunker (December 1995). The usual practice to combat a coal "fire" is to expose the hot spots inside the coal stock, by using mobile equipment, so as to allow cooling of the heated coal.

Ways to avoid spontaneous combustion are varied. If the coal is to have a long residence time, say 3-6 months, the coal heaps can be stored in the so-called "roll packing" form (i.e. compacting coal layers by rolling over them). This practice is to reduce oxygen exposure. Another alternative can be to spray the surface with surface sealant. At the Lamma Power Station, the drop height from the end of the stacker/reclaimer boom is minimised because excessive drop height will generate more fines which has a greater area of fresh surface subject to oxidation. Water spray is also applied regularly to the piles for cooling and dust suppression purposes.

Coal being transported by conveyors to the bunkers of the boiler should also be cautioned for fire protection. A coal fire in a conveying system may initiate a "running" fire (i.e. a fire being carried along the moving belt). A hidden danger associated with a running fire is for the conveyor belt itself to catch fire. At the Lamma Power Station, all the conveyor belting are fire-retardant type so that any fire will not propagate by the belt itself. Automatic water spray systems are equipped with coverage for all of the conveyors and the junction towers. When the coal is delivered to the bunkers, it would not be retained for excessive length of time as it can be readily consumed by the boiler.

At the Lamma Power Station, the chance of a fire occurring is reduced as various fire protection systems are installed at strategic locations. They include sufficient fire hydrants and water supply, portable extinguishers and hose reel stations, and automatic sprinkler and water spray systems.

Incidents Arising At the Existing Lamma Power Station: Other Hazards

There are other hazards relating to coal being used as a fuel in power plants and they are considered to be worth mentioning here. Incomplete removal of foreign substances, such as scrap iron, wood scrapings and rocks in raw coal being delivered to the electricity generating plant can interrupt coal feed, jam or damage equipment, or become a source of ignition within the pulverizer.

The failure of pipework (eg failures of gaskets, flexible connectors etc.) that links the boiler and the pulverizer, where coal is ground to a very fine powder and transported to the boiler by an air stream, can also present a hazardous situation. A local dust cloud can build up in the area in which failure occurs. Consequently, an explosion may occur if an ignition source is introduced. A "blow torch" effect may result if the cloud is ignited in the initial stage of the release. A common cause of pipework failure is erosion, particular at bends.

Duct or burner pipe fires and explosions generally result from excessive air temperatures, other cases being improper control of air velocities that allows fuel settling or when pipelines are not properly purged. When proper air flows are re-established, the fuel mixture may pass through the explosive range, causing an explosion if an ignition source is introduced.

The air stream velocities within the pipeline must be sufficient to prevent potential pre-ignition within the burner pipeline. Also, the air-coal stream temperature must be maintained between specific limits, which are determined by type of coal being burned. Temperatures too low will impair the efficiency of the pulverization process while temperatures too high may cause coking and increase the risk of fire occurring within the pulverizer and piping.

Clearing pipelines and ducts by hammer blows must be avoided as this may cause a local explosive dust/air cloud to form within the structures, causing unnecessary danger.

A special hazard is the release of methane gas from freshly pulverized coal. Such a gas may accumulate in enclosed spaces such as within the pulverizer and cause a gas explosion hazard.

Incidents Arising At the Existing Lamma Power Station: Hazard to Lamma Extension

The preceding sections identify various types of hazard at a coal-fired power station, including spontaneous heating of coal during storage/transfer and fire/explosion hazards associated with the pulverisers and boiler-furnaces. The fuel gas facilities at the new Lamma Extension will be located over 600 metres from the coal handling areas at the existing power station. Therefore, it is considered that the chance of an incident initiating at the existing power station and escalating to involve the fuel gas facilities at the new power station is remote. It is possible that missiles generated by failure of pressure vessels or catastrophic failure of rotating machinery may travel this distance, but the risk associated with such incidents would be expected to be low.

Incidents Arising At the Existing Lamma Power Station: Conclusions on Possible Interaction Hazards

Various types of incident have been identified which could occur at the Lamma Extension (and the existing power station) which could escalate to involve the fuel gas facilities. These include:

- major fire/explosion at the new DG store on the Lamma Extension;
- fires involving the alternate fuel system at the Lamma Extension (in vicinity of the gas turbines); and
- catastrophic failure of pressure vessels or rotating machinery (at either the existing power station or the Lamma Extension).

