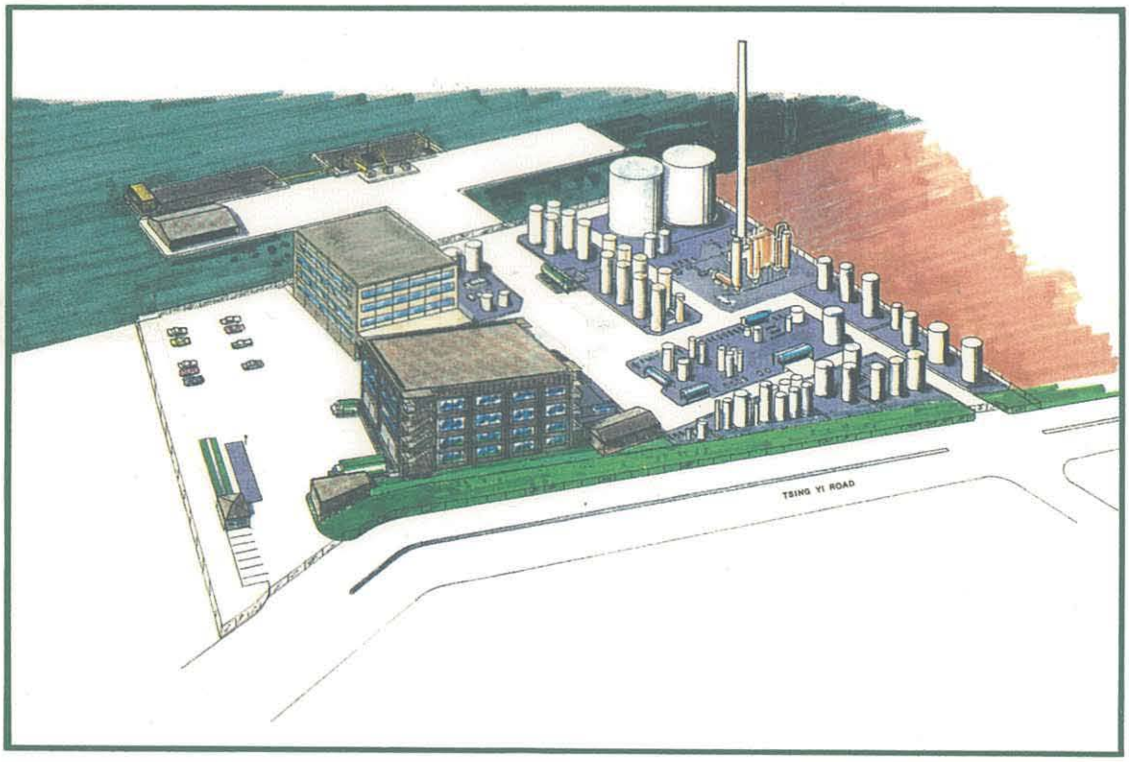
HONG KONG CHEMICAL WASTE TREATMENT FACILITIES

HAZARD ASSESSMENT



Enviropace Limited

CHEMICAL WASTE TREATMENT FACILITIES
HAZARD ASSESSMENT
FINAL REPORT

Prepared for:
Environmental Protection Department
Government of Hong Kong

Prepared by:
Waste Management International, Inc.
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Technica, Ltd.

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TABLE OF CONTENTS

LIST OF APPENDICES

MANAGEMENT SUMMARY

Technica Limited has carried out a Risk Assessment of the Chemical Waste Treatment Facilities (CWTF) currently being planned to serve Hong Kong and to be sited on Tsing Yi Island. They have employed the 'Classical Risk Assessment Methodology' and used their proprietary software package SAFETI, approved by the Government of Hong Kong for such studies, for the computational and database elements of this.

The risks quantified are specifically those of fatality to people outside the CWTF site as a result of acute exposure to an accidental release to the atmosphere of hazardous material.

The Hazard Assessment addresses the operations intended to be carried out on the site, with their associated plant and equipment, and transport to the facility of waste materials and reagents for use in the treatment processes. Also included is the risk arising from a major fire in stored packaged waste. After reviewing the hazardous properties of both the materials intended to be present on the site and those which could be produced unintentionally, representative failure cases are identified to cover all releases considered plausible and for each of these the likely size of the release is determined. These cover: storage, treatment processes, incineration, reception of incoming waste and reception of incoming reagents for use in the treatment processes, transport to the facility of waste materials and transport to the facility of reagents for use in the treatment processes.

Screening was carried out to determine which of these releases could generate risk beyond the site boundary; the remainder being eliminated from further analysis. Possible consequences were modelled, and the likely frequencies of occurrence were determined for those release cases retained.

For onsite release cases, both individual and societal ('F-N') risks were calculated. This is done by combining the consequence results with event frequencies, meteorological probabilities and (for flammable releases only) ignition probabilities to determine the geographical distribution of individual risk, thence applying this to the population distribution. For transport release cases, individual risk was calculated in the form of a risk transect or cross-section of risk against distance from the road.

The risks thus calculated were compared with the Interim Risk Guidelines laid down by the Government of Hong Kong. The greatest risks by far are associated with the storage and handling of pressurized liquefied chlorine and sulphur dioxide drums used as reagents in various processes. If ordinary designs and procedures typical of low hazard plants are employed, then the Interim Risk Guidelines could not be met. However, if high quality engineering design features and safety management procedures are adopted, then the Interim Risk Guidelines should be met for individual risk, but may still be slightly exceeded for societal risk. Further engineering controls once the design is finalized may resolved this exceedence. Some transport risk mitigation is considered warranted for $C1_2$ and SO_2. Removal of these two reagents from the site was investigated as a mitigation measure. If these were removed, then the site would meet the Interim Risk Guidelines without any difficulty. Alternative system may be more costly, but would not introduce any significant reaction or reagent hazards.

The analysis includes a Solvent Recovery Unit, although it has been stated that this will not be built; however, risks from this are not among the major contributors to the overall risk, so its inclusion has not influenced the results.

Based on the results of this quantitative hazard assessment, several recommendations are made which need to be taken into consideration in the detailed design of the facility.

Complementary to the quantitative assessment described above, the proposed operating and storage procedures and the proposed safety systems have been reviewed to assess their likely impact on operational safety. A comprehensive review has not been possible since these are not fully developed; however, some recommendations have been made which should be taken into account in developing management, training and operational procedures for the site.

Further, safety studies are recommended for a later stage to ensure that the plant as designed, constructed, commissioned and operated, conforms to modern safety standards.

Summary of Recommendations

The recommendations made are given in Section 10.2. Each has been identified by a letter and number. They have been classified under various headings which are given here together with their identifiers. Further details should be sought in Section 10.2.

- Plant and Equipment
    - Storage Facilities (*Recommendations R1 to R4*)
    - Process Facilities (*Recommendations R5 to R7*)
    - Fire Protection (*Recommendations R8 and R9*)
- Procedures
    - Fire Protection (*Recommendation R10*)
    - Occupational Health (*Recommendation R11*)
- Further Studies
    - Engineering (*Recommendations R12 to R14*)
    - Systems and Procedures (*Recommendations R15 to R18*)

1. INTRODUCTION

1.1 Background

The Hong Kong Government has recently accepted a tender bid for the design, construction, commissioning and operation of the Chemical Waste Treatment Facilities (CWTF) to be built on Tsing Yi Island, adjacent to the New Territories. As part of the outline design process, Dames & Moore has been contracted to carry out an Environmental Impact Assessment and Hazard Assessment of the proposed facility; Dames & Moore in turn invited Technica to participate in the Hazard Assessment.

In Hong Kong, the control of major hazards is achieved under the PHI (Potentially Hazardous Installation) system, whereby installations having onsite more than certain threshold levels of specified hazardous materials are required to meet specified risk guidelines. Although the CWTF inventories of such materials will not exceed the threshold levels, it is the clear intention of the Government that hazards on the CWTF should receive attention appropriate to their scale.

Technica carried out a coarse QRA (Quantitative Risk Assessment) of the conceptual design of the CWTF as it existed towards the end of 1988 as part of the Tsing Yi Island Risk Reassessment Study for the Hong Kong Government (also in association with Dames & Moore). As part of this study, comprehensive databases of population, meteorology and ignition sources on Tsing Yi were compiled. The risk results presented there showed that the facility was acceptable under the Government's Interim Risk Guidelines.

The design, construction, commissioning and operation of the CWTF was then put out to tender by the Hong Kong Government in mid-1989; at this stage Dames & Moore and Technica submitted a joint proposal to carry out the Environmental Impact Assessment (EIA) and Hazard Assessment (HA) required by the Hong Kong Government, with Technica to carry out the revised HA.

The contract for the facility was awarded in November 1990 to Waste Management International, which has set up a subsidiary company, Enviropace, to manage the project and operate the facility. The Hazard Assessment was required prior to detailed design of the facility in order to identify any part of the proposed operations needing to be addressed in the detailed design with regard to the risks posed.

The proposed Chemical Waste Treatment Facilities will not have large enough inventories of hazardous substances for it to be classified as a PHI. However, the potential offsite risks to the public and the environment are considered sufficiently significant for a detailed risk assessment to be required.

This document reports the Hazard Assessment carried out for the CWTF according to the Scope of Work defined below in order to meet the requirements of the Hong Kong Government. The basis for the study and methodology adopted are set out; the results, conclusions and resulting recommendations from the study are given.

1.2 Scope of Work

The Scope of Work, developed by the Hong Kong Government on the basis of Key Inception Report 3 (a brief preliminary risk assessment by ERL) recommended that the following be addressed and reported:

1. Potential hazard review of anticipated waste chemicals imported onto the site in terms of their fire, explosion and toxic risks.

2. Review of potential hazards due to interactions between chemical wastes should inadvertent mixing occur.

3. Review of tank storage and operating procedures to ensure safe storage and separation of incompatible chemicals.

4. Review of the physical/chemical treatment system and incineration system; identification of potentially hazardous incidents in normal and abnormal operating conditions of these systems.

5. Estimates of failure frequencies for potential releases identified, using generic data where available and simplified fault trees where necessary. (Note: it is not possible at this stage to carry out a quantitative assessment of the effect of management systems on failure rates).

6. Calculation of offsite individual and societal risks.

7. Development of a list of Key Issues to be addressed in the Detailed Design.

1.3 Basis of This Study

This Study addresses the **offsite risks of fatality from acute exposure to hazardous materials** which would be generated by the Chemical Waste Treatment Facilities. It includes consideration of potential hazards due to safety management and treatment process failures as well as those intrinsic to the materials, storage and processes.

The information on which the study has been based is that provided in December 1990 and is contained in the following documents and extracts produced by Enviropace Limited:

TENDER VOLUME 3: DETAILS OF FACILITIES DESIGN AND EQUIPMENT

Section 1 (with revisions)
Appendix A - Technical Schedules

TENDER VOLUME 5: DETAILS OF THE PROPOSED OPERATING SYSTEM

Main text (with revisions)
Table 9.3-2: Work Schedule
Appendix A: Definition of MARPOL Wastes
Appendix D: Training Plan
Appendix E: Emergency Response and Fire Fighting

PLANS

Main Site Plan
Waste/Reagent Storage
MARPOL Waste

2. METHODOLOGY AND EVALUATION CRITERIA

2.1 Classical Risk Assessment Method

Quantitative Risk Assessment (QRA) is a means of making numerical estimates of the risk from hazardous activities using an accepted methodology and making a rational evaluation of their risk implications. Taking each of these words in turn:

* the **quantitative** nature of the assessment provides a precise and objective means of assessing the risk from hazardous activities;

* it can be used to calculate both **individual** and **societal** risk as defined below (Section 2.3.1);

* **assessment** of the calculated risk against agreed criteria is required in order to make decisions.

The five normal components of a full quantitative risk assessment are:

* hazard (or failure case) identification and specification
* failure frequency estimation
* consequence calculation
* risk analysis
* risk assessment

Figure 2.1 shows their relationship. In order to undertake such an assessment, information is required about the plant under consideration and the context in which it is set. Figure 2.1 also shows these external data requirements.

Failure Case Identification

The aim of failure case identification is to define a set of cases that represent the infinite number possible. Failures can occur in several ways:

- In normal service (for example, due to pipe wall corrosion or external impact)

- Under abnormal conditions (for example, pressure exceeding design pressure)

- Due to operator error

- Due to failure of safety systems

Consideration of all these potential failures results in the inclusion of all hazards. Historical records of accidents, experience and checklists can all be used in developing the failure case set.

Failure Frequency Analysis

For each failure case identified, the failure frequency must be determined. This can be carried out by a number of means:

- Analysis of historical data
- Fault-tree analysis
- Reliability database
- Expert judgement based on experience

In general, Technica regards the use of historical data as the most accurate since the set of recorded incidents of a given type of failure in principle covers all causes, whereas a fault-tree or reliability analysis depends on the analyst considering all causes.

Consequence Modelling

Consequence modelling covers the following:

- Modelling dispersion of gas releases
- Calculation of thermal radiation effect distances for the different fire consequences of flammable releases
- Calculation of distances to specified overpressures or damage levels resulting from explosions
- Calculation of risk of fatality from toxic releases as a function of distance

This is carried out for each failure case identified, under a number of different characteristic weather conditions.

Risk Calculation

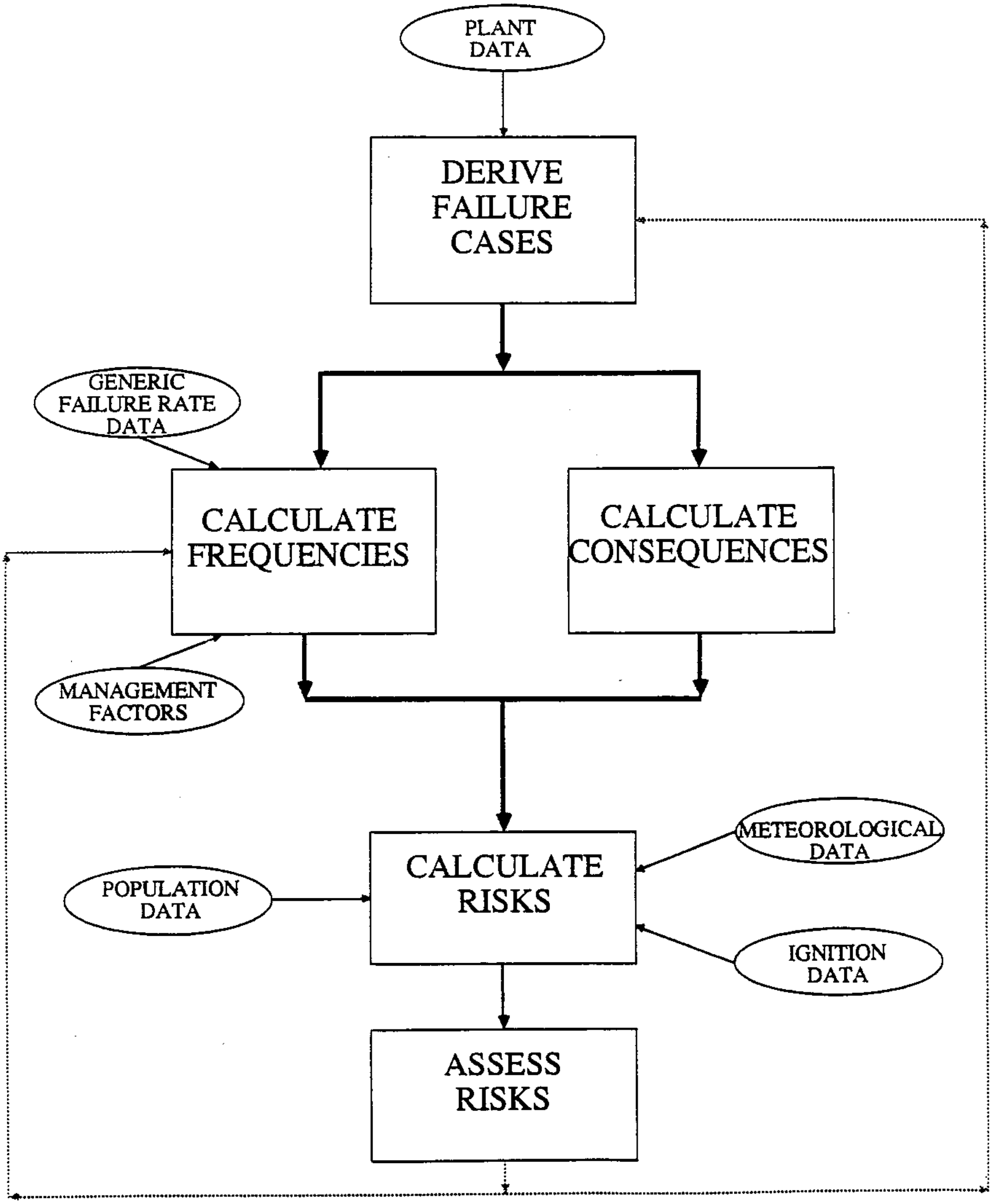
The results of the Consequence Modelling are combined with the failure frequencies for the cases, with wind direction and weather condition probabilities and (for flammable gas releases) with ignition probabilities based on a map of ignition sources in the locality. These are used to generate risk contours to show individual risk and F-N curves to show societal risk (see definitions in Section 2.3.1 below). The contributors to both individual and societal risk can be ranked to show which dominate.

Risk Review

The results generated by the Risk Calculations are thoroughly reviewed. Both risk contours and F-N curves are compared with criteria (see Section 2.3 below). Problem areas can be highlighted and their causes traced back via the rankings to the major contributors. The assumptions leading to the specification of these or to their failure frequencies can then be checked and ways of reducing significantly their contribution considered either for frequency reduction or consequence mitigation. This may be applied to the item itself (e.g. vessel inventory reductions), to the safety systems or to the human element (e.g. management training). The sequence of steps shown in Figure 2.1 can then be repeated until the plant meets the criteria.

The ranking of risk generators also facilitates identification of those which are significant for the purposes of developing an emergency response plan.

FIGURE 2.1: THE CLASSICAL RISK ASSESSMENT METHOD



2.2 The SAFETI Package

Technica has developed a suite of computer programs (the SAFETI package) to implement the methods of risk assessment described above. The programs which make up the package enable the analyst to enter all the data required and to proceed through the various stages of the risk analysis in a logical sequence. This is illustrated in Figure 2.2. The package is described in more detail in Appendix V.

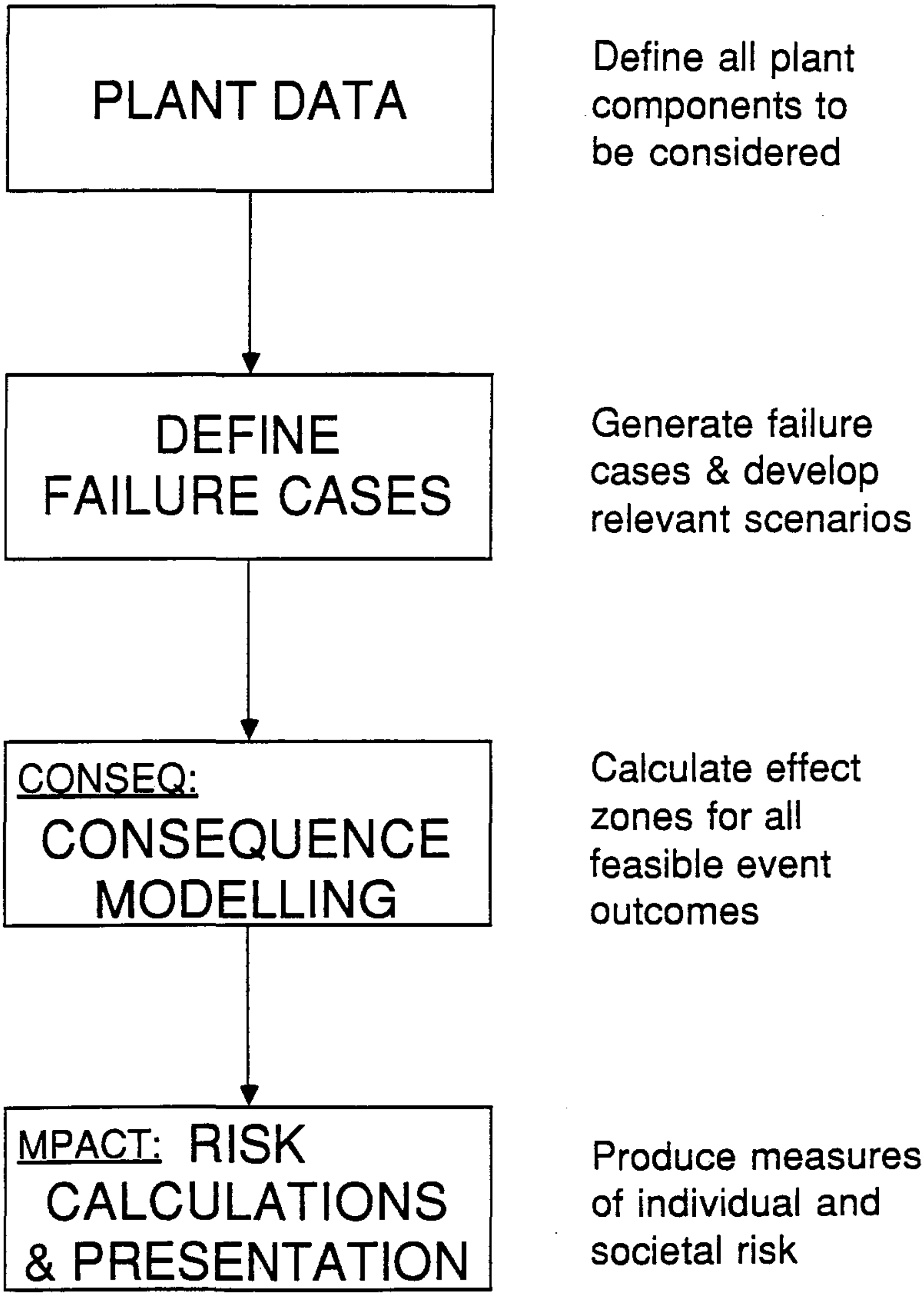
Once the initial conditions for each event have been specified, the analyst can first use the package to calculate the release conditions (e.g. flow rate, velocity, thermodynamic conditions) which provide the initial conditions for the consequence modelling, the next stage in the procedure. A wide range of release types can be modelled: instantaneous and continuous releases from pressurised, refrigerated or atmospheric storage or process vessels and associated pipework. Pool fires and BLEVEs can also be specified directly. The consequence models consist of atmospheric dispersion models for both flammable and toxic materials, explosion and thermal radiation models for flammable materials and a toxic effect model for toxic materials. Dose criteria (such as probit equation coefficients) may be modified by the user.

Following the consequence modelling, risk results are calculated in the MPACT program. For flammable materials this incorporates event trees which allocate feasible outcomes (pool fire, jet fire etc.) to each failure case according to conditional probabilities (which the analyst can change from default values). The consequence results are combined within the program with population, meteorology and ignition data as well as the event tree probabilities to compute individual and societal risk and to plot the results as risk contours and F-N curves respectively. The contribution and ranking of each incident may be printed.

The SAFETI package is sometimes thought of as applying only to pressurized continuous process plant as this has historically been the area of its most frequent application. In fact this is not the case. The Dutch Government, which specified the basis for the package, insisted that it have the capability to deal with the full range of process incidents. These can arise in atmospheric equipment (e.g. storage tanks) as well as pressure vessels and in batch operations as well as continuous ones. The input format to the program specifically allows for all types of incidents. As with all general purpose programs, careful thought and experience is required on the part of the risk analyst to ensure that specific release cases are suitably defined for the program. Once a hazardous material is lost from containment, whether this be from continuous or batch processes, pressurized or ambient conditions, then the wide variety of possible outcomes are all investigated rigorously by SAFETI through its general purpose routines.

Where a risk does not fit well into the context of SAFETI, then special analysis is preformed. This was done for the CWTF for a fire in Building 16.

FIGURE 2.2: MAJOR COMPONENTS OF THE SAFETI PACKAGE



2.3 Risk Evaluation Criteria

2.3.1 Definitions

Risk is commonly evaluated by two measures: **individual risk** and **societal risk.** Both measures are required by the Hong Kong Government.

Individual risk has been defined by the UK Institution of Chemical Engineers as:

> **"The frequency at which an individual may be expected to sustain a given level of harm from the realisation of specified hazards."**

It is calculated at individual points and often presented as an iso-risk contour plot overlaid on a map of the area of concern.

The same Institution has defined **societal risk** as:

> **"The relationship between frequency and the number of people suffering from a specified level of harm in a given population from the realisation of specified hazards."**

Societal risk is calculated for the exposed population being considered; it is often presented in the form of a plot showing the cumulative frequency of accidents involving N or more people sustaining the specified level of harm (e.g. fatality) per year (F-N curves).

2.3.2 Hong Kong Government Criteria

The Hong Kong Government has established **Interim Risk Guidelines** for **Potentially Hazardous Installations** (PHIs). These are intended for new PHIs, the expansion of existing ones and control of future development adjacent to PHIs. While the CWTF does not fall within the strict definition of a PHI (which is based on the inventories of hazardous materials stored on the site), it is the clear intention of the Government that hazards on it should receive attention appropriate to their scale; a detailed Risk Assessment was therefore required of the successful tenderer as an integral part of the design process. It is sensible to evaluate the risks according to the criteria in the Interim Risk Guidelines.

It should be noted that, first of all, these are not Regulations but **guidelines**; this suggests that they are one of several inputs to the decision-making progress and that they will not be interpreted absolutely rigidly. Secondly, they are **interim** guidelines, indicating that they are not yet fixed but open to possible future refinement. However, they are the criteria enforced at present, and Technica will base its assessment and recommendations on these.

The **"level of harm"** used in the guidelines is **fatality.**

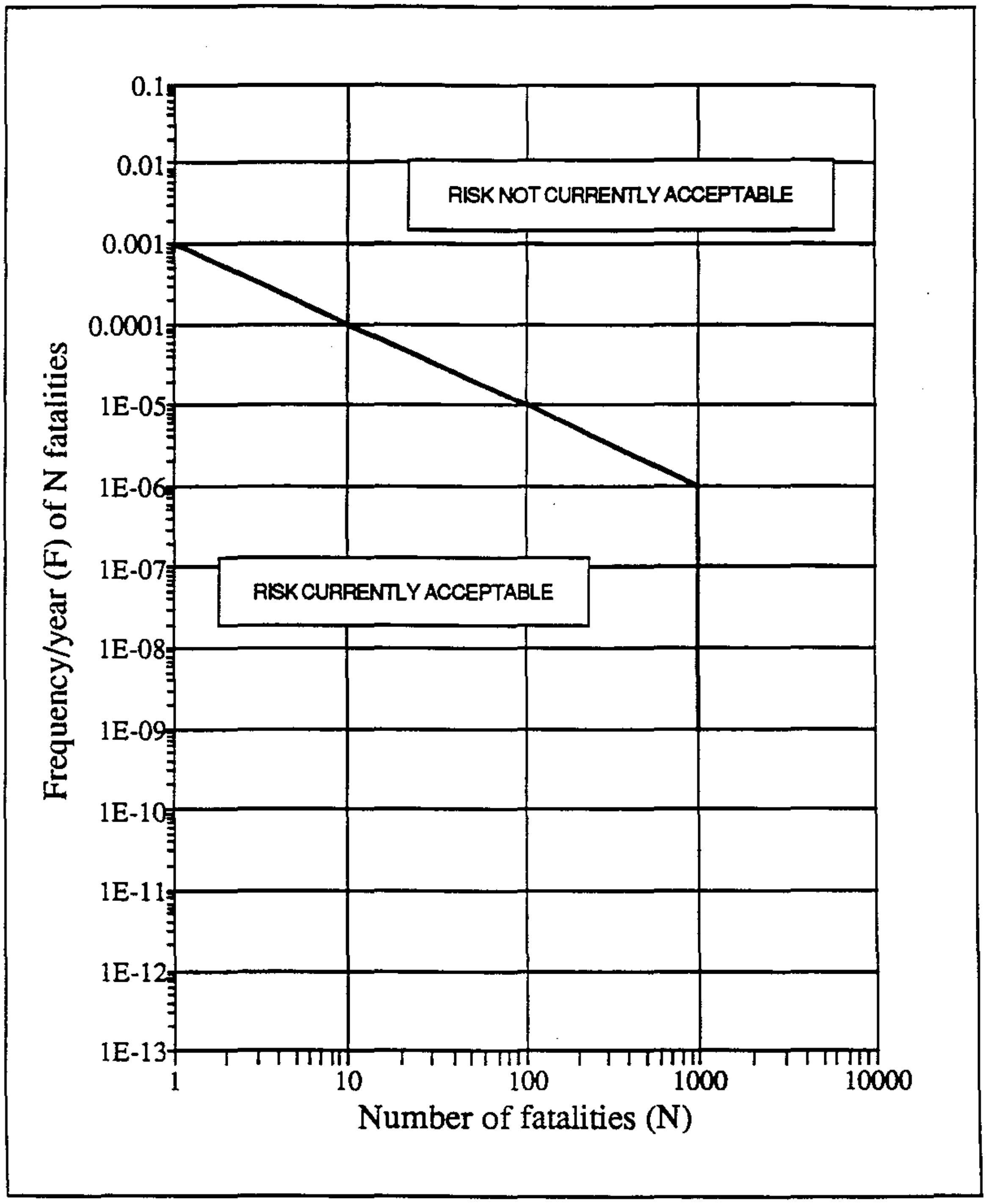
The substance of the guidelines is that developments in the vicinity of PHIs will be restricted if either of the following criteria is violated:

- *the Individual Risk of fatality contour of* 1×10^{-5} *per year passes outside the site boundary*
- *the Societal Risk of fatality exceeds the limits shown in Figure 2.3*

The criteria apply to offsite populations and refer to **involuntary** risk. Staff involved in the hazardous activity may be considered to be benefitting directly from the activity and accepting the risk voluntarily (assuming they are properly educated about it); they should also have specific training to cope with realised hazards, reducing their exposure to risk.

The population for whose protection the criteria apply therefore include nearby residents, occupants of schools and hospitals, people passing on roads and workers on nearby sites.

FIGURE 2.3: HONG KONG GOVERNMENT INTERIM GUIDELINES FOR SOCIETAL RISK



Note: Hong Kong Government wishes societal risk plots to terminate as with their regulations at 10^{-9}/yr.

3. DESCRIPTION OF FACILITIES

3.1 Location

The CWTF is to be built on a site occupying approximately 2 hectares in the south-eastern corner of Tsing Yi Island, illustrated in Figure 3.1. It would be situated to the east of the China Resources Petroleum and Chemical Company Limited (CRC) Tsing Yi Terminal. The Tsing Yi Road, which follows the island's coast, would form the north-western boundary of the site; the Dow Chemicals and TCVT Chemical Plants are situated on the opposite side of the road.

3.2 Site Activities

3.2.1 Purpose of Facilities

The Chemical Waste Treatment Facility is to receive and process a wide range of chemical waste produced by land based chemical and industrial processes in Hong Kong and by marine operations covered by the MARPOL convention. At present there is no similar establishment in the Territory. The design basis for the facility is to treat waste from an estimated 10,000 generators.

The range of chemical wastes to be treated includes waste oils, oily water, acids, alkalis, solvents and other organic and inorganic compounds. These will be delivered both by road and by sea.

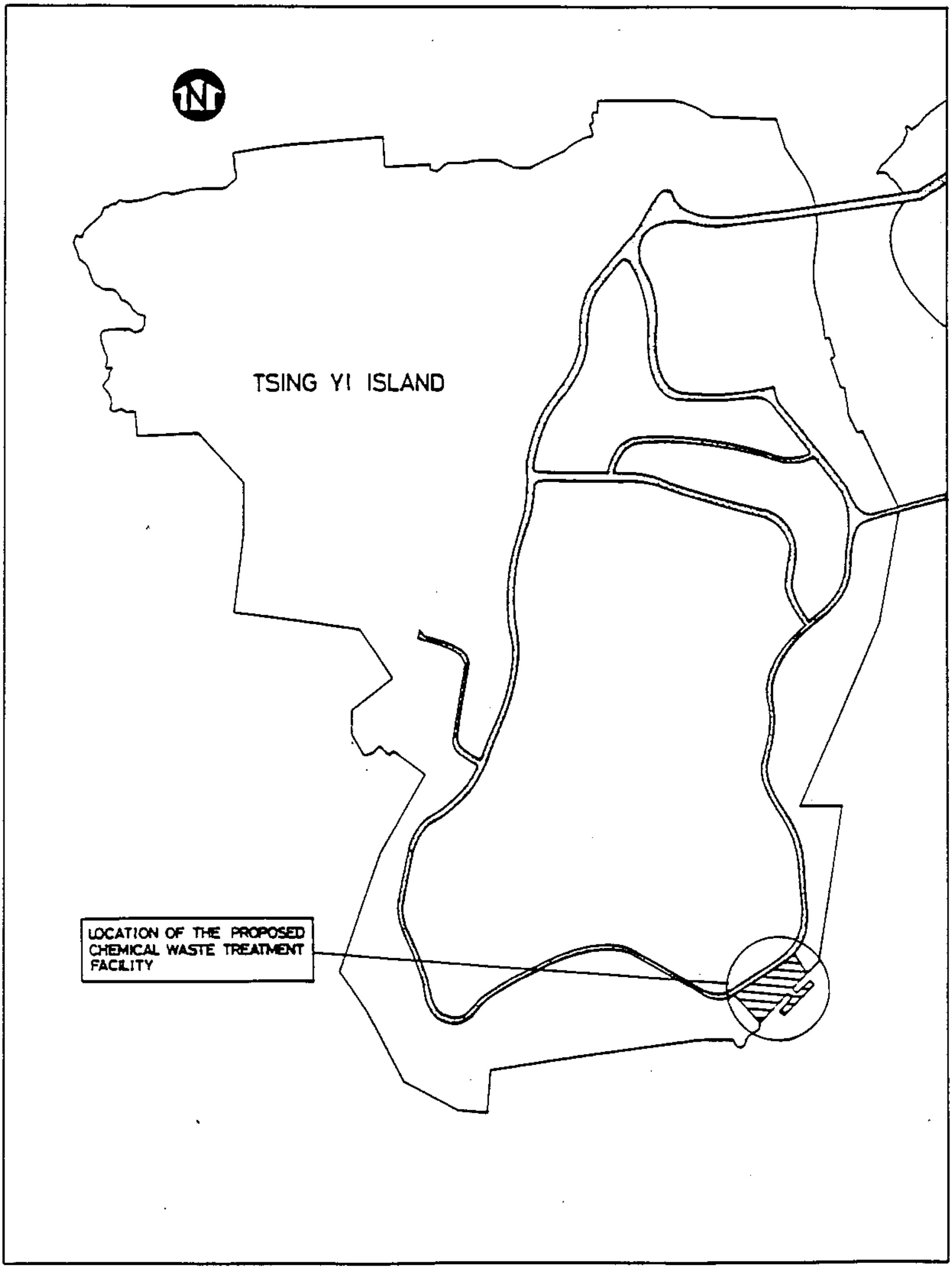
Changing patterns of industry and technology, the impact of regulatory controls, the opportunities for waste disposal presented by a new treatment facility, and the need to ensure that risks to health, property and the environment do not exceed the threshold of acceptability, are key factors in determining the most appropriate design for the Hong Kong CWTF. The Chemical Waste Treatment Facilities are designed to permit maximum processing flexibility in the treatment of waste.

Most of the treatment processes at the CWTF will operate for one or two shifts per day on 5-6 days per week. The incinerator will operate 24 hours per day, 7 days per week and has excess capacity for both solid and liquid wastes. The neutralization and the PO*WW*ER processes will also operate continuously.

The broad range of chemical wastes it is expected that the CWTF will be called upon to deal with is shown in Table 3.1. Also shown in this Table is the anticipated method of treatment for each waste category. Some of the individual groups of wastes indicated in the Table contain a very wide variety of individual chemical substances that may require to be treated.

This calls for a corresponding flexibility in the treatment capabilities of the CWTF. Also, for the reasons stated above, there is an uncertainty in the nature of the arisings and there is a likelihood of receiving chemical wastes additional to those in Table 3.1 For example, there may be a future need to treat hospital waste and redundant pesticide stocks; also, the phasing out of the use of acid-alkali etchants in favour of other processes is likely, as has occurred in the US.

FIGURE 3.1: MAP SHOWING LOCATION OF CHEMICAL WASTE TREATMENT FACILITY ON TSING YI ISLAND



In order to accommodate the widest range of chemical wastes, three broad-spectrum workhorse treatment processes have been included, that surpass the performance of conventional systems. These are: rotary kiln incineration, stabilization, and a proprietary aqueous treatment process called PO*WW*ER.

The incinerator can treat most anything organic substances, PO*WW*ER can treat most aqueous streams, and stabilization can immobilize toxic metals in the residues of these or other processes. The treatment facilities are discussed in further detail in Section 3.2.5.

3.2.2 Materials Handled

The total chemical waste arisings in Hong Kong in 1987 were estimated at 97,755 tons per year. This is forecast to have risen to 100,000 tonnes by 1992 and to 130,000 tonnes by 1997, an overall increase of almost 40%. Acid and alkali together constitute approximately 56% of the total arisings. Forecasts for 1992 and 1997 are based on a similar proportion of acid/alkali waste. Detailed forecasts are summarised in Section I.4 of Appendix I.

The other major contributors to the waste and their approximate percentages are: spent Printed Circuit Board Etchants and other Copper containing waste solutions (13%). oil/water mixtures (12%), mineral oils (6%), MARPOL (Annex I and II) wastes (6%), solvents (including halogenated and non-halogenated solvents) (3%) tank cleaning sludge (1%), other metal salts containing waste (1%), and another twenty waste types that together constitute approximately 2% of the total.

MARPOL-I wastes are petroleum-based wastes. MARPOL-II wastes are inorganic and organic chemicals resulting from the washing of tanks that have been used to transport chemical products. Representative selections of MARPOL-I wastes are shown in Table II.2, Section II.5 of Appendix II.

The anticipated materials handled are specified in Table 3.1, along with their method of disposal. The exact composition of these wastes can vary within a very wide band, and they invariably consist of a number of different materials.

The different waste categories and their likely composites are now discussed.

TABLE 3.1: WASTE ARISINGS AND TREATMENT ANTICIPATED

		ANTICIPATED DISPOSAL METHOD		
WASTE TYPE	1987 AMOUNT GENERATED (tpa)	PHYSICAL/ CHEMICAL TREATMENT	OIL/ WATER SEPAR-ATION	INCINER -ATION
Acid	20000	20000		
Alkali	35000	35000		
Copper-Containing Waste Solution:				
• Acid Spent Printed Circuit Board Etchant	7600			
• $FeCl_3$	6300	6300		
• $CuCl_2$	1300	1300		
• Alkali Spent Printed Circuit Board Etchant	4900	4900		
• Copper Waste Solution from Other Factories	140	140		
Zinc-Containing Waste Solution	13	13		
Nickel-Containing Waste Solution	120	120		
Other Metal Salts Containing Waste Solution	1200	1200		
Cyanide-Containing Solution	100	100		
Non-Chromium-Bearing Oxidizing Agents	10	10		
Chromium-Bearing Oxidizing Agents	55	55		
Halogenated Solvents	1300			1300
Non-Halogenated Solvents	1500			1500
Phenol and Derivatives	2			2
Polymerization Precursors and Production Wastes	40			40
Mineral Oils	5600		1300	4300
Fuel Oil	50			50
Oil/Water Mixture	12000		11400	500
Pharmaceutical Products	1			1
Mixed Organic Compounds	130			130
Mixed Inorganic Compounds	70	70		
Miscellaneous Chemical Waste	30	15		15
Interceptor and Treatment Plant Sludge	40	20		20
Tank Cleaning Sludge	1000			1000
Tar, Asphalt, Bitumen and Pitch	140			140
Tannery Waste	400	400		
Printing Wastes	90			90
Dyestuff Wastes	70			70
Plating Bath Sludges	10	10		
Paint Wastes	640			640
Waste Catalysts	4			4
MARPOL Annex I	5000		250	4750
MARPOL Annex II	500	250		250
TOTAL (tpa)	97755	69903	12950	14902

NOTES Physical/chemical treatment includes oil/water separation
tpa = Tonnes per annum

Inorganic Wastes

These make up in excess of 70% of the total waste to be processed, of which almost 80% is acid and alkali. These wastes may contain heavy metals, such as lead and cadmium.

Alkalis

Alkali is the most abundant of the waste arisings and is forecast to increase dramatically by 1997 (Appendix I, Section I.4).

The major industrial alkalis are:

Calcium oxide (quicklime)
Calcium hydroxide (slaked lime)
Sodium carbonate (soda ash)
Sodium hydroxide (caustic soda)
Ammonium hydroxide
Sodium phosphates
Sodium silicates
Potassium carbonate
Potassium hydroxide

Acids

The most common acids are the inorganic mineral acids: sulphuric, nitric, hydrochloric and phosphoric acids.

Copper-containing Wastes

Copper-containing wastes are predominantly from the manufacture of printed circuit boards. They arrive as either acidic or basic wastes, and are treated separately.

Other Metal-containing Wastes

Other wastes may contain metals, and these must be removed before the treatment process for the bulk of the waste. These wastes are listed as:

Zinc-containing waste solution
Nickel-containing waste solution
Other metal salts waste solution
Chromium-bearing oxidising agents
Plating bath sludges

In addition, the following materials listed may contain metals, but this may be in smaller quantities:

Non-chromium-bearing oxidising agents
Mixed inorganic compounds

Miscellaneous chemical waste
Tannery waste
Printing waste
Paint waste
Waste catalyst

Oils, including MARPOL Annex I Wastes

The MARPOL (MARine POLlutants) Annex I wastes are listed in Appendix II, Section II.5, and consist of a range of different hydrocarbons classified according to volatility. These are primarily from tanker "washout", but other oils and oil-water mixtures are also treated.

Halogenated Solvents

The term halogenated solvent embraces a wide range of organic halogen compounds, not all of which find use as solvents. Examples include polychlorinated biphenyls and mixed halogenated carbons.

Non-Halogenated Solvents

Common solvents in this category are alcohols, ethers and ketones. Aliphatic hydrocarbon solvents such as pentane and hexane and aromatic hydrocarbons such as benzene and toluene are also in this category.

3.2.3 Transport and Reception of Incoming Wastes

Most waste to be treated at the CWTF will be delivered by road. The exceptions are MARPOL I and II wastes which will be delivered routinely by lighter to the CWTF jetty. Non-routine deliveries may also be received at the jetty, for example where it is required to offload a chemical product from a ship to allow repairs to be carried out. In addition to these deliveries, some CWTF treatment chemicals e.g, chlorine and sulphur dioxide will be delivered by road.

Approximately 50% of all waste is expected to be received in containers. However, the CWTF design allows for the receipt of 70% of the waste in containers. Non-MARPOL wastes make up approximately 64,000 tpa (1987 equivalent) which equates to approximately 54 truck deliveries per day. It was assumed that 75% of all containerized waste would be in 200-litre containers and the rest in 20-litre containers. Based on 1987 quantities, the minimum average quantity of containers per operating day is 800 200-litre containers and 2,700 20-litre containers.

Given 300 operating days per year these assumptions predicate that more than 1M containers per year must be handled.

It is also suggested that up to 15 bulk truckloads of approximately 6m^3 of liquid waste will be received per day. Wastes received in this manner are expected to include acids, alkalis, solvents and oils.

Road Transport of Hazardous Wastes and CWTF Treatment Chemicals

The bulk of waste to be transported by road will be in packaged form i.e. in containers of 20 and 200 litres capacity. The rest will be in road tankers. Liquid chlorine and sulphur dioxide for treatment processes such as oxidation of cyanide wastes will be delivered as required in pressurised containers. Both chlorine and sulphur dioxide will be delivered in 1 tonne drums. These are all welded drums of 2m height and 0.8m diameter. Two liquid discharge valves are usually provided, and the valves themselves are protected within a removable cover. Fusible plugs provide suitable fire protection.

Theoretical route options for road transport are:

(i) dedicated RO-RO ferries operating between the container port and Tsing Yi;

(ii) transport via Hong Kong Harbour Tunnel;

(iii) combined road-marine transport utilising jetty points along Kowloon;

(iv) transportation along the existing road network.

Options (i) - (iii) are eliminated on the grounds of cost, impracticable combinations of loading and unloading, and Hong Kong restrictions on use of the tunnel for certain categories of substance. Ferries between Hong Kong Island and West Kowloon will be used for transporting vehicles carrying wastes not permitted in the Cross Harbour tunnels. Thereafter the road system would be used to the site via either the north or south bridge. Marine transport of chlorine and sulphur dioxide drums to Tsing Yi is considered as a transport risk mitigation measure later.

Waste Reception Facilities

It is anticipated that as much as 70% of all waste generated on land will be received at the CWTF by road, packaged in 20- or 200-litre containers. The remainder of the land generated waste will be received in tanker trucks. MARPOL I and II wastes will be received at the CWTF jetty.

Packaged Waste Reception Facilities

Packaged wastes are received at a four-storey reception building. This has facilities for: reception, characterisation, and sorting of wastes into compatible wastes for storage or treatment; decanting of packaged wastes into bulk storage; storage of packaged wastes; cleaning of containers; and storage of clean containers.

Other chemical reagents used will include Portland Cement, Hydrated Lime, Sodium Hydroxide, Sulphuric Acid, Phosphoric Acid, Polyelectrolytes etc. These will be transported by bulk tanker trucks or in packaged forms.

The main reception area has three lines: acid, alkali, and organic-oil/water. Decant wash areas are segregated by floor-to-ceiling walls: each has a dedicated extraction hood system which exhausts through canisters and finally to roof vents, and a floor sump and bund to contain spills.

The three upper floor areas are used for storage as follows:

(i) miscellaneous wastes;
(ii) acids;
(iii) alkalis;
(iv) organics and miscellaneous containers;
(v) clean containers.

The reception procedures for packaged wastes and for bulk wastes delivered by road tanker are illustrated schematically in Figures 3.2 and 3.3. The contents analysed stage is the key to ensuring the appropriate disposition and subsequent treatment of wastes. It consists of a laboratory fingerprinting for the verification of waste characteristics. Quality control is further assured by the requirement for three signatures on documentation.

FIGURE 3.2: RECEPTION PROCEDURE FOR WASTE CONTAINERS

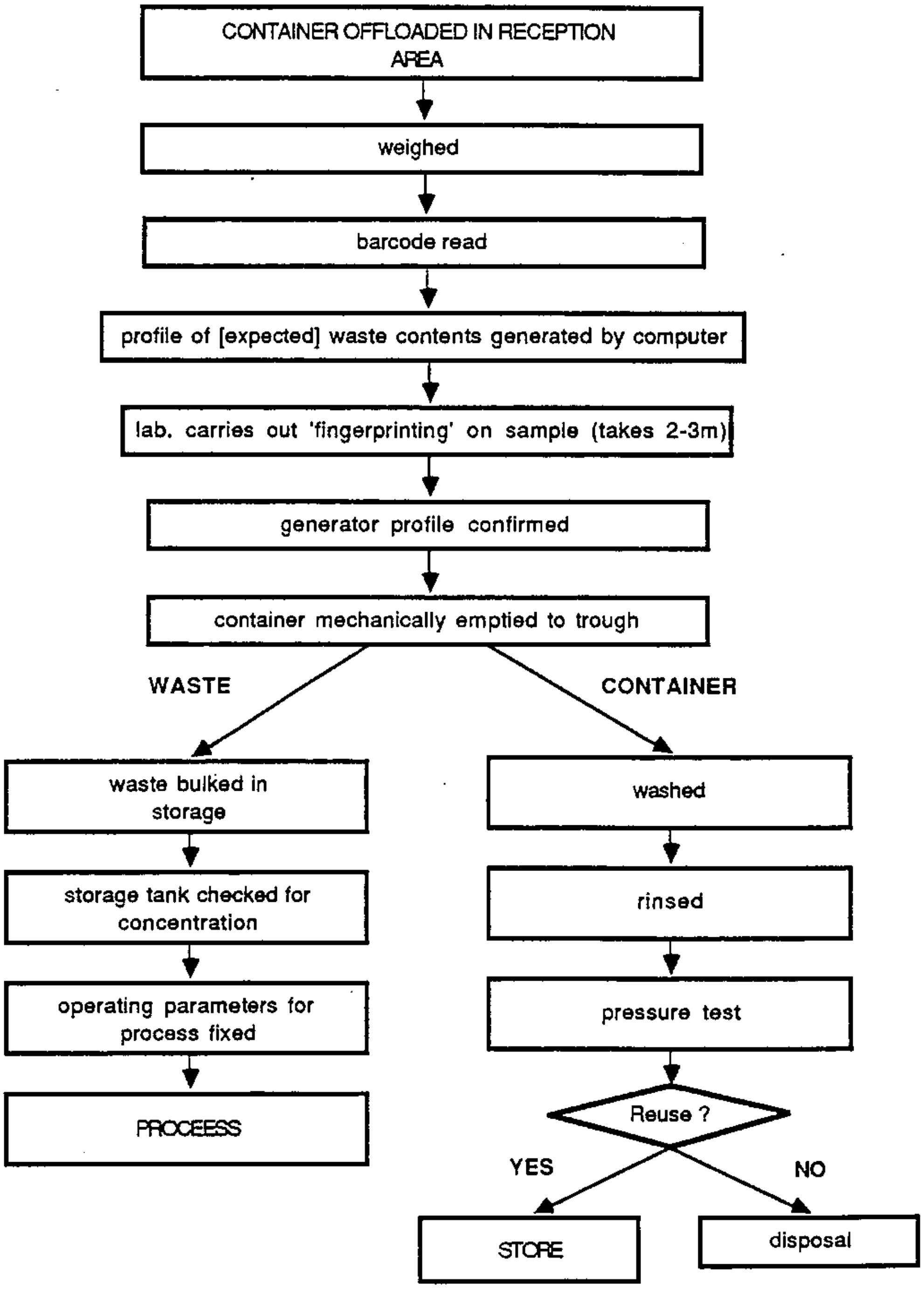
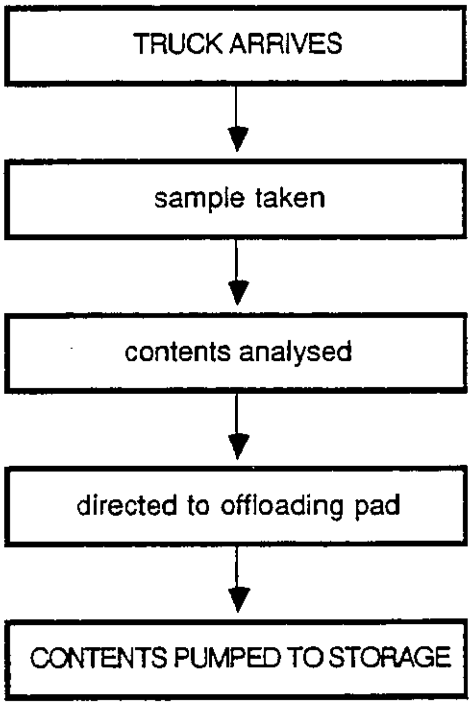


FIGURE 3.3: RECEPTION PROCEDURE FOR BULK WASTE



Reception of Bulk Road Tanker Wastes

The CWTF will have five unloading stations for road tankers. These points are:

(i) a common unloading point for organic wastes and bulk oily waste with segregated piping and unloading facilities for the organic and oily water wastes;

(ii) a common unloading point for acid and alkali waste storage with separate acid and alkali piping;

(iii) a dedicated unloading point for chelated metal wastes;

(iv) an unloading point for non-chelated etchants;

(v) an unloading point for miscellaneous chemical wastes.

All unloading points have hose connections to permit the transfer of wastes into dedicated storage. Sloped concrete sumps and sump pumps will be available to contain and transfer any localised spills, and will be roofed to minimise the accumulation of rainwater in sumps.

Reception of Wastes at the CWTF Jetty

Four categories of wastes will be unloaded at the jetty:

(i) oil/oily wastes (including MARPOL Annex I);
(ii) organic wastes (including MARPOL Annex II);
(iii) acid wastes (including MARPOL Annex II;
(iv) alkaline wastes (including MARPOL Annex II).

MARPOL wastes will be transported by a 1000-tonne (3 compartment) barge. The barge will be making 4-5 laden trips (8-10 movements) per week based on the assumption that an average payload of 40 tonnes in the case of MARPOL Annex I wastes and 20 tonnes in the case of MARPOL Annex II wastes will be carried.

Unloading will be through dedicated flexible hoses and pumps. A mobile crane will be available to assist in the positioning of hoses on the marine vessels. As with the road tanker reception area, there will be facilities to contain and transfer any spills onshore. Any spills into the sea will be dealt with by chemical dispersants and an oil boom kept at the jetty for this purpose.

3.2.4 Storage Facilities

It is necessary to keep most of the wastes that arrive separate from one another because of the different treatment methods they require.

The majority of waste arriving on the site is placed into tank storage. The tanks on the site and the materials they contain are listed in Appendix I.

Also listed in Appendix I are the materials of which each tank is constructed. These are mainly to limit corrosion.

It is very difficult to predict the exact corrosion characteristics of the fluid, since the corrosion rate can be influenced by the presence of a number of materials in the fluids. Some of these catalyse the corrosion reaction and increase the rate; the tanks therefore have been built to quite high corrosion resistance to take account of this.

Vinyl ester has been used to line a number of large carbon steel tanks; this is an acid- and base-resistant lining suitable for use in large vessels due to its relatively low cost.

High density polyethylene is used mainly for the metal-containing inorganic solutions, to eliminate any possibility of catalytically enhanced corrosion by metals. Metallic containers are generally regarded as being unsatisfactory for inorganic salts. Plastics are also insensitive to changes in pH or impurities, changes which can affect metals adversely. Their major limitation, not being able to survive high temperatures, is irrelevant in normal operations and storage. However, in the event of flame impingement from a fire or other source, the integrity of these containers could be damaged or destroyed. Consideration will have to be given to the siting of the polythene-lined tanks with respect to process or storage facilities which are potential sources of flame and to the need for providing protection against flame impingement.

3.2.5 Treatment Facilities and Processes

The CWTF and its processes are based on a combination of: physical/chemical treatment including oily water/oil separation, incineration and stabilization. The process block diagram Figure 3.4 shows a typical flow scheme for an integrated chemical waste treatment facility. A solvent recovery system is referred to in the Tsing Yi Risk Reassessment Study report (Technica/Hong Kong Government 1989) dealing with the Chemical Waste Treatment Facility and also in ERL's preliminary risk assessment but not in the current CWTF plant process design by Enviropace. For the purposes of the present report it will be assumed that there will be a solvent recovery plant incorporated in the future.

Physical/Chemical Separation

The type of physical/chemical treatment required for a particular type of waste depends whether it is primarily an aqueous or an organic liquid phase or a solid.

Treatment of aqueous phase wastes includes physical processes such as:

(i) gravity settling to separate solids from liquids;
(ii) removal of excess liquid by gravity thickening or pressure filtration;
(iii) flocculation of suspensions to improve filtration properties;
(iv) disposal of hazardous solid residue to the immobilization process.

In addition, there are chemical processes to chemically convert hazardous wastes to non-hazardous forms. These include:

(i) neutralization of acidic wastes by alkali;
(ii) neutralisation of alkaline wastes by acid;
(iii) oxidation of cyanide and possibly sulphide wastes;
(iv) reduction of oxidising wastes such as some chromium wastes;
(v) oxidation of aqueous ammonia in etchants;
(vi) precipitation and immobilisation of heavy metals.

A schematic flow diagram of a typical physical/chemical treatment section of an integrated chemical waste treatment facility is shown in Figure 3.5.

Chemical processes are also used to exploit the potential for the recovery of metals, for example by using caustic boil or iron cementation processes to recover copper from etchant solutions.

Metals dissolved in water as their soluble chelates must be removed by chemical processing in order to bring the water quality to the required standard for discharge from the facility. The method of choice is simple precipitation of the metal oxide or hydroxide using alkali. However, as there is a considerable variety of metals and chelates, this can be the most complex of the chemical processing activities.

Two additional processes are available for bringing waste water to the required quality: biological treatment and PO*WW*ER treatment.

Biological treatment consists of aerobic microbial metabolism of organic constituents in the waste water, settling of the sludge and sand filtration of the treated water. Activated carbon filtration is also available in the event that the COD (Chemical Oxygen Demand) of the waste water exceeds set limits.

The incorporation of the biological treatment section of an integrated chemical waste treatment facility is shown in Figure 3.6. This also shows oil recovery and solvent recovery options.

PO*WW*ER is a proprietary treatment system for final treatment of rinse water and waste water from physical/chemical treatment processes. One reason that this process is required is to ensure that the organics content of essentially inorganic solutions is reduced to an acceptable level. The process consists of a combination of evaporation and catalytic oxidation of organics in steam provided by the heat recovery boiler of the incinerator.

Toxic or otherwise hazardous gases can be liberated in the event of inadvertent mixing of certain combinations of chemicals. In order to provide protection against this eventuality, the chemical treatment plant is to be provided with fume extraction facilities which exhaust into the incinerator or scrubbers.

The physical/chemical processes are dealt with in further detail in Appendix I, Section I.3.1.

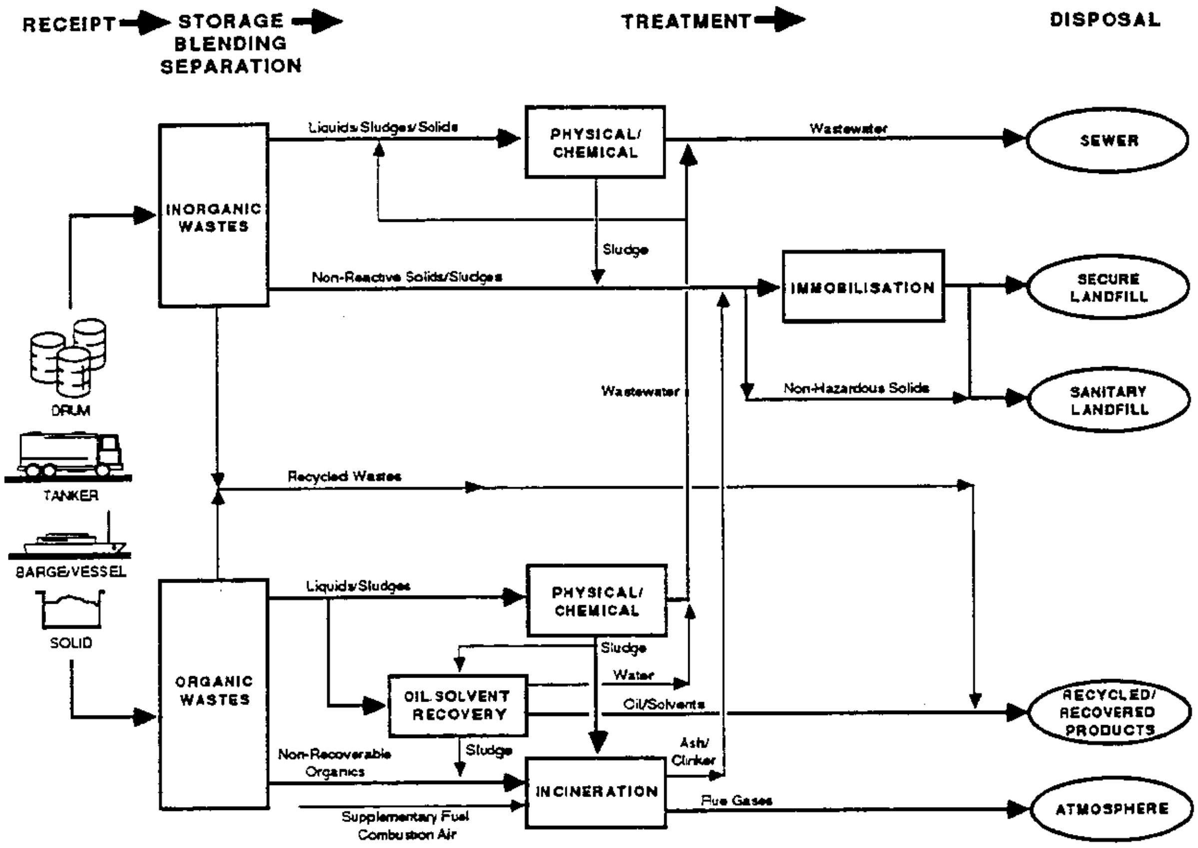
Two reagents used in Physical/Chemical Treatment are of significant potential hazard (see Section 5.2). These are chlorine and sulphur dioxide, stored as pressurized liquefied gases in 1 tonne drums. Chlorine is used in two processes:

1) copper cementation (estimated usage 340 tonnes/yr)) Max usage 371 tpa
2) cyanide oxidation (estimated usage 31 tonnes/yr))

Sulphur dioxide is used in much smaller amounts for the reduction process. Estimated usage is 9 tonnes/yr.

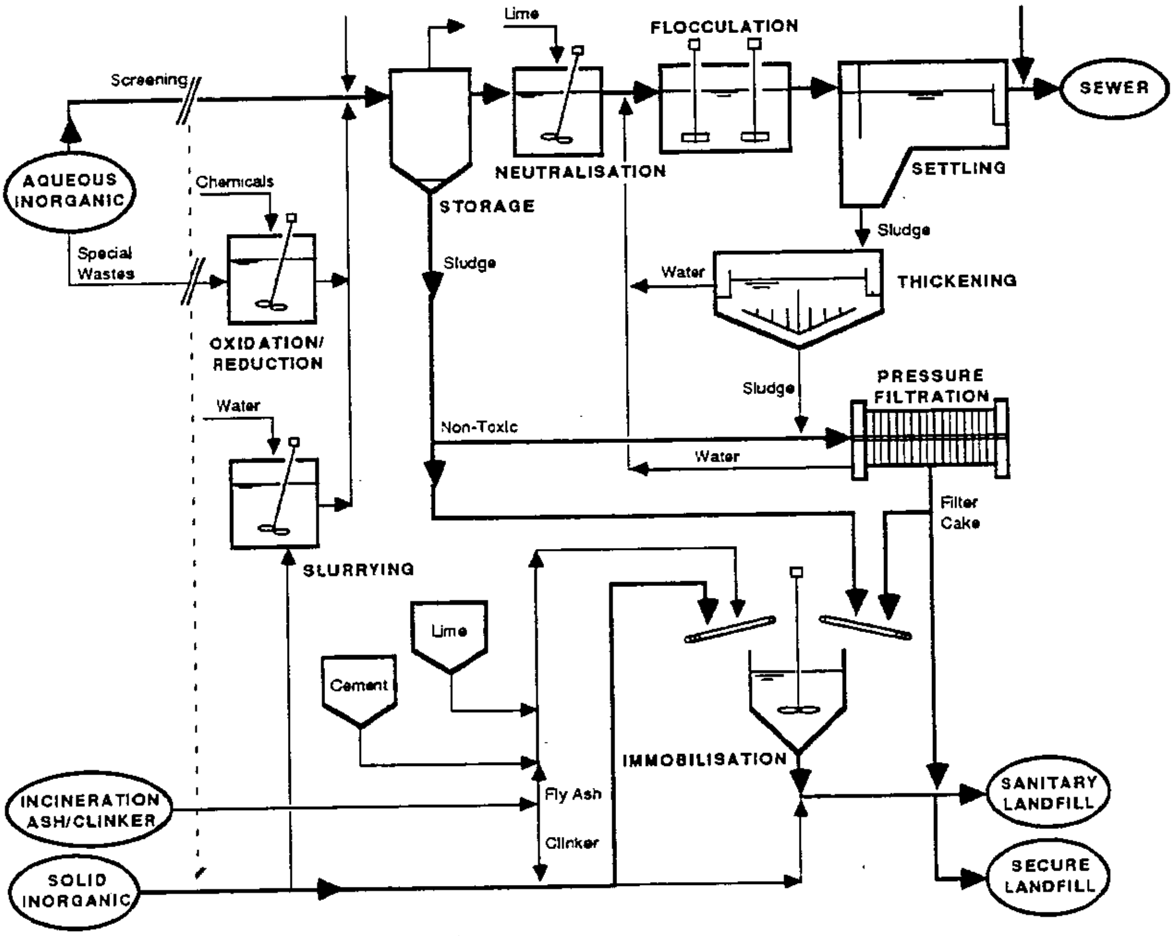
These drums will be stored adjacent to the Physical/Chemical Treatment area.

FIGURE 3.4: SCHEMATIC FLOW DIAGRAM FOR A TYPICAL INTEGRATED CHEMICAL WASTE TREATMENT FACILITY



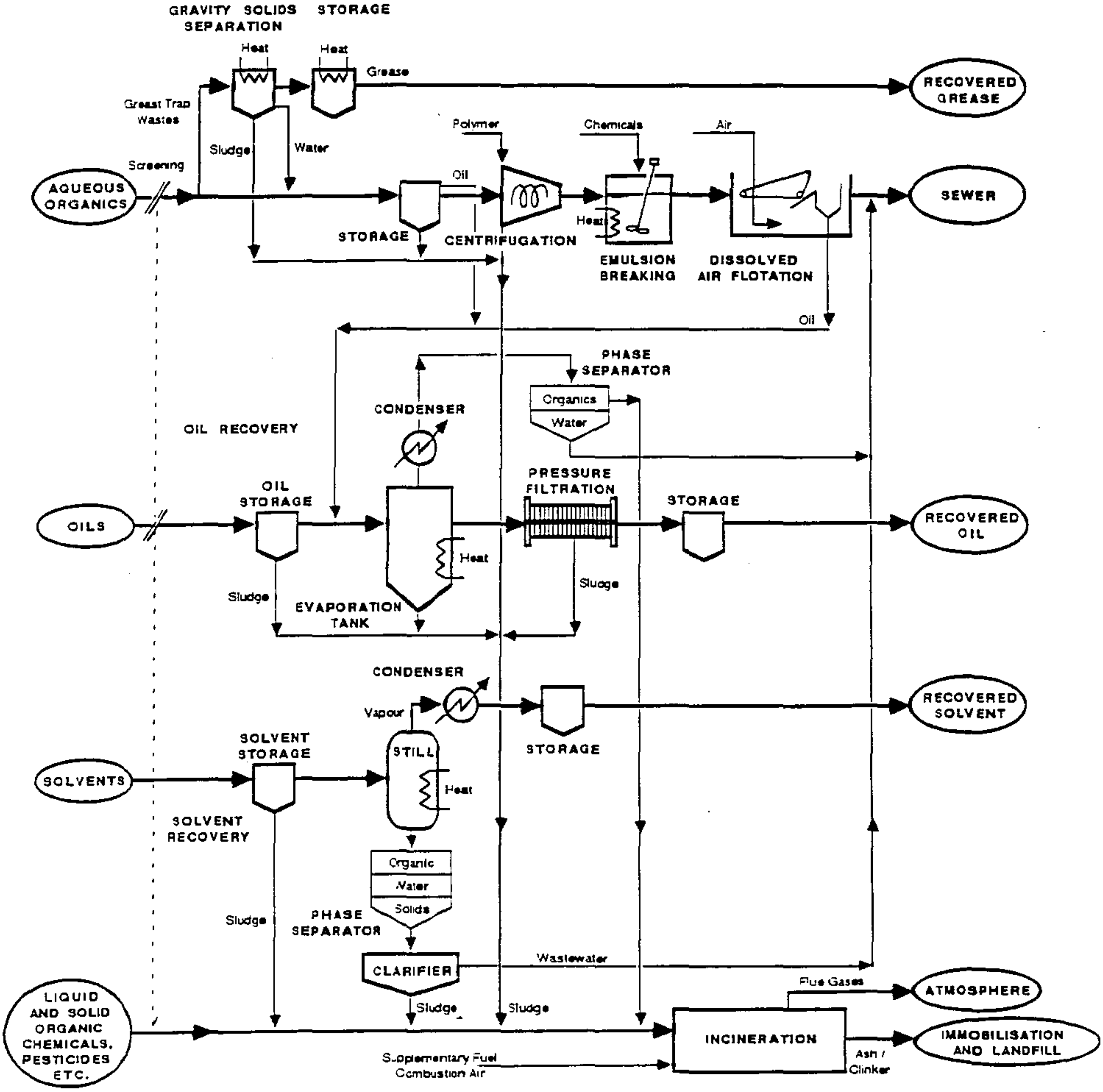
Note: This schematic flow diagram is based on many typical designs but does not necessarily conform to the final design of the Tsing Yi CWTF. The diagram identifies the key aspects that are relevant for assessing risks.

FIGURE 3.5: SCHEMATIC FLOW DIAGRAM FOR THE PHYSICAL/CHEMICAL TREATMENT SECTION OF A TYPICAL INTEGRATED WASTE TREATMENT FACILITY



Note: This schematic flow diagram is based on many typical designs but does not necessarily conform to the final design of the Tsing Yi CWTF. The diagram identifies the key aspects that are relevant for assessing risks.

FIGURE 3.6: SCHEMATIC FLOW DIAGRAM FOR THE ORGANICS TREATMENT SECTION OF A TYPICAL INTEGRATED WASTE TREATMENT FACILITY



Note: This schematic flow diagram is based on many typical designs but does not necessarily conform to the final design of the Tsing Yi CWTF. The diagram identifies the key aspects that are relevant for assessing risks.

Incineration

The incinerator will comprise:

- (i) feed chute;
- (ii) main combustion chamber and feed-air/fuel system;
- (iii) wet ash discharge system;
- (iv) secondary combustion chamber or afterburner;
- (v) exhaust gas stream cooling with heat recovery;
- (vi) spray dryer;
- (vii) dust collector;
- (viii) induced draught fan;
- (ix) incinerator stack.

High temperature incineration involves the two-stage burning of wastes in the presence of an excess of air at temperatures around 1000°C. This is intended to convert carbon and hydrogen to carbon dioxide and water respectively, chlorine to hydrogen chloride, sulphur to sulphur dioxide and nitrogen to nitrogen oxides. Carbon dioxide and water vapour are discharged to the atmosphere. The other gases are scrubbed from the gas stream using injected lime slurry. Metallic and some non-metallic components of the waste form a solid ash which is dropped into a water sump and disposed of as wet ash. An induced draught fan located before the stack accelerates the exhaust gas discharge to atmosphere and maintains a slight negative pressure in the incinerator system to guard against the possibility of leaks of hazardous gases to the atmosphere. The incinerator system is described in further detail in Appendix I, Section I.3.3.

Oil-Water Separation

Heating in a heat exchanger system will be used to break oil-water emulsions with the separated oil being sent to organics storage.

Treatment of oily water is a three-stage process involving primary gravity settling with removal of the free oil or emulsions by a skimmer, an API separator and Dissolved Air Flotation, and a final stage which could be biological treatment, PO*WW*ER treatment or incineration. Further detail of this process is given in Appendix I, Section I.3.4.

Stabilization

Stabilization involves the immobilization of solid residues from treatment by mixing with Portland cement or other appropriate chemical reagents. The residues to be treated in this way are:

- (i) bottom ash and fly ash from various stages of incineration;
- (ii) dust from the dust collector;
- (iii) filter cake from physical/chemical treatment processes;
- (iv) brine slurry from the PO*WW*ER process;
- (v) waste activated sludge from biological treatment.

Solvent Recovery Unit

A solvent recovery unit is not in the current CWTF design but may be considered in the future. The potential risks from such a unit are included in this study.

A typical solvent recovery unit consists of an intermediate storage vessel for the contaminated solvent, a reboiler (usually steam-fed) to heat the contaminated solvent, a distillation column to effect the separation of the pure solvent from the contaminants, a water-fed condenser system to condense solvent vapour, a reflux pump to establish and maintain the optimum ratio of liquid solvent product to liquid solvent column return, and an intermediate storage vessel for the storage of recovered solvent pending its analysis.

Distillation may be effected at atmospheric pressure or under a slight positive pressure depending on the properties of the solvent to be recovered. Pressure relief valves are required for the positive pressure operation. The distillation process may be run as a batch operation or continuously according to the quantities of solvent to be recovered.

An instrumentation and control system will be fitted with facilities for flow, pressure and temperature indication, recording and control.

3.3 Site Layout

The site layout is constrained on the one hand by the site available for construction of the facility and on the other by the requirements of the facilities described above.
The site to be used lies between the Tsing Yi Road and the Rambler Channel, varying between 100 m and 135 m wide; it will be approximately 200 m long. The jetty to be used is an existing one. However it will need to be reprovisioned when reclamation for the container terminal and related developments are implemented.

The facilities to be provided require the following:

- Packaged waste reception
- Packaged waste container storage
- Bulk waste reception
- Liquid waste storage, with separate bunded areas for each group of compatible materials
- Reagent storage
- Physical/chemical treatment process areas
- Incinerator
- Solids stabilization
- Water effluent treatment
- Truck wash/gas station
- Administration/warehouse building
- Laboratory
- Truck parking
- Water effluent treatment
- Utility area

The proposed layout is shown in Figure 3.7. Note that the organics storage and treatment have been grouped together at the southern corner of the site, likewise the inorganics storage and treatment are grouped at the western corner. The loading dock for packaged waste is close to the main gate entrance.

Fire Services Department requires good access to each block or tank for fire appliances and this aspect will need due consideration.

3.4 Site Population

Since the risk criteria in the Hong Kong Government's Interim Risk Guidelines relate to non-PHI population it is not necessary to include the site population in societal risk calculations. However, the presence of people on the site is a potential source of ignition of flammable liquids and vapours released to the atmosphere as a result of some of their activities, even though such activities as smoking will (presumably) be banned. (For example, canteen facilities, driving vehicles about the site, carrying out welding in situ.) The location of personnel on the site is therefore used to add to the ignition source database.

Three shifts will be operated: Day (0700-1500), Evening (1500-2300) and Night (2300-0700). The numbers of people currently planned to be in each major building/area of the site during each shift are given in Table 3.3.

3.5 Site Ignition Sources

Ignition of a dispersing cloud of flammable vapour depends on the number, activity and strength of ignition sources it encounters within its LFL. Those identified within the site, together with their references on the site plan (Figure 3.7), are:

- Incinerator and associated plant (3)
- Air compressors (15)
- Workshop (18)
- Substation (25)
- Auxiliary boiler (39)
- Vehicles

The sources are characterised by their location, their strength and their 'presence factor', i.e. proportion of time for which they are active. This is described in more detail in Appendix IV, Section IV.4.

FIGURE 3.7: PROPOSED SITE LAYOUT FOR CHEMICAL WASTE TREATMENT FACILITY

Note: Key follows as Table 3.2.