The fuel gas facilities at the Lamma Extension are well located with respect to incidents which could arise from other hazardous activities at the site. They also include design safety features typical of such installations, including an emergency shutdown valve on the main gas supply pipeline and an emergency depressurising and flare system.

These interactions hazards will need to be considered further and it is considered that this is best done in the detailed Hazard Assessment to be undertaken for the fuel gas facilities at the Lamma Extension so as to provide a single, coherent assessment of all fuel gas-related hazards.

12.6 ASSESSMENT SUMMARY

12.6.1 Fuel Gas Hazards

Overview

This report presents a high level assessment of the risks to the public associated with the fuel gas facilities at the proposed Lamma Power Station Extension.

Gas-fired power stations are an increasingly important component in the energy supply industry in many countries and recent years has seen a proliferation of this type of plant. Indeed, Hong Kong already has a large gas-fired power station (CLP's Black Point Power Station) using similar technology to that proposed by HEC.

The hazards associated with gas-fired power stations are generally well-understood and this is reflected in the numerous standards and codes of practice which exist to cover the design, construction, installation, testing, commissioning, operation and maintenance of such facilities.

The purpose of the risk assessment is to determine whether there are any insurmountable risk issues for this project, by examining any new or unusual features. The risk assessment firstly identifies the hazards associated with the operation of power station and gas supply pipeline, then examines the potential impacts on the public and, finally, assesses the risks, making reference to the requirements of the various standards and codes of practice referred to above.

Hazard Identification

For the gas receiving station (and other fuel gas facilities at the power station) loss of integrity is the primary hazard, but there are additional hazards associated with internal explosions within items of equipment and catastrophic failure of rotating machinery.

Consequence Assessment

No fuel gas storage is provided on site, except that a gas receiving station will be required to receive natural gas delivered from a regional LNG terminal through a pipeline. The consequences of a major release of gas could be severe with little scope for escape. For releases which are ignited a large fireball or flash fire may result with fatal effects extending several hundred metres from the release location. The siting of the gas receiving station is generally favourable from an off-site risk perspective as it lies over 1 km from the nearest residential population. Therefore, in the event of an accident, the hazardous effects would be expected to be confined largely to the transient marine population.

Risk Assessment

Various standards and codes of practice exist for high pressure systems such as gas receiving stations and other gas facilities at the power station. These standards recognise all of the hazards which have been identified and offer a variety of design solutions.

One issue worthy of particular mention, however, is the design of the acoustic enclosure for the gas turbines. In their *Interim Advice Note on Health and Safety at CCGT and CHP Plant*, the UK Health and Safety Executive cite evidence that, despite provision of dilution ventilation, air distribution in enclosures is often inadequate, giving rise to the hazard of a gas explosion. This issue will require careful tracking through the design, construction, testing and commissioning of the power station.

One further issue which emerges from the risk assessment for the gas receiving station is the importance of safety management. Whilst the standards of "hardware" on gas-fired power plant may be similar, the standards of "software" (eg people, training, organisation) may vary considerably and this is a key determinant of the risk posed by such facilities to the public. The need for effective safety management arises from the recognition that most industrial accidents have their root cause in human error. Comprehensive safety management systems are nowadays regarded as essential in the major hazard industries. They provide clear management commitment to safety and comprise all the necessary components for effective, pro-active management of risks including coordination between concerned parties, written work procedures, communication, contractor control, training, risk assessment, auditing and management of change. An effective safety management system will assist HEC in meeting the requirements which GSO may impose when HEC come to apply for registration as a gas supplier.

Conclusions on Fuel Gas Hazards

From the high level review which has been undertaken of the hazards associated with the fuel gas facilities at the Lamma Extension it is concluded that there are no insurmountable risk issues.

12.6.2 *Non-Fuel Gas Hazards*

Overview

A systematic review has been undertaken of the hazards posed by the transport, storage and handling of non-fuel gas DGs at the Lamma Extension. This covers the alternative fuel (light gas oil) system, the additional hydrogen piping to be provided for generator cooling at the Lamma Extension and the various packaged DGs which will be stored and handled at the Lamma Extension.

The assessment also includes a brief review of possible incidents involving the non-fuel gas facilities (including the existing power station) which could escalate to involve the fuel gas facilities.