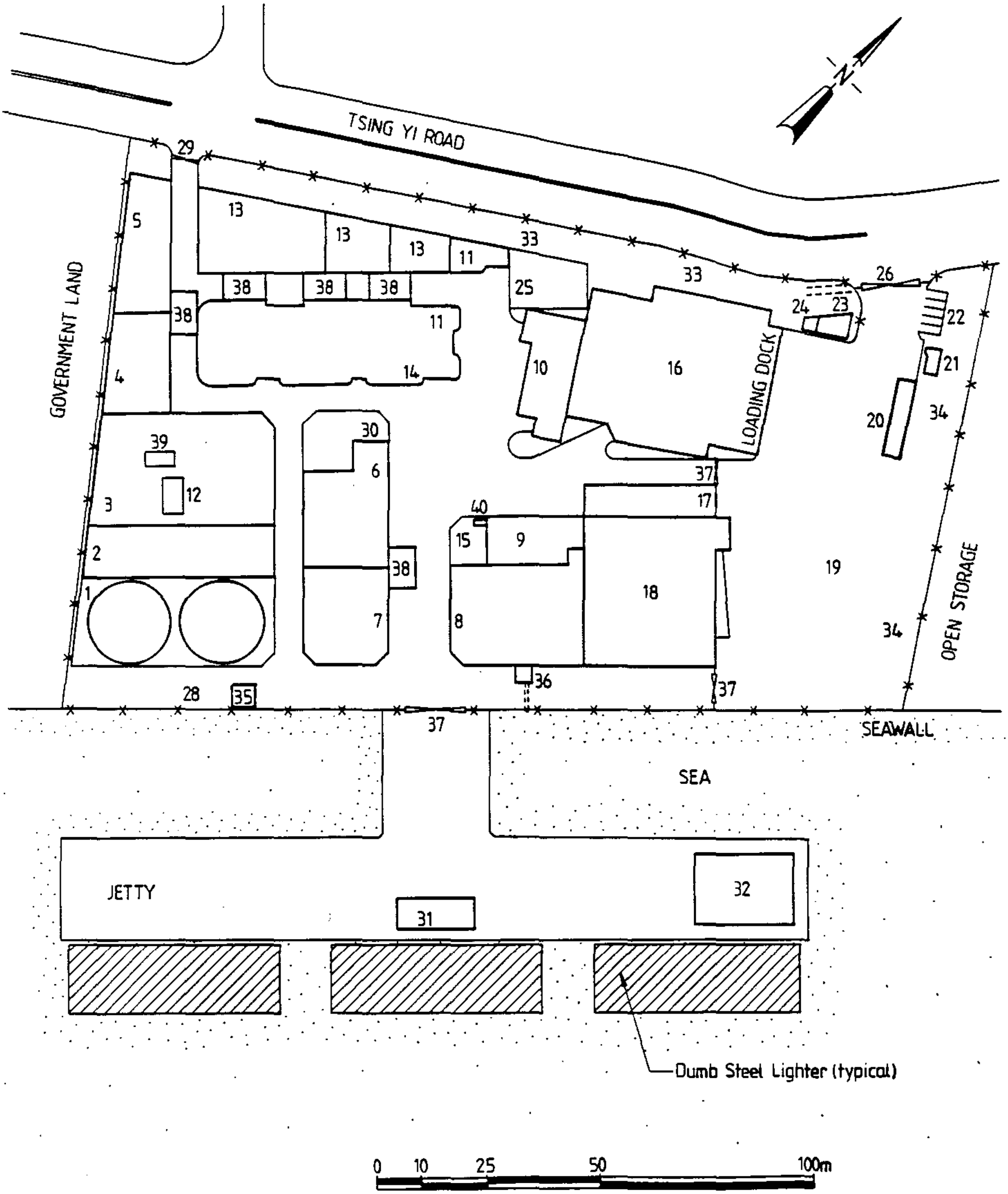


TABLE 3.2: KEY TO SITE LAYOUT (FIGURE 3.7)

1	MARPOL Annex I Storage Tanks
2	Organic Waste Blending Primary & Secondary Oily Water Separation
3	Incinerator
4	Acid Waste Storage Tanks
5	Alkali Waste Storage Tanks
6	Organic Waste Storage Tanks
7	Bulk Oily Waste Storage System
8	Final Water Effluent Treatment
9	Evaporation Unit
10	Solids Stabilization
11	Chemical/Physical Treatment Layout Acid/Alkali Continuous Treatment System
12	Incinerator Control Building
13	Waste/Reagent Storage Tank Farms
14	Cyanide/Chromate Processing Area
15	Air Compressor Area
16	Packaged Waste Reception/Storage Building
17	Truck Wash/Gas Station Building
18	Administration/Warehouse Building
19	Parking and Future Expansion
20	Weighbridge
21	Gatehouse
22	Visitor Parking
23	Fire Water Pump House
24	Sewer Pump & Lift Station
25	Substation
26	Main Gate Entrance
27	
28	Lugger Box Storage
29	Emergency Gate
30	Utility Area
31	MARPOL Waste Reception
32	Oil Dispersant/Boom Storage
33	Reserve for Road Widening/Overnight Truck Parking
34	Reserve for Drainage/Overnight Truck Parking
35	Seawater Intake Pumping Station
36	Seawater Outfall Chamber
37	Secured Secondary Access Gates
38	Bulk Unloading Stations
39	Auxiliary Boiler
40	Evaporation Unit Control Room

TABLE 3.3: PLANNED SITE POPULATION DURING EACH SHIFT

LOCATION	SITE PLAN REFERENCE	PEOPLE ON SHIFT		
		DAY (0700-1500)	EVENING (1500-2300)	NIGHT (2300-0700)
Administration Building	18	58	2	2
Gatehouse	21	1	1	0
Drum Reception Building	16	38	46	0
Warehouse/ Workshop/ Transportation	18, site roads, parking	97	23	0
Processing Areas	2/3/9/ 10/11/14	17	18	8
Laboratory	18	24	26	0
TOTAL	▨	235	116	10

4 BACKGROUND DATA

4.1 Land Use and Population in Vicinity of CWTF

Land use in the vicinity of a PHI determines the nature and density of the population exposed to the risk generated by the installation. Population numbers and locations are in turn needed in order to calculate societal risk. Assessment should also be made of whether there are any specially vulnerable groups (e.g. children in schools, patients in hospitals) exposed to this risk.

The land-use in the vicinity of the CWTF is shown in Figure 4.1. Technica supports the generally good land-use planning strategy developed by the Government, demonstrated by the layout, especially if the planned SETY Development (Container Terminal 9) proceeds. This will give a gradation west to east of high hazard bulk LPG storage at the Esso and CRC sites, moderate hazard fuel storage at CRC, lower hazard CWTF, then lower density industrial usage (lorry parking). There has been some variation to the initial concept in that the Outboard Marine site might be intensified by the addition of about 1070 employees. Also the CWTF site will introduce some hazardous materials (chlorine and sulphur dioxide) not envisaged in 1988, which do pose offsite risk. This report shows later the potential to reduce the risk by various engineering and management system mitigation measures.

The sites nearest to the CWTF are all industrial, with the majority being PHI sites with similar management systems and safety procedures. Technica believes there are additional benefits in concentrating chemical facilities on Tsing Yi Island. This will allow the Fire Services Department to concentrate its chemical specialist officers and firefighters and all the various specialist firefighting and spill control equipment and foam stocks relatively near to the sites.

The nearest residential populations are at Mayfair Gardens (4000 residents) 1.3 km to the North, and the Cheung Ching Estate (25000 residents plus schools) 1.5 km to the North. The Dow and TCVT site populations have been added to the population file. It is understood that a Technical Institute is proposed for the site immediately to the south of Mayfair Gardens: this has not been added to the database, the risk there being negligible as shown in Section 8.

A brief comment on population grid size is warranted. Technica normally employs a 100m grid for population definition. This has been shown over many studies to provide an adequate balance between final study resolution and effort required to specify the input. With reference to the potential risks from the CWTF, the larger incidents involving chlorine travel up to 1000m, and cover over 10 grid squares (for any wind direction). We believe that finer resolution would not be justified.

The population in vehicles is also to be included in the societal risk calculations.

The population on the whole of Tsing Yi Island was researched and presented in detail for the Tsing Yi Risk Re-Assessment Study (Technica/Hong Kong Government 1989); the analysis is not repeated here. It was prepared in a form suitable for use in SAFETI as described in Appendix IV, Section IV.2. In particular, the data were allocated to 100 m grid squares: they are shown in Figure 4.2 in this form.

4.2 Meteorology

The dispersion of vapour released directly into the atmosphere or evaporating from a liquid pool is controlled by the wind speed and atmospheric stability, its direction of travel by the wind direction.

The risk analysis therefore requires a joint frequency distribution of all three variables. The hazard zone due to a pool fire is also strongly dependent on wind speed and direction.

For the consequence modelling, wind speed and atmospheric stability classes were grouped into six representative weather classes defined by combinations of speed and stability.

Again, the meteorology for Tsing Yi Island was developed for the Risk Re-Assessment Study. This took account of the influence of local topography, a significant consideration for atmospheric dispersion on the island. The weather classes and frequency distribution used are given in Table 4.1. The data sources and analysis procedure are described in Appendix IV, Section IV.3.

The other key meteorological parameters are as follows:

Ambient Temperature: 23°C
Relative Humidity: 78%
Ground Temperature: 17°C
Surface Roughness length: 0.1 m

FIGURE 4.1: LAND USE IN VICINITY OF CWTF

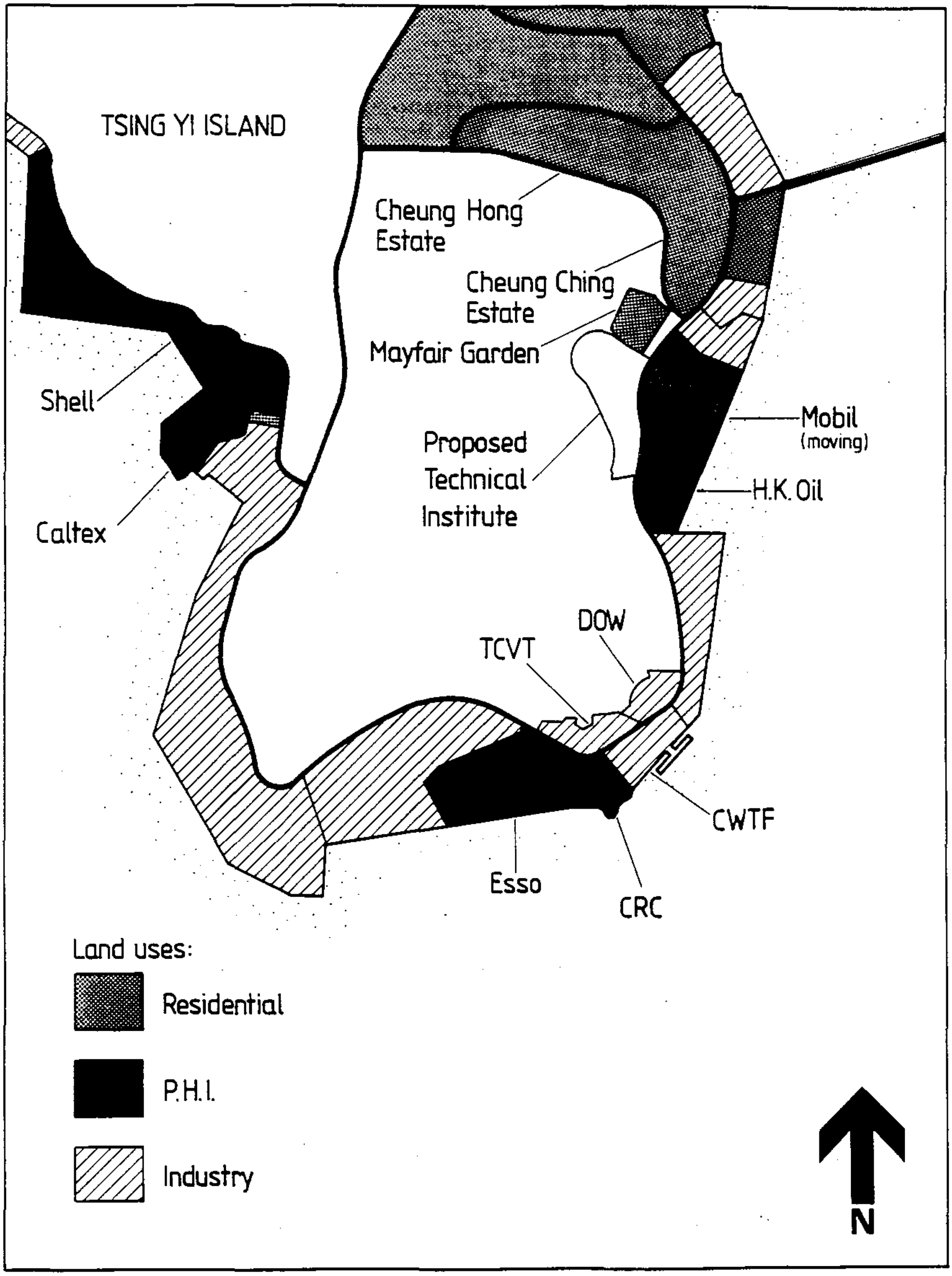


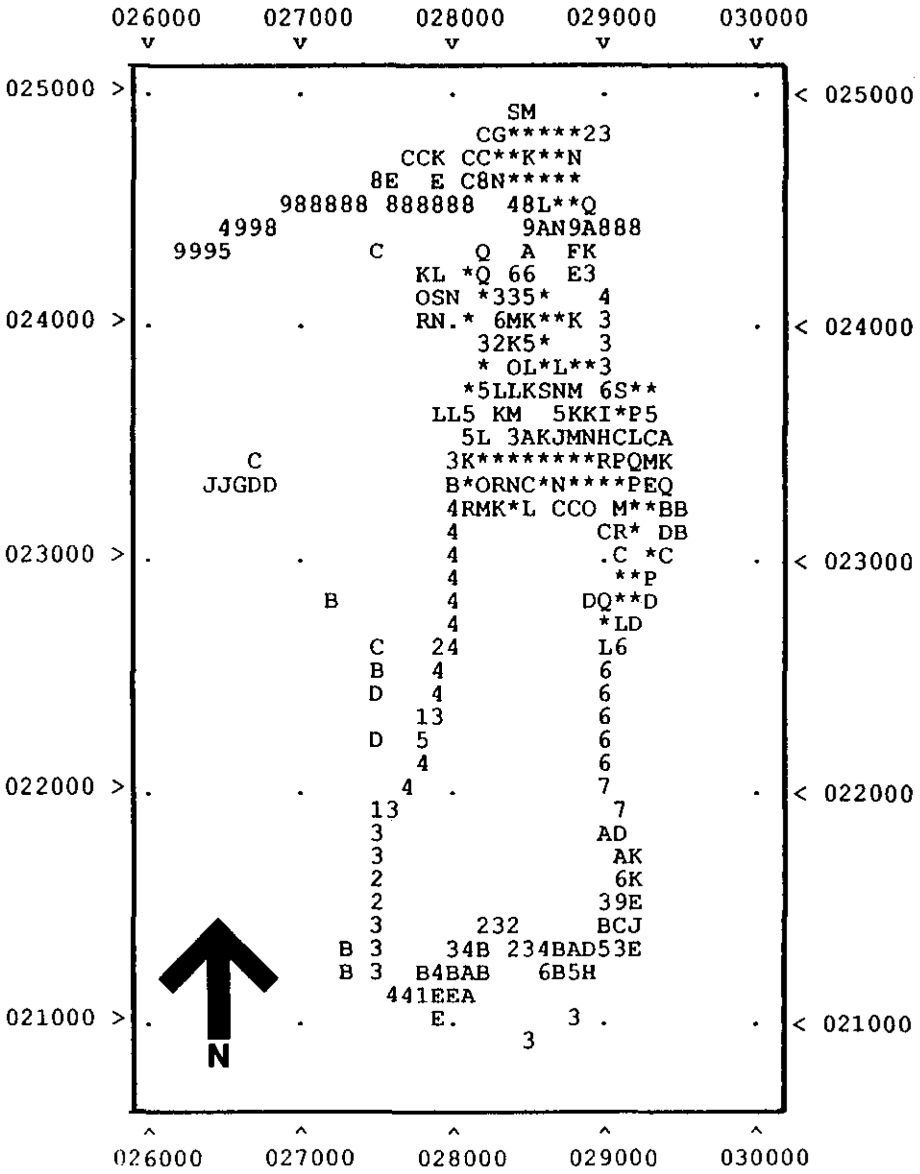
TABLE 4.1: METEOROLOGICAL DATA USED IN SAFETI ANALYSIS

DIRECTION	WEATHER CLASS						TOTAL
	I 2.5 m/s B	II 1.0 m/s D	III 3.5 m/s D	IV 7.0 m/s D	V 3.0 m/s E	VI 1.0 m/s F	
016°-045°	0.002	0.013	0.008	0.000	0.008	0.018	0.049
046°-075°	0.009	0.014	0.029	0.002	0.015	0.020	0.089
076°-105°	0.015	0.017	0.076	0.010	0.043	0.031	0.192
106°-135°	0.042	0.026	0.116	0.020	0.038	0.035	0.277
136°-165°	0.000	0.000	0.000	0.000	0.000	0.000	0.000
166°-195°	0.000	0.000	0.000	0.000	0.000	0.000	0.000
196°-225°	0.027	0.022	0.041	0.001	0.028	0.028	0.147
226°-255°	0.002	0.004	0.001	0.000	0.001	0.005	0.013
256°-285°	0.004	0.006	0.005	0.000	0.003	0.007	0.025
286°-315°	0.003	0.015	0.015	0.000	0.008	0.014	0.055
316°-345°	0.005	0.018	0.029	0.003	0.012	0.018	0.085
346°-015°	0.003	0.015	0.013	0.001	0.012	0.023	0.067
TOTAL	0.112	0.150	0.333	0.037	0.168	0.199	1.000

FIGURE 4.2: TSING YI ISLAND POPULATION FOR SAFETI ANALYSIS

KEY

Population range	letter code
0 - 0	0
1 - 1	1
2 - 2	2
3 - 3	3
4 - 4	4
5 - 5	5
6 - 6	6
7 - 7	7
8 - 8	8
9 - 9	9
10 - 10	A
11 - 20	B
21 - 30	C
31 - 40	D
41 - 50	E
51 - 60	F
61 - 70	G
71 - 80	H
81 - 90	I
91 - 100	J
101 - 200	K
201 - 300	L
301 - 400	M
401 - 500	N
501 - 600	O
601 - 700	P
701 - 800	Q
801 - 900	R
901 - 999	S
1000 ->	*



```
       026000    027000    028000    029000    030000
         v         v         v         v         v
025000 > .         .         .         .         . < 025000
                                 SM
                               CG*****23
                          CCK CC**K**N
                        8E  E C8N*****
                  988888 888888  48L**Q
              4998                9AN9A888
           9995         C      Q  A  FK
                           KL *Q 66  E3
                           OSN *335*   4
024000 > .         .       RN.* 6MK**K 3         . < 024000
                               32K5*   3
                               * OL*L**3
                              *5LLKSNM 6S**
                            LL5 KM  5KKI*P5
                              5L 3AKJMNHCLCA
                C            3K********RPQMK
             JJGDD           B*ORNC*N****PEQ
                             4RMK*L CCO M**BB
                             4         CR* DB
023000 > .         .         4         .C *C     . < 023000
                             4          **P
                     B       4        DQ**D
                             4         *LD
                        C   24         L6
                        B   4          6
                        D   4          6
                           13          6
                        D  5           6
                           4           6
022000 > .         .      4  .         7         . < 022000
                        13              7
                        3              AD
                        3               AK
                        2               6K
                        2              39E
                        3      232     BCJ
                      B 3    34B 234BAD53E
                      B 3  B4BAB   6B5H
                         441EEA
021000 > .         .        E.       3 .         . < 021000
                                  3
         ^         ^         ^         ^         ^
       026000    027000    028000    029000    030000
```

4.3 Offsite Ignition Sources

Ignition of a dispersing cloud of flammable vapour depends on the number, activity and strength of ignition sources it encounters within its LFL. Beyond the CWTF site boundary these would include:

- Motor vehicles
- Electricity transmission lines, transformers and switchgear
- Potential ignition sources on other PHI and other industrial sites such as:
  - Incinerators
  - Boilers
  - Stacks
  - Workshops
  - Diesel generators
  - Electrically-powered equipment such as compressors
- Activities associated with people, e.g. cooking, smoking, use of electrical equipment etc.

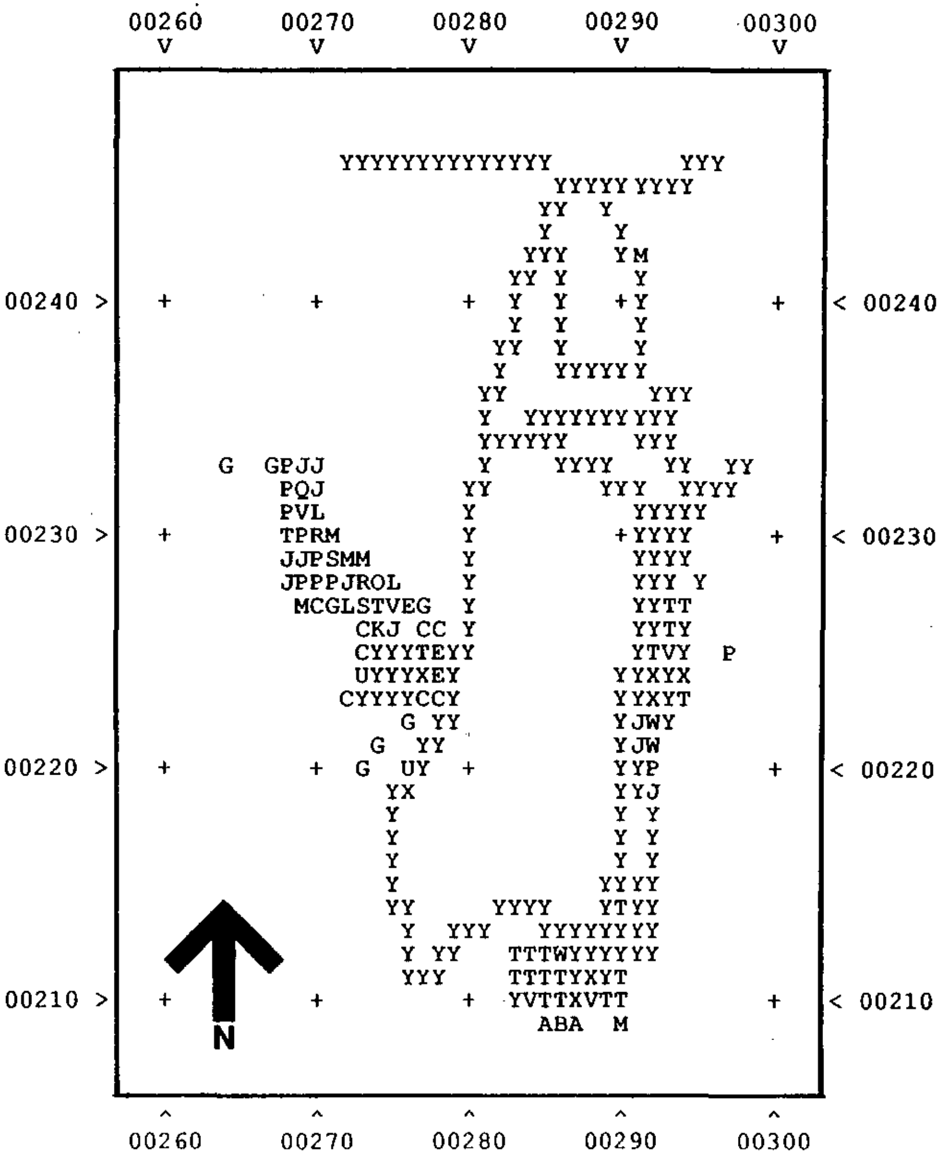
An extensive survey of all such sources was carried out for the Tsing Yi Island Risk Re-Assessment already referred to. The sources are characterised by their location, their strength and their 'presence factor', i.e. proportion of time for which they are active. This is described in more detail in Appendix IV, Section IV.4. Figure 4.3 is a schematic map showing the location (within 100 m squares) of ignition sources (apart from people, for which the population data base is used) identified and their presence factors.

FIGURE 4.3: SCHEMATIC MAP OF IGNITION SOURCES ON TSING YI ISLAND, BY 100m SQUARES

KEY TO CODES USED FOR PRESENCE FACTORS

Probability range	Letter code
0.00 < P <= 0.04	A
0.04 < P <= 0.08	B
0.08 < P <= 0.12	C
0.12 < P <= 0.16	D
0.16 < P <= 0.20	E
0.20 < P <= 0.24	F
0.24 < P <= 0.28	G
0.28 < P <= 0.32	H
0.32 < P <= 0.36	I
0.36 < P <= 0.40	J
0.40 < P <= 0.44	K
0.44 < P <= 0.48	L
0.48 < P <= 0.52	M
0.52 < P <= 0.56	N
0.56 < P <= 0.60	O
0.60 < P <= 0.64	P
0.64 < P <= 0.68	Q
0.68 < P <= 0.72	R
0.72 < P <= 0.76	S
0.76 < P <= 0.80	T
0.80 < P <= 0.84	U
0.84 < P <= 0.88	V
0.88 < P <= 0.92	W
0.92 < P <= 0.96	X
0.96 < P <= 1.00	Y

NB Coordinates refer to 100m squares.



```
        00260     00270     00280     00290     00300
          V         V         V         V         V

                      YYYYYYYYYYYYYY        YYY
                                    YYYYYYYYY
                                   YY  Y
                                   Y    Y
                                  YYY   YM
                                 YY Y    Y
00240 >   +         +         +  Y  Y   +Y        +  < 00240
                                 Y  Y    Y
                                YY  Y    Y
                                Y   YYYYYY
                               YY         YYY
                               Y  YYYYYYYYYY
                               YYYYYY    YYY
              G  GPJJ          Y    YYYY YY    YY
                  PQJ         YY       YYY  YYYY
                  PVL         Y          YYYYY
00230 >   +       TPRM        Y         +YYYY     +  < 00230
                  JJPSMM      Y          YYYY
                  JPPPJROL    Y          YYY Y
                   MCGLSTVEG  Y          YYTT
                       CKJ CC Y          YYTY
                       CYYYTEYY          YTVY  P
                       UYYYXEY          YYXYX
                      CYYYYCCY          YYXYT
                          G YY          YJWY
                        G  YY           YJW
00220 >   +         +  G  UY  +         YYP       +  < 00220
                         YX             YYJ
                         Y              Y Y
                         Y              Y Y
                         Y              Y Y
                         Y             YYYY
                         YY     YYYY   YTYY
                          Y  YYY   YYYYYYYY
                          Y YY   TTTWYYYYYY
                          YYY    TTTTYXYT
00210 >   +         +         +  YVTTXVTT         +  < 00210
                                   ABA  M

          ^         ^         ^         ^         ^
        00260     00270     00280     00290     00300
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5 HAZARD IDENTIFICATION

5.1 Introduction

Most potentially hazardous incidents on a chemical waste treatment facility are likely to arise from the uncontrolled release of hazardous substances from containment. The releases can occur from a very wide variety of sources. However these can be grouped to provide representative releases, such as:

(i) leaks from seals and gaskets, hoses and hose connections, partially open valves, defective containers;

(ii) spills due to operational errors e.g., overfilling containers or storage tanks, breaching of containers caused by vehicular accidents;

(iii) releases caused by reaction between incompatible wastes.

Such releases can in principle give rise to fires, explosions and/or acute or chronic health effects. Released material can be ignited by, for example, heat or sparks from electrical faults, sparks from welding and other hot work or contact with hot surfaces.

Fires in drums of stored waste materials are another potential source of major incidents. Minor fires escalating to major proportions may also trigger releases which could generate large quantities of toxic combustion products. Contaminated fire water runoff from large fires has created major pollution, however pollution effects are outside the scope of this hazard assessment.

Whether the outcome of the release of flammable material is a fire or an explosion and the type of fire depends on factors such as whether the hazardous material is released from a hole or from a catastrophic failure, whether it is highly volatile or involatile, and whether the release is driven by high pressure.

Pool fires are most likely from the ignition of releases of relatively involatile liquids, or from the early ignition of pools of more volatile liquids before there has been time for extensive vaporisation. Escalation from pool fires on this site is likely to lead to complex mixtures and "messy releases" to air and ground. Special review of such complex fire plumes was given for Building 16 and this is generally applicable around the site. Offsite fatalities are not expected and thus do not fall within a PHI-style review. This is confirmed by a review of Dangerous Goods fires in Hong kong and elsewhere. The EIA deals with the impoundment requirements. Certainly, the first flush of firewater runoff should be impounded. Jet fires result from high pressure releases of flammable gases or volatile liquids. High pressure processing conditions are not typical of chemical waste treatment plants. Therefore jet fires are not likely to be significant contributors to risk. One exception to this would be the heating of a vessel by an adjacent fire: if the affected vessel is pressurised by thermal expansion a jet release could occur.

Explosions may occur inside tanks in the event of the ignition of an explosive air/vapour mixture or with material that has condensed phase explosive properties.

If a flammable liquid is at a temperature above its normal boiling point when its containment vessel fails, the liquid will flash violently and the conditions for a BLEVE would exist. These conditions could be generated, for example, in a fire. Explosions could also occur in containers being fed to the incinerator or in the body of the incinerator if the fuel/waste/air mixture were to enter the flammability zone.

For those incidents which occur as the result of a release of flammable material which undergoes early ignition, the consequences of the incident are generally confined to the vicinity of the point at which the release occurred.

Serious though these incidents can be, their impact on the general public and the environment in the neighbourhood of the facility are not as great as that from the effects of large scale releases of highly volatile liquids, refrigerated or pressurised liquified gases or pressurised gases. Such events can result in the formation of flammable or toxic vapour clouds which can drift over populated areas. Late ignition of a flammable vapour cloud can result in an unconfined vapour cloud explosion which can cause extensive damage in areas well removed from the original point of release.

For such an event to occur relatively large amounts of material have to be released into the atmosphere within a small time period. However as toxic materials may still be very hazardous even at low atmospheric concentrations, much less of the material is required to be released to produce a serious hazard at some distance from the release point. A further complicating feature of toxic releases is that their effects on health may be acute (high dose, short term) or chronic (low dose,long term). Therefore a slow release into the atmosphere of small amounts of toxic material over a long time period may be at least as significant for the health of the public as the instantaneous release of much larger amounts. Although of course the perceived effects may be very different.

Major hazards may be caused by the release of hazardous material from process vessels and equipment, storage vessels, pipelines, transport containers such as road tankers and from marine vessels.

The rate of loss of material, and hence the potential scale of the incidents, is dependent on the original material inventory, its properties - especially normal boiling point, vapour pressure/temperature relationship, vapour density, flammability and toxicity - the temperature and pressure of the material and the size of the hole through which it is released. A major hazardous incident requires the uncontrolled release of a significant quantity of flammable and/or toxic material as its first step. In the case of the release of a flammable material, the released material then has to find a source of ignition. Consequent upon the release and subsequent ignition there also has to be a failure of containment, emergency shutdown and fire control systems to contain the incident. Clearly, some of these contributing factors are interdependent. For example the larger the release, the more likely it is to find an ignition source, and the less likely it is that the containment and other consequence limitation systems will be able to contain it.

5.2 Classification of Hazardous Materials

Chemical hazards are generally considered to be of 3 types: **toxic**, **flammable** and **explosive**.

Toxic materials cause injury and fatality through inhalation, ingestion or skin absorption. Injury and/or fatality need not occur immediately on exposure. In this study it is specifically the risk of **acute fatality** that is considered.

Ignition of a **flammable** material can cause a number of different consequences depending on the type of material, nature of the release and time of ignition. External heating or a catastrophic failure of a pressurised tank can cause a BLEVE or fireball: the thermal dose received can cause fatality even several hundred metres away (depending on the material and mass involved). A continuous jet from a hole or ruptured pipe, if ignited close to the release point, will cause a jet fire which can cause fatalities by thermal radiation in an approximately elliptical zone whose direction is determined by the direction of the jet as modified by the prevailing wind. The basis for selecting a direction with the wind is that this maximises the effect zone distance (i.e. some conservatism) and the wind rose specification ensures that jets in all directions are considered. In fact, for the CWTF study there are no pressurized jet scenarios. The dispersing cloud of material may be ignited by any ignition sources (see Sections 3.5 and 4.3 and Appendix IV, Section IV.4) over which it passes: this is a flash fire and anyone within the fire is likely to suffer fatality. Finally, if a liquid pool is formed (either by release of a liquid or by rain-out of liquid droplets from the dispersing gas cloud) and ignited, a pool fire results: thermal radiation from this in an approximately elliptical zone around it will again be fatal, usually to some tens of metres beyond the edge of the fire.

Explosions of both gas (including two-phase mixtures of gas with liquid droplets) and dust clouds are possible. They often produce overpressures which can cause fatalities both through direct action on people and through structural damage killing both people inside and people adjacent to the structure. Dust explosions tend to have local (on-site) effects since they occur at the point of dust generation, whereas a drifting cloud may be ignited and explode at some distance from the release point. The CWTF site has very virtually no potential for vapour cloud explosions since sufficient amounts of flammable vapour are very unlikely to be generated by a release (see Section 6.3.3).

In this study it is major hazards which are being considered: that is, those with a potential to cause off-site fatalities.

Though many of the materials to be dealt with present chronic hazards (where exposure to them over a period of time causes damage), such hazards are not within the scope of this study.

In addition to incoming waste, other hazardous materials may be present or produced on site:

- Reagents for use in treatment processes
- Products of mixing 'incompatible materials' (e.g. acid with cyanide-bearing wastes produces hydrogen cyanide and with tannery waste containing sulphide produces hydrogen sulphide)
- Internal explosion, incomplete combustion or other failure of incinerator system leading to discharge of hazardous gases to atmosphere

Physical properties of materials which are significant in determining the consequences of an accidental release include: specific heat, normal boiling point, vapour pressure/temperature relationship and enthalpy of vaporisation. These determine the propensity of the material for release into the vapour state. Vapour density is the property of the material which is most significant in its dispersion into the atmosphere and its dilution with air to a safe concentration; this in turn depends on the molecular weight of the material.

Other properties which must be considered are: autoignition temperatures, flammable limits in air and toxicity parameters.

Properties of materials likely to be present at the CWTF are tabulated in Appendix II. Those which are significant in terms of acute risk are summarised in Table 5.1 below.

5.3 Identification and Development of Release Scenarios

In this section, the principles of identifying and developing release scenarios for further analysis are outlined. The ensuing sections apply these to the various aspects of the operation of the facility.

In general, there are two major causes of the release of material from containment:

(i) accidental loss of containment as a result of operational deviations and equipment failures;

(ii) loss of containment when this has been breached deliberately for example during maintenance and procedural safeguards against loss of containment have failed.

TABLE 5.1: POTENTIAL ACUTE HAZARDS FROM MATERIALS ON SITE

Material	Origin	Potential Hazard	
		Flammable	Toxic
Phenol	Incoming waste	YES	YES
Fuel oil	Incoming waste	YES	NO
Crude oil	Incoming waste	YES	NO
Heavy oil	Incoming waste	YES	NO
Mineral oil	Incoming waste	YES	NO
Lubricating oil	Incoming waste	YES	NO
Hydrogen cyanide	Interaction	YES	YES
Hydrogen sulphide	Interaction	YES	YES
Hydrogen chloride	Process failure	NO	YES
Sulphur dioxide	Reagent/Process failure	NO	YES
Chlorine	Reagent	NO	YES

Release of material from accidental breaking of the containment envelope

Accidental breaking of the containment envelope could occur as a result of:

(i) some failure in a pipe, vessel, valve, seal or other plant containment item under normal operating conditions;

(ii) an undetected or uncontrolled operational deviation beyond the plant design limits;

(iii) an external fire leading to release through relief systems.

As outlined in Section 2.1, such incidents are identified by a combination of several techniques. 'Generic' failures are derived from industrial experience: they cover a wide range of possible causes from material defect or corrosion to maloperation or breakdown of safety systems; the principle here is that all the possible causes lead to the same range of events, from small leaks through to catastrophic failures.

Application of analytical methods such as HAZOP and Event Tree analysis helps to identify events which are the outcome of deviations from normal operating conditions or complex combinations of initiating events (for example the responses of detection, alarm, control and shutdown systems) including common mode failures and to assess the size of the release.

Release of material from deliberate breaching of the containment envelope

Release scenarios arising from the failure of procedural safeguards to protect against loss of containment during maintenance are carried out as part of the HAZOP studies.

5.4 Hazards in Transport to Site and Reception

The involvement of a road tanker or lorry carrying packaged waste, or sulphur dioxide or chlorine drums, in a serious traffic accident is the major potential source of offsite risk. This may be localised as in the case of a release of flammable liquid and subsequent ignition, or more widespread in the case of, for example, a release of liquid sulphur dioxide or chlorine.

The hazards from road transport of hazardous substances is directly related to the availability of transport routes and traffic density. At present, all chlorine transport to Tsing Yi island passes over the southern Tsing Yi bridge.

The shortest route to the CWTF and the one which passes the least amount of residential property so minimising hazards, is the one which passes over the southern Tsing Yi bridge and south along Tsing Yi road.

Traffic statistics from 1986 for the Tsing Yi bridge supplied by Hong Kong Traffic Transport and Survey Division show an annual average daily traffic (AADT flow on weekdays of 33,000 vehicles with a peak flow rate (0800-0900 hours) of 2,600 vehicles per hour.

Since the CWTF will receive not more than about 70 vehicles per day, the overall increase in daily traffic flow is less than 0.2%.

Restricting the travel of high hazard transport such as sulphur dioxide or chlorine delivery vehicles to the times when traffic density is normally at its lowest and ensuring that all appropriate safety precautions required for such transport are observed should ensure that hazards from this source are minimised. An alternative delivery option would be to employ a local barge to move chlorine drums directly to the CWTF jetty. Water Supplies Department uses barge transport to some of its sites and is considering increasing barge usage to mitigate road transport risks. If this option were employed then much of the road transport risk would be eliminated, including all of the risk through heavily populated residential or commercial areas. There would be some small transport risk transferring the chlorine from the jetty to the CWTF, if the SETY development proceeds and CWTF is separated from its jetty. An alternative risk reduction option would be to employ truck deliveries, but to route the trucks via the new Dangerous Goods jetty to be constructed as part of the SETY development. This option is probably more economical than barge transport and would not require double handling of the chlorine drums as with the barge option (which will require local road delivery to the CWTF site). Another delivery option being considered is to shift some waste collection and delivery activities out of the rush hours and into the night hours. This option will be developed when more detailed surveys of waste generators are carried out and in the initial period after the CWTF goes into operation.

Proper design of vehicles for transporting hazardous wastes or chemical reagents should also serve to reduce hazards from this source. Details of vehicle design were not available at the time of the hazard assessment, therefore no mitigation allowance has been given for good vehicle design. However even without this allowance the risks from transport have been found to be within the Hong Kong Government Guidelines.

A loss of containment of material in transit from a road tanker delivering waste or reagent could occur. Although this could be facilitated by corrosion in the tanker body, a more likely cause is a leak or loss of containment at the delivery point, either at the valve system on the tanker (for example, accidentally leaving a valve open, or not closing it completely), or in the connection to the storage system (for example, a rupture of the delivery hose or the vehicle leaving without disconnecting). The basis for our previous chlorine transport risk study did include fire exposure as one of the mechanisms of loss of containment. This mechanism has been carried forward here, bulked with all other release mechanisms.

Transport of chlorine and sulphur dioxide typically is by 1-tonne drums (up to 7 per truck) and smaller cylinders. A detailed risk assessment of chlorine transport has recently been carried out by Technica (1990): this identified potential failure scenarios involving one drum and for a truckload of drums. Sulphur dioxide transport is treated similarly to chlorine drums, but the much smaller trade (9 tonnes/yr) means that never more than one drum will be transported at a time. Special vehicles are used for transfer of pressurised drums: this information has been used in our assessment, based on our previous work on chlorine transport hazards in Hong Kong.

TABLE 5.2: FAILURE SCENARIOS FOR TRANSPORT AND RECEPTION

TANK CONTENTS	FAILURE SCENARIO
Solvents (non-halogenated)	Pool Fire Vapour Cloud Explosion or Flash Fire
Solvents (halogenated)	Toxic Cloud
Oily waste	Pool Fire
Chlorine	Toxic Cloud
Sulphur Dioxide	Toxic Cloud

5.5 Intrinsic Hazards in Storage

5.5.1 Hazards in Normal Operation

Tank Storage

Hazards in tank storage are caused by the failure of the tanks in two different ways: catastrophic failure of the vessel or a leak from the vessel or attached pipework. Catastrophic failure means any failure which releases the whole contents of the tank from its normal containment in a relatively short period. This could be up to a few minutes. Thus catastrophic failure includes large hole size failures, not just some spontaneous whole tank failure.

The causes of a catastrophic failure of a storage vessel (when the whole tank fails and the entire contents are released) depends on the material the tank is constructed from, the material it contains and the physical conditions under which it is stored (i.e. temperature and pressure). On the CWTF, all on-site storage is at ambient temperature and atmospheric pressure. The liquid head in a full or part-full tank gives rise to some overpressure near the bottom: extensive corrosion or a 'cold fracture' due to a defect (usually metallurgical) present in the walls could lead to catastrophic failure.

Overpressure in the tank is also a possible cause of a catastrophic rupture: this could arise from its being engulfed in a fire or the contents themselves being ignited with consequent evaporation at a greater rate than the venting system can cope with and a pressure build-up causing the tank to rupture. An internal explosion could also cause a catastrophic rupture.

For pressurised vessels (such as the chlorine and sulphur dioxide drums to be used on site: see Section 3.2.3 above), operational overload appears from failure statistics (Smith and Warwick 1981) to be the dominant cause of a catastrophic rupture.

Leaks can occur from a number of points in the storage system, though the possibility and severity of many of these is reduced due to the lack of pressure in the storage vessels.

Localised corrosion in the tank from any of a number of sources can cause a small hole to develop, permitting a leak of material out of the vessel. These holes can be any size, but are usually quite small. The amount of material escaping through one of these holes is likely to be quite small.

Similarly, corrosion can lead to a failure of areas of the attached pipework at the base of the tank, particularly if the storage vessel is large and thus has considerable pressure (liquid head) at the bottom. Failures of this type may just be small holes in the pipe, or total rupture of the line, perhaps at a weld or junction. The rate of loss of material from a pipe rupture is likely to be quite high because of the head of liquid.

Additionally, pipe or vessel failure can also be caused by physical impact, for example by a vehicle: this could lead to a catastrophic rupture or a leak.

On the CWTF, the incoming wastes are all liquids at atmospheric temperature and pressure. Neither a catastrophic rupture nor a leak is therefore likely to produce a dispersing vapour cloud; however, a flammable liquid may be ignited and hence give rise to a pool fire. Toxic hazards in storage are limited to inadvertent mixing of incompatible materials (see Section 5.7 below) generating a vapour cloud which is vented to atmosphere and release of low-boiling-point halogenated solvents.

The potential failures scenarios for storage vessels are listed in Appendix III; those which could lead to a hazardous release are summarised in Table 5.3 below.

TABLE 5.3: FAILURE SCENARIOS FOR WASTE AND REAGENT STORAGE

TANK CONTENTS	RELEASE SCENARIOS
Solvents (non-halogenated)	Pool Fire Vapour Cloud Explosion or Flash Fire
Solvents (halogenated)	Toxic Cloud
Oil-water wastes	Pool Fire (of oil) (Flash Fire)
Water-oil wastes: non-MARPOL	Pool Fire (of oil) (Flash Fire)
MARPOL Annex 1	Pool Fire (Flash Fire)
Incinerator fuel	Pool Fire
Fuel recovered from wastes	Pool Fire
Waste feed blend	Pool Fire
Fuel feed blend	Pool Fire

Note

Where the scenario (Flash Fire) is shown in parentheses, it is unlikely that the hazard zone will extend beyond the boundaries of the corresponding Pool Fire (the distance to LFL and hence the flammable mass will be small).

5.5.2 Hazards Under Abnormal Conditions

Packaged Waste Fire

A major serious fire in combustible material stored in Building 16 is a potential major source of toxic fumes. This scenario is developed in Appendix VI, Section VI.2.2.

5.6 Intrinsic Hazards in Treatment Processes

5.6.1 Hazards in Normal Operation

The hazards outlined in Section 5.5 are also applicable to the operational part of the plant: reaction vessel catastrophic ruptures and leaks and pipe failures can all occur in the same ways as outlined previously.

There are an additional number of failure cases that can occur, although many will be minor due to the absence of high temperature or pressure operations.

Loss of containment of a material in transfer or process is the most probable potentially hazardous event under normal operating conditions. This could occur as a result of any of the following events:

- pipe rupture caused by mechanical impact;
- pipe leak caused by corrosion;
- valve failure;
- pump seal failure;
- leak from or failure of a process or storage vessel caused by corrosion;
- failure of a process or storage vessel caused by mechanical impact;
- road tanker leak caused by corrosion or impact;
- loss of containment from the incinerator system;
- loss of containment from the solvent recovery system

Failure of a pump seal is a common cause of loss of material, but release rates would be low as the operating pressures are close to atmospheric; furthermore it appears from the Technical Schedules supplied by Enviropace that diaphragm pumps will be used in the majority of the process units, which do not have such a seal. The material would form a pool around the base of the pump given the normal operating conditions; however, circulation pumps on the solvent recovery system could release clouds of flammable and/or toxic vapour.

Oil-Water Separation

There is a potential fire hazard from oil-water separation operations. A variety of oil/water mixtures are likely to be presented for processing. The risks from these will depend very much on the nature of the oil. For example, crude oil from tank washings may contain significant quantities of light hydrocarbons. These will increase the fire risk from the separation facility. It should be classified a Zone 1 hazardous area, have appropriate electrical equipment for the classification and adequate fire protection capacity to deal with the risk. If a fire were to occur, its effects will be localized and there would not be any significant offsite risk. Around the site perimeter and next to the storage vessel and processing areas, a fire fighting ring is provided. This ring includes fire hydrants, a sprinkler system, a foam system, portable and hand-held fire extinguishers and fire hoses. If the fire spread and if it involved toxic materials or materials capable of releasing toxic combustion products then a significant offsite risk might well be generated.

Physical/Chemical Treatment Plant

The physical/chemical treatment plant will be processing almost exclusively aqueous wastes. These are non-volatile and non-flammable. Typical chemical treatments were detailed in Section 3.2.5.

In view of the nature of the substances likely to be present in the chemical treatment plant, there is no potential for offsite risk arising solely from loss of containment of waste materials for treatment or their treatment products during normal operation of this plant.

However, because of the variety of chemical treatments, to maximise operational flexibility and to minimise costs, it is common practice to operate on a batch process basis using the same vessel for more than one reactor. This raises the possibility of inadvertent mixing of chemicals resulting in the release of toxic gases. This possibility is dealt with in Section 5.7.

Incinerator

There are two types of incident involving the incinerator with the potential for off-site risk. They are:

(i) emission of hazardous materials such as the products of partial combustion under poor operating conditions or as a result of breaching of containment by an explosion;

(ii) incinerator failure leading to incomplete combustion.

Both of these events are considered in Section 5.6.2.

Solvent Recovery Unit

With centrifugal pumps, loss of liquid through a failed pump seal is most likely to result in a liquid pool given the probable operating conditions in most of the CWTF. The exception to this would be circulation pumps on the solvent recovery system. However, we note that diaphragm pumps are to be used elsewhere on the CWTF; we therefore assume that such pumps would also be used on any solvent recovery unit and that they would not be susceptible to seal failure. In the case of a liquid spill, the volatility of the solvent will determine the amount of evaporation taking place and therefore the extent of any hazard from flammable or toxic vapour; the liquid pool may also ignite as a pool fire.

Loss of containment from the solvent recovery system could result from failure of a liquid or vapour connection, a failure of the condenser system, or a control system failure leading for example to overheating . Such a release could result in volatile organic liquid at or near its normal boiling point flowing out of the liquid side of the system or solvent vapour flowing out from the vapour side. Vaporisation of the liquid could result in a flammable vapour/air cloud which could explode if ignited.

Given that solvent recovery inventories are likely to be small - for example, 200 litre containers are proposed - the loss of more than a few m^3 of liquid is unlikely.

Although the explosion of a vapour cloud produced by this amount of material may cause extensive local damage to plant and equipment its effects should not extend offsite. A toxic vapour cloud is also possible for halogenated solvents.

5.6.2 Hazards Under Abnormal Conditions

Incinerator

Poor Operating Conditions

The consequences of poor operating conditions in the incinerator are likely to be most serious when halogenated solvents and other organohalogen compounds are being processed.

Incineration of halogenated solvents

The term 'halogenated solvent' is often used to encompass a wide range of organic halogen compounds not all of which find use as solvents. Examples of non-solvent organic halogen compounds include polychlorinated biphenyls (PCBs) and mixed chlorofluorocarbons, bromochlorofluorocarbons and bromofluorocarbons.

Incineration of halogenated solvents and related organohalogen compounds can produce hydrogen chloride, hydrogen bromide and hydrogen fluoride. In addition, compounds such as PCDDs (Polychlorodibenzodioxins) and PCDFs (Polychlorodibenzofurans) have been identified in stack emissions from the incineration of PCBs (polychlorinated biphenyls).

Dioxin (PCDD and TCDD) is a popular abbreviation for chlorinated dibenzodioxin. Tetrachloro dibenzo-p-dioxin (TCDD) has 22 possible isomers according to how the four chlorine atoms are located among positions 1 to 9. 2,3,78 - TCDD is assumed to be extremely toxic. The LD_{50} (dosage at which 50% of test animals die) ranges widely being as low as about 1 μg/kg of body weight for guinea pigs to about 280 μg/kg for mice. Only trace amounts of TCDDs have been detected in incinerator emissions. These amounts are well below those that cause acute (short term, high dose) effects in animals.

The seriousness of the risk from Dioxins is well commonly accepted. It is however chronic risk (long term, low dose effects) and these are outside the scope of this hazard assessment which deals only with acute risk. The EIA Report deals with this issue at greater length for chronic exposures to dioxin and to furans using the Unit Risk Factors method. Refer to the EIA Report for greater detail.

Incomplete combustion of organohalogen wastes has been shown to produce compounds such as chloroform and bromoform. Chloroform concentrations as high as 1330 μg/l of emission have been reported.

Incinerator failure

As the generalised event tree Figure 5.1 shows, a potentially hazardous incident involving the failure of the incinerator could be initiated by any one of a large number of events. These events are analyzed in this study to determine whether there are any significant risks.

Flameout

Loss of the flame in the primary combustion chamber could result from:

(i) power failure on the support fuel feed system;
(ii) rupture or blockage of the fuel feed line;
(iii) inadvertent closure of a supply-side valve;
(iv) loss of fuel supply from the supply tank.
(v) how quickly the release is detected.

Loss of flame may result in the discharge into the atmosphere of minute quantities of unburnt waste and the products of incomplete combustion. These have been referred to in Section 5.2. However, the residual heat and oxygen in the incineration system continues to destroy organic compounds even after loss of flame.
The amounts discharged would depend on factors such as:

(i) how quickly the fuel supply could be re-established;

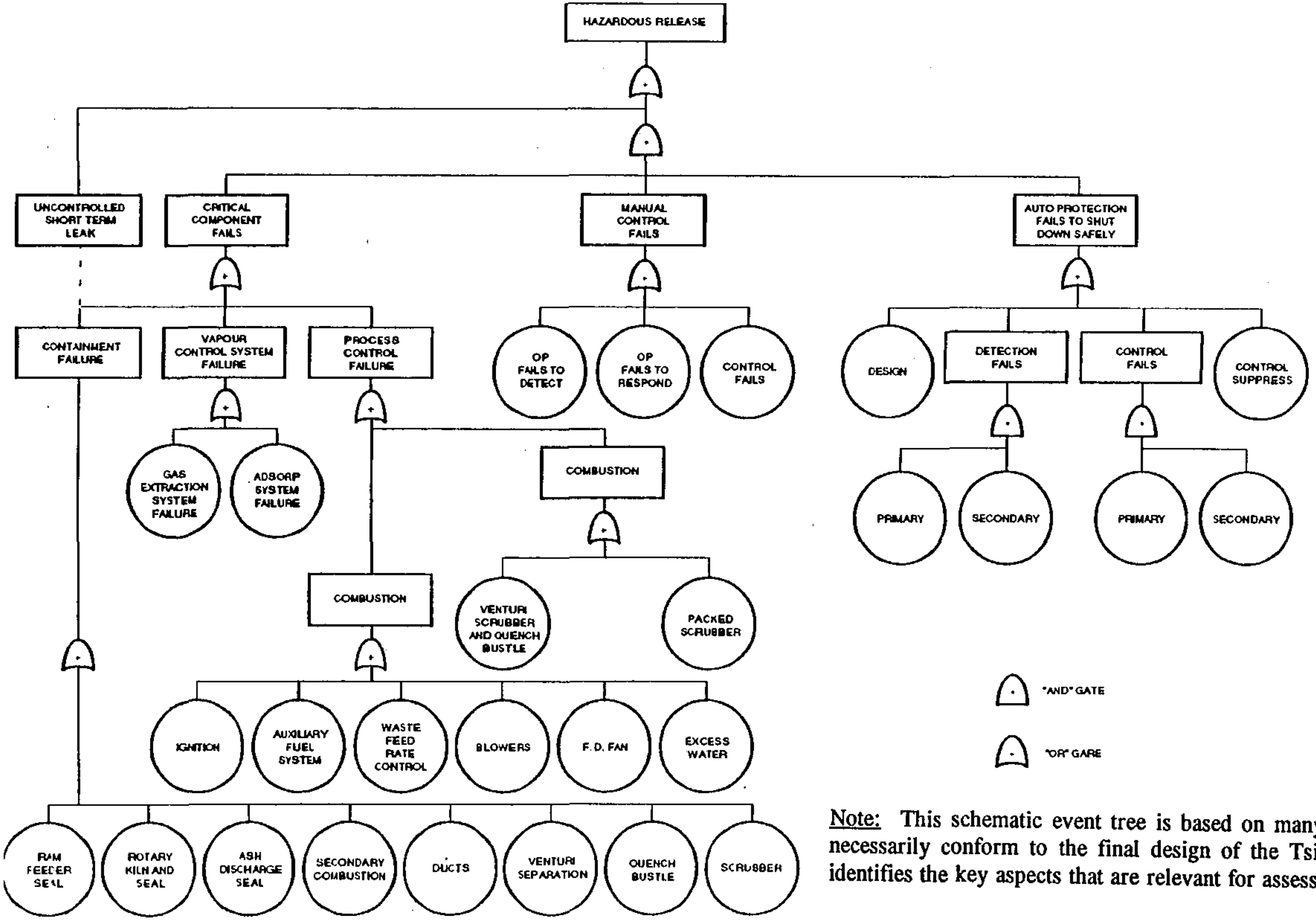
(ii) how quickly the waste feed supply could be stopped pending the re-establishment of the flame;

(iii) how effectively the afterburner operates as a means of combustion;

(iv) the operating mode of the induction fan, i.e. whether or not it shuts down immediately on flame failure;

(v) how quickly the release is detected.

FIGURE 5.1: EVENT TREE FOR INCINERATOR FAILURE



Note: This schematic event tree is based on many typical designs but does not necessarily conform to the final design of the Tsing Yi CWTF. The diagram identifies the key aspects that are relevant for assessing risks.

Scrubber failure

Any type of failure in the scrubber system that resulted in it being unable to remove gases such as sulphur dioxide or hydrogen chloride from the incinerator exit gas stream would result in the release of these gases into the atmosphere. Assuming a feed rate of 400 kg/hr - the ultimate feed rate quoted in Technical Schedule SI 1.7.1 is 480 kg/hr at 44.7 MJ/kg - and a sulphur content in the feed of 1% w/w, the sulphur dioxide discharge rate to the atmosphere would be approximately 8 kg/hr.

However, the CWTF incinerator has an emergency water supply to cool the off gas and remove HCl in the event of a lime slurry failure. Also, the lime deposits on the bag filters will continue to remove HCl and SO_2 passively. For extra conservatism, neither of these mitigative factors in the CWTF design were included in this risk assessment.

The most obvious source of failure would be the loss of lime slurry to the scrubber section. In this event the incinerator is shutdown automatically. The scrubber will also have a range of operational alarms to warn of malfunction.

Misrouting of Waste to the Incinerator

Alkali, acid and heavy metal wastes could be misrouted to the incinerator in the event of a failure in segregation and/or transfer procedures. This could result in damage to the burner system through severe corrosion if it occurred for an extended period of time. However, the burner management system should detect any serious change in calorific values of the incoming feed and should initiate the appropriate control function, including possible shutdown, while the source of the problem is investigated.

Heavy metals will almost certainly be present in a significant proportion of wastes being sent for incineration. However, these should be converted to their oxides or oxy-salts by the excess of air in the two combustion chambers. Most heavy metal content should accumulate in the incinerator and would be treated in the normal way along with other heavy metal residues.

The likelihood of heavy metals in the form of fine dusts penetrating the exhaust gas cleaning system is very small. The programme of environmental monitoring which is a contractual requirement for the CWTF recognises the possibility of some heavy metal emission from the incinerator. If any significant emission, i.e. over accepted environmental pollution limits, were to occur it would represent a chronic rather than an acute risk.

Misrouting of large quantities of oxygen-rich substances to the incinerator could result in a serious explosion on-site and possible destruction of part or all of the incinerator. Such substances include some nitrates, per- and oxy-salts such as perchlorates, chlorates, peroxides etc.

An explosion in the incinerator could have knock-on effects involving the MARPOL Annex I waste storage and the organic waste blending area. Fires in these facilities have been considered elsewhere in this report.

The waste characterization required for the Waste Analysis Plan to be implemented should flag potentially hazardous substances such as these. Special disposal treatments would be required. In the event of a very serious breakdown of the proposed control systems and operational procedures and the misrouting of the substances to the incinerator there could be a serious on-site incident leading to loss of the incinerator facility. If this occurred at a time when the incinerator was handling the disposal of hazardous gases like hydrogen cyanide then there could in principle be a hazardous release. We consider such a combination of untoward circumstances and events extremely unlikely; it will not be analysed further but is highlighted to ensure consideration in the detailed design of the facility and planning of its operational procedures.

PO*WW*ER Process

*Misrouting of Untreated Aqueous Wastes to the PO*WW*ER Process*

Any misrouting of untreated aqueous phase waste to the PO*WW*ER process could cause some operational problems such as interference with the crystallisation process and an increase in toxic metal concentration in the residue, however there is no potential in this for offsite acute risk.

TABLE 5.4: SUMMARY OF FAILURE SCENARIOS FOR PROCESSING

PROCESS FAILURE	MATERIAL RELEASED	RELEASE SCENARIO
Solvent recovery system failure	Flammable organic liquid	Pool Fire Flash Fire
	Vapour of toxic solvent	Toxic Cloud
Incinerator combustion failure	Vapour of halogenated solvent	Toxic Plume
Incinerator explosion (including drum explosion)	Vapour of toxic solvent Vapour of halogenated solvent Acid gases, HCl, SO_2, NO_x	Toxic cloud Toxic plume Toxic cloud
Incinerator scrubber failure	Acid gases	Toxic Cloud

5.7 Potential Hazards due to Mixing

5.7.1 Identification of Hazardous Mixtures

Hydrolysis of inorganic materials

The addition of acids to certain inorganic substances results in the addition of hydrogen ion to the anion of the substance and the release of a gas which is toxic. A list of the substances that can enter into this type of reaction and the gases that they can release is given below.

Cyanides	Hydrogen Cyanide
Sulphides (also Selenides and Tellurides)	Hydrogen Sulphide (Selenide, Telluride)
Hypochlorites	Chlorine
Sulphites	Sulphur Dioxide

Sodium sulphide and hydrosulphide are used in tanning and fellmongering as dehairing agents, in organic synthesis and as precipitants for precipitating insoluble metal sulphides from aqueous solution. Tannery wastes are identified in the list of wastes for treatment at the CWTF.

Selenium and its compounds are quite widely used in industry but in relatively small amounts. Selenides may liberate toxic hydrogen selenide on contact with acid. Inorganic tellurides could give rise to hydrogen telluride on contact with acid.

However the use of tellurium-containing materials is on an even smaller scale than that of selenium. It is not envisaged that either hydrogen selenide or telluride will constitute a significant offsite hazard.

Mixing of organic waste with aqueous inorganic solutions

With rather few exceptions, organic substances are immiscible with water or with aqueous solutions. Phase separation would therefore be one likely consequence of the misrouting of organic materials to the inorganic treatment processes; emulsification may also occur. These events may well cause operational problems such as interference with settling and filtration but appear to have little potential for serious risk on or off site.

5.7.2 Potential for Creating Hazardous Mixtures

There are two main routes to the creation of hazardous mixtures in storage and processing. They are:

(i) misdirection of one waste stream onto an incompatible waste already in storage or process;

(ii) misdirection of a treatment chemical onto an incompatible waste in storage or process.

In general, hazardous mixtures capable of releasing toxic gases can only be produced by adding acid to a reactive waste, or vice versa. Therefore special procedural controls on the disposition of acidic wastes and acid for treatment will be implemented to minimise the risk of hazardous mixing. Engineering controls such as automatic shut-off of reagent isolation valve when incompatible waste solution is detected in the storage and reaction tank are an additional means of minimising the risk of hazardous mixing.

TABLE 5.5: SUMMARY OF FAILURE SCENARIOS FOR INADVERTENT MIXING

MIXING PROCESS	MATERIAL RELEASED	RELEASE SCENARIO
Acid with Cyanide	Hydrogen Cyanide	Toxic Cloud
Acid with Sulphide	Hydrogen Sulphide	Toxic Cloud

6 CONSEQUENCE ANALYSIS

6.1 Introduction

There are 3 stages in the consequence analysis of the failure cases identified in Section 5 above:

1: Release modelling, to determine flow rate, temperature and other parameters defining the release, as listed in Table V.2 of Appendix V. These pertain at the point where the material released through loss of containment begins to interact with the environment and hence form the initial conditions for the next stage.

2: Atmospheric dispersion modelling (not required for releases specified as BLEVEs or Pool Fires) to determine concentrations of the released material downwind of the release point.

3: Hazard effects modelling. For **toxic** materials, the probability of fatality (calculated from the dose received) as a function of distance is calculated; for **flammable** materials the dimensions of the effect zone are calculated for each of the possible outcomes and also the mass available for explosion.

[Sometimes Stage 1 is considered as part of the Failure Case Identification; Consequence Analysis can be seen as applying to the consequences of a failure or of a release.]