Light Gas Oil System

The hazards associated with the light gas oil system relate mainly to fire, although explosion is also possible in certain circumstances (eg tank explosion due to poorly-controlled maintenance). An assessment of the thermal radiation levels which could arise in a major fire at the Lamma Extension shows that the radiation levels will not exceed injury levels at the nearest residential population on Lamma (over 900 metres from the site of the Lamma Extension), but may be exceeded beyond the site boundary in the immediately vicinity of the LGO storage area and the LGO unloading jetty. This is unlikely to lead to fatal injury, however, as these areas are not routinely accessed by the public and escape is likely within the time required to receive a fatal dose of thermal radiation. This aspect is further considered, in a quantitative manner, below. The effects of an explosion involving the light gas oil system would be confined to the Lamma Extension site itself and are not considered to present an off-site fatality risk.

Additional Hydrogen Pipework

The hazards of hydrogen relate to fire and explosion. The effects of an incident involving hydrogen, however, would not lead to fatal off-site injury, as the additional hydrogen pipework to be provided for this project is small bore, operating at relatively low pressure (4 - 10 barg).

Packaged DGs

The various packaged DGs to be stored at the Lamma Extension present a hazard in terms of fire, explosion, toxic injury (due to the generation of toxic gases by fire, decomposition or chemical reaction) and projectiles (rocketing of drums and cylinders in a fire). The toxic products released in a fire may cause injurious effects at the site boundary (eg respiratory difficulties) but it is not considered that fatal effects could arise. Furthermore, the effects of fire, explosion or accidental mixing of chemicals (leading to toxic gas release) would also not extend off-site. The only hazard for which fatal off-site effects could conceivably arise is that of projectile generation due to a major fire at the DG store. The risk associated with this hazard is considered further below.

Hazardous Interactions

This section has identified various types of incident which could occur at the Lamma Extension (and the existing power station) which could escalate to involve the fuel gas facilities. These include:

- major fire/explosion at the new DG store on the Lamma Extension;
- fires involving the alternate fuel system at the Lamma Extension (in vicinity of the gas turbines); and
- catastrophic failure of pressure vessels of rotating machinery (at either the existing power station or the Lamma Extension).

The fuel gas facilities at the Lamma Extension are well located with respect to incidents which could arise from other hazardous activities at the site. They also include design safety features typical of such installations, including an emergency shutdown valve on the main gas supply pipeline and an emergency depressurising and flare system.

Conclusions on Non-Fuel Gas Hazards

From the risk assessment which has been undertaken for the transport, storage and handling of non-fuel gas DGs at the Lamma Extension it is concluded that it is highly unlikely that there could be fatal injuries to persons off-site due to accidents involving these DGs. Based on the information available for this assessment, the only situation in which this could happen would be as follows:

- a major incident at the Lamma Extension (eg a major tank farm fire, with overtopping of the bund or a major fire at the DG store);
- failure of all safety systems (fire fighting equipment etc);
- particular weather conditions (or directions of travel of missiles); and
- a member of the public present close to the site boundary (nearest the location of the incident).

A simple, "order of magnitude" quantitative risk assessment has been undertaken for three scenarios to address the risks which arise to the general public. This is presented in *Tables 12.6a to 12.6c and Figure 12.6a* below.