In the analysis being performed for the CWTF using the CWTF, Stages 2 and 3 are combined in the same computer program.

In this Section, results for each stage are summarised; fuller details are given in Appendix VI. In particular, some failure cases identified in Section 5 above have not been taken through Stages 2 and 3 as a result of screening which showed that the release rates would not give rise to significant offsite risk.

6.2 Release Modelling

6.2.1 Storage Failure Cases

Failures of tanks storing oily waste have been specified as pool fires contained within the bund. SAFETI models pool fires as being circular, therefore these cases have been specified as having the diameter of a circle with the same area as the bund.

Failures of tanks containing solvents have been based on calculating the mass available assuming the tanks to be 50% full and using the liquid head to calculate flow rates.

A serious fire of combustible packaged waste in Building 16 has been modelled as a toxic plume (see Appendix VI, Section VI.2.2). Full details of each release case are given in Appendix III, Table III.6.

These cases are summarised in the following table.

TABLE 6.1: SUMMARY OF STORAGE FAILURES

CASE IDENTIFIER	RELEASE CONDITIONS		
	RELEASE RATE (kg/s) OR MASS RELEASED (kg)	RELEASE DURATION (s)	POOL OR BUND DIAMETER (m)
S11	62 992	-	24.6
S12	34.1	1848	24.6
S13	10.9	600	24.6
S21	127 600	-	24.6
S22	68.7	1857	24.6
S23	12.2	600	24.6
S31	-	-	24.6
S32	-	-	19.5
S33	-	-	34.8
S41*	163	3600	-

* Case modelled as starting 12m above the ground

6.2.2 Treatment Process Failure Cases

The only cases identified were in the Solvent Recovery System. No details of this have been given in the data provided by Enviropace since no such unit is planned for the initial phase of construction and operation. However, since one may subsequently be added to the facilities, the cases identified have been developed for analysis as described in Appendix VI, Section VI.2.3. They are summarised in the following table.

TABLE 6.2: SOLVENT RECOVERY SYSTEM FAILURES

CASE IDENTIFIER	RELEASE CONDITIONS		
	RELEASE RATE (kg/s)	RELEASE DURATION (s)	BUND DIAMETER (m)
P11	4.0	200	11.3
P12	0.5	60	11.3

6.2.3 Incinerator Failure Cases

The likely flow rates of toxic gases in the event of one of the failures identified in Section 5 has been calculated from the incinerator feed rate and the likely maximum concentration of the toxic gas generating substance in the feed, as detailed in Section VI.2.4 of Appendix VI. The duration is in each case assumed to be 10 minutes, assuming that the release of toxic gas will be detected and the feed shut off within that time. The release cases are summarised in the following table.

TABLE 6.3: INCINERATOR FAILURES

CASE IDENTIFIER	RELEASE CONDITIONS		
	RELEASE RATE (kg/s)	RELEASE DURATION (s)	RELEASE HEIGHT (m)
I11	0.003	600	0
I12	0.014	600	0
I21	0.014	600	76.2
I31	0.003	600	76.2
I32	0.014	600	76.2

All these flow rates are below the screening criteria established in Appendix VI, Section VI.1. **None of the cases in Table 6.3 above is considered further.**

6.2.4 Inadvertent Mixing Cases

The only cases identified in Section 5.7 above were addition of acid to cyanide or sulphide solutions in storage. Likely flow rates have been calculated as shown in Section VI.2.5 of Appendix VI; it is assumed that such an inadvertent addition can be detected and escape of toxic gas to the atmosphere stopped within 5 minutes. In current design, the cyanide waste storage tank vent line will vent to atmosphere via a caustic scrubber instead of to the incinerator; a release of hydrogen cyanide would be from this vent. Likewise, the tannery waste storage tank vents to atmosphere via a caustic scrubber, hence a hydrogen sulphide release would be at vent level.

TABLE 6.4: INADVERTENT MIXING CASES

CASE IDENTIFIER	RELEASE CONDITIONS		
	RELEASE RATE (kg/s)	RELEASE DURATION (s)	RELEASE HEIGHT (m)
M11	0.13	300	76.2
M12	0.16	300	3.0

Both of these flow rates are below the screening criteria established in Appendix VI, Section VI.1. **Neither of the cases in Table 6.4 above is considered further.**

6.2.5 Waste and Reagent Reception Failures

The cases identified are failures of bulk unpressurised tankers bringing in waste solvent and oily waste and failures of pressurised cylinders used to supply chlorine and sulphur dioxide for use in the treatment process.

Failures of unpressurised tankers carrying solvents are based on the tankers being full, using the tank diameter as the liquid head. Hose failures result in a flow rate equal to the pumping rate. The pool resulting from the liquid spill is assumed to be uncontained.

Failure of a bulk tanker bringing in oily waste (waste oil or oil/water mixture) is assumed to lead only to the possibility of a pool fire, limited in area by nearby bund walls, giving an effective bund diameter of 20 m.

Failures of drums used to supply chlorine and sulphur dioxide have been specified based on the methodology applied in the Risk Assessment of Liquid Chlorine Transport for Water Supplies Department, Hong Kong (Technica 1990), as described in Appendix VI, Section VI.2.5; large leaks have been taken as equivalent to ruptures of the hose used to connect the drums to process, with the flow rate being that required to discharge the contents over two hours. Similarly, catastrophic failure refers to any leakage which would discharge the whole contents of a drum in a short period: for example a 50mm (2") hole would empty a drum in less than a minute. Such holes could be caused by several mechanisms ranging from mechanical impact (crane dropped object or sharp item puncture) to spontaneous failure of the vessel by corrosion (possible but unlikely).

The cases are summarised in the following table.

TABLE 6.5: WASTE AND REAGENT RECEPTION CASES

CASE IDENTIFIER	RELEASE CONDITIONS		
	RELEASE RATE (kg/s) OR MASS RELEASED (kg)	RELEASE DURATION (s)	POOL OR BUND DIAMETER (m)
R11	4725	-	20
R12	23.2	200	20
R13	7.6	568	20
R21T	9570	-	20
R22T	46.9	200	20
R23T	7.5	568	20
R31	1000	-	10
R32	0.14	600	10
R33	0.06	600	10
R41	1000	-	10
R42	0.14	600	10
R43	0.03	600	10
R51	-	-	20

6.2.6 Waste and Reagent Transport Failures

These are specified in a similar manner to the Reception failures given above. The liquid pool diameter is taken to be 20 m (as in the Tsing Yi Island Risk Reassessment study). An additional failure case identified in the earlier study for chlorine drums being transported by road is a leak due to a fire from all drums carried; this has been applied to sulphur dioxide transport also.

TABLE 6.6: WASTE AND REAGENT TRANSPORT CASES

CASE IDENTIFIER	RELEASE CONDITIONS		
	RELEASE RATE (kg/s) OR MASS RELEASED (kg)	RELEASE DURATION (s)	POOL OR BUND DIAMETER (m)
T11	4725	-	20
T12	23.2	200	20
T21T	9570	-	20
T22T	46.9	200	20
T31	1000	-	20
T32S	0.44	3600	20
T32M	2.6	3600	20
T33	0.06	3600	20
T41	1000	-	20
T42S	0.24	3600	20
T43	0.03	3600	20
T51	-	-	20

6.3 Hazard Effects Modelling

In this section, the results of the hazard effects modelling are reviewed, in particular identifying those releases which could lead to offsite risk. For events occurring on the CWTF, since the distance to the Tsing Yi road from the centre of the site is only about 50 m, and from the process areas even less, 'offsite' is defined as being beyond 50 m. Results for all transport cases are reviewed. Appendix VI presents numerical detail of the effect distances generated by all events.

These results show how far from the release point people could be affected if the release were to occur. Events with significant hazard effects extending offsite will contribute to offsite risk, however when these results are taken in conjunction with the event frequencies and meteorological probabilities to calculate the risk (as described in Section 2) it may be found that the risk from the facility is nevertheless acceptable within the established criteria.

6.3.1 Dispersion of Toxic Clouds

Dispersion of toxic clouds is modelled to a maximum effect distance such that the total toxic dose received is equivalent to LD_{001}, i.e. a probability of death of 0.001, on the cloud centreline.

Onsite Events

All the potential releases of Carbon Tetrachloride, taken as being representative of a **halogenated solvent**, can at least under some weather conditions give rise to offsite risk. All failures of chlorine and sulphur dioxide drums and hoses at reception also give rise to offsite risk. The maximum effect distances at ground level for these releases are given in the following table together with the weather conditions under which they occur.

TABLE 6.7: MAXIMUM EFFECT DISTANCES FOR ONSITE RELEASES

EVENT	MAXIMUM EFFECT DISTANCE (m)	WEATHER CLASS (Windspeed, stability)
S21T	225	1.0 m/s, F
S22T	1025	1.0 m/s, F
S23T	113	3.0 m/s, E 1.0 m/s, F
P12	88	1.0 m/s, F
R21T	113	1.0 m/s, F
R22T	500	1.0 m/s, F
R23T	100	3.0 m/s, E
R31	1300	1.0 m/s, F
R32	650	1.0 m/s, F
R33	275	1.0 m/s, F
R41	912	1.0 m/s, F
R42	300	1.0 m/s, F
R43	125	1.0 m/s, F

The toxic plume resulting from a warehouse fire is very buoyant and rises rapidly so that at or close to ground level the risk is minimal.

No residential population would be affected by any of the releases from storage or process, however people on the non-PHI industrial sites immediately to the north of the CWTF could be affected as well as personnel on the nearby non-PHI sites.

It should also be noted that, for the storage cases (S21T, S22T, S23T) these effect distances result from evaporation of the liquid pool resulting from failure of the tank. Measures to minimise bund evaporation in the event of such an incident should therefore be effective in reducing the resulting risk.

The maximum effect distance for case R31 (catastrophic rupture of a chlorine cylinder) almost reaches the southern edge of the Mayfair Gardens estate under the weather conditions shown: the probability of this occurring with a wind in the right direction (i.e. from due south) is 0.028 (Table 4.1). The significance of this in risk terms is discussed in the next section. Given the long dispersion hazard zones associated with failures in reception of chlorine and sulphur dioxide, this report subsequently examine means of reducing these risks.

Failure of a bulk tanker of halogenated solvent at reception also gives rise to offsite risk, with a major leak from the tanker giving the longest effect distance.

Transport Events

Maximum effect distances for all failure cases involving release of toxic materials (halogenated solvents and liquefied gases) considered for transport are given in the following table.

TABLE 6.8: MAXIMUM EFFECT DISTANCES FOR TOXIC RELEASES FROM TRANSPORT

EVENT	MAXIMUM EFFECT DISTANCE (m)	WEATHER CLASS (Windspeed, stability)
T21T	113	1.0 m/s, F
T22T	500	1.0 m/s, F
T31	1300	1.0 m/s, F
T32S	1025	1.0 m/s, F
T32M	2325	1.0 m/s, F
T33	450	1.0 m/s, F
T41	912	1.0 m/s, F
T42S	400	1.0 m/s, F
T43	150	1.0 m/s, F

As can be seen from this table, all potential failures arising in transport to CWTF give rise to significant effect distances. In particular, the chlorine supply gives very long effect distances which, in a built-up area with high population density could lead to a considerable number of fatalities and serious injuries.

6.3.2 Dispersion of Flammable Clouds

Dispersion of flammable events is modelled down to a concentration equal to the LFL (lower flammable limit) of the material concerned, usually of the order of a few percent (see Appendix II). The LFL contour is taken to be the boundary of a flash fire should the cloud be ignited; only people within the flash fire zone are assumed to suffer fatality.

Since there will be no flammable materials handled by the CWTF which are gases at normal atmospheric temperature, dispersion will only take place as a result of evaporation of pools formed as a result of failures leading to a spill of flammable liquid: this means that the vapour release rate is controlled mainly by the physical mechanisms causing evaporation (heat input from ground and surroundings and mass diffusion).

Besides flash fires, there is some possibility of a vapour cloud explosion arising from the dispersion, hence the flammable mass within the cloud is also calculated during the course of the dispersion modelling. The effect zones for an explosion can be much larger than for the equivalent flash fire; these are dealt with in Section 6.3.3 below. The liquid pool formed by the spill may also be ignited as a pool fire; the effect zones for these are also dealt with below.

Onsite events

None of the flammable releases on the facility gives rise to dispersion distances beyond 50 m, the criterion defined above as being a typical distance to the boundary for the CWTF. No distances to LFL are presented here for these events, therefore.

Transport

Maximum distances to LFL for the flammable releases (of non-halogenated solvent) are given in the following table.

TABLE 6.9: DISTANCES TO LFL FOR FLAMMABLE RELEASES FROM BULK ROAD TANKERS

EVENT	MAXIMUM EFFECT DISTANCE (m)	WEATHER CLASS (Windspeed, stability)
T11	5	3.0 m/s, E 1.0 m/s, F
T12	6	3.5 m/s, D

These distances show that the risk from a flash fire is very localised, however in a road traffic accident the occupants(s) of the vehicle(s) involved or passing could be caught within the fire.

6.3.3 Thermal Radiation and Explosions

The pool fire effect zone is modelled by an elliptical contour of thermal radiation of 12.5 KW/m^2. Two circular effect zones are modelled for explosions: these are defined not by overpressures but by damage levels, taken as 'heavy building damage' and 'light building damage' respectively. The explosion model has a threshold of 100 kg of vapour, below which it is not considered valid, hence explosion effect zones are only calculated if the flammable mass available exceeds this.

Onsite events

Failures involving oil and oil/water mixtures were modelled simply by pool fires. None of these gave hazard effect zones extending offsite.

Failure of non-halogenated waste solvent were modelled by releases from storage, process and reception, with pool fires and explosions possible outcomes. Again, none of the pool fires gave hazard effect zones extending offsite; the flammable mass of vapour produced is never more than a few tens of kg, hence no explosions were modelled.

Transport events

Failures of a bulk tanker carrying waste solvent (non-halogenated) can lead to a pool fire or explosion, however as for onsite events the flammable mass is too small for an explosion to be modelled. Maximum effect distances for the possible pool fires are given in the following table together with the windspeed giving rise to them.

TABLE 6.10: POOL FIRE HAZARD ZONE DIMENSIONS FOR LIQUID SPILLS FROM BULK ROAD TANKERS

EVENT	MAXIMUM EFFECT DISTANCE (m)	WINDSPEED (m/s)
T11	36	7.0
T12	36	7.0
T51	21	7.0

The effect distances for lower windspeeds are not significantly shorter. Comparing them distances with the distances presented in Table 6.9 for flash fires, a pool fire would be a more significant outcome of such a failure, extending beyond the immediate accident zone some distance along the road or to one side of the road depending on the wind direction and hence probably involving a greater number of people.

7 FREQUENCY ANALYSIS

7.1 Introduction

The failure cases developed in Sections 5 and 6 above require the assignment of frequencies of occurrence. This section describes the approach used and gives the frequencies assigned to each case. Appendix VII gives the historic failure rate data on which these are based.

7.2 Approach

The failure frequency to be assigned to each failure case identified can be determined by a number of means:

- Analysis of historical data
- Fault-tree analysis
- Reliability database
- Expert judgement based on experience

Historical data are preferred where available since they cover most causes, regardless of their origin, and thus are appropriate for events under normal operating conditions. Since they cover incidents from plants with a wide range of management, maintenance and safety standards, frequencies derived from them are averages for the whole of the chemical industry (or of that part analysed): they are therefore referred to as 'generic' failure rates. Care is necessary in using historical data to differentiate where possible between local data and effects and worldwide experience. Thus, Hong Kong historical data are preferred to world or USA data as they reflect better local conditions and operator skill levels. Naturally, such data are limited in availability. It should be recognized that Waste Management will provide training for local operators.

For a plant already in operation it is possible to take into account in a quantitative way the effects of management factors, modifying the generic rates. This is done by interviewing key site personnel and observing how well stated procedures are implemented in practice. As the CWTF is only at the design stage this cannot be done with the required degree of confidence: although it would be possible to interview personnel on similar plants operated by the same company and to review the proposed management procedures for the Hong Kong CWTF, it is impossible to determine how these would relate to the implementation of procedures when the plant becomes operational. The effect of management systems on safety performance was evaluated for a range of Tsing Yi plants in 1988. This showed for large international chemical industry companies that a factor of three difference in performance was possible depending on the quality and detail of the safety management systems implemented at the site. The Hong Kong Government has now implemented a remediation program to ensure all hazardous sites on Tsing Yi employ management systems better than generic average for the industry.

It is necessary to use fault tree analysis for cases where generic data are not available or when a chain of events is necessary for the failure to occur. An example of this latter type would be a process event where it is necessary for both the cooling water and the automatic shutdown to fail.

Technica's database of generic failure rates includes frequencies of incidents involving failure of the following:

- Atmospheric storage vessels (including resulting pool fires)
- Pipework (including flanges), according to diameter
- Pumps
- Condensers
- Bulk road tankers (atmospheric storage)
- Road tanker transfer hoses

Details of these will be found in Appendix VII.

Both incinerator failures and inadvertent mixing scenarios would require fault tree analysis, since they arise from chains of events, but these have been eliminated as described in Section 6.

7.3 Failure Frequencies

7.3.1 Waste and Reagent Reception Failure Cases

EVENT NUMBER	FREQUENCY (/YEAR)	ORIGIN	
R11	9.9×10^{-6}	Catastrophic failure	One tanker delivery per day, 300 days per year. Average unloading time 20 minutes.
R12	9.9×10^{-5}	Major leak from vessel	
R13	3.99×10^{-4}	Hose rupture	
R21T	9.9×10^{-6}	Catastrophic failure	One tanker delivery per day, 300 days per year. Average unloading time 20 minutes.
R22T	9.9×10^{-5}	Major leak from vessel, pipe or flange	
R23T	3.99×10^{-4}	Hose rupture	
R31	1.37×10^{-4}	Catastrophic failure of vessel	Annual usage 371 te, 1 deliveries per week of 7 one- tonne drums.
R32	3.3×10^{-2}	Major leak from vessel plus hose rupture	
R33	1.84×10^{-3}	Minor leak from vessel	
R41	6.38×10^{-5}	Catastrophic failure of vessel	Delivery of 9 one-tonne drums per year.
R42	1.51×10^{-3}	Major leak from vessel plus hose rupture	
R43	9.22×10^{-4}	Minor leak from vessel	
R51	3.81×10^{-5}	Catastrophic failure plus major leak; ignition probability = 0.05 for pool fire	Delivery of 3 tankers per day, 300 days per year, of which 50% contain highly flammable material. Unloading time is approximately 20 minutes

Note: For clarity, the derivation of the two most significant failure cases (R31 and R32) is given here.

R31: Catastrophic Release of the contents of one chlorine drum.
(This corresponds to any hole larger than about 1" in size.)

From Table VII.13 in Appendix VII, the catastrophic failure frequency for pressurized drums is given as 5.2 x 10^{-9} per hour. Given 6 drums on the site, assume on average 3 are full, the annual frequency of catastrophic release is:

Frequency = [3 drums] x [5.2 x 10^{-9}/hr] x []8760 hr/yr]
= 1.37 x 10^{-4}/yr

R32: Major Leak (8mm) from vessel or connecting hose.

From Appendix VII, Section VII.5, the Hong Kong chlorine transfer failure rate is given from Water Supplies Department experience as being 2 releases in 25 years operations, averaging 910 drums per year. This averages to a rate of 1 leak per 11375 drum connections. As the CWTF will handle a maximum of 371 drums/yr the expected frequency would be:

Frequency = [371 movements/yr] x [1 release/11375 connections]
= 3.3 x 10^{-2}/yr

7.3.2 Storage Failure Cases

EVENT NUMBER	FREQUENCY (/YEAR)	ORIGIN
S11	6.0×10^{-6}	Catastrophic failure of tank
S12	1.22×10^{-4}	Major leak from vessel, pipe or one of two flanges
S13	1.21×10^{-5}	Rupture of pump, bunded delivery line or flange, pro rated for time in use
S21T	6.0×10^{-6}	Catastrophic failure of tank
S22T	1.22×10^{-4}	Major leak from vessel, pipe or one of two flanges
S23T	1.21×10^{-5}	Rupture of pump, bunded delivery line or flange, pro rated for time in use
S31	2.4×10^{-4}	Bund fire
S32	6.0×10^{-4}	Bund fire
S33	2.4×10^{-4}	Bund fire
S41	3.0×10^{-4}	Elevated toxic plume

7.3.3 Process Failure Cases

EVENT NUMBER	FREQUENCY (/YEAR)	ORIGIN
P11	6.21×10^{-5}	Large hole in bottom half of vessel plus rupture of 50mm pipe at base
P12	7.21×10^{-5}	Large hole in top half of vessel plus rupture of delivery line to condenser

7.3.4 Transport Failure Cases

EVENT NUMBER	FREQUENCY (/KM YEAR)	ORIGIN	
T11	3.45×10^{-7}	Catastrophic failure	1 trip per day, 300 days per year
T12	3.15×10^{-6}	Major leak from tanker	
T21T	3.45×10^{-7}	Catastrophic failure	1 trip per day, 300 days per year
T22T	3.15×10^{-6}	Major leak from tanker	
T31	8.78×10^{-8}	Catastrophic failure of drum	1 delivery per week of seven 1-tonne drums, based on estimated use of 371 tpa.
T32S	4.26×10^{-5}	Major leak from one drum	
T33M	4.40×10^{-6}	Major leak from six drums	
T33	6.93×10^{-6}	Minor leak from drum	
T41	8.78×10^{-11}	Catastrophic failure of drum	One delivery every 120 days (approximate) of 3 one tonne drums.
T42S	8.48×10^{-7}	Major leak from one drum	
T43	6.92×10^{-9}	Minor leak from drum	
T51	1.05×10^{-6}	Spill by any failure, ignition probability = 0.1 for pool fire	Delivery of 3 tankers per day, 300 days per year, of which 50% contain highly flammable material.

8 RISK RESULTS

8.1 Individual Risk

8.1.1 Form of Presentation

For site activities, whose locations can be fairly precisely defined, individual risk is shown by **risk contour plots**. The routes to be used for transport to the site have not been defined and indeed, except in the final stage along Tsing Yi Road, will be numerous. Therefore, individual risks have been calculated on the assumption of all traffic considered - oily wastes, solvents, chlorine and sulphur dioxide - travelling along a common stretch of road (i.e. on the final stage of the inward journey, along Tsing Yi Road). By assuming the distribution of ignition sources to be roughly independent of exact location it is possible to present individual risk results in the form of a risk transect: that is, a cross-section of risk as a function of perpendicular distance from the centreline of the transport route.

8.1.2 Risk from Site Activities

Contours of individual risk from all site activities, including the chlorine and sulphur dioxide reception assumed, are shown in Figure 8.1. The risk contours for the cases associated with chlorine and sulphur dioxide reception alone and for all cases expect these have been plotted in Figures 8.2 and 8.3 respectively. These plans also show the boundaries of the different PHIs, industrial sites and residential areas identified in Figure 4.1.

Figure 8.1 shows that, with chlorine and sulphur dioxide (particularly the chlorine, since the amount to be used is much greater - see also Section 8.3 below) reception included, the Interim Risk Guideline as implemented by the Government for Individual Risk of 10^{-5}/year will be exceeded out to about 200 m beyond the site boundary. To the north of the CWTF this will take in workers on the adjacent non-PHI industrial sites, covering the southern half of this area: since the individual risk is calculated for someone continuously exposed, whereas industrial populations are generally only present for around 30% of the time, it should be noted that the contour for 3 x 10^{-5}/year individual risk (corresponding to the worker exposure to risk) would lie about 150 m beyond the site boundary. This means that the facility as originally defined here will **not be acceptable** within the Interim Risk Guidelines. The area to the northwest and west of the CWTF lying within the 10^{-5}/year risk contour is solely occupied by PHI installations: these populations do not come within the scope of the Guidelines.

Figure 8.3 shows that, excluding reception of chlorine and sulphur dioxide, the 10^{-5}/year risk contour does not extend beyond the site boundary and indeed that the 10^{-6}/year contour only encroaches a short distance onto the road and other land users' facilities.

FIGURE 8.1: CONTOURS OF INDIVIDUAL RISK FOR ALL ACTIVITIES ON CWTF SITE

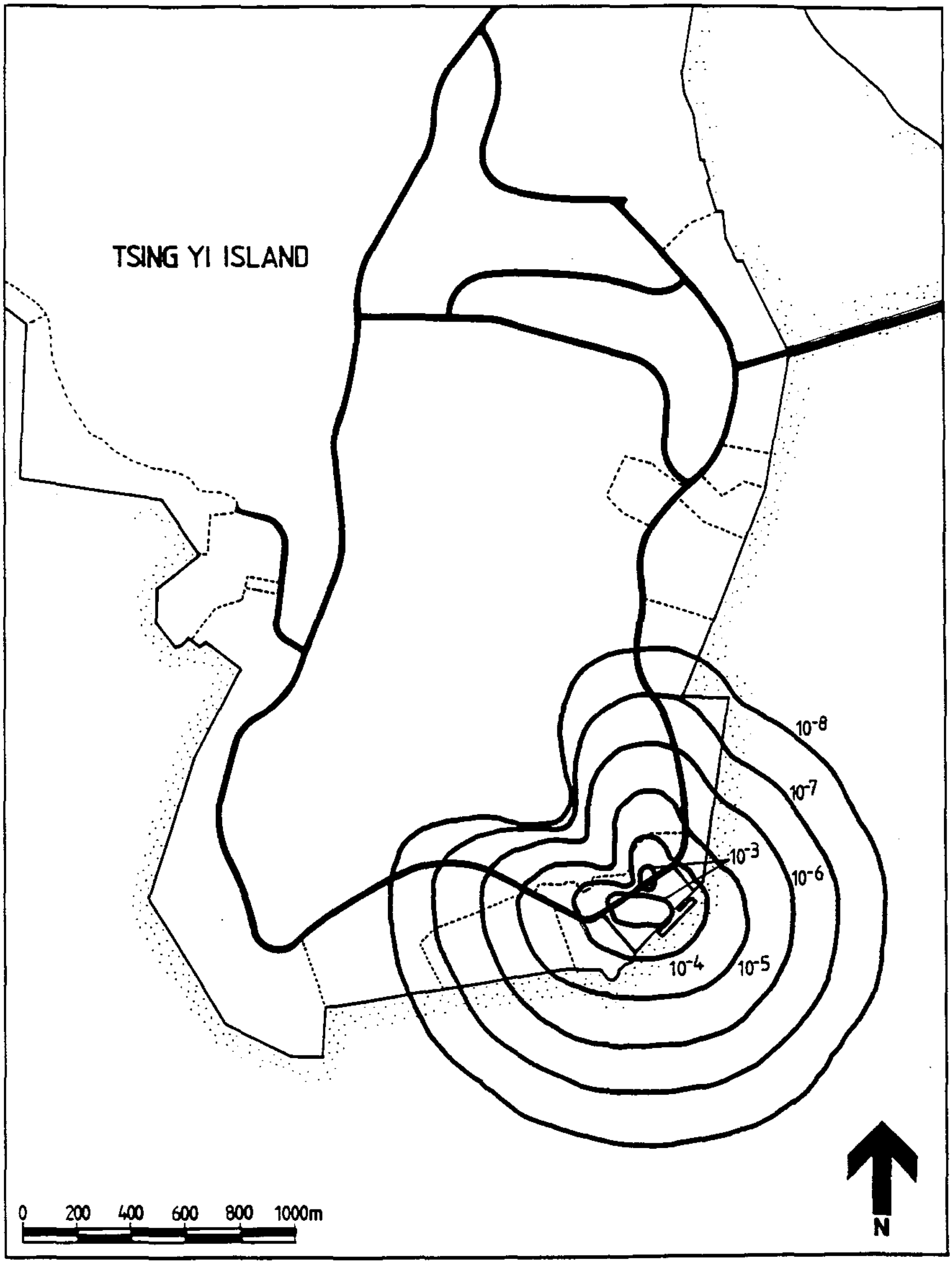


FIGURE 8.2: CONTOURS OF INDIVIDUAL RISK FOR CHLORINE AND SULPHUR DIOXIDE RECEPTION AT CWTF SITE

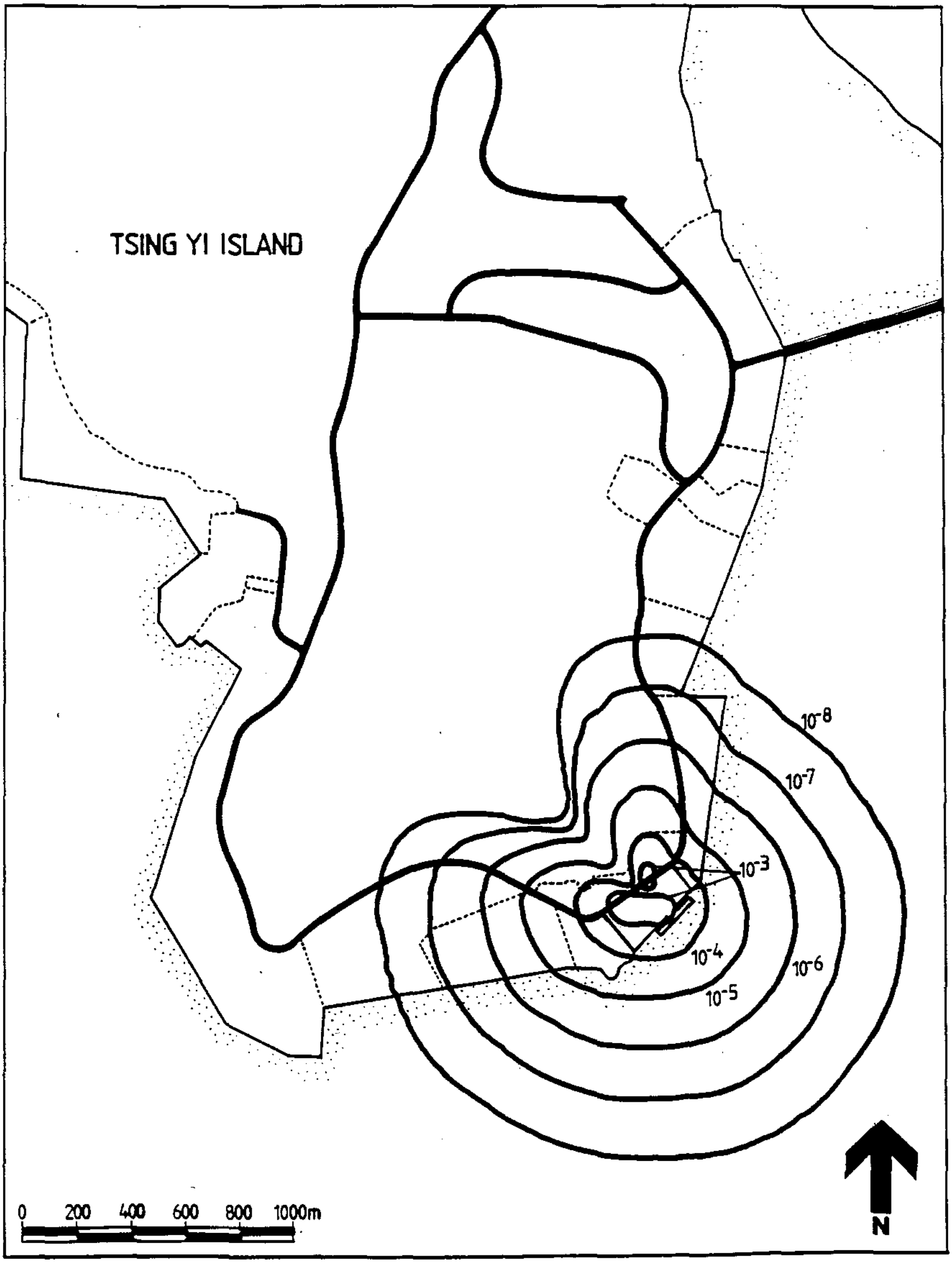
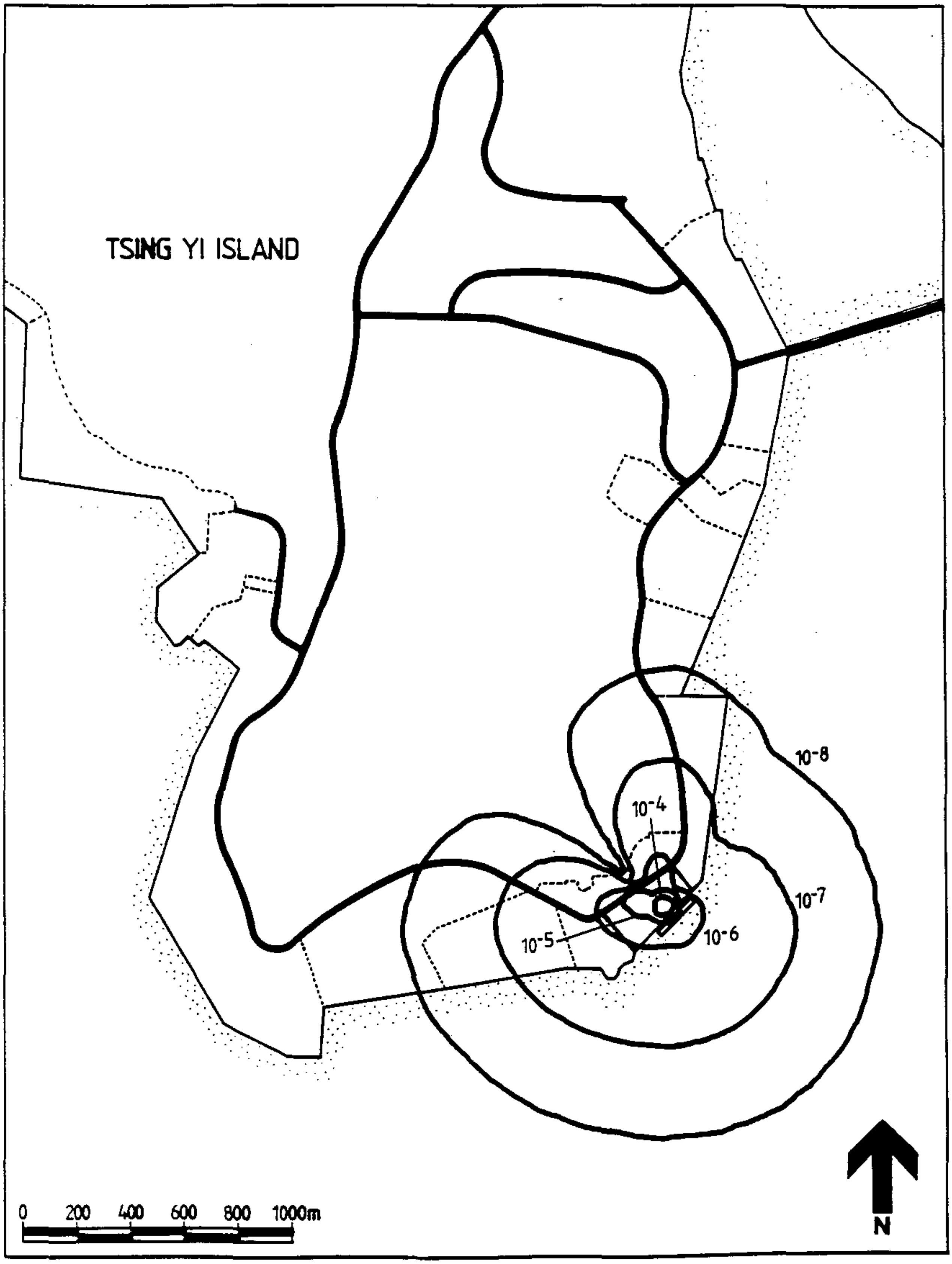


FIGURE 8.3: CONTOURS OF INDIVIDUAL RISK FOR STORAGE, PROCESS AND BULK TANKER RECEPTION AT CWTF SITE



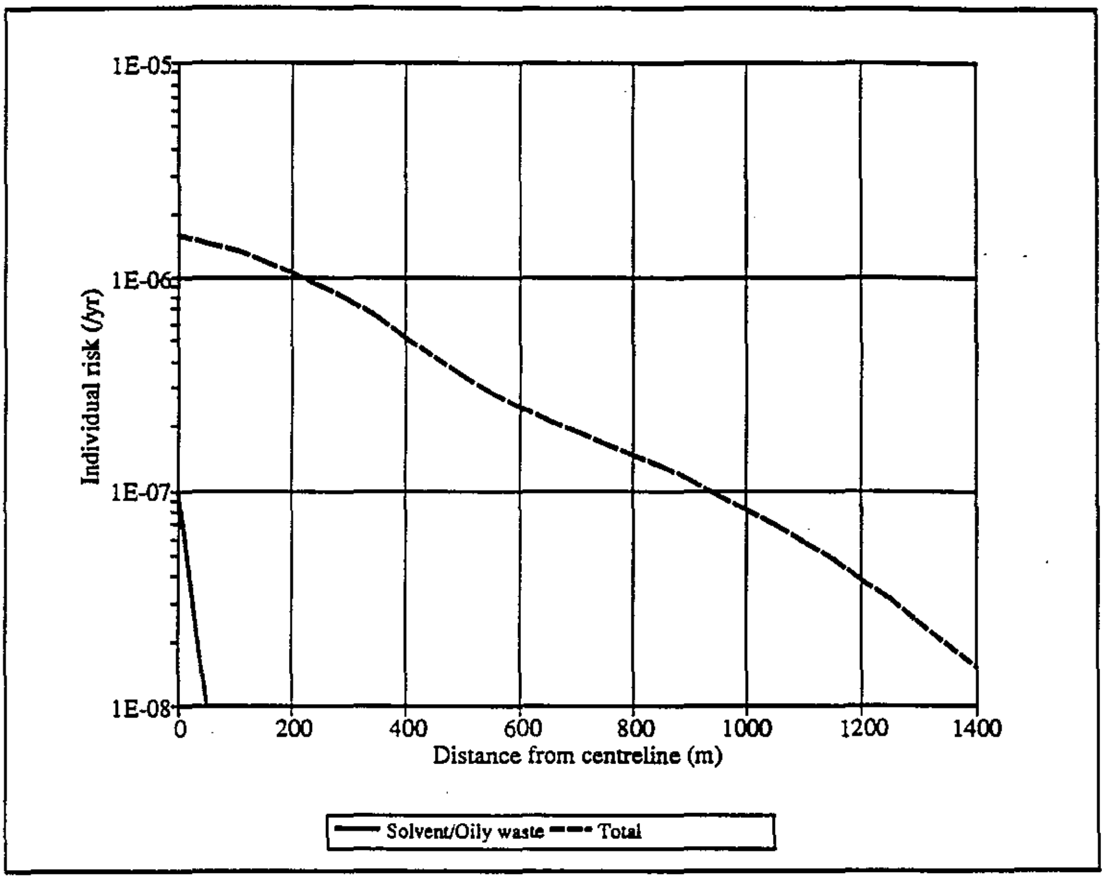
A brief comment on the shape of the risk contours is useful. There is a significant indent in the contours in the NW direction. This is due to the steep hill which minimizes dispersion in this direction. Also, the contours appear almost circular, while there are predominant winds from the NE and E directions (see Table 4.1). This is in fact an artefact of the logarithmic individual risk diagram which only plots risk decades (10^{-4}, 10^{-5} etc). As predominant winds typically only cause a factor 3 or so difference (when plume width is considered), this will appear only as a minor deviation on logarithmic plots.

It is therefore clear that the CWTF can operate within the requirements of the Hong Kong Government if arrangements for chlorine (and sulphur dioxide) supply are substantially revised. This is considered in more detail below (Section 8.1.3) and recommendations regarding how this might be achieved discussed further in Section 10.

8.1.3 Risk from Transport Activities

Risk transects for transport to the CWTF are shown in Figure 8.4. The total risk is shown, and also that generated by transport of solvent and oil-based wastes only; the difference between these is the risk generated by the assumed chlorine and sulphur dioxide supply. These show that the risk does not exceed the Hong Kong Government's Interim Guideline of 10^{-5}/year as specified in Section 2.3.2 even on the road. However, in view of the dense population adjacent to many roads in Hong Kong and transit distances involved, transport of chlorine and sulphur dioxide to the CWTF is undesirable. Transport by bulk tanker of solvents presents low risk, no more than 1% of the Interim Guideline.

FIGURE 8.4: INDIVIDUAL RISK TRANSECT FOR ROAD TRANSPORT TO CWTF

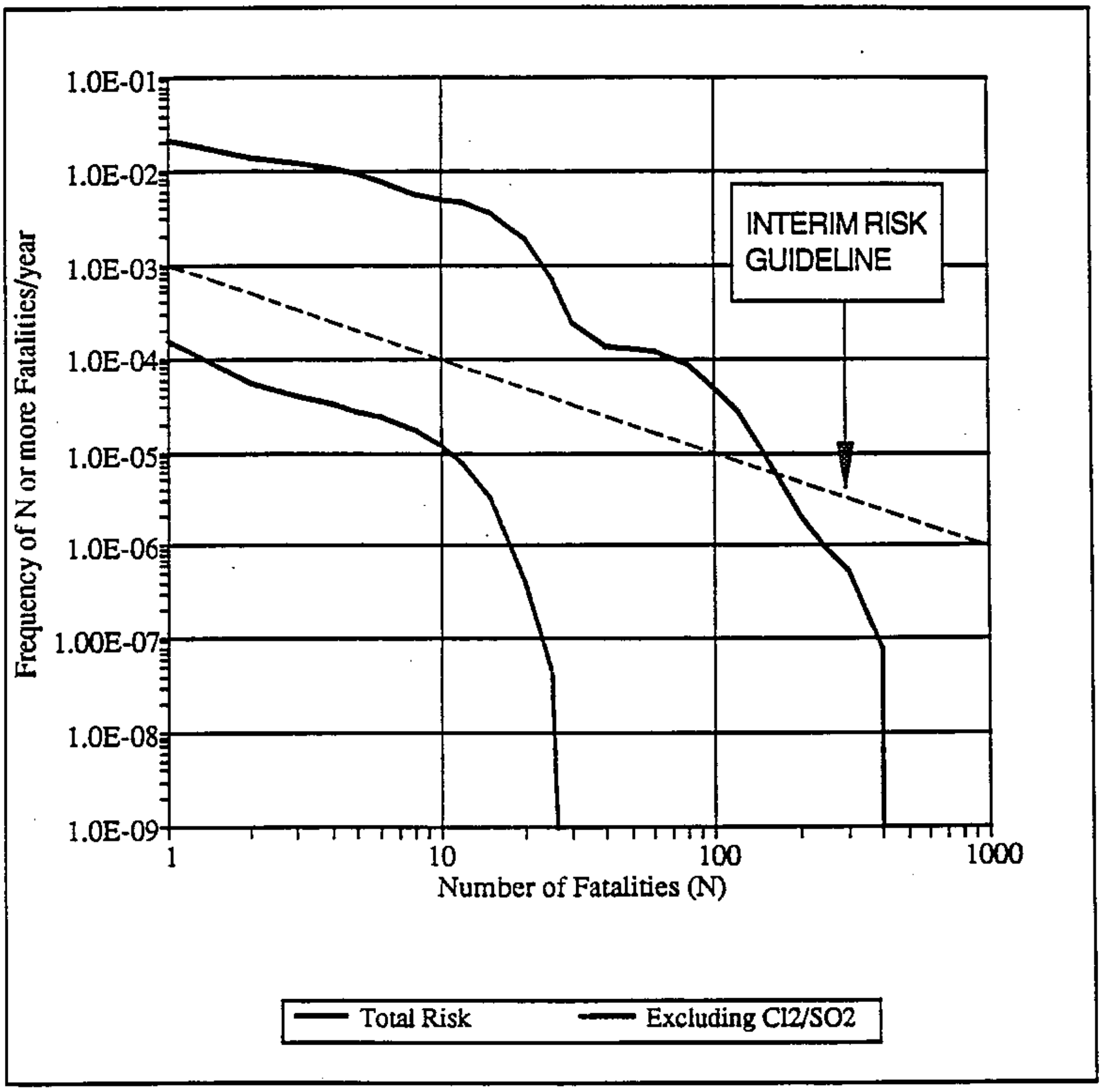


8.2 Societal Risk

8.2.1 Risk from Site Activities

The societal risk curve for the whole facility including chlorine and sulphur dioxide reception is shown in Figure 8.5 below. This figure also shows the effect of excluding the chlorine/sulphur dioxide reception from the risk calculations. Clearly, with chlorine being received in the quantities anticipated, the facility will be unacceptable; without this, it will have no difficulty in meeting the requirements of the Risk Guideline. This reinforces the conclusions drawn above from the individual risk results.

FIGURE 8.5: SOCIETAL RISK CURVES FOR CWTF SITE



8.2.2 Risk from Transport Activities

Since the routes to be taken by bulk tankers bringing waste materials to the CWTF and by lorries supplying chlorine and sulphur dioxide drums are at present unspecified and also open to a number of possible variations even on Tsing Yi Island, it is not considered practical or appropriate to calculate F-N curves for the transport. However, the consequence results and transects of individual risk already given allow some useful conclusions to be made.

- Societal risks from bulk transport of solvent and oil wastes should be minimal
- Societal risks from the supply of chlorine and sulphur dioxide will probably be acceptable. The results of the Risk Assessment of Liquid Chlorine Transport for Water Supplies Department, Hong Kong (Technica 1990) should be reviewed for further guidance on this matter.

8.3 Risk Ranking

8.3.1 Introduction

Risk ranking is used to identify which of the events considered are the major contributors to the overall risk results presented above, by looking at the risk contribution of each. This can take two forms:

- **Individual Risk Ranking**: the contribution from each event to the total risk at one or more specified locations
- **Societal Risk Ranking:** the contribution from each event (i.e. from all the pairs of F-N values generated by each event) to the overall risk. Since societal risk is a two-dimensional measure of risk (viz. F and N), this is most easily achieved by ranking the **rate of death** from each event.

8.3.2 Individual Risk Ranking

Two locations were considered, for onsite events only:-

(1) In the middle of Tsing Yi Road, just outside the CWTF's main gate (i.e. a point just beyond the site boundary).

(2) In the middle of Tsing Yi Road, opposite the boundary between the Mobil and Hong Kong Oil sites (i.e. a point remote from the CWTF site, only affected by releases travelling a long distance).

The ranked individual risk contributions at Location 1 are given in the following table. There were no significant risk contributions (greater than 10^{-12}/year) at Location 2.

TABLE 8.1: INDIVIDUAL RISK CONTRIBUTIONS AT LOCATION 1 (BY CWTF MAIN GATE)

CASE IDENTIFIER	RISK CONTRIBUTION (/year)
R32	1.12×10^{-4}
R31	1.41×10^{-5}
R41	8.22×10^{-6}
R42	3.73×10^{-6}
S22T	7.95×10^{-7}
R33	6.07×10^{-7}
R22T	8.40×10^{-8}

These results indicate that the most significant events are large leaks from chlorine and sulphur dioxide drums or from the hoses used to discharge them, in particular from the chlorine drums; the next largest contributor is catastrophic failure of a chlorine drum. The prime reason for the high frequency ascribed to chlorine drum and hose leaks is the high frequency ascribed to hose failure (see Section 7.3.1): this arises from the assumption of flexible hose connections to the cylinders for discharging them.

The only events in the above list (and contributing to the offsite risk) are leaks from storage and bulk tankers containing halogenated solvent, the former being more important by an order of magnitude. This results from the volatility of carbon tetrachloride (used to represent such solvents) and consequent high evaporation rate from the liquid pool resulting from the spill; possible measures to minimise this evaporation rate are recommended in Section 10.

From the results for Location 2 it is clear that no residential population is likely to be exposed to any significant risk from the planned site activities.

8.3.3 Societal Risk Ranking

Each event contributes a pair of F and N values for each wind direction and weather class. Taking the product of each of these pairs and summing over all wind directions and weather classes gives the rate of death for that event. The calculated rates of death which are greater than 1 fatality per million years are ranked and tabulated in the following table.

TABLE 8.2: RATES OF DEATH FROM CWTF ONSITE ACTIVITIES

CASE IDENTIFIER	RATE OF DEATH (Number of fatalities per year)
R32	1.25×10^{-1}
R31	8.69×10^{-3}
R41	5.37×10^{-3}
R42	4.40×10^{-3}
R33	1.07×10^{-3}
S22T	3.46×10^{-4}
R43	2.04×10^{-4}
S12	6.57×10^{-5}
R22T	1.46×10^{-5}
S11	2.88×10^{-6}

Also useful are the contributions from each activity planned for the site to the overall rate of death, given in the following table.

TABLE 8.3: CONTRIBUTIONS TO RATE OF DEATH FROM EACH ACTIVITY ON CWTF SITE

ACTIVITY	TOTAL RATE OF DEATH (number of fatalities per year)	PERCENTAGE CONTRIBUTION TO TOTAL
Storage	4.15×10^{-4}	0.3
Process	0	0
Solvent/Oil Waste Reception	1.46×10^{-5}	0.01
Chlorine/Sulphur Dioxide Reception	0.146	99.71
TOTAL	0.147	100

It is clear from all these results that the societal risk, like the individual risk, is dominated by the discharge via hose of chlorine from drums to process and hence that the risk reduction measures required for the planned operation of the CWTF to be acceptable must be focused on one of the following: either fixed discharge equipment must be fitted or chlorine supply must be by some other means or process changes to eliminate the use of chlorine and sulphur dioxide must be made.

In societal risk terms, a spill of halogenated solvent from storage is still one of the principal risk contributors: although small compared with chlorine supply as assumed here, a reduction in the risk from the chlorine supply would make this event more significant, hence risk reduction recommendations regarding such an event should be given prime consideration once the issue of chlorine and sulphur dioxide supply has been resolved.

8.4 Risk Reduction Measures

The base case individual and societal risk levels determined in Sections 8.1 to 8.3 are too high to meet the Hong Kong Government Interim Risk Guidelines. This is mainly attributable to the pressurized liquefied chlorine handling operations on the site, and to a significantly lesser degree the sulphur dioxide operations on the site. Transport risks due to chlorine were found to generate low individual risk, as would be expected for infrequent loads passing by a particular place relatively quickly. Societal risk would be significantly higher but, as there is no risk guideline for transport, this has not been produced as this would have required full definition of transport routing which is not yet available.

In order to proceed, the CWTF will need to consider a range of mitigation measures which taken together might reduce the risk to comply with the Interim Risk Guidelines. Where economically feasible, risks should be reduced to the lowest practicable value. Risk reduction efforts should not terminate simply because the Interim Risk Guideline is complied with. This is particularly true if the proposed SETY development proceeds and if the Outboard Marine intensification occurs, increasing the adjacent site population by over 1000 people.

Technica suggest the following means to reduce risks from the CWTF site:

1) Enhanced connector system for the chlorine drums to reduce chlorine leak frequency and to limit release duration.

2) Enhanced handling and drum storage systems to minimize dropped object or impact damage to chlorine drums.

3) Similar enhancements to measures 1 and 2 for sulphur dioxide drums.

4) Reduce transport risk by transporting toxic pressurized liquefied gases (chlorine and sulphur dioxide) by barge to the CWTF jetty or by DG Ferry provided the SETY development proceeds.

5) Substitution of chlorine with another less hazardous reagent.

6) Substitution of sulphur dioxide with a less hazardous reagent.

Measure 1) Improved Chlorine Drum Connection System

Table 8.1 shows Case R32, large (8mm) leak from chlorine drums as the major individual risk contributor: 1.12×10^{-4}/yr at the CWTF gate.

If the leak frequency of the flexible hose connection could be reduced significantly to values approaching those achieved with hard-arms as in the LPG industry on Tsing Yi, then a large reduction in risk would be obtained. Table VII.14 shows that up to a 3 orders of magnitude reduction is possible. However, this refers to conventional rubber core/outer steel braided hose. The Chlorine Institute nominates either hoses or the mechanically stronger cadmium plated copper tubing flexible connection. Technica believes that if a connection of maximum mechanical strength, consistent with the need to make and break connections frequency, is employed then a reduction of at least 1 - 2 orders of magnitude can be expected. An equivalent alternative might be a double pipe design so that any leaks discharge into an outer pressure rated tube and not into the environment. Good maintenance, inspection and prior test procedures for flexible connections before use should also reduce the loss frequency.

Technica also suggest that a factor of 2 reduction in frequency might be achieved if the CWTF implements a high quality safety management system (consistent with API RP 750 or Draft OSHA 1910: see Section 9.1 for further details).

Finally, a further factor of 3 - 10 might be achieved by the ability to terminate a leakage incident rapidly, rather than the 60 minutes assumed here. This would require both procedural modifications (e.g. two operators present during all connection actions, the wearing of 30 minute emergency respirators) and a quarter turn shutoff valve to be connected directly to the chlorine drum before the hose connection. Drums will probably be imported from local sources and the quality of the drum's own valve cannot be guaranteed. Connecting a quick shut-off CWTF owned and maintained valve before the flexible connection should enable most releases to be terminated quickly with no off-site safety implications. A leak detection system would quickly alert other operators of a leakage so that other emergency measures could be instituted.

Overall, Technica believes that technical and safety management procedures can reduce the frequency of a continuous 8mm liquid leak from the flexible connection by: [1 - 2 orders of magnitude due to enhanced mechanical strength] x [factor of 2 for high quality safety management] x [factor of 3 - 10 for incident termination potential]. This would reduce the frequency we employed in the risk analysis by a factor of 2 - 3 orders for magnitude. This would reduce the individual risk contribution at the site boundary from the present 1.12×10^{-4}/yr to closer to 1.4×10^{-7}/yr. We believe that other failure modes would start to dominate, such as 8mm leaks from the drum itself. In total, this might lead to a 2 order of magnitude reduction in this release case.

Measure 2) Improved Chlorine Drum Handling and Storage Arrangements

Table 8.1 shows the contribution of the catastrophic failure of a chlorine drum to be 1.4×10^{-5}/yr at the CWTF gate.

There are again a number of means that might be employed to reduce the risk of this scenario. However, compared to the risk reduction possible for R32, the hose failure case, there is less scope.

The most likely scenario leading to catastrophic failure is either dropping the drum in lift operations or puncturing the drum with a hard sharp object during handling. Recall, a catastrophic failure is any release case that can discharge the whole drum contents in a short period (e.g. a 50mm hole).

Spontaneous failures are less likely. The recommended means to reduce this scenario in frequency would be a combination of improved safety management systems (a potential gain of a factor of 2) and improved handling and storage arrangements. Drum lifting equipment should be in accordance with the Chlorine Institute requirements, and particular attention should be given on this small site to reduce as much as possible the potential for the crane operator to collide with adjacent structures or other drums. Cranes are preferred to forklift trucks as the latter have a greater chance for accident. Procedures will need to address special factors in Hong Kong such as typhoons, precluding unsheltered lift operations in high wind conditions. Transfer arrangements from the jetty if marine transfer of chlorine drums is employed need careful attention, particularly if the CWTF is separated from its jetty should the proposed SETY CT9 development proceed. The storage area should be properly designed, dedicated to storage of toxic pressurized drums, with good access, protection from adverse weather, and fire protection. Again, Technica believes that at best a factor of 2 improvement is achievable due to these procedures.

Overall, therefore the frequency of case R31 might be reduced by a factor of 4. This would reduce the individual risk contribution of R31 at the site boundary from 1.4 x 10^{-5}/yr to 3.5 x 10^{-6}/yr.

Measure 3) Enhanced Connections and Handling of Sulphur Dioxide Drums

Assuming the same arguments for sulphur dioxide as for chlorine, then risk reductions of the same order might be expected. Recommendations for plant equipment design and operation of the Compressed Gas Manufacturing Association will be employed. This would reduce the individual risk contributions of cases R41 and R42 (shown in Table 8.1) down to 2.1 x 10^{-6}/yr and 4 x 10^{-7}/yr respectively.

Combined Risk Reduction Benefits

Combining the effects of Measures 1 - 3, the total risk at the CWTF gate would be reduced from around 1.5 x 10^{-4}/yr down to 5 x 10^{-6}/yr. This would put the plant within the Interim Risk Guideline for individual risk.

A similar argument can be made for societal risk. Table 8.2 shows the relative contributions of the chlorine and sulphur dioxide release cases. Again the R32 case (8mm liquid chlorine release) dominates. Applying the same reduction factors as above implies a total rate of death for the four key cases of:

R32 - 1.3 x 10^{-3}/yr
R31 - 2.2 x 10^{-3}/yr
R41 - 1.4 x 10^{-3}/yr
R42 - 4.4 x 10^{-5}/yr

This reduces the total rate of death statistic from 1.45 x 10^{-1}/yr down to 6.6 x 10^{-3}/yr. This is a factor of 22 reduction in societal risk. In an approximate manner, this factor of 22 can be applied to the F-N societal risk plot of Figure 8.5. While not rigorous, as all the incidents of major importance are toxic and as only the frequencies are being modified, this will give an indication of societal risk of acceptable quality. The factor of 22 is sufficient to bring most of the societal risk graph down to or below the Interim Risk Guideline in Figure 8.5. There would still be small exceedence at around 10 fatalities, by about a third order of magnitude. However, given the assumptions made here, more detailed analysis of handling procedures for drums might reduce the frequency further. This is not a matter that can be resolved until detailed engineering of the drum handling and storage system is developed by the Enviropace contractor.

Measure 4) Marine Transfer of Drums

Transport risk was demonstrated to be low in terms of individual risk. This is essentially always the finding with infrequent transport of hazardous materials. Societal risks are greater but there is no risk guideline established for transport.

The basis of assessment of transport risks often consists of reviewing potential alternatives and determining whether these are economically viable. The consequence affected areas for transport incidents are essentially the same as for processing incident as the same hole sizes are possible, although often for quite different reasons. It was the finding for Water Supplies Department, operating a trade 4 - 5 times the size of that for the CWTF that risk reduction was warranted due to societal risks. Technica similarly regards reduction of transport risk for CWTF as a desirable objective. This is because the Water Supplies Department trade is distributed all around Hong Kong, whereas the CWTF trade will most likely use the same route.

There are some alternatives for the delivery of liquid chlorine and sulphur dioxide. Shipments will most likely arrive by coastal tanker into Hong Kong. This ship would be too large to tie up at the CWTF jetty, therefore it might berth in Kowloon as it does for the Water Supplies Department shipments. Two marine transport alternatives exist: 1) the drums could be loaded onto a barge and towed around to the CWTF site, or 2) they could be loaded onto a truck and the truck could use a Dangerous Goods Ferry to move from Kowloon to the DG Wharf proposed to be built as part of the SETY CT9 project. Alternative 2) would not be possible until some years after the CWTF site opened, depending on if and when the plans for CT9 are implemented.

Measures 5 and 6) Substitution of $C1_2$ and SO_2 Reagents

Substitution of chlorine with other reagents would produce the most significant and certain risk reduction. There are two processes which use chlorine in the CWTF: cyanide oxidation and copper cementation. The cyanide streams are relatively small and may be easily destroyed in the incinerator. There is no replacement for chlorine in the copper cementation process, but it is possible that there will be reducing need for this type of process due to changing methods used in printed circuit board manufacture. The alternative process for this stream is acid neutralization by PO*WW*ER.

Substitution of sulphur dioxide with sodium metabisulphite in the chromium reduction process is also possible, again at some cost. It is possible that some minor usage of sulphur dioxide may still be required for the effective treatment of some other wastes. This would involve much less SO_2 than the 9 tonnes here.

Removal of liquid chlorine entirely from the site eliminates release case R31, R32 and R33 from the risk assessment. Removal of sulphur dioxide would eliminate release cases R41, R42 and R43. Additionally, the transport cases for these two gases would also be removed. The effect of removal of these two reagents from the process has been plotted in Figure 8.3. This clearly shows that the 10^{-5}/yr individual risk contour is held within the site and that most of the 10^{-6}/yr contour is similarly within the site. This is almost one order of magnitude within the Interim Risk Guidelines criteria.

Societal risk is substantially reduced as shown in Figure 8.3. This F-N plot shows the residual societal risk left on the CWTF site once chlorine and sulphur dioxide reagents are eliminated. Risks are one order of magnitude below the Interim Risk Guideline for 1 to 10 fatalities and no incident is predicted to lead to more than 25 offsite fatalities. Thus societal risk would also fully comply with the Interim Risk Guideline.

8.5 Effect of SETY Development

The main feature of the proposed SETY CT9 development is an intensification in land use on the eastern side of Tsing Yi by about 17,000 people. Of particular note are the developments adjacent to the CWTF site. The adjacent site to the NE, Outboard Marine, is to be intensified by the addition of 1070 people; to the S and E there will be lorry parks for around 220 people. The CRC site will be expanded by the transfer of oil storage operations from Nga Ying Chau to a site S and W of CWTF. This might involve 20-30 staff, but this is a PHI site.

As the risk from the CWTF site is presently dominated by dispersion of toxic plumes, the risk contours will essentially not be altered. Contours dominated by flammable risks can change as extra people introduce extra ignition sources.

Therefore, it can still be assumed that, provided the mitigation measures identified earlier are adopted, the Individual Risk result should be within the Interim Risk Guideline as discussed in Section 8.4 Measures 1 - 3 above.

Societal risk is however likely to be significantly exceeded. It was shown above that societal risk would likely marginally exceed the Interim Risk Guideline even with implementation of the risk reduction strategies. It was argued that further reduction might be possible once detailed design was completed and that the risk guideline might in fact still be met. However, the addition of more than 1500 people at sites adjacent to the CWTF would significantly increase potential impacts of accidents without modifying their frequency. With reference to the F-N plot, this would essentially push the curve horizontally to the right, as incidents at whatever previous frequency now have the potential to cause more casualties. The new people affected would be at the closest range, within 300m, where casualty effects are most certain, and thus significant extra fatalities would be expected compared to the earlier findings. Thus what previously was a marginal failing of the Interim Risk Guideline would now become a major exceedence. It is unlikely that mitigation measures could cancel the great increase in numbers of people affected.

8.6 Accuracy

Risk assessment by its very nature is an inexact science. Historical accident frequencies are applied to the specific consequence potentials of new sites in a manner best to predict from past experience what risk the new facility could cause.

Conventional reviews on this topic suggest that an order of magnitude is the typical range in accuracy that can be expected between different analysts. This error band can be reduced to a half order of magnitude if a consistent modelling approach and failure rate database are applied. This view has been supported by the recent European Benchmark exercise which compared the independent risk results of 11 teams assessing a toxic ammonia facility. Those teams applying methodologies similar to that adopted here did obtain results within the one order of magnitude accuracy generally claimed.

Special factors for the CWTF site have been discussed with the Government. The chlorine probit used in this study is only slightly different from the Hong Kong chlorine probit as shown in Appendix II, Section II.6 and results in some extra conservatism in our predictions. The degree of conservatism is small however, with LC_{50}s for 30 minutes being 290 ppm vs 250 ppm. Thus Technica might predict at most a factor of 2 greater fatalities and probably less than a factor of 1.5 compared with the Hong Kong probit. The fatalities predicted here by Technica have been shown to generate a Fatality Ratio (deaths/tonne of chlorine released) of about 30. The historical average is closer to 1. However, examination of Lees' text *Loss Prevention in Process Industries* (Butterworths, London,

1980) shows higher ratios for smaller releases of chlorine, in the range 14 - 45. Thus our consequence results are possibly high (i.e. conservative but not excessively so). The relatively high population concentration around the CWTF site, compared to world experience, would also contribute to the high result. Technica has run the SAFETI model for recent disasters (e.g. Bhopal MIC release and the Texas HF release). We were in agreement with both incidents: 2 - 3000 fatalities for Bhopal and nil for Texas. Thus experience running SAFETI for actual disasters does not suggest excessive overprediction.

Overall, Technica feels the accuracy for this study is in line with industry experience. Risk analysis is not an exact science, but the values developed here are of sufficient accuracy that sensible planning and engineering design decisions can be taken.

8.7 Summary of Findings

The findings of the risk assessment of the CWTF were that a basic plant with ordinary procedures and using relatively less sophisticated engineering would generate risks well above the Hong Kong Interim Risk Guidelines. This is true for both Individual and Societal Risk. More than 98% of the risk could be traced to the use of pressurized toxic liquefied gases: chlorine and sulphur dioxide.

Applying best engineering methods and using management systems consistent with best current guidelines (API RP 750, OSHA 1910, CCPS etc), the CWTF should be able to reduce risk significantly. Individual risk can be reduced to a point meeting the Interim Risk Guidelines at the plant gate by a factor of 2 approximately. Societal risk just exceeds the Interim Risk Guidelines in the region around 10 deaths, by less than a half order of magnitude. It may be possible to reduce risk further once the detail design becomes available. However, this will not be easy as the assumptions employed here already assume major risk reduction.

Some significant risk reduction is achievable in the transport of chlorine and sulphur dioxide by using marine transport. This could be either using barges to the CWTF jetty or by using the proposed DG Wharf on the SETY CT9 development now being planned. The justification for this would be the reduction in societal risk, as individual risk from transport activities is small.

If chlorine and sulphur dioxide were eliminated from the site, then the CWTF meets the Interim Risk Guidelines with ease, both in terms of individual and societal risk. Elimination is possible, at some cost. The substitute processes do not represent an increased risk of themselves. Likewise, the substituted reagent (metabisulphite) is essentially non-hazardous.

9 REVIEW OF PROPOSED STORAGE AND OPERATING SYSTEMS

9.1 Introduction

This section is concerned primarily with those aspects of the proposed procedures and practices for the collection, transport, reception, storage and treatment of chemical wastes at the CWTF that have a particular impact on its overall safe operation and in particular on its potential for the generation of offsite risk.

As operator of the CWTF, Enviropace will collect, transport, store, treat and dispose of all types of chemical wastes generated in Hong Kong. Its procedures and practices have been developed on the basis of the worldwide experience of a WMI affiliated company, Chemical Waste Management, in the operation of CWTFs.

There has been a substantial increase in attention given to the proper management of safety in hazardous process plant. In the 1980s there was a major emphasis on hardware items safety (emergency shutdown systems, isolation valves, gas detection systems etc). However, the number of accidents did not reduce and two of the largest incidents in real terms to affect the process industry occurred in the 1980s (Phillips Pasadena Polymer Plant explosion and the Piper Alpha offshore disaster) were both attributable to poor safety management procedures.

The recent Tsing Yi Risk Reassessment Study (1988) employed a management system review methodology called MANAGER. This is described in full in a paper by Pitblado et al, *Quantitative Assessment of Process Safety Programs*, Plant Operations Progress 9 p169 (1990). The application of this review to Tsing Yi demonstrated that amongst the large international process industry operators a factor of 3 difference (best to worst) in safety performance might be expected. Best industry performance, by companies such as Dow Chemicals, achieved risk reductions we estimated of a factor of 2 compared to industry averages.

Recently, three publications/standards have been issued which address in more detail the requirements of process safety management. These are:

> American Petroleum Institute, API RP 750, Management of Process Hazards (1990).
>
> Center for Chemical Process Safety, American Institute for Chemical Engineering, Guidelines for the Technical Management of Chemical Process Safety (1989).
>
> Occupational Safety and Health and Administration, US Dept of Labor, 29 CFR Part 1910, Process Safety Management of Highly Hazardous Chemicals, Notice of proposed Rulemaking (1990).

It is assumed that the CWTF will employ process safety management systems implementing the requirements of API RP 750 or OSHA 1910. It is Technica's experience in auditing safety management systems that sites implementing programs such as these should expect risk reductions of at least a factor of 2 compared to historical generic average performance (for good companies).

Of particular benefit to the chlorine handling operations will be the recommendations of the Chlorine Institute. Technica understands that the CWTF will implement in full the recommendations of the Chlorine Institute in the design and operations of this part of the facility. The Chlorine Institute has been instrumental in achieving better than average safety performance at a wide range of chlorine handling sites, with a consequent reduction in risk compared to generic statistics.

9.2 Policies and Procedures

Enviropace's policies and procedures for safe operation are stated to be based on "protection of the public, employees and the environment, ... compliance with all health, safety and environmental regulations..... (and) safe, effective, and complete service to customers". These objectives are to be realised through:

- selection, placement and training of personnel;
- use of best available processes, procedures and equipment;
- installation of appropriate and effective safety and emergency response systems staff training, operations monitoring and two-way communications between all levels of staff.

9.3 Organisation and Management

The organisational structure for the CWTF is illustrated schematically in Figure 9.1.

9.3.1 Safety Management

Safety is a direct managerial responsibility of the Environment Manager who is supported by a Safety Supervisor.

9.3.2 Management of Change

The rapid pace of change in waste treatment technology, and the patterns of waste generation that are different from those originally envisaged are just two of the factors that could contribute to a requirement for modifications of plant and treatment process. Such modifications should be the subject of formal independent safety audits in order to provide assurances that they will in no way compromise the safety of the facility and its operations.

9.3.3 Supervision Levels Outside Normal Working Hours

Normal working hours are defined as Monday to Friday (0700-1500 hours, 8 hours) and Saturday (3 hours). Therefore there will be approximately 125 hours out of 168 hours per week when senior management personnel will not be present on site. It will be vital to the safe operation of the CWTF that an adequate level of supervision is maintained during these periods and that effective communications are maintained between site supervision and management who are on call.

9.4 Health and Safety Programme

The health and safety programme supplied for review includes a list of health and safety procedures and guidelines that form the basis of the programme. The list is quite extensive but omits some areas of safety that are of prime concern in terms of accident prevention, e.g. scaffolding, excavation, general electrical safety. Specimen examples of the procedures and guidelines will be developed in conjunction with the plant operating manuals, as will the detailed CWTF Emergency Response Plan.

9.5 Operations

The facility design and operating policy is based on: reducing waste, conserving energy, minimising air pollution and recovering resources. A particular feature of processing is the integration of energy-consuming processes with waste-energy production. Waste treatment processes are described in Section 3.

9.5.1 Transport

Transportation of waste or treatment chemicals such as chlorine to the CWTF is one of the operations that has a high potential for offsite risk impact. Two types of accident can be envisaged:

- traffic accident involving collision with another mobile vehicle or with a stationary object;
- spill of waste from equipment or procedural failure.

Vehicle Maintenance Plan

A comprehensive vehicle maintenance plan has been developed in recognition of the need to ensure that all vehicles used for the transport of chemical waste must be subject to high standards of mechanical maintenance. The effective implementation of this plan should go a long way to reducing the frequency of traffic accidents caused by transport vehicle failures.

Spill Contingency Plan

The rapid and effective response to a spill of hazardous chemical can prevent a minor spill from becoming a major one. Therefore the effectiveness of the spill contingency plan is an important consideration in terms of offsite risk. For this reason and as the spill contingency plan is one of the few items which is described in detail, it is appropriate to make some specific comment on it.

It is assumed that the documentation provided for review is a reproduction of the spill contingency plan that will be implemented.

The spill contingency plan does not attempt to distinguish between different types of emergency. Given the types of vehicles and containers to be used for the transport of waste, a relatively small number of emergency types can be envisaged:

(i) spillage from a single 20 litre container;
(ii) spillage from a single 200 litre container;
(iii) spillage from several containers simultaneously;
(iv) spillage from a bulk tanker.

The action to be taken will depend both on the size of the spillage and on the nature of the material released. The spill contingency plan should be sufficiently specific to take these various possibilities into account.

The plan contains a mixture of responsibilities and actions. These are not clearly separated and this could lead to confusion. Emergency actions and the sequence in which they should be taken should be more clearly laid out. Responsibilities and action plans will be detailed in the CWTF Emergency Response Plan.

Some of the instructions to the driver imply some inconsistencies in the plan, or do not indicate how they are to be carried out. For example the driver is instructed not to "handle waste materials without qualified assistance" this appears to be inconsistent with the degree of training and qualification implied in the section on training. Also the driver is instructed to "inform all pedestrians and motorists of the danger involved" however no reference is made in the equipment list for the vehicle to a megaphone or other PA system that would assist the driver to carry out this instruction.

The list of emergency equipment to be carried on the transport vehicle gives some cause for concern. For example, one fire extinguisher is insufficient given the possibility that one will not operate. Also, if the vehicle carries two crew members, then both could be engaged in controlling a fire thus preventing it from escalating to major proportions. Overshoes are not adequate for dealing with chemical spills. Chemicals resistant boots must be used. This comment applies also to the rain suit, it should be replaced by a chemicals resistant suit. The provision of a five minute air escape pack implies that the driver would need to escape from a toxic atmosphere. If this is so, then the driver would not be able to re-enter the immediate scene of the spill without supplied air respiratory equipment. The inclusion of a 30 min breathing apparatus (BA) set on the vehicle is also recommended.

A hazard action card of the TREMCARD type would provide the driver with the basic information on emergency action for the range of wastes to be carried.

The spill contingency plan will be part of the overall CWTF Emergency Response Plan to be prepared when the detail engineering phase is completed.

9.5.2 Operational Procedures

This section deals with on-site operations from the receipt of waste for treatment to the final despatch of stabilised solid waste for landfill.

Laboratory Operations and Waste Characterisation

Accurately characterising waste to be treated at the CWTF is the crucial step in ensuring its appropriate and safe storage and treatment. This is the first main stage of the site's Waste Analysis Plan (WAP). Advanced analytical procedures supported by a computerised tracking system and qualified and experienced staff will be applied to the initial characterisation stage. In order to avoid the time and expense of total testing of every consignment of waste a system of waste profiling, pre-acceptance and delivery acceptance will be adopted.

A Generator's Waste Material Profile Sheet is used as the basis of the characterisation of the waste to be processed. In order to take account of the various factors that could give rise to inaccuracies and variations in the waste profile, a system of Service Representatives who interface between the waste generator and the CWTF will be implemented.

Initial laboratory testing - fingerprinting - on a representative sample submitted by the waste generator is used to verify that the waste behaves in the manner indicated by its profile and constitutes the pre-acceptance delivery stage. Once sufficient information is obtained on the waste, trained staff decide on the appropriate method of treatment. When the bulk waste is delivered laboratory testing is used to determine that it behaves in the same way as the sample. Abbreviated fingerprinting is usually used here.

Assuming that the waste to be treated conforms to its original pre-acceptance delivery profile it may be sent to storage, blending, or intermediate testing without further treatment.

Transfer of Waste to Storage or Treatment

This stage is the interface between laboratory and plant operations and represents one of the most significant areas for the introduction of error in the operation of the facility.

A treatment slip or some other form of documentation is to be used to give the receiving unit the necessary information to prevent the waste being transferred to the wrong tank.

Process Control

The degree of process control envisaged is indicated by Figure 5.1 which refers to the incinerator. This is the main item of plant on the CWTF which will is designed to run as a continuous process unit.

Treatment of Discharges from Vents, Hoods etc.

It is stated that "Streams that may contain significant contamination will be vented to the incinerator during incinerator operation. When it is not operating, as during phased startup, venting through activated carbon beds will be provided". This raises two questions: (i) what constitutes significant contamination? and (ii) will carbon beds deal with all potential contaminants? Where the risk exists of generating gases such as hydrogen cyanide or hydrogen sulphide in storage or treatment operations, there must be physical interlocks and/or procedural controls that prevent the possibility of such discharges when the incinerator is not running.

9.6 Maintenance

There is relatively little reference in the documentation provided by Enviropace to the proposed maintenance system. Given the nature of the facility and the common implementation of the practice in the process industries, a Programmed Preventative
Maintenance (PPM) system should be established from the outset of operation of the CWTF. Such a PPM system should be based on one of the well-established computerised tracking systems for maintenance. A permit-to-work system is included among items listed in the contents of the Health and Safety Programme. Such a system must be effectively operated especially in areas where flammable materials are present.

Maintenance programmes and practices should be the subject of independent review during the early operating phase of the CWTF. This is a convenient time to identify shortcomings and to correct them before they become an established feature of the system.

9.7 Training

The term 'training' as used in the Enviropace documentation covers staff development and training. The difference is that staff development is an educative process concerned with influencing attitudes, and with imparting knowledge and understanding but not necessarily basic skills. Training on the other hand is very much concerned with these basic skills.

The training programme plan provided as Appendix D in the Enviropace documentation for review gives an extensive list of training modules and activities. So far as safety is concerned, the training involves general training, job-specific training, and special skills training in the following areas:

9.7.1 General Training

Initial training

(i) health and environmental hazards awareness;
(ii)regulation awareness;
(iii) review of contingency plan;
(iv) local, regional and national rules and standards;
(v) site rules and practices for safety;
(vi) basic personal protective equipment (care, use and limitations review);
(vii) basic protective equipment (inspection, donning and removal);
(viii) basic fire fighting;
(ix) emergency simulation/evacuation drills.

Yearly refresher

(i) contingency plan review;
(ii) fire fighting practice and evacuation drills.

9.7.2 Job-specific training

Safety-related aspects of job-specific training expands on some of the initial training.

In particular there is additional training in the use of protective equipment as required for the job, emergency shutdown procedures, decontamination procedures, and inspection, repair and replacement of emergency equipment. Training in topics such as compressed gas cylinder handling is given where the job-specification requires it.

A permit-to-work system is to be operated at the CWTF and appropriate training will be given in: confined space entry, hot work, and lockout.

9.7.3 Special Skills Training

For the most part, specified skills training is reserved for facilities personnel with specified duties and responsibilities in areas such as First aid, CPR, and other emergency response areas. Exceptions to this rule include training in gas testing (oxygen deficiency/toxic gas/flammable gas).

This list of safety-related training components is quite comprehensive. However the extent and depth of training will determine its effectiveness and that cannot be evaluated without more detailed information on content and timing.

Emergency Response Training

Emergency response training will include the following topics:

(i) potential emergencies viz fires, explosions, spills, hazardous releases, natural events;
(ii) emergency evacuation, site exits;
(iii) safety, fire and First Aid equipment location and use;
(iv) communication systems including emergency telephone numbers;
(v) alarms and their meaning;
(vi) evacuation drills.

Chemistry, Environment and Health Training

Chemistry, environment and health training will be used to emphasize the need for safe handling of chemical wastes.

9.8 Safety Documentation and Communications

Safety documentation will include a health and safety manual, safe work procedures, fact sheets and news letters. These are to be developed during the commissioning and running of the CWTF.

Reviews of the documentation and communications should be made part of the review procedures recommended in Section 9.9 below.

9.9 Systems, Operations and Performance Monitoring

Effective management of the safety of a facility such as the CWTF requires provision for the periodic monitoring of systems and performance. This will be a normal part of management's function.

However, in view of the environmental and other sensitivities attached to the operation of chemical waste disposal facilities, it is recommended that formal systematic monitoring of systems and performance is undertaken by an independent specialist body. This should be started as systems and procedures are developed and documented and should continue periodically throughout the lifetime of the facility.

Reviews of this type combined with engineering reviews make a major contribution to the safe operation of process plants worldwide.

9.10 Environmental Monitoring

Enviropace will undertake environmental monitoring program that includes air emissions, water effluents, and site soil and groundwater. This program represents certain minimum provisions defined in the Contract Document by the Government of Hong Kong, EPD, the ultimate owner of the CWTF. Both Enviropace and EPD are considering separate additional monitoring programs, but these have not been defined at this time.

10 CONCLUSIONS AND RECOMMENDATIONS

It is emphasised that all results presented above, all the conclusions drawn and all the recommendations made are based on information provided by Enviropace. Although most data requirements have been satisfied, some assumptions have inevitably had to be made using best engineering judgement. Nevertheless, we believe that this report provides significant results and important recommendations for incorporation in the detailed design of the plant and planning of its operation.

10.1 Conclusions

The CWTF site operations using a basic level of design and operation, normally consistent with low hazard plants, would not be able to meet the Hong Kong Interim Risk Guidelines for either Individual or Societal Risk. This is due to the use as reagents of moderate amounts of chlorine and smaller amounts of sulphur dioxide.

Applying best engineering methods and using management systems consistent with best current guidelines (API RP 750, OSHA 1910, CCPS etc) the CWTF should be able to reduce risk significantly. Individual risk can be reduced to a point meeting the Interim Risk Guidelines at the plant gate, by a factor of approximately 2. Societal risk just exceeds the Interim Risk Guidelines in the region around 10 deaths, by less than a half order of magnitude. It may be possible to reduce risk further once the detail design becomes available. However, this will not be easy as the assumptions employed here already assume major risk reduction.

The introduction of up to 1500 additional people near to the site due to the SETY development will alter the societal risk situation. Individual risk would not be altered, and this should still be acceptable with the 10^{-5}/yr contour not leaving the site. However, the Societal Risk which previously just exceeded the Interim Risk Guideline would now substantially exceed it.

Some significant risk reduction is achievable in the transport of chlorine and sulphur dioxide using one of two marine transfer options. The justification for such modification would be the reduction in societal risk, as individual risk from transport activities is small.

If chlorine and sulphur dioxide were eliminated from the site, then the CWTF would meet the Interim Risk Guidelines with ease, both in terms of individual and societal risk. Elimination is possible, at some cost, and the substituted processes and materials (metabisulphite) are essentially non-hazardous.

We recognise that Enviropace have given much attention to onsite safety and risk minimisation, with particular regard to the incinerator: we commend this approach of designing in safety from the start. Nevertheless, some other areas of possible concern have been identified regarding plant and equipment; recommendations regarding these are given below.

Operational safety is brought about not only by plant and equipment but also by attention to management and training elements. These have been reviewed and a number of recommendations made.

There is also a need for further safety studies to be carried out after the detailed design has been executed and operational plans formulated in order to ensure that recommendations have been implemented and that the plant will be operated to best modern standards.

10.2 Recommendations

10.2.1 Introduction

The scope of work for this detailed hazard assessment required the addressing of key issues concerning the detailed design of the CWTF. However as design safety, though very important, is only one in a set of relevant safety factors, attention has also been paid to other key issues which will affect the safety of the CWTF. The recommendations arising from this risk study relate to providing assurances about the safe design, construction, commissioning, operations and maintenance of the CWTF. To some extent such recommendations as are made in this section may pre-empt the detailed design and operation of the CWTF. However in order to avoid any possibility of the omission of some important features for safety, those recommendations for additional plant and equipment and others that have been indicated by the hazard assessment are given in this section. This is considered necessary for two reasons. First, although the facility will not have present sufficiently large inventories of hazardous substances for it qualify as a Potentially Hazardous Installation (PHI), the Government of Hong Kong takes the position regarding the risk from the facility that the same requirements as are applied to PHIs should also be applied to the CWTF. Second, there are several industrial sites within 500 metres of the site; therefore risks to persons present on these sites should be kept as low as reasonably practicable.

The tender documentation provided by Enviropace and reviewed as part of the risk study provides a great deal of information on the proposed layout, design and operation of the facility. However, by its nature such documentation is not able to give the level of detail required to develop fully such assurances referred to above. The risk analysis is based on a range of assumptions about how the CWTF will be built and operated. Its predictions about risk potential are based on Technica's extensive experience in the risk analysis field in general and on its experience with hazardous chemicals facilities in particular. However the risk associated with a facility in practice comes from a combination of factors related to the details of its design, engineering, construction and operation. The recommendations shown below are made on this basis and identify specific additional actions which should be taken to help ensure the safety of the CWTF.

Some of these recommendations have already been made in ERL's preliminary risk assessment and formed part of the tender requirements: two items that were not included in the conceptual design documents are repeated here, marked with an asterisk. These items are typically addressed during the detail engineering phase of a project. The government intends that this report be based on the Enviropace conceptual design in order to update the previous risk assessment work on the CWTF project.

10.2.2 Site Layout

R1. The site layout, including spacings of facilities, road widths and bends and a second entrance for outside fire fighting support has been provided for in the CWTF design.

10.2.3 Plant and Equipment

Storage Facilities

There will be two main sets of storage facilities at the CWTF. One will be used for the bulk storage of inorganic wastes including acids and alkalis. The other will be dedicated to the storage of organic wastes.

R2. Protection against corrosion is a key feature of the conceptual design for construction of the inorganic wastes storage facilities to ensure their continued integrity. The detailed design should pay particular attention to features included for protection against corrosion.

R3. As the inadvertent mixing of certain combinations of incompatible wastes in storage could result in the evolution of hazardous gases, consideration should be given to how the design of the storage facilities will protect against a release of these gases into the atmosphere. For example, the storage tank which is to receive tannery waste is vented to the caustic scrubber rather than directly to atmosphere in order to remove the potential risk from generation of hydrogen sulphide by inadvertent addition of acid.

R4. The hazard assessment has identified the failure of a solvent storage tank and the subsequent evaporation of the released liquid pool as one of the major sources of risk. This can be protected against by sloping the bund areas to sumps which can be pumped out in the event of a major spillage. The sumps could be provide with fixed pumps or mobile submersible pumps could be provided in conjunction with an available (i.e. empty) tank as an emergency response resource. In fact, WMI designs do incorporate these measures whenever solvents are stored.

Process Facilities

R5. Protection against accidental release of hydrogen cyanide into the atmosphere due to inadvertent mixing of acid and cyanide waste is to be provided in the form of a process vessel vent caustic scrubber and connection of the vent from this to the incinerator. An additional protection in the form of a system for rapidly detecting the evolution of gas in the reaction vessel and automatically shutting down the feed of the waste or the acid would minimise the amount of gas evolved and provide a safer system*.

R6. In view of the risk of hydrogen cyanide being produced through heating of the cyanides tank by thermal radiation from a fire nearby, some protection such as water spray should be provided for this tank. This is incorporated in the conceptual design for CWTF.

R7. Use of chlorine and sulphur dioxide gas reagents can probably be made sufficiently safe to meet the Hong Kong Interim Risk Guidelines for Individual Risk by the introduction of best quality engineering design and operating and emergency procedures. The Societal Risk Criterion might just be met, but this would be difficult. A conclusion cannot be finalized here until final design details are available.

Further development of Tsing Yi, if the SETY project proceeds, would introduce so many people near to the CWTF site that the Societal Risk Criterion could not be met.

Fire protection

R8. The fire protection part of the tender document appears to be based on the assumption that the facility will rely heavily on the assistance of the public fire service. For an installation such as the CWTF, where substantial amounts of flammable and highly flammable liquids could be present at any one time, there should be a high degree of self-reliance in fire fighting. This should be reflected in the fire protection hardware provisions. In fact, this is the intent of the CWTF design. The fire ring system incorporates hydrants, hoses, hand held equipment, and redundant pumps. For the container processing and storage building and for initial storage tanks, sprinkler and foam systems will also be installed. These must be in accord with applicable codes for installations that store and handle flammable and highly flammable liquids.

Fire protection design can only be assessed once final design details are complete. These must as a minimum meet local Ordinances and the relevant NFPA Codes. Technica notes that fires in general, and in Building 16 in particular, could lead to serious environmental problems. The recent amendments to the European Seveso Directive specifically addressed potential hazards from warehouse fires. Features such as impoundment basins are now routinely required. Management procedures for the warehouse need careful review and where relevant guidance should be sought from high quality industry recommended practices (e.g. CEFIC Code on Hazardous Warehouse Operations).

R9. In the operating procedures for the fire protection system, note that the post indicator valves are intended to be locked in the open position for all operational purposes to assure quick response.

The CWTF Fire system should be reviewed, along with all other safety systems, as recommended by API RP 750 in a properly documented systematic manner. A Pre-startup Review should ensure that all aspects of the Fire Protection System and other safety systems are all in place.

10.2.4 Procedures

Fire Protection

R10. The fire protection programme and detailed procedures for response in the event of fire, monitoring and maintenance of the fire protection equipment, training in fire protection methods is planned for the site operations manual. Adequate documentation should be supplied to Fire Services Department to demonstrate suitable systems have been installed.

Occupational Health

R11. In view of the reliance placed on colour coding as an operational means of differentiating between the twelve categories of waste, it would be prudent to ensure that all operations personnel are checked for colour discrimination ability.

10.2.5 Further Studies

Engineering

R12. Tender documents provide a statement of intent but it is only the detailed design and engineering that translate part of this intent into reality. Given the widespread use of design audits in the process industries worldwide and the success of these in verifying the safety of plant designs, it is appropriated to recommend that such an audit be undertaken on the design and engineering of the CWTF. Typically, this would involve Hazard and Operability (HAZOP) studies on the engineering flow diagrams for the facility.