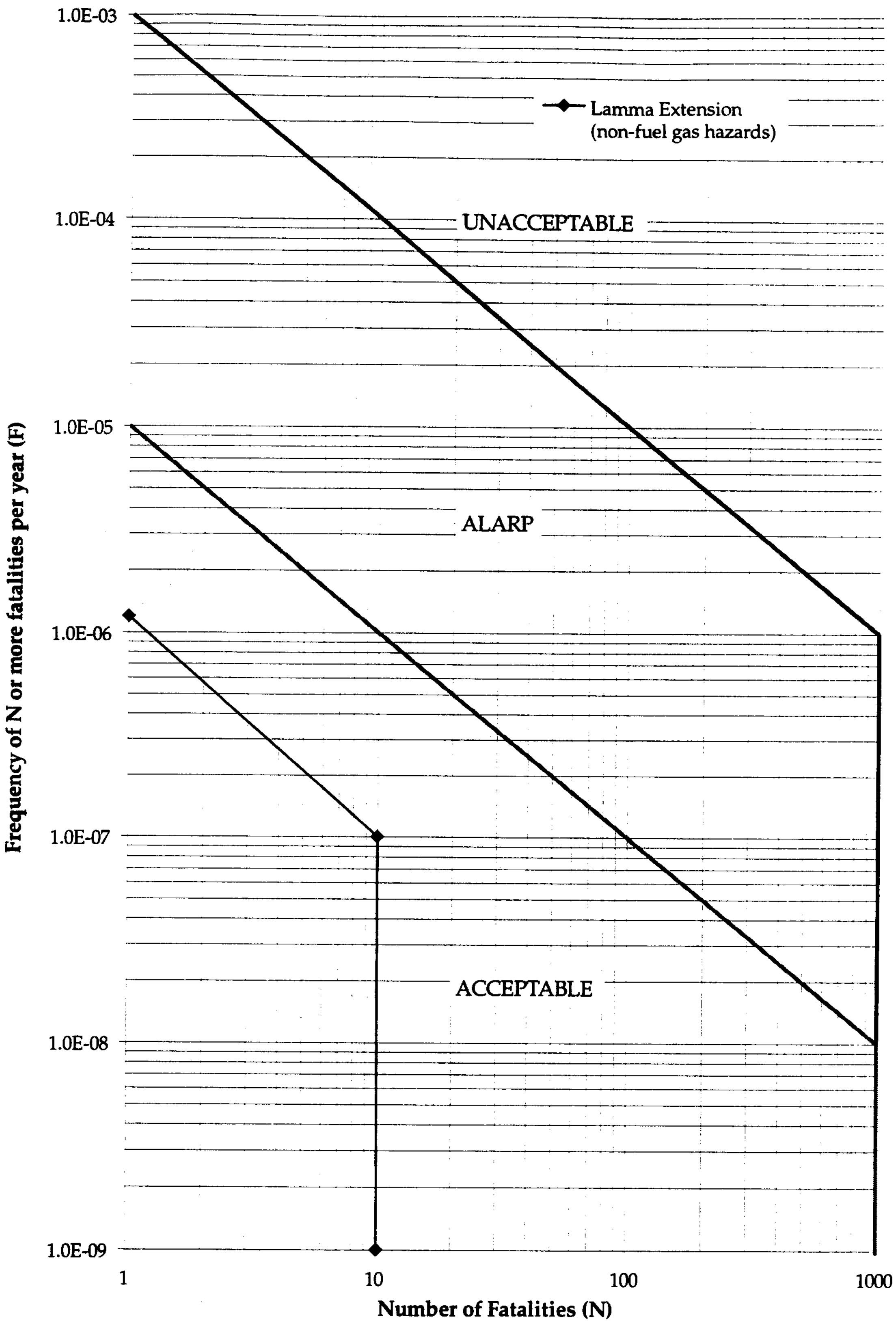


FIGURE 12.6a f-N CURVE FOR NON-FUEL GAS HAZARDS AT LAMMA EXTENSION

FILE: C1830_25
DATE: 21/12/98

Environmental Resources Management

ERM

Table 12.6a ***Risk Assessment - Major Fire at LGO Storage Area***

Item	Value	Notes
Fire in LGO Storage Area with overtopping of bund	10^{-5} /year	From Davies et al (1996) for fires of flammable liquids in bunds
x p (wind blows flames towards nearest off-site areas)	10^{-1}	Thermal radiation levels are most severe downwind of a pool fire due to tilting of the flame.
x p (member of the public present in immediate vicinity of site nearest incident)	10^{-1}	Area affected is that within 100 metres of the site boundary nearest to the LGO storage area.
x p (member of public receives fatal dose of thermal radiation)	10^{-2}	Radiation levels within this area are above 5 kW/m^2. 18 kW/m^2 gives a 1% chance of fatality for a 20s exposure using the Eisenberg (1975) probit equation
Individual risk	**10^{-9} /year**	
Societal risk	**frequency = 10^{-7} per year Number of fatalities = 1 (maximum)**	

Table 12.6b ***Risk Assessment - Major Fire at LGO Jetty (due to hose connection error)***

Item	Value	Notes
Major release at LGO Jetty	10^{-4} /year	Based on an LGO delivery frequency of 1 per year (upper bound) and an initial human error probability of 10^{-2} (failure to connect hose correctly) and subsequent probability of 10^{-2} (failure to recover by stopping pump, deployment of booms etc).
x p (ignition)	10^{-2}	Low ignition probability for high flash point material released to marine environment.
x p (nearby fishing vessel or other boat is engulfed by flames)	10^{-1}	Area affected would be limited due to nature of release (prolonged, pumped release). No ferries pass by unloading jetty.
Individual risk	**10^{-7} /year**	
Societal risk	**frequency = 10^{-7} per year Number of fatalities = 10 (typical, for small boat)**	