A HAZOP study would be of particular value, for example, in examining the safety systems in place in the cyanide treatment. Interlocks to prevent inadvertent of mixing of incompatible wastes and to engage the vent to incinerator and scrubber system have been referred to elsewhere*.

R13. A reliability assessment of critical trip systems, complementary to the HAZOP, should be carried out.

R14. A pre-commissioning construction audit should be used to verify that construction standards comply with the design intentions.

Systems and Procedures

The following recommendations are concerned with ensuring that the systems and procedures developed for the CWTF are appropriate and effective.

R15. Organisation and management systems, and written operations and maintenance procedures should be audited for safety features as soon as is practicable.

R16. Emergency plans and procedures should be fully documented and distinguish clearly between duties and responsibilities on the one hand and specific actions required in identified emergency situations on the other.

R17. Emergency equipment provisions and emergency procedures should be documented to include all potential emergencies e.g., chlorine leak.

R18. Training programmes and sessions should be examined by training professionals on government behalf.

APPENDIX I

DESCRIPTION OF FACILITIES

CONTENTS PAGE

APPENDIX I SITE DESCRIPTION

I.1 Reception of Waste and Transfer to Storage or Processing

Enviropace will provide waste containers conforming to the requirements of Technical Schedules SC6.3 and SC7a.2. Each type of waste is assigned a specific container colour thus allowing ready segregation of groups of compatible wastes on the transport vehicle by the container colour and providing some protection against incompatible wastes being transferred to the same bulk storage container.

Twelve groups of compatible wastes have been identified. They are:

(i) acids (oxidising);
(ii) acids (non-oxidising);
(iii) alkali;
(iv) alkaline PCB etchant;
(v) ferric chloride etchant;
(vi) cupric chloride etchant;
(vii) cyanides;
(viii) chromium;
(ix) halogenated organics;
(x) non-halogenated organics;
(xi) oily water;
(xii) other inorganics.

All waste materials to be handled by the CWTF are anticipated to fall into one of these categories.

A fingerprint analysis of the waste in each container will be performed and verified against the bar coded label which has been fixed to the container at the generator's premises.

A similar fingerprinting will be done on bulk wastes arriving by tanker. Assuming an acceptance, the waste will be passed to the appropriate decant/emptying line. Or in the case of bulk wastes, taken for transfer to storage tanks.

The decant equipment automatically opens, empties, washes and reseals the container, and performs a pressure check for leaks.

Wastes bulked from individual containers are sent to intermediate storage prior to processing.

The most efficient alternative to cyanide oxidation by chemical reaction is to destroy the cyanide waste streams in the incinerator at the CWTF. If this is used, it will remove the risks associated with the transport and handling of chlorine in the liquid and gaseous states.

I.2 Storage

Bulk storage on site can be divided into several categories:

• Inorganic waste	(Table I.1)
• Inorganic reagents	(Table I.2)
• Organic wastes	(Table I.3)
• Incinerator fuel/reagents/other organic	(Table I.4)

(The table numbers refer to the tables giving details of each of the storage tanks included in these categories.)

These are further subdivided where necessary in order to ensure separation of chemicals into 'compatible groups', i.e. groups of chemicals which do not generate any hazard if inadvertently mixed. Each of these groups of storage tanks has its own bund as shown on the Site Layout, Figure 3.7 of the Main Report. The bund areas, numbered by the corresponding labels on that figure, are:

1 : MARPOL Annex I
4 : Acid Wastes
5 : Alkali Wastes
6 : Organic Wastes
7 : Oily Wastes (i.e. oil/water mixtures)
13: Other Wastes and Reagents

Tables I.1 to I.4 also indicate which area each tank is in.

Storage areas, vessels and associated equipment are also colour coded in order to minimise the risk of mixing of incompatible materials. Storage areas are bunded and sealed to contain spillages and to prevent seepage into the water table.

The description below (Section I.3.3) of the incineration process allows for possible use of ammonia for NO_x removal from the exit gas stream. Small amounts only, in liquid solution, will be held, that are produced by the caustic boil of ammoniacal etchants (see Section I.3.1 below), condensed and recovered. Alternatively, the ammonia may be converted in the reactor to ammonium sulphate, a fertilizer.

TABLE I.1: DETAILS OF TANK STORAGE; BULK INORGANIC WASTE (Sheet 1 of 2)

TANK CONTENTS	MATERIAL	NUMBER	TANK CAPACITY (m^3)	DIMENSIONS (m)		AREA NUMBER ON SITE LAYOUT (See Figure 3.7)
				DIAMETER	HEIGHT	
Alkali waste	Carbon steel, vinyl ester lined	2	445	7.0	11.8	5
Oxidising acid waste	Carbon steel, vinyl ester lined	1	160	5.0	8.6	4
Other acid waste	Carbon steel, vinyl ester lined	1	480	7.0	12.7	4
Chromic acids	Stainless steel	1	6.5	1.4	4.7	
Cyanide solutions	Hastelloy C	1	12	1.6	6.2	
Acidic copper etchants	High density Polyethylene	1	50	3.7	5.3	13
Ammoniacal copper etchants	Carbon steel, vinyl ester lined	1	223	5.2	11.0	13
MARPOL Annex II Acid	Carbon steel, vinyl ester lined	1	120	5.0	6.5	4
MARPOL Annex II Alkali	Carbon steel, vinyl ester lined	1	120	5.0	6.5	5

TABLE I.1: DETAILS OF TANK STORAGE: BULK INORGANIC WASTE (Sheet 2 of 2)

TANK CONTENTS	MATERIAL	NUMBER	TANK CAPACITY (m^3)	DIMENSIONS (m)		AREA NUMBER ON SITE LAYOUT (See Figure 3.7)
				DIAMETER	HEIGHT	
Recoverable ferric etchant	Carbon steel, vinyl ester lined	1	170	5.2	9.0	13
Unrecoverable ferric etchant	Carbon steel, vinyl ester lined	1	85	4.0	7.0	13
Chelated ferric etchant	High density Polyethylene	1	50	3.7	5.3	13
Chelated zinc	High density Polyethylene	1	9.0	1.8	3.8	13
Other metal solutions	High density Polyethylene	1	39	3.0	6.2	13
Tannery wastes	High density Polyethylene	1	10.5	2.5	2.6	13
Mixed inorganics	High density Polyethylene	1	9.0	1.7	4.0	13
Miscellaneous chemical	High density Polyethylene	1	9.0	1.7	4.0	13
Intercept/treat sludge	High density Polyethylene	1	9.0	1.7	4.0	13
Chelated copper	High density Polyethylene	2	9.0	1.8	3.8	13

TABLE I.2: DETAILS OF TANK STORAGE: BULK INORGANIC REAGENTS

TANK CONTENTS	MATERIAL	NUMBER	TANK CAPACITY (m^3)	DIMENSIONS (m)		AREA NUMBER ON SITE LAYOUT (See Figure 3.7)
				DIAMETER	HEIGHT	
Caustic soda solution	Carbon steel, vinyl ester lined	1	34	3.0	5.0	5
Acid reagent	Carbon steel, vinyl ester lined	1	9.0	1.8	3.4	4
Lime slurry	Carbon steel	1	39.0	3.0	5.5	30
Lime silo	Carbon steel	1	290	5.0	15.0	30
Solidification	Carbon steel	2	50			11

TABLE I.3: DETAILS OF TANK STORAGE: BULK ORGANIC WASTE

TANK CONTENTS	MATERIAL	NUMBER	TANK CAPACITY (m^3)	DIMENSIONS (m)		AREA NUMBER ON SITE LAYOUT (See Figure 3.7)
				DIAMETER	HEIGHT	
Solvents (non-halogenated)	Carbon steel	1	160	5.0	8.6	6
Solvents (halogenated)	Carbon steel	1	160	5.0	8.6	6
Oil-water wastes	Carbon steel	2	160	5.0	8.6	6
Water-oil wastes: non-MARPOL	Carbon steel	4	165	5.0	8.6	?
MARPOL Annex I	Carbon steel	2	2800	14.7	16.5	1
MARPOL Annex II Organics	Carbon steel	2	150	4.8	8.3	6

TABLE I.4: DETAILS OF TANK STORAGE; INCINERATOR FUEL/REAGENT/ORGANIC

TANK CONTENTS	MATERIAL	NUMBER	TANK CAPACITY (m^3)	DIMENSIONS (m)		AREA NUMBER ON SITE LAYOUT (See Figure 3.7)
				DIAMETER	HEIGHT	
Incinerator fuel (Fuel Oil 2)	Carbon steel	1	235	5.0	12.1	7
Waste feed blend	Carbon steel	1	60	3.5	7.94	2
Fuel feed blend	Carbon steel	1	60	3.5	7.94	2
Lean water blending	Carbon steel	1	18			2
Sludge blending	Carbon steel	2	8.3			2
Special organic	Carbon steel	2	6.0	1.75	2.4	2

I.3 Processes

I.3.1 Aqueous Waste Treatment

Aqueous wastes for treatment include those received from generators and those produced in treatment processes including washing.

Neutralization

The bulk of aqueous wastes to be treated are acid (estd. 20 000 tpa) and alkali (estd. 35 000 tpa). This volume is considered sufficient for continuous operation in a single reactor. This is an agitated two stage vessel with provision for metering lime slurry into the reaction mixture. Closed vent scrubbers prevent the escape of compounds such as amines, ammonia and acid gases. The neutralization process is designed for approximately 1 hour residence time. Overflow from the reactor will be dosed with polyelectrolyte for clarification, with the clarified phase being sent to effluent water treatment. Underflow goes to a filter which produces a filter cake containing about 30% to 40% solids which is further treated by stabilization.

Additional treatment of waste water from neutralization is necessary to meet effluent requirements. This treatment consists of a Sequencing Batch Reactor and the proprietary process PO*WW*ER. These processes are described further in Section I.3.4.

Oxidation of Aqueous Wastes

Cyanide Wastes

An estimated 100 tpa of cyanide waste is expected to be received for treatment. This will be destroyed in a 12.5 m^3 reactor by alkaline oxidation using chlorine gas and caustic soda.

The overall reaction is:

$$2NaCN + 5Cl_2 + 12NaOH \rightarrow N_2 + 2Na_2CO_3 + 10NaCl + 6H_2O$$

Waste will be charged to the reactor from containers or, infrequently, from a tank truck. Chlorine consumption can exceed the amount indicated by the stoichiometric equation if there are oxidisable impurities such as organics also present in the waste stream. For safety reasons, the process is operated under a slight negative pressure and offgas is directed through a caustic scrubber.

Reduction of Aqueous Wastes

Chromium Wastes

Some 55 tpa of chromium wastes are anticipated to be sent for treatment. Chromium is to be reduced using sulphur dioxide introduced in the gas phase under the liquid surface. The most efficient alternative to the reduction of hexavalent chromium with SO_2 is to use sodium metabisulphite as a reagent.

Metals Treatment and Recovery

Metals recovery will be practised on concentrated aqueous waste solutions containing iron, copper or other metals in chelated or non-chelated form.

Ferric Chloride Printed Circuit Board (PCB) Etchants

Facilities for treating ferric chloride PCB etchants are to be provided although the replacement of these etchants by more effective and easily recoverable etchants which has happened elsewhere in the world may render these facilities redundant.

For the purposes of waste treatment and metals recovery, ferric chloride etchants are divided into three classes:

(i) chelated;
(ii) non-chelated recoverable;
(iii) non-chelated non-recoverable.

These are now briefly described.

(i) <u>Chelated ferric chloride etchants</u>

Treatment of chelated waste streams will require a variety of reagents depending on the characteristics of the waste. The list of reagents includes lime, aluminium chloride, sodium bisulphate, hydrogen peroxide, phosphoric acid, sodium hypochloride and other organic polyelectrolytes. All filtrates will go to the PO*WW*ER for final effluent treating, with the exception of that from the continuous neutralization. Approximately 25% of the continuous neutralization filtrate is being diverted to incinerator ash quenching and to the stabilization system. The remaining 75% is still going to PO*WW*ER.

(ii) <u>Non-chelated recoverable ferric chloride etchants</u>

Scrap iron is added to the solution to reduce dissolved copper salts to copper metal and ferric iron to ferrous iron. Most of the scrap iron dissolves during the process leaving a rich copper-bearing filter cake which represents recovered copper metal. Ferrous iron in the filtrate is oxidised to ferric chloride with chlorine gas. There is no alternative to the ferric chloride/upper recovery process without chlorine. These streams can be safely treated by acid neutralization, followed by the PO*WW*ER process, but they are not then recoverable.

(iii) Non-chelated non-recoverable ferric chloride etchants

Non-chelated non-recoverable ferric chloride etchants are pumped into the main neutralization reactor and metals precipitated along with the main precipitate from neutralization.

Ammoniacal Copper and Cupric Chloride PCB Etchants

Both waste streams are processed by essentially the same route: caustic boil of an ammoniacal solution. Ammonia is driven off and condensed for recovery or converted using sulphuric acid to ammonium sulphate for possible use as fertilizer. The ammonia-free cupric chloride has to be made ammoniacal prior to the caustic boil.

Other Metal-Bearing Waste

A variety of metal-bearing wastes including other copper wastes, zinc- and nickel-containing wastes and other metal salt wastes will have to be treated. Treatment chemicals for such wastes include: phosphoric acid, ferrous chloride, ferrous sulphate, aluminium sulphate, sodium sulphide, organic precipitants and activated carbon. Given the variety of wastes and treatment chemicals there is a high potential for the misdirection of streams. However the volumes of the wastes are likely to be small so that any misdirection should not give rise to any offsite risk. In addition a series of interlocks will be employed to reduce the likelihood of misdirection.

I.3.2 Oily Water Treatment

Oily water separation is not always a simple matter of skimming the lighter oil from the heavier water. In addition to these components, there can be heavier-than-water oil phases, emulsions, and suspended solids. In the worst case there can be as many as five phases.

Flotation

Flotation is the main process for the separation of suspended solids from oily water mixes. The solid particles are attracted to the surfaces of the bubbles and the solids-bubbles mass rises to the surface of the liquid leaving the clarified water. The flotation process does not present any major risk potential.

I.3.3 Incineration

The incinerator comprises:

- (i) a rotary kiln;
- (ii) a secondary combustion chamber;
- (iii) a waste heat recovery boiler and gas stream cooler;
- (iv) a spray dryer;
- (v) a fabric filter;
- (vi) an induced draught fan;
- (vii) an incinerator stack

Rotary Kiln

The rotary kiln has been proved to be the most versatile of the primary combustion systems for the incineration of the widest variety of solid and liquid wastes. The angle to the horizontal of the kiln chamber and the speed of rotation determine the residence time in the chamber for solid wastes.

Waste feed systems

In most cases, solid and medium-to-high viscosity sludge wastes will be shredded and fed into the incinerator with a hydraulic charge ram. Low viscosity sludge wastes will be fed via a sludge lance operating on flow control.

Some wastes, such as those containing highly toxic substances, PCBs etc can be fed directly into the incinerator kiln without being taken out of their containers.

Kiln

The refractory-lined rotating kiln will be driven by a DC motor and will operate at gas exit temperatures above 980°C. A fixed hood assembly will connect the kiln to the integrally-mounted, vertical secondary combustion chamber. Residual ash and non-combustible material exits the assembly through a bottom port which is water sealed. The ash falls into a water-filled sump and the wet ash is removed from this on a chain-link drag conveyor.

An auxiliary fuel (No. 2 fuel oil) and organic waste liquid fired burner will used to burn liquid wastes.

Control of the combustion air blower will be effected by monitoring oxygen levels in the kiln

A burner management system on each burner will be used to monitor and control the following functions:

(i) system air purge cycle before burner flame-off;
(ii) burner lighting;
(iii) burner flame;
(iv) air/oxygen supply pressure;
(v) fuel supply pressure;
(vi) atomising air pressure (where required).

The burner management system will be interlocked with the fuel double-block valves so that they can be closed immediately if unsafe conditions occur.

Other controls on the kiln system include kiln draught control to maintain a negative pressure along the entire combustion train. This eliminates fugitive emissions into the atmosphere from the incinerator system. Control of kiln outlet temperature is necessary to ensure stable operation of the secondary combustion chamber. This controller will control the set point of the fuel feed if the exit temperature is outside the desired range.

Secondary Combustion Chamber

All the gaseous products of combustion from the rotary kiln enter the secondary combustion chamber (SCC). This operates on a 2 s residence time with combustion in an excess of air and a minimum exit gas temperature of 1200°C. A turbulence promoter will be fitted to ensure adequate mixing of materials passing through the SCC. An auxiliary fuel (No. 2 fuel oil)/waste liquid burner will be mounted on the SCC. The burner will be used to preheat the SCC to the required temperature using fuel oil, and to burn liquid waste. In each case, the burner firing rate will be controlled by a temperature controller in the afterburner chamber flue gas exit.

Heat Recovery System

Heat will be recovered using a vertical water tube waste heat boiler with the gases entering from the top and being directed vertically downwards. This is to minimise the deposition of particulate products of combustion onto the exchanger tubes. Mechanical rappers are provided to clear minor deposits from the tubes. Particulate matter falls into a hopper from which it is removed by an air-locked screw conveyor. Adequate cooling of the gas stream is ensured by a temperature controller which controls the water flow through the tube bundles.

NO_x Removal System

Injection ports are provided for ammonia injection into the exit gas stream for NO_x removal when required.

Flue Gas Cleaning System

Spray Absorber Dryer

Injection of a water-lime slurry into the gas exiting the waste heat boiler at about 400°C absorbs the acid gases and produces a solid residue which falls out of the gas stream into a cone-shaped collector at the bottom of the Spray Absorber Dryer.

Fabric Filter

The fabric filter will be used to remove solids remaining suspended in the exit gas stream from the spray absorber dryer.

Incinerator Stack

The 76.2 m high stack will discharge exit flue gases at approximately 175°C. This is significantly above their saturation temperature, therefore there should not be a condensation plume from the stack.

Shutdown Interlock Systems

Kiln Waste Feed Shutdown

All kiln waste feed systems will be shut down in the event of:

(i) kiln discharge temperature too low;
(ii) primary burner failure;
(iii) ash conveyor failure (solid feeds only).

Kiln Waste Feed and Fuel Shutdown

Both kiln feed and fuel shutdown is initiated by:

(i) kiln discharge temperature too high;
(ii) kiln rotational speed too low;

All Waste Feeds Shutdown

All waste feeds to both kiln and SCC are shutdown by:

(i) kiln pressure positive (> 0 mm water column for 2 s);
(ii) SCC pressure positive (> 0 mm water column for 2 s);
(iii) SCC discharge temperature < 1200°C;
(iv) less than 3% oxygen in stack gas;
(v) CO in stack gas >100 ppm for 1 hour rolling average;
(vi) Failure of both oxygen analysers;
(vii) Failure of both carbon dioxide analysers;
(viii) Failure of both carbon monoxide analysers;
(ix) Fuel pressure < 250 kPa to SCC burners;
(x) Stack gas flow too high;
(xi) Combustion efficiency < 99.9%

All Waste Feed and Fuel Shutdown

All waste feed and fuel shutdown to all elements of the incinerator will be initiated by:

(i) SCC discharge temperature >1315°C;
(ii) failure of both SCC burners.

Emergency Shutdown

Emergency system shutdown will be initiated by:

(i) loss of water supply;
(ii) electrical source power failure;
(iii) dust collector inlet gas temperature too high;
(iv) heat recovery system low water flow;
(v) induced draught fan failure;
(vi) spray dryer failure.

Induced Draught Fan Failure

The induced draught fan shutdown will be initiated by:

(i) low water flow to the heat recovery system;
(ii) heat recovery discharge system too low.

I.3.4 Disposal of Residues from Treatment Processes

Gases and Vapours

Gases and vapours from processes are to be vented through hoods and either into the incinerator system or, if this is not operating, through active carbon beds. In the case of the cyanide oxidation reactor, offgas will be vented through a caustic scrubber to absorb any hydrogen cyanide that may be released. This scrubber is likely to be sized to deal with relatively small amounts of gas. The incinerator system will burn anything combustible while the spray dryer system will take out any acid gases.

Wastewater

Sequencing Batch Reactor (SBR)

Aerobic microbial breakdown of organics remaining in wastewater will take place in the SBR. As this has no significance for offsite risk, it is not considered further here.

*PO*WW*ER System*

PO*WW*ER is a combined distillation/catalytic oxidation process for obtaining high grade water from wastewater contaminated with both inorganic and organic materials. Catalytic oxidation of the organics occurs in the steam phase from distillation before condensation. As the solids content in the evaporating liquor reaches 50% to 60% concentrated liquor is drawn off for crystallisation and stabilisation.

I.4 Forecast Waste Arisings

	VOLUME (tonnes per annum)		
WASTE TYPE	1987 AMOUNT GENERATED	1992 FORECAST	1997 FORECAST
Acid	20000	22000	25000
Alkali	35000	42000	50000
Copper-Containing Waste Solution:			
• Acidic spent PCB* etchant	7600	19000	25000
• Alkaline spent PCB* etchant	4900		
• Copper Waste Solution from Other Factories	140	150	160
Zinc-Containing Waste Solution	13	13	14
Nickel-Containing Waste Solution	120	140	160
Other Metal Salts Containing Waste Solution	1200	1300	1400
Cyanide-Containing Solution	100	130	160
Non-Chromium-Bearing Oxidizing Agents	10	11	12
Chromium-Bearing Oxidizing Agents	55	59	68
Halogenated Solvents	1300	1700	2000
Non-Halogenated Solvents	1500	1800	2100
Phenol and Derivatives	2	2.2	2.4
Polymerization Precursors and Production Wastes	40	42	44
Mineral Oils	5600	5700	5900
Fuel Oil	50	51	53
Oil/Water Mixture	12000	13000	13000
Pharmaceutical Products	1	1	1
Mixed Organic Compounds	130	140	150
Mixed Inorganic Compounds	70	74	78
Miscellaneous Chemical Waste	30	32	35
Interceptor and Treatment Plant Sludge	40	42	44
Tank Cleaning Sludge	1000	1000	1000
Tar, Asphalt, Bitumen and Pitch	140	140	150
Tannery Waste	400	400	400
Printing Wastes	90	93	94
Dyestuff Wastes	70	59	52
Plating Bath Sludges	10	11	12
Paint Wastes	640	700	750
Waste Catalysts	4	4	4
TOTAL (tonnes per annum)	97755	110000	130000

* PCB stands for Printed Circuit Board

Note: All figures rounded up to 2 significant figures.
No projections have been made for MARPOL arisings due to the very wide range of possibilities.

APPENDIX II

PROPERTIES OF HAZARDOUS MATERIALS ON SITE

CONTENTS PAGE

APPENDIX II. PROPERTIES OF HAZARDOUS MATERIALS ON SITE

II.1 Introduction

This Appendix details the hazardous properties of each chemical substance likely to be found on the CWTF site and presenting a major chemical hazard. As described in Section 5, the types of chemical hazard considered are: toxic, explosive and flammable. In addition, for this study the reactivity must be considered since certain mixtures of non-hazardous waste materials could produce hazardous substances by reaction. For each material here presented, some basic physical properties are also given.

As an important contribution to risk comes from the toxicity of materials such as chlorine, further information on toxicity including the selection of the probits used in this study is also included in this section.

The properties given for each substance are as follows:

Material Name

General Properties

- Molecular weight
- Normal physical state (phase)
    i.e. at ambient temperature and atmospheric pressure
- Normal boiling point
    i.e. at atmospheric pressure

Flammable Hazards

- Whether these exist
- Flash point
    The lowest temperature at which vapour above a volatile combustible substance will ignite in air when exposed to flame.
- Flammable limits
    These are the percent concentrations by volume in air: lower and (if pertinent) upper limits (LFL and UFL).
- Fire (-Fighting) agents to use
- Fire (-Fighting) agents to avoid
- NFPA Flammability (See Table II.1)

Toxic Hazards

- Whether these exist
- Toxicity

TLV -	Threshold Limit Value (maximum acceptable average for working day)
IDLH -	Immediate Danger to Life and Health (for short exposure)

- Probit Equation coefficients N, A, B
  The probit value Pr (used to calculate risk of fatality) for a given exposure for time t to concentration c is given by $Pr = A + B \ln (c^N t)$
- NFPA Health Hazard (See Table II.1)

Reactivity

- Solubility in Water
- Reactivity

In addition, general comments are given where pertinent.

All data apart from probit coefficients are taken from CHRIS (Chemical Hazards Response and Information System) Hazardous Chemical Data, published by US Coast Guard. Probit coefficients (where given) have been taken from a variety of sources and are incorporated in Technica's material properties database.

The materials are subdivided into three groups:

- Incoming Waste Materials
- Reagents for Treatment Processes
- Materials which may be produced on site (through inadvertent mixing or process failure) and released to atmosphere

The NFPA toxicity measures apply to fire conditions as they are a guide to firefighters. The toxicity of some materials can be less under normal conditions. This is the reason that crude oil, normally non-toxic, is ranked as NFPA 3: when heated it can give off toxic dissolved hydrogen sulphide gas.

TABLE II.1: EXPLANATION OF NFPA HAZARD CLASSIFICATIONS

CLASSIFICATION	DESCRIPTION
HEALTH HAZARD	
4	Materials which on very short exposure could cause death or major residual injury even though prompt medical treatment were given
3	Materials which on short exposure could cause serious temporary or residual injury even though prompt medical treatment were given
2	Materials which on intense or continued exposure could cause temporary incapacitation or possible residual injury unless prompt medical treatment is given
1	Materials which on exposure would cause irritation but only minor residual injury even if no treatment if given
0	Materials which on exposure under fire conditions would offer no hazard beyond that of ordinary combustible material
FLAMMABILITY	
4	Materials which will rapidly or completely vaporise at atmospheric pressure and normal ambient temperature or which are readily dispersed in air and which will burn readily
3	Liquids and solids that can be ignited under almost all ambient temperature conditions
2	Materials that must be moderately heated or exposed to relatively high ambient temperatures before ignition can occur
1	Materials that must be preheated before ignition can occur
0	Materials that will not burn
REACTIVITY	
4	Materials which in themselves are readily capable of detonation or of explosive decomposition or reaction at normal temperatures and pressures
3	Materials which in themselves are capable of detonation or explosive reaction but require a strong initiating source or which must be heated under confinement before initiation or which react explosively with water
2	Materials which in themselves are normally unstable and readily undergo violent chemical change but do not detonate. Also materials which may react violently with water or which may form potentially explosive mixtures with water
1	Materials which in themselves are normally stable but which can become unstable at elevated temperatures and pressures or which may react with water with some release of energy but not violently
0	Materials which in themselves are normally stable even under fire exposure and which are not reactive with water

II.2 Incoming Waste Materials

The properties defined in Section II.1 above are tabulated for the following incoming materials listed in Appendix I, Section I.4:

Phenol
Mineral oil
Fuel oil
Crude oil
Heavy oil
Lubricating oil
Copper chloride
Sodium hydrosulphide (aqueous)
Methanol (representative non-halogenated solvent)
Carbon tetrachloride (representative halogenated solvent)

<table>
<tr><th colspan="8">MATERIAL: PHENOL</th></tr>
<tr><th colspan="2">GENERAL PROPERTIES</th><th colspan="2">FLAMMABLE HAZARDS</th><th colspan="2">TOXIC HAZARDS</th><th colspan="2">REACTIVITY</th></tr>
<tr><td colspan="2"></td><td colspan="2">YES</td><td colspan="2">RISK OF INJURY ONLY</td><td colspan="2"></td></tr>
<tr><td>Molecular Weight</td><td>94</td><td>Flash Point (°C)</td><td>85 oc
79 cc</td><td>TLV (ppm)</td><td>5</td><td>Solubility in Water</td><td>8.4%</td></tr>
<tr><td>Normal State</td><td>Solid or Liquid</td><td>LFL (%)</td><td>1.7</td><td>IDLH (ppm)</td><td>100</td><td></td><td></td></tr>
<tr><td>Normal Boiling Point (°C)</td><td>181.8</td><td>UFL (%)</td><td>8.6</td><td>Probit Equation
N
A
B</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>Fire Agents to Use</td><td>Water fog, foam, carbon dioxide, dry chemical</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>Fire Agents to Avoid</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>NFPA Flammability</td><td>2</td><td>NFPA Health Hazard</td><td>3</td><td>NFPA Reactivity</td><td>0</td></tr>
<tr><td colspan="2">Often stored as liquid by steam heating</td><td colspan="2">Yields flammable vapours when combusted and can form explosive mixture</td><td colspan="2">Burns eyes and skin. Analgesic effect. Rapidly absorbed through the skin. Increased heart rate, possible death.</td><td colspan="2"></td></tr>
</table>

NP = Not Pertinent

NA = Not Available

ppm = parts per million

MATERIAL: MINERAL OIL							
GENERAL PROPERTIES		FLAMMABLE HAZARDS		TOXIC HAZARDS		REACTIVITY	
		YES		MINIMAL			
Molecular Weight	NP	Flash Point (°C)	193.3 oc	TLV (ppm)	5mg/cub. m.(mist)	Solubility in Water	
Normal State	Liquid	LFL (%)	NA	IDLH (ppm)	NA		
Normal Boiling Point (°C)	Very high	UFL (%)	NA	Probit Equation N A B			
		Fire Agents to Use	Dry chem, foam, CO2				
		Fire Agents to Avoid	Water may cause frothing				
		NFPA Flammability	1	NFPA Health Hazard	0	NFPA Reactivity	0
Oily liquid, floats on water							

NP = Not Pertinent

NA = Not Available

ppm = parts per million

MATERIAL: FUEL OIL							
GENERAL PROPERTIES		FLAMMABLE HAZARDS		TOXIC HAZARDS		REACTIVITY	
		YES		MINIMAL			
Molecular Weight	NP	Flash Point (°C)	37.8 cc	TLV (ppm)	NA	Solubility in Water	
Normal State	Liquid	LFL (%)	1.3	IDLH (ppm)	NA		
Normal Boiling Point (°C)	193-293	UFL (%)	6.0	Probit Equation N A B			
		Fire Agents to Use	Dry chem, foam, CO2				
		Fire Agents to Avoid	Water may be ineffective				
		NFPA Flammability	2	NFPA Health Hazard	0	NFPA Reactivity	0
Fuel oils are heavy oils used in burners, and fall into different categories. 1-D is taken as an example.		Often produce heavy smoke that can reduce sight and cause respiratory problems.					

NP = Not Pertinent

NA = Not Available

ppm = parts per million

MATERIAL: CRUDE OIL							
GENERAL PROPERTIES		FLAMMABLE HAZARDS		TOXIC HAZARDS		REACTIVITY	
		YES		RISK OF INJURY ONLY			
Molecular Weight	NP	Flash Point (°C)	-6.3 - 32.2 cc	TLV (ppm)	NA	Solubility in Water	
Normal State	Liquid	LFL (%)	NA	IDLH (ppm)	NA		
Normal Boiling Point (°C)	32->400	UFL (%)	NA	Probit Equation N A B			
		Fire Agents to Use	Dry chem, foam, CO2				
		Fire Agents to Avoid	Water may be ineffective				
		NFPA Flammability	3	NFPA Health Hazard	1	NFPA Reactivity	0
Crude oils differ in appearance and smell according to source				Different crudes have different toxicities depending on the benzene, hydrogen sulphide, and other minor toxic components.			

NP = Not Pertinent NA = Not Available ppm = parts per million

MATERIAL: HEAVY OIL							
GENERAL PROPERTIES		FLAMMABLE HAZARDS		TOXIC HAZARDS		REACTIVITY	
		YES		MINIMAL			
Molecular Weight	NP	Flash Point (°C)	>54.4	TLV (ppm)	NA	Solubility in Water	
Normal State	Liquid	LFL (%)	1	IDLH (ppm)	NA		
Normal Boiling Point (°C)	218-570	UFL (%)	5	Probit Equation N A B			
		Fire Agents to Use	Dry chem, foam, CO2				
		Fire Agents to Avoid	Water may be ineffective				
		NFPA Flammability	2	NFPA Health Hazard	0	NFPA Reactivity	0
Heavy oil is a heavy fuel oil, eg fuel oil 5							

NP = Not Pertinent NA = Not Available ppm = parts per million

MATERIAL: LUBRICATING OIL							
GENERAL PROPERTIES		FLAMMABLE HAZARDS		TOXIC HAZARDS		REACTIVITY	
		YES		NA			
Molecular Weight	NP	Flash Point (°C)	148.9	TLV (ppm)	NA	Solubility in Water	
Normal State	Liquid	LFL (%)	NA	IDLH (ppm)	NA		
Normal Boiling Point (°C)	Very high	UFL (%)	NA	Probit Equation N A B			
		Fire Agents to Use	Dry chem, foam, CO2				
		Fire Agents to Avoid	Water may cause frothing				
		NFPA Flammability	1	NFPA Health Hazard	0	NFPA Reactivity	0
Yellow-brown oily liquid, floats in water.							

NP = Not Pertinent

NA = Not Available

ppm = parts per million

<table>
<tr><th colspan="8">MATERIAL: COPPER CHLORIDE</th></tr>
<tr><th colspan="2">GENERAL PROPERTIES</th><th colspan="2">FLAMMABLE HAZARDS</th><th colspan="2">TOXIC HAZARDS</th><th colspan="2">REACTIVITY</th></tr>
<tr><td colspan="2"></td><td colspan="2">NONE</td><td colspan="2">NA</td><td colspan="2"></td></tr>
<tr><td>Molecular Weight</td><td>170.48</td><td>Flash Point (°C)</td><td></td><td>TLV (ppm)</td><td>1mg/m3 as Cu</td><td>Solubility in Water</td><td></td></tr>
<tr><td>Normal State</td><td>Solid</td><td>LFL (%)</td><td></td><td>IDLH (ppm)</td><td>NA</td><td></td><td></td></tr>
<tr><td>Normal Boiling Point (°C)</td><td>NP</td><td>UFL (%)</td><td></td><td>Probit Equation
N
A
B</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>Fire Agents to Use</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>Fire Agents to Avoid</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td>NFPA Flammability</td><td></td><td>NFPA Health Hazard</td><td>Not listed</td><td>NFPA Reactivity</td><td>Not listed</td></tr>
<tr><td colspan="2">Copper chloride is most commonly encountered as a dihydrate. It is green-blue in colour, and crystalline.</td><td colspan="2">Combustion can produce irritating hydrogen chloride gas.</td><td colspan="2">Is irritating to eyes, will burn eyes in solid form, respiratory problems.</td><td colspan="2"></td></tr>
</table>

NP = Not Pertinent

NA = Not Available

MATERIAL: SODIUM HYDROSULPHIDE (AQUEOUS)							
GENERAL PROPERTIES		FLAMMABLE HAZARDS		TOXIC HAZARDS		REACTIVITY	
		NONE		NA			
Molecular Weight	NP	Flash Point (°C)	Not flammable	TLV (ppm)	NA	Solubility in Water	
Normal State	Liquid	LFL (%)	NP	IDLH (ppm)	NA		
Normal Boiling Point (°C)	c.100	UFL (%)	NP	Probit Equation N A B			
		Fire Agents to Use	NP				
		Fire Agents to Avoid	NP				
		NFPA Flammability	NP	NFPA Health Hazard	Not listed	NFPA Reactivity	Not listed
Light yellow to red liquid, with a rotten egg odour.				Fairly severe skin irritant; may cause pain and second degree burns after a few minutes.			

NP = Not Pertinent

NA = Not Available

ppm = parts per million

ppm = parts per million

MATERIAL: METHANOL							
GENERAL PROPERTIES		FLAMMABLE HAZARDS		TOXIC HAZARDS		REACTIVITY	
		YES		NONE			
Molecular Weight	32.04	Flash Point (°C)	285.4 cc 289.3 oc	TLV (ppm)	200	Solubility in Water	
Normal State	Liquid	LFL (%)	6.0	IDLH (ppm)	25000		
Normal Boiling Point (°C)	64.5	UFL (%)	36.5	Probit Equation N A B			
		Fire Agents to Use	Alcohol foam, dry chemical or CO2				
		Fire Agents to Avoid	Water may be ineffective				
		NFPA Flammability	3	NFPA Health Hazard	1	NFPA Reactivity	0
Methanol is taken as a representative of the class of non-halogenated solvents for the purpose of solvent release modelling							

NP = Not Pertinent NA = Not Available ppm = parts per million

MATERIAL: CARBON TETRACHLORIDE							
GENERAL PROPERTIES		FLAMMABLE HAZARDS		TOXIC HAZARDS		REACTIVITY	
		NOT FLAMMABLE		RISK OF ACUTE INJURY			
Molecular Weight	153.83	Flash Point (°C)		TLV (ppm)	5	Solubility in Water	
Normal State	Liquid	LFL (%)		IDLH (ppm)	300		
Normal Boiling Point (°C)	76.5	UFL (%)		Probit Equation* N A B	2.5 -6.29 0.408		
		Fire Agents to Use					
		Fire Agents to Avoid					
		NFPA Flammability		NFPA Health Hazard	3	NFPA Reactivity	0
Colourless, watery liquid with sweet odour. Also called tetrachloromethane.		Dizziness is an immediate symptom, as is nausea. Liver and kidney damage result from longer exposures.					

NP = Not Pertinent NA = Not Available ppm = parts per million

* See Section II.6 for further details.

II.3 Reagents for Treatment Processes

The properties defined in Section II.1 above are tabulated for the following reagents:

Chlorine
Sulphur dioxide
Sulphuric acid

MATERIAL: CHLORINE							
GENERAL PROPERTIES		FLAMMABLE HAZARDS		TOXIC HAZARDS		REACTIVITY	
		NONE		RISK OF INJURY ONLY			
Molecular Weight	70.91	Flash Point (°C)	Not Flammable	TLV (ppm)	1	Solubility in Water	
Normal State	Gas	LFL (%)	NP	IDLH (ppm)	25		
Normal Boiling Point (°C)	-34.1	UFL (%)	NP	Probit Equation* N A B	2.0 -8.29 0.92		
		Fire Agents to Use	NP				
		Fire Agents to Avoid	NP				
		NFPA Flammability	0	NFPA Health Hazard	3	NFPA Reactivity	0
Greenish yellow gas with an irritating, bleach like odour.		Toxic products are generated when combustibles burn in chlorine.					

NP = Not Pertinent NA = Not Available ppm = parts per million

* See Section II.6 for further details.

MATERIAL: SULPHUR DIOXIDE							
GENERAL PROPERTIES		FLAMMABLE HAZARDS		TOXIC HAZARDS		REACTIVITY	
Molecular Weight	64.06	Flash Point (°C)	NP	TLV (ppm)	NP	Solubility in Water	
Normal State	Gas	LFL (%)	NP	IDLH (ppm)	NA		
Normal Boiling Point (°C)	-10	UFL (%)	NP	Probit Equation* N	3.7		
				A	-23.695		
				B	1.140		
		Fire Agents to Use	NP				
		Fire Agents to Avoid	NP				
		NFPA Flammability	0	NFPA Health Hazard	2	NFPA Reactivity	0
Colourless gas, with a sharp irritating odour.				Irritating to eyes, nose and throat.			

NP = Not Pertinent NA = Not Available ppm = parts per million

* See Section II.6 for further details.

MATERIAL: SULPHURIC ACID (AQUEOUS)							
GENERAL PROPERTIES		FLAMMABLE HAZARDS		TOXIC HAZARDS		REACTIVITY	
		NOT FLAMMABLE		ACUTE INJURY POSSIBLE			
Molecular Weight	[98.8]	Flash Point (°C)		TLV (ppm)	1 mg/m^3	Solubility in Water	
Normal State	Liquid	LFL (%)		IDLH (ppm)	80 mg/m^3		
Normal Boiling Point (°C)	[340]	UFL (%)		Probit Equation N A B			
		Fire Agents to Use					
		Fire Agents to Avoid					
		NFPA Flammability		NFPA Health Hazard	3	NFPA Reactivity	2
Bracketed properties refer to 98% sulphuric acid. Reagent acid is likely to be more dilute.				Mist is highly irritating to eyes, nose and throat.			

NP = Not Pertinent NA = Not Available ppm = parts per million

II.4 Materials Produced on Site

The properties defined in Section II.1 above are tabulated for the following materials which could be produced through inadvertent mixing of incompatible wastes and/or reagents (see Main Report, Section 5.7 and Appendix III, Section III.4):

Hydrogen cyanide
Hydrogen sulphide

MATERIAL: HYDROGEN CYANIDE							
GENERAL PROPERTIES		FLAMMABLE HAZARDS		TOXIC HAZARDS		REACTIVITY	
		YES		RISK OF ACUTE FATALITY			
Molecular Weight	27.03	Flash Point (°C)	-17.8 cc	TLV (ppm)	10	Solubility in Water	
Normal State	Liquid	LFL (%)	5.6	IDLH (ppm)	50		
Normal Boiling Point (°C)	25.7	UFL (%)	40	Probit N	2.0		
				Equation* A	-79.47		
				B	6.7		
		Fire Agents to Use	Stop flow of gas				
		Fire Agents to Avoid	None				
		NFPA Flammability	4	NFPA Health Hazard	4	NFPA Reactivity	2
Hydrogen cyanide is a watery liquid or colourless gas with a bitter almond odour.		Extremely toxic vapours generated at even ordinary temperatures.					

NP = Not Pertinent NA = Not Available ppm = parts per million

* See Section II.6 for further details.

MATERIAL: HYDROGEN SULPHIDE							
GENERAL PROPERTIES		FLAMMABLE HAZARDS		TOXIC HAZARDS		REACTIVITY	
		YES		RISK OF INJURY ONLY			
Molecular Weight	34.08	Flash Point (°C)	Flammable gas	TLV (ppm)	10	Solubility in Water	
Normal State	Gas	LFL (%)	4.3	IDLH (ppm)	300		
Normal Boiling Point (°C)	-60.4	UFL (%)	45	Probit Equation* N A B	2.0 -40.348 2.9		
		Fire Agents to Use	NP				
		Fire Agents to Avoid	NP				
		NFPA Flammability	4	NFPA Health Hazard	3	NFPA Reactivity	0
Colourless gas, with a rotten egg odour.		Toxic gases are generated in fires.					

NP = Not Pertinent NA = Not Available ppm = parts per million

* See Section II.6 for further details.

II.5 MARPOL Wastes

MARPOL wastes are designated marine pollutants that were established by international Ship Pollution Convention. They constitute a wide range of environmentally problematic materials, and the conventions prohibit the discharge of these into the sea. Thus, the major source of MARPOL wastes is from the tank washouts of marine tankers used for the transportation of chemical products.

The wastes are categorised according to their constituents: organic (essentially hydrocarbon) products are designated Annex I compounds, whilst inorganic and non-hydrocarbon organic materials are designated Annex II.

The major materials covered by Annex I are listed in Table II.2, based on International Environment Reporter, Ship Pollution Convention, pp 21:2318-9. This list is extensive and reflects the wide variety of material potentially arriving at the site. Volumes of materials like crude oil, Jet fuel, naphtha, etc will in fact be small.

Annex II covers a wide range of chemicals. It is not known which will pass through Hong Kong, but potentially any and all may at some stage in the future do so.

TABLE II.2 MARPOL ANNEX I WASTES

CATEGORY	MATERIAL
Asphalt solutions	Blending stocks Roofers flux Straight run residue
Oils	Clarified Crude oil Mixtures containing crude oil Diesel oil Fuel oil no. 4 Fuel oil no. 5 Fuel oil no. 6 Residual fuel oil Road oil Transformer oil Aromatic oil (excluding vegetable oil) Lubricating oil and blending stocks Mineral oil Motor oil Penetrating oil Spindle oil Turbine oil
Distillates	Straight run Flashed feed stocks
Gas oil	Cracked
Gasoline blending stocks	Alkylates - fuels Reformates Polymer - fuel

CATEGORY	MATERIAL
Gasolines	Casinghead (natural) Automotive Aviation Straight run Fuel oil no. 1 (kerosene) Fuel oil no. 1-D Fuel oil no. 2 Fuel oil no. 2-D
Jet fuels	JP-1 (kerosene) JP-3 JP-4 JP-5 (kerosene heavy) Turbo fuel Kerosene Mineral spirit
Naphtha	Solvent Petroleum Heartcut distillate oil