Table 12.6c ***Risk Assessment - Major Fire/Explosion at DG Store***

Item	Value	Notes
Major fire in DG store	10^{-3} /year	Estimated - assumed more likely than major fire at bulk liquid fuel storage facility
x p (member of the public present in immediate vicinity of site nearest incident)	10^{-1}	As above
x p (missile has necessary direction and range to impact member of public)	10^{-2}	Assumed member of public would be on boat passing near southern edge of Lamma Extension site (approximately 120 metres from DG Store)
x p (fatal injury due to missile strike)	10^{-1}	Member of public on boat would not necessarily be directly exposed to injury through missile damage.
Individual risk	**10^{-7} /year**	
Societal risk	**frequency = 10^{-4} per year Number of fatalities = 1 (maximum)**	

It can be seen from *Tables 12.6a-c* above that individual off-site risks due to accidents associated with the transport, storage and handling of the non-fuel gas DGs at the Lamma Extension (approximately 2 x 10^{-7} per year overall) are well below Government Risk Guidelines (10^{-5} per year). Furthermore, from *Figure 12.6a* it can be seen that the F-N curve for the non-fuel gas hazards lies well within the acceptable region of the Risk Guidelines.

These risks will need to be added to those for the fuel gas hazards (to be evaluated in a separate Hazard Assessment study) to determine the overall level of risk to the public from the Lamma Extension.

12.7 *SUMMARY OF MITIGATION MEASURES*

12.7.1 ***Fuel Gas Hazards***

The high level risk assessment which has been undertaken for the fuel gas hazards confirms that there are no insurmountable risks but identifies two key issues: gas explosions in the gas turbine enclosures and safety management.

The following recommendations are made in respect of these key issues.

Gas Explosions within the Gas Turbine Enclosures

It is recommended that HEC follow the guidelines in the HSE *Interim Advice Note on Health and Safety in CCGT and CHP Plant* in developing the design of the gas turbine enclosure, namely to:

- avoid the need for acoustic enclosures, wherever reasonably practicable (eg by installation within acoustically-sealed turbine halls);
- implement a Permit-to-Work system for any entry into an acoustic enclosure;

- provide safe systems of work for investigation of fuel leaks within the enclosure (recognising that typical plant designs make off-load pressure testing or use of tracer gases difficult);

- ensure adequate dilution ventilation, through competent design and verification by techniques such as smoke testing, air flow measurement, and use of Computational Fluid Dynamics (CFD);

- minimise the chance of a fuel leak through minimisation of the number of joints, adherence to relevant standards for pipework, provision of fuel safety shut-off and vent valves with valve proving systems;

- provide explosion relief/suppression systems where dilution ventilation is inadequate; and

- conduct an engineering risk assessment to verify that the chosen means of control are effective.

Safety Management

HEC should review their existing safety management system against current best practice, as outlined in documents such as the UK Health and Safety Executive's *Successful Health and Safety Management* and *A Guide to the (UK) Pipelines Safety Regulations 1996*. The former document sets out the broad requirements for effective safety management, whilst the latter sets out more specific requirements for major hazard pipelines.

The detailed Hazard Assessment to be undertaken for the fuel gas hazards associated with the Lamma Power Station Extension should include further consideration of "domino" incidents which may arise from the other hazardous activities at the site, building on the initial assessment undertaken in this report.

12.7.2 *Non-Fuel Gas Hazards*

Although the risks associated with the non-fuel gas DGs at the Lamma Extension have been shown to lie well within Government Risk Guidelines, the following recommendations are made in accordance with the principle of reducing risks to as low a level as reasonably practicable:

- storage quantities of the non-fuel gas DGs should be minimised as far as reasonably practicable;

- the design and operation of the various non-fuel gas DG facilities should follow current best practice, such as provided by US National Fire Protection Association and UK Health and Safety Executive; and

- any significant reduction in separation distance between the locations of the various non-fuel gas DG facilities and the site boundary (ie a reduction which might reasonably affect the conclusions reached herein) should require review of the Hazard Assessment.

12.8 SUMMARY AND CONCLUSIONS

Separate risk assessments have been undertaken for the fuel gas-related and non-fuel gas hazards associated with the power station component of the proposed Lamma Extension project. Although a more detailed assessment of the fuel gas hazards is still required by GSO, the results of the assessments reported above have indicated the risks associated with the proposed project are acceptable.

An assessment of the gas pipeline is provided in Part D of this Report.