This list is etensive and reflects the wide variety of material potentially arriving at the site. Volumes of materials like crude oil, jet fuel, naphtha etc. will in fact be small.

II.6 Probit Equation Coefficients

II.6.1 Lethality Probits

Lethality probits relate the received toxic load to the proportion of deaths among the exposed population. They account for the observed fact that, even in a population of healthy adults, there is variability in the dose which results in death and an element of chance as to which members will be killed by a given dose. They may also (but usually do not) account for the fact that a population may include people who are more vulnerable than healthy adults.

The probability of death of an individual selected from the population is found to be approximately a log-normal distribution, i.e. the logarithm of the lethal dose is normally distributed. The proportion of deaths among the population receiving a given dose may then be determined by integrating the single-tailed distribution up to that dose.

By convention, this is achieved by converting the dose to a probit number which is the variate of a normal distribution with mean 5 and standard deviation 1. In acute toxicity studies, the probit is expressed in the form:

$$Pr = a + b \ln (c^N t)$$

where a, b and N are constants for the material, c is the concentration in ppm and t is the time exposure in minutes.

The dose $c^N t$ which is lethal for 50% of the population gives a probit number Pr = 5. Other lethalities can be determined from the normal distribution (Finney 1971, summarised in Lees 1980). Probit numbers for 10% and 90% fatalities are 3.724 and 6.276 respectively.

II.6.2 Chlorine Probit

There is considerable uncertainty about the quantification of the lethal toxicity of chlorine. Most evidence is taken from animal experiments. The known differences between human and animal sensitivity to chlorine and their behaviour in its presence are generally small and mutually opposing, so lethal concentrations for animals are assumed appropriate for humans (I Chem E 1987). However, animal data is very scattered (Figure II.1 after I Chem E 1987).

The relationship between concentration (c) and duration (t) of exposure is even less certain, but the animal data is roughly satisfied by a lethal toxic dose of the form c^2t (I Chem E 1987).

Lethality may be significantly increased by exercise, such as walking or running to escape the chlorine, which both increase the inhalation rate (Withers & Lees 1985).

Lethality is also greater for members of the population vulnerable to lung damage, such as children, old people, and people with chronic heart decrease or respiratory illness. This aspect is particularly poorly quantified.

The experimental basis for particular lethality probits for chlorine is even weaker than for the average lethal dose. Some authorities prefer not to use probits for this reason, but in general their advantages in risk assessment outweigh their uncertainty.

Some suggested chlorine lethality probits are compared below:

- Hong Kong probit, used by ERL:

$$Pr = -2.815 + 0.53 \ln (c^2 t)$$

- Technica preferred probit (Withers & Lees 1985):

$$Pr = -8.29 + 0.92 \ln (c^2 t)$$

This was developed for the regular population (i.e. healthy adults) at a standard level of physical activity (e.g. walking). In fact, it is similar to the probit developed for vulnerable population at a base level of activity (e.g. resting in bed), and so may be used quite realistically for the overall population.

- HSE probit (Purdy et al 1988):

$$Pr = -4.4 + 0.52 \ln (c^{2.75} t)$$

This has been used in the HSE's study of bulk chlorine shipments by road and rail in the UK.

- Eisenberg probit (Eisenberg et al 1975):

$$Pr = -17.1 + 1.69 \ln(c^{2.75} t)$$

This was one of the earliest chlorine probits, and has been widely quoted, but is now regarded as conservative.

Figure II.1 shows that the concentration-time relationship for LD_{50} (i.e. the dose causing 50% fatalities) is similar for the Hong Kong, Technica and HSE probits, and agrees well with animal tests. They are all somewhat conservative compared to the estimate of LC_{60} of 400 ppm for a 30 minute exposure (IChem E 1987), but this may be regarded as allowing for the vulnerable population affecting the average lethal dose compared to that for healthy adults.

The range of vulnerability in the population is indicated by the ratio LC_{90}/LC_{10} (i.e. the concentration causing 90% fatalities divided by that causing 10% fatalities). The values for each probit are given in Table II.3. The Technica and HSE probits have similar values, but the Hong Kong probit has an unusually high value. This may be regarded as making a conservative allowance for the presence of very vulnerable members, and may over-predict fatalities in small spills or at long distances from the spill.

TABLE II.3: COMPARISON OF CHLORINE PROBITS

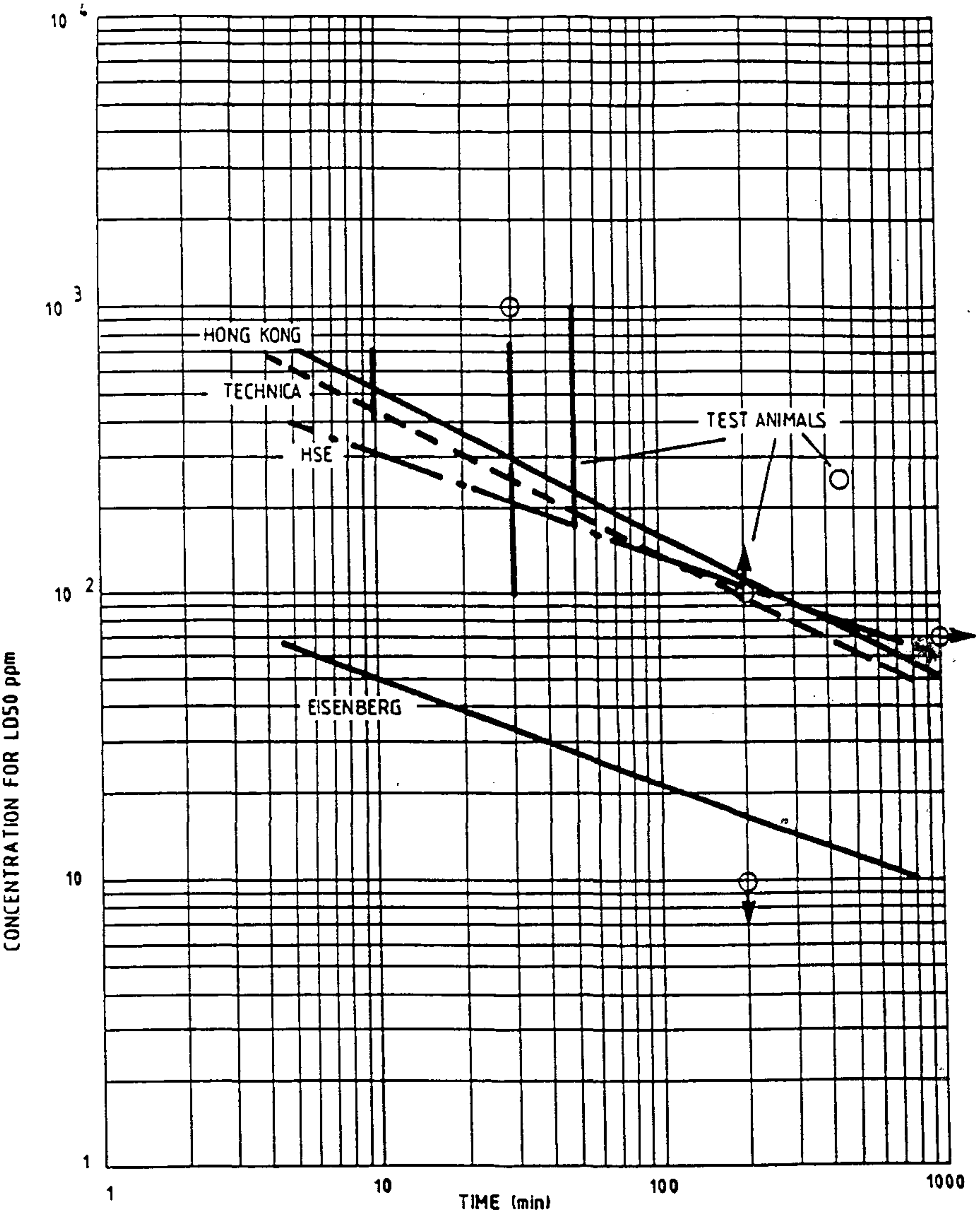
PROBIT	LC_{50} at 30 min (ppm)	LC_{90}/LC_{10}
Hong Kong	291	11.1
Technica	250	4.0
HSE	208	5.9
Eisenberg	34	1.7

Overall the Technica and Hong Kong chlorine probits are very similar, with the Technica probit being slightly more conservative. Use of the Hong Kong Government probit would reduce predicted fatalities slightly, probably by less than a factor of 2.

II.6.3 Other Probits

The probit used for Carbon Tetrachloride is due to the US Coastguard (1980). The remaining toxic materials considered (Hydrogen Cyanide, Hydrogen Sulphide, Sulphur Dioxide) use probits published by DSM (1978).

FIGURE II.1: CHLORINE TOXICITY PROBITS



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APPENDIX III

HAZARD IDENTIFICATION

CONTENTS PAGE

APPENDIX III HAZARD IDENTIFICATION

This Appendix gives details of the hazards identified in Section 5 of the main report and of the failure scenarios associated with them. That Section described the basis of the identification, which is not repeated here.

III.1 Hazards in Transport to Site and Reception

III.1.1 Transport to Facility

Waste is transported to the site either in containers on a lorry or in bulk tankers. The potential exists for any such vehicle to be involved in a road traffic accident (RTA): either a collision with another vehicle or rollover through taking a corner or bend too fast. It would also be possible for a spontaneous failure of a bulk tanker to occur, for example a leak due to corrosion in the tank body.

Collision or rollover of a lorry carrying containers could lead to a number of containers being punctured or crushed and discharging their contents. However, the small quantities involved and the generally non-hazardous (in terms of acute risk of fatality) nature of the materials transported means that the resulting liquid spill is likely to be small and the resulting risk minimal. Only if fire were to break out, engulfing the containers and possibly leading to production of toxic gases, for example HCN from cyanide waste, could a more major incident take place leading to a greater risk. The risk from the fire would probably be localised, however dispersion of toxic gases produced could extend beyond the immediate incident zone. Therefore, although no RTA-induced failure case has been specified for container-carrying lorries, the procedures proposed for handling such incidents has been reviewed as part of the assessment of proposed operating procedures (Main Report, Section 9) and recommendations are made to minimise the risk from this part of the planned operations.

An incident involving a waste-carrying bulk tanker is potentially more serious as the inventory likely to be involved is greater. However, again the materials presenting a major risk are limited to organic materials. For this study we consider the scenario of a release of a volatile solvent from a tanker leading to an evaporating liquid pool as being the most credible risk-generating incident. It is possible for a tank to be ruptured leading to rapid release of the contents; a major leak could also allow release of a significant inventory before the spill were contained, however a small leak such as would arise from corrosion is not considered likely to lead to a significant spill.

The transport of reagents to the site must also be considered. While most are non-hazardous, the occasional use of chlorine and sulphur dioxide, which are to be supplied in pressurised cylinders, does present a potential hazard due to their toxicity and the conditions of storage (i.e. under pressure at ambient temperature). Releases of these are therefore considered. It should however be noted that Technica has recently undertaken a major study of chlorine transport in Hong Kong: a detailed analysis is therefore unnecessary and is not here attempted.

The failure cases to be considered are detailed in the following table.

TABLE III.1: POTENTIAL HAZARDS FROM BULK TRANSPORT OF WASTE MATERIALS AND DRUMS OF REAGENTS

MATERIAL	FAILURE SCENARIO	HAZARDOUS OUTCOME
	TANKERS	
Non-halogenated solvent	Catastrophic rupture	Pool fire Vapour Cloud Explosion* or Flash Fire*
	Major leak	Pool fire Vapour Cloud Explosion* or Flash Fire*
Halogenated solvent	Catastrophic rupture	Toxic cloud
	Major leak	Toxic cloud
Oily waste	Rupture or leak	Pool Fire
	DRUMS	
Chlorine	Catastrophic rupture	Toxic cloud
	Major leak: 1 drum	Toxic cloud
	Major leak: 6 drums	Toxic cloud
	Small leak	Toxic cloud
Sulphur Dioxide	Catastrophic rupture	Toxic cloud
	Major leak: 1 drum	Toxic cloud
	Small leak	Toxic cloud

Note

* This possibility is dependent on the solvent being transported and in particular on its volatility.

** Catastrophic rupture here means any release capable of emptying the drum in a short period (e.g. 50mm hole)

III.1.2 Reception at Facility

RTAs of the type described above and leading to a major spill are less likely to occur within the CWTF site boundary as vehicle speeds will be lower and movement of vehicles will be strictly controlled, with a one-way system being imposed. However, the same range of failure scenarios is considered possible, albeit due partly to different causes. A collision leading to a catastrophic rupture of a bulk waste tanker is unlikely but not impossible given the requirement for manoeuvring within a confined space; a leak is more likely. A leak could also result from tank body material failure (probably only leading to a very small spill), equipment failure (for example of the valves or inlet/outlet covers) or human error (for example failure to close a valve, opening a valve while not connected to the delivery system or driving off without disconnecting). There is also the possibility of failure of the delivery hose, which would take place downstream of the pump integral to the tankers.

The chlorine and sulphur dioxide supplies similarly present the possibility of failure in the same ways as for transport to the facility plus the additional case of delivery hose rupture. Again, small leaks as well as large are considered.

All cases to be considered are detailed in the following table.

TABLE III.2a: POTENTIAL HAZARDS FROM RECEPTION: BULK TRANSPORT OF WASTE MATERIALS

MATERIAL	FAILURE SCENARIO	HAZARDOUS OUTCOME
Non-halogenated solvent	Catastrophic rupture	Pool fire Vapour Cloud Explosion* or Flash Fire*
	Major leak	Pool fire Vapour Cloud Explosion* or Flash Fire*
	Delivery hose rupture	Pool fire Vapour Cloud Explosion* or Flash Fire*
Halogenated solvent	Catastrophic rupture	Toxic cloud
	Major leak	Toxic cloud
	Delivery hose rupture	Toxic cloud

Note

* This possibility is dependent on the solvent being transported and in particular on its volatility.

TABLE III.2b: POTENTIAL HAZARDS FROM RECEPTION: REAGENT DRUMS

MATERIAL	FAILURE SCENARIO	HAZARDOUS OUTCOME
Chlorine	Catastrophic rupture	Toxic cloud
	Major leak OR Delivery hose rupture	Toxic cloud
	Small leak	Toxic cloud
Sulphur Dioxide	Catastrophic rupture	Toxic cloud
	Major leak OR Delivery hose rupture	Toxic cloud
	Small leak	Toxic cloud

III.2 Hazards in Storage

III.2.1 Tank Storage

For each of the storage tanks referred to in Appendix I, the following possible modes of failure have been considered:

- Catastrophic failure
- Full bore rupture of associated pipework or connections to tank
- Leak from tank or connected pipework

Of these, since none of the materials stored is particularly volatile, leaks have not been considered further since the amount evaporated from a liquid spill would be small and hence the hazard zone produced by the dispersing cloud would not extend off the site.

For tanks containing oils or oil/water mixtures, the principal hazard arises from a pool fire in the bund surrounding the tank which fails. It is assumed that both a catastrophic failure and a major leak will eventually fill the bund and that if ignition takes place a pool fire covering the whole area of the bund will occur. Although some evaporation will take place, the hazard zone from a flash fire or explosion of the resulting dispersing vapour cloud is unlikely to be greater than that generated by the pool fire. Using the data on hazards for each material given in Appendix II, the possible hazardous outcomes for each tank have been determined. These are detailed in Table III.2.

In order to model releases of the waste materials given, representative materials are used which are typical of the substances likely to be involved, as given in the following table.

TABLE III.3: REPRESENTATIVE TYPICAL MATERIALS

WASTE MATERIAL	REPRESENTATIVE MATERIAL
Halogenated organic solvent	Carbon Tetrachloride
Non-halogenated organic solvent	Methanol
Oil/water mixtures, incinerator fuel oil	N-Octane (C8)
MARPOL Annex I	N-Eicosane (C20)

TABLE III.4: <u>POTENTIAL HAZARDS FROM STORAGE TANKS</u>

TANK CONTENTS	FAILURE SCENARIO	HAZARDOUS OUTCOME
BULK INORGANIC WASTE STORAGE		
Alkali waste	Failure of tank	NONE
	Leak from tank/delivery pipe	
Oxidizing acid waste	Failure of tank	NONE
	Leak from tank or delivery pipe	
Other acid waste	Failure of tank	NONE
	Leak from tank or delivery pipe	
Chromic acids	Failure of tank	NONE
	Leak from tank or delivery pipe	
Cyanide solutions	Failure of tank	NONE
	Leak from tank or delivery pipe	
Acidic copper etchants	Failure of tank	NONE
	Leak from tank or delivery pipe	
Ammoniacal copper etchants	Failure of tank	NONE
	Leak from tank or delivery pipe	
MARPOL Annex II Acid	Failure of tank	NONE
	Leak from tank or delivery pipe	
MARPOL Annex II Alkali	Failure of tank	NONE
	Leak from tank or delivery pipe	

TANK CONTENTS	FAILURE SCENARIO	HAZARDOUS OUTCOME
Recoverable ferric etchant	Failure of tank	NONE
	Leak from tank or delivery pipe	
Unrecoverable ferric etchant	Failure of tank	NONE
	Leak from tank or delivery pipe	
Chelated ferric etchant	Failure of tank	NONE
	Leak from tank or delivery pipe	
Chelated zinc	Failure of tank	NONE
	Leak from tank or delivery pipe	
Other metal solutions	Failure of tank	NONE
	Leak from tank or delivery pipe	
Tannery wastes	Failure of tank	NONE
	Leak from tank or delivery pipe	
Mixed inorganics	Failure of tank	NONE
	Leak from tank or delivery pipe	
Miscellaneous chemical	Failure of tank	UNKNOWN
	Leak from tank or delivery pipe	
Intercept/treat sludge	Failure of tank	PROBABLY NONE
	Leak from tank or delivery pipe	
Chelated copper	Failure of tank	NONE
	Leak from tank or delivery pipe	

TANK CONTENTS	FAILURE SCENARIO	HAZARDOUS OUTCOME
BULK INORGANIC REAGENT STORAGE		
Caustic soda solution	Failure of tank	NONE
	Leak from tank or delivery pipe	
Acid reagent	Failure of tank	NONE
	Leak from tank or delivery pipe	
Lime slurry	Failure of tank	NONE
	Leak from tank or delivery pipe	
Lime silo	Failure of tank	NONE
	Leak from tank or delivery pipe	
Solidification	Failure of tank	NONE
	Leak from tank or delivery pipe	

TANK CONTENTS	FAILURE SCENARIO	HAZARDOUS OUTCOME
BULK ORGANIC WASTE STORAGE		
Solvents (non-halogenated)	Failure of tank	Pool fire Vapour cloud explosion* or flash fire*
	Leak from tank or delivery pipe	
Solvents (halogenated)	Failure of tank	Possible toxic cloud Pool fire Vapour cloud explosion* or flash fire*
	Leak from tank or delivery pipe	
Oil-water wastes	Failure of tank	Pool fire (of oil) Vapour cloud explosion** or flash fire** Tank explosion***
	Leak from tank or delivery pipe	
Water-oil wastes: non-MARPOL	Failure of tank	Pool fire (of oil) Vapour cloud explosion** or flash fire** Tank explosion***
	Leak from tank or delivery pipe	
MARPOL Annex I	Failure of tank	Pool fire Vapour cloud explosion** or flash fire** Tank explosion***
	Leak from tank or delivery pipe	
MARPOL Annex II Organics	Failure of tank	NONE
	Leak from tank or delivery pipe	

<u>Notes</u>

* This possibility is dependent on the mixture of solvents present, and, particularly, their volatility. The more volatile the solvent, the greater the possibility that this may occur.

** Although a flash fire is a possibility, especially if there is a high proportion of volatile components, the vapour cloud is unlikely to travel very far beyond the hazard effect zone of the pool fire.

*** Tank explosions can result if the flash point of the oil stored is below ambient temperature. These tend to cause onsite damage rather than offsite risk.

TANK CONTENTS	FAILURE SCENARIO	HAZARDOUS OUTCOME
INCINERATOR FUEL AND REAGENT STORAGE AND ORGANIC WASTE		
Incinerator fuel (Fuel Oil 2)	Failure of tank	Pool fire
	Leak from tank or delivery pipe	
Fuel (recovered from wastes)	Failure of tank	Pool fire
	Leak from tank or delivery pipe	
Waste feed blend	Failure of tank	Pool fire
	Leak from tank or delivery pipe	
Fuel feed blend	Failure of tank	Pool fire
	Leak from tank or delivery pipe	
Lean water blending	Failure of tank	NONE
	Leak from tank or delivery pipe	
Sludge blending	Failure of tank	NONE
	Leak from tank or delivery pipe	
Special organic	Failure of tank	UNKNOWN
	Leak from tank or delivery pipe	

III.2.2 Packaged Waste Storage

The principal hazard from packaged waste stored in Building 16 has been taken as arising from a fire. The acute offsite risk of fatality from material generated by a fire in waste materials stored in Building 16 has been assessed on the basis of a mixture of products of combustion of the waste, unburnt liquid and unburnt solid in the plume from the fire. As the composition of the waste will vary an approach has been adopted in which all the waste available to the fire is modelled as a composite organic molecule whose atomic ratios are intended to correspond to the elemental distribution in the waste materials. This approach is based on previous work by Technica on chemical warehouse fires.

A very wide variety of fire scenarios are possible for Building 16 from the worst conceivable which burns or vaporises all the material in the building to the 'most likely' which involves only the combustible materials present on a single floor. This analysis treats the most likely case and assumes burning of the entire inventory of the organics floor of Building 16.

III.3 Process Hazards

The hazards in the treatment processes were identified and discussed in detail in Section 5.6 of the Main Report. They can be subdivided into those which are the counterparts of those identified in storage (see above) and those which are specific to the process equipment. Thus, under normal and correct operation only the organics are considered to present hazards in process. Only the solvent recovery unit and the incinerator are considered to be potential sources of a hazardous release.

III.3.1 Solvent Recovery Unit

Possible causes of failure were discussed in Section 5.6.1 of the Main Report. The resulting failure cases to be considered are detailed in Table III.3 below.

III.3.2 Incinerator

Within the incinerator, the basic failure modes are either failure of combustion or failure of scrubbing.

Failure of Combustion

This requires failure of both the rotary kiln and the secondary combustion chamber. This could arise from a number of causes, as discussed in the Main Report. It would lead to discharge from the top of the stack into the atmosphere of unburnt or partially burnt waste, and in the latter case the products of incomplete combustion. The discharged mixture could therefore be both toxic and flammable, however the interlocks on the system are such that shutdown would take place rapidly (see Appendix I, Section I.3.3) and discharge would be limited to the contents of the incineration system. The residual heat in the linings would ensure some combustion of most flammable materials, hence a significant flammable release is not considered credible. Therefore, the only likely hazard from failure of combustion is discharge of a plume containing toxic materials; however a significant amount would only be released if the automatic shutdown systems failed and waste material continued to be fed to the incinerator. Such a scenario is modelled by a release of toxic (halogenated) organic solvent.

Failure of Scrubbing

Prior to scrubbing, the combustion gases may include acid gases, hydrogen chloride, sulphur dioxide and oxides of nitrogen. A discharge of these to atmosphere may take place under two circumstances:

- A leak from the incinerator system upstream of the scrubber. The induced draught fan maintains a negative pressure in the system, however if a line rupture occurred the negative pressure would not be maintain upstream of the break and the shutdown systems should operate (see Appendix I, Section I.3.3) so that discharge would be limited to the contents of the section of the incinerator upstream of the break emerging at a low velocity. Only if the automatic shutdown systems failed could a potentially significant release to atmosphere take place. Anything less than a rupture is not likely to lead to loss of underpressure and hence escape of material will be minimal.

- Failure of the scrubber itself, which would lead to unscrubbed gases passing directly out of the top of the stack under the action of the induced draught fan.
  The events to be considered for detailed analysis are detailed in Table III.5 below. The potential release rate and consequences are considered in Section 6 of the Main Report.

TABLE III.5: POTENTIAL HAZARDS FROM TREATMENT PROCESSES

PROCESS FAILURE	MATERIAL RELEASED	RELEASE SCENARIO
Loss of containment in Solvent Recovery System	Liquid flammable solvent	Pool Fire Vapour Cloud Explosion* or Flash Fire*
	Vapour of toxic solvent	Toxic Cloud
Incinerator combustion failure	Vapour of halogenated solvent	Toxic Plume
Incinerator scrubber failure	Acid gases, HCl, SO_2, NO_x	Toxic Cloud

Note

* This possibility is dependent on the mixture of solvents present, and, particularly, their volatility. The more volatile the solvent, the greater the possibility that this may occur.

III.4 Mixing Hazards

The most significant hazardous mixtures of waste materials with one another or with treatment chemicals were identified in Section 5.7 of the Main Report as being the addition of **acid to cyanide and sulphide** wastes. It is necessary to consider how such inadvertent mixing could occur and how much toxic gas would be produced in order to decide whether such cases should be analysed further.

There are four ways such mixing could occur:

(i) Direction of acid waste onto cyanide/sulphide waste
(ii) Direction of cyanide/sulphide waste onto acid waste
(iii) Direction of acid reagent onto cyanide/sulphide waste
(iv) Direction of cyanide/sulphide waste onto acid reagent

In principle, this could occur either in storage or in process. However, the cyanide reactor is to vent via a caustic scrubber to the atmosphere; therefore any hydrogen cyanide generated in the reactor will only escape to atmosphere if the caustic scrubber fails: this, taken together with the necessity first of all direct acid to the reactor (against which precautions can be taken by good engineering design) makes a significant release of hydrogen cyanide from process extremely unlikely and this case is not considered further. Sulphide-containing tannery wastes will routinely be treated to neutralise them; hydrogen sulphide would only be generated if excess acid were added (i.e. the mixture became acidic), requiring failure of the acid dosing control, and would only be released to atmosphere if the incinerator (to which it would be vented) failed: again, this combination is considered extremely unlikely (given good engineering design) and this case also is not considered further.

Cyanide is to be received only in 200 l containers, never in bulk tankers. We assume for this study that the same applies to (sulphide-containing) tannery wastes. This limits the amount of hydrogen cyanide or hydrogen sulphide which would be liberated if cyanide or sulphide waste were directed onto acid.

Therefore, the only mixing cases to be considered further are those involving direction of a significant quantity of acid onto cyanide and sulphide wastes in storage.

III.5 Knock-on Failures

It is in principle possible for a fire in one area of the plant to cause a more serious failure elsewhere on the plant. For example, an adjacent vessel may be heated by the fire: as a result of this its contents may vaporise or a chemical reaction may produce a toxic vapour. With such a variety of materials being handled by the facility it is difficult to identify precisely what materials might be produced, however using the materials data presented in Appendix II the most likely escalation scenarios are:

- Fire surrounding tank containing **phenol**. However, the annual volume of phenol to be handled is very small (2 tonnes: see Table 3.1 of Main Report), so this scenario is highly unlikely and would not lead to large volumes of vapour being produced.

- Thermal radiation from fire impinging on **cyanides** storage tank leading to generation of **hydrogen cyanide**. The cyanides tank is at least 15 m away from the nearest organics storage tanks: thermal radiation from a fire could heat the contents, however the tank vents to atmosphere via a scrubber (see Section III.4 above), therefore this case can be treated in the same way as hydrogen cyanide production by inadvertent mixing of acid.

III.6 Summary of Failure Cases Identified

The full set of failure cases identified as meriting further consideration is summarised in the following table. Each has been allotted an identifier for future reference.

TABLE III.6: FAILURE CASES IDENTIFIED (Sheet 1 of 3)

CASE IDENTIFIER	MATERIAL	FAILURE TYPE
STORAGE		
S11	Non-halogenated solvent	Catastrophic rupture
S12		Major leak
S13		Line rupture (while pumping)
S21	Halogenated solvent	Catastrophic rupture
S22		Major leak
S23		Line rupture (while pumping)
S31	Oil-water mixture (2 tanks)	Pool fire in bund
S32	Water-oil mixture: non-MARPOL (4 tanks) Incinerator fuel	Pool fire in bund
S33	MARPOL Annex I (2 tanks)	Pool fire in bund
S41	Packaged Waste: (Building Waste)	Toxic elevated plume

TABLE III.6: FAILURE CASES IDENTIFIED (Sheet 2 of 3)

CASE IDENTIFIER	MATERIAL	FAILURE TYPE
TRANSPORT TO FACILITY		
T11	Non-halogenated solvent	Catastrophic failure
T12		Major leak
T21	Halogenated solvent	Catastrophic failure
T22		Major leak
T31	Chlorine	Catastrophic failure
T32S		Major leak: 1 drum
T32M		Major leak: 6 drums
T33		Small leak
T41	Sulphur Dioxide	Catastrophic failure
T42S		Major leak: 1 drum
T43		Small leak
T51	Oil	Pool fire
RECEPTION		
R11	Non-halogenated solvent	Catastrophic failure
R12		Major leak
R13		Delivery hose rupture
R21	Halogenated solvent	Catastrophic failure
R22		Major leak
R23		Delivery hose rupture
R31	Chlorine	Catastrophic failure
R32		Major leak/Hose rupture
R33		Small leak
R41	Sulphur Dioxide	Catastrophic failure
R42		Major leak/Hose rupture
R43		Small leak
R51	Oil	Pool fire

TABLE III.6: FAILURE CASES IDENTIFIED (Sheet 3 of 3)

SOLVENT RECOVERY SYSTEM

CASE IDENTIFIER	MATERIAL	SCENARIO	FAILURE TYPE
P11	Toluene	Liquid release	Major leak - flammable
P12	Carbon tetrachloride	Vapour release	Major leak - toxic

INCINERATOR FAILURE

CASE IDENTIFIER	MATERIAL	SCENARIO	FAILURE TYPE
I11	Sulphur dioxide	Line rupture	Toxic cloud
I12	Hydrogen chloride		
I21	Carbon tetrachloride	Flameout	Toxic plume
I31	Sulphur dioxide	Scrubber failure	Toxic plume
I32	Hydrogen chloride		

INADVERTENT MIXING

CASE IDENTIFIER	MATERIAL	FAILURE TYPE
M11	Hydrogen cyanide	Toxic elevated plume
M21	Hydrogen sulphide	Toxic elevated plume

APPENDIX IV

BACKGROUND DATA

CONTENTS PAGE

APPENDIX IV BACKGROUND DATA

IV.1 Introduction

The calculation of risk in SAFETI requires databases of **population** (both for societal risk calculations and also as potential sources of ignition of flammable clouds), **meteorology** (probabilities of occurrence of weather conditions and wind directions) and **ignition sources** (i.e. potential sources of ignition of flammable clouds).

All these databases were developed by Technica for the Tsing Yi Island Risk Reassessment carried out for the Hong Kong Government in 1988-9; their development was described in detail in Intermediate Reports 9-11 submitted during the course of that study. This Appendix contains summaries only of those reports as they should be available from the Hong Kong Government if required.

IV.2 Population Data

The population database contains numbers of people in 100m x 100m squares on a grid covering the area required. It was previously agreed with the Hong Kong Government that this should include all residential, school and transport populations and working populations excluding that on PHI sites. The populations working on the Dow and TCVT sites have been added to the database.

The static population used was supplied by the Tsuen Wan Project Office: this was based on a combination of existing and irrevocably planned numbers taken to be at the beginning of 1992. The traffic population was based on forecast vehicle movements, average vehicle speeds and typical vehicle occupancies. The potential additional SETY CT9 population was not treated with the same numerically rigorous methods applied to existing conditions. However, the likely effect of such population has been treated in the risk assessment (see Main Report, Section 8.5).

The residential population fluctuates with time (in particular between the working day and the remainder including weekends) while the school and working populations are only present for part of the time. The transport population also fluctuates. To take account of this, first the various populations were separately allocated to grid squares, then a weighted average of these populations was calculated taking into account the proportion of time each population would be present. These proportions were:

Residential	: 100% of population for 14 hours/day, 7 days/week 65% of population for 10 hours/day, 7 days/week
Working	: 10 hours/day, 5.5 days/week
Schools	: 2 shifts, each for 5 hours/day, 5 days/week
Transport	: calculated average for 24 hours/day, 7 days/week

The resulting population distribution is shown in Figure 4.2 of the Main Report.

The choice of grid resolution is always a compromise between accuracy and computation time. Experience and the data originally made available for the Tsing Yi Risk Re-assessment together suggested that 100m is appropriate for calculations of offsite risk: it is often difficult to assign the population more accurately than this. The consequence calculations, however, are carried out to finer resolution than this.

IV.3 Meteorology

IV.3.1 Data Requirements

Meteorological data are required at two stages of the risk assessment. First, the dispersion modelling part of the consequence modelling requires specification of wind speeds and atmospheric stabilities, atmospheric (and, for evaporating liquid pools, surface) temperature, humidity and surface roughness. Second, the impact (risk) calculations require wind-rose frequencies for each combination of wind speed and stability used. Additionally, account should be taken at both stages of the effect of terrain.

For the dispersion modelling, a suitable number (generally 6) of combinations of wind speeds and stability is chosen. These combinations must reflect the full range of observed variations in these quantities; at the same time it is neither necessary nor computationally efficient to consider every combination observed. The procedure used is therefore to group these combinations into representative weather classes which together cover all conditions observed. The chosen classes must be sufficiently different to produce significant variations in dispersion modelling results but must not smooth out important variations between the speed-stability combinations grouped into each. In particular, the conditions most likely to give rise to large effect distances must not be grouped with those leading to shorter effect distances.

Once the weather classes have been chosen, frequencies for each weather direction can be assigned for each class; the resulting distribution can then be further modified to take account of local terrain.

IV.3.2 Data Sources and Processing

The Hong Kong Royal Observatory made available to Technica a full three-dimensional annual frequency distribution of wind speed, wind direction and atmospheric stability at Kai Tak International Airport. In addition, wind roses were supplied for five stations, including three on Tsing Yi Island.

These data sets were merged by applying the stability frequencies from the Airport to the Tsing Yi wind roses. This was described in the Tsing Yi Risk Reassessment Study already referred to.

Tables of the resulting speed-stability frequency distribution were used to group combinations of these into the following 6 weather classes.

WEATHER CLASS	WIND SPEED (m/s)	STABILITY CLASS
I	2.5	B
II	1.0	D
III	3.5	D
IV	7.0	D
V	3.0	E
VI	1.0	F

The wind-rose frequencies for each speed-stability combination were then summed into their allocated weather classes to give the frequency distribution finally used for the SAFETI analysis, shown in Table 4.1 of the Main Report. 12 wind directions, each covering a 30° sector, were used.

For modelling of thermal radiation from pool fires, atmospheric stability is assumed to have no effect, however the wind speed and direction do influence the hazard zone dimensions: the above windspeeds were therefore used for this modelling and the corresponding frequencies applied in calculating the resulting risk.

IV.3.3 Terrain Effects

The PHI sites on Tsing Yi Island, including the CWTF, are constructed on the flat coastal strip; behind this the land rises steeply. Technica investigated in detail the effect of such terrain on dispersion for the Tsing Yi Island Risk Reassessment and concluded that this could be modelled adequately by cutting off dispersion towards the hills at their foot and diverting dispersion at an angle to them to run parallel. For CWTF, wind from between 105°E-165°E was assumed to be diverted to the sectors either side and the frequencies correspondingly reallocated.

IV.4 Ignition Sources

A dispersing cloud of flammable material will only be ignited if it passes over an active ignition source. SAFETI calculates the probability of ignition using a database of the distribution and strength of 3 types of sources:

• **Point sources**	:	known specific sources such as flares, workshops, electrical switchgear
• **Line sources**	:	roads, electrical transmission lines
• **Area sources**	:	population; industrial sites where location of point sources is not available

Each is defined by its *location, ignition factor* (related to the probability per unit time of ignition, a measure of its strength) and *presence factor* (the proportion of time for which it is active).

By contrast with population, the database must include sources on the PHI sites as well as outside them. For the Tsing Yi Risk Reassessment study Technica developed a complete database, including sources on the CWTF as then envisaged. Table IV.1 below shows the types of sources identified; also shown are the assumed probabilities of ignition per unit time.

For the present study, the existing database was modified to use the most recent site plan for the CWTF. The ignition sources identified were:

- Incinerator and associated plant
- Air compressors
- Workshop
- Substation (i.e. transformer)
- Vehicles on site

One vehicle with its engine running was assumed to be present continuously throughout the 'Day' and 'Evening' shifts in the area between the main gate and the unloading dock.

Site personnel were also included (as they are not in the population database). The numbers given in Table 3.3 of the Main Report were assumed to be present in the administration/laboratory/warehouse/workshop building for 2 shifts per day, similarly those in the drum reception building (an average being taken between the two shifts). A rectangular area covering most of the process areas, truck wash/gas filling station and remaining site roads was defined with the average processing area population over 3 shifts allocated to this plus one vehicle present 10% of the time.

TABLE IV.1: IGNITION PROBABILITIES FOR SOURCES ON TSING YI ISLAND

SOURCE	PROBABILITY OF IGNITION PER UNIT TIME
1 Person	0.01
1 Car or offsite vehicle	0.4
1 Dangerous Goods lorry onsite	0.1
Boiler (indoor)	0.23
Workshop with welding taking place	0.45
Incinerator	0.45
Ship	0.3
Transformer	0.05*
Electrical switchgear	0.1*
Transmission Line	0.2/100m
Diesel generator	0.4
Compressor	0.05*

Note

UNIT TIME is **60 s** *except* for those items marked * for which it is **600 s.**

APPENDIX V

THE SAFETI PACKAGE

APPENDIX V. THE SAFETI PACKAGE

V.1. Background to the development of SAFETI

The SAFETI package is an integrated suite of computer programs developed by Technica on behalf of the Dutch Government and is now in use with a number of major chemical companies and Government Authorities world-wide.

The program was originally commissioned by the Dutch Government as it was recognised that approaches current in 1982 suffered from problems that would inhibit the full application of the risk assessment methodology. These were:

Full assessments, involving many failure cases and a realistic range of weather conditions, were extremely time consuming and costly to undertake. Frequency estimations were often based on detailed fault tree analysis; these were subject to error and tended to divert effort to the technical execution of the basic study and away from final objectives such as remedial measures and land-use planning. There was significant potential for calculation error as many steps in the analysis were manual and overall quality assurance was hard to achieve.

The SAFETI program was developed to provide for a consistent approach using high quality consequence models and standardised failure frequencies (see later discussions) which would permit a rigorous study in reasonable time and at reasonable cost. The first version of the program was released in 1983 and it has had two revisions since then, improving models and capabilities. Over 7 man-years of development effort has been invested in the code. The program runs on a mainframe or mini-computer.

A number of 'so-called' risk assessment programs have been released in recent years; none of these has the full functionality of the SAFETI program. Some are essentially consequence-only models, some are frequency-only. One package, now being released in its first version by one of our competitors employs simplified correlation models and substantially constrains the problem in order to allow it to be run on a personal computer.

Technica has used the SAFETI package on over 100 risk assessment assignments which have covered onshore, offshore and marine terminal facilities, for flammable and toxic materials, and for both coarse preliminary studies and more rigorous detailed assessments. It has proved particularly suitable for reviewing engineering remedial measures and for the development of land-use guidelines.

The SAFETI package represents a major technical achievement which has been recognised by the Government Authorities and private companies which have purchased it (after considerable review). These include the Hong Kong Government and also the following:

- the Dutch Government Ministry for Housing, Physical Planning and Environment
- the Rijnmond Public Authority (largest petrochemical area in The Netherlands)
- the Limburg provincial authority in The Netherlands
- the New South Wales Department of Environment and Planning
- Ansaldo and an Italian Government agency
- Air Products
- Exxon Corporation
- Mobil
- Rohm and Haas
- Union Carbide
- American Cyanamid
- Shell International

- ICI
- DSM
- Akzo

A regular series of User-Group meetings is coordinated by Technica to collect user experience and to direct continuing development effort into the most important areas.

It should be stressed that the SAFETI package has been designed as a general purpose package, capable of handling the full variety of process plants. These range from pressurized continuous operations, through ambient pressure batch operations.

V.2. An overview of the SAFETI Package structure

The flow structure of the SAFETI package is shown in Figure V.1. The data printouts required are shown at the top, together with "material properties" (which are discussed below in Section V.7). The conceptual flow of data through failure case generation, consequence and impact modelling is shown to the final presentation of individual and societal risk.

The following figures (V.2 - V.5) show this structure in more detail. It should be noted that all data files specific to one plant or site are identified in their names by a number which the analyst allocates at the start to that site.

Figure V.2 shows the programs used in the first two stages of the analysis: defining Plant Data and Failure Cases.

Program PLANT is used to enter plant data (see Section V.3.1). Failure cases are defined using the programs PIPE, NONPIP, LINEDF and OTHEDF (see Section V.4). The cases defined using each of these programs can be collected together automatically using program CRFEDF.

The database of leak and rupture frequencies for pipes, vessels and other components is maintained by the program FALURE.

The grouping of identical and/or similar failure cases is carried out using program CLUSTR; this can be guided using the output from PCLUST which shows which failure cases are suitable for such treatment.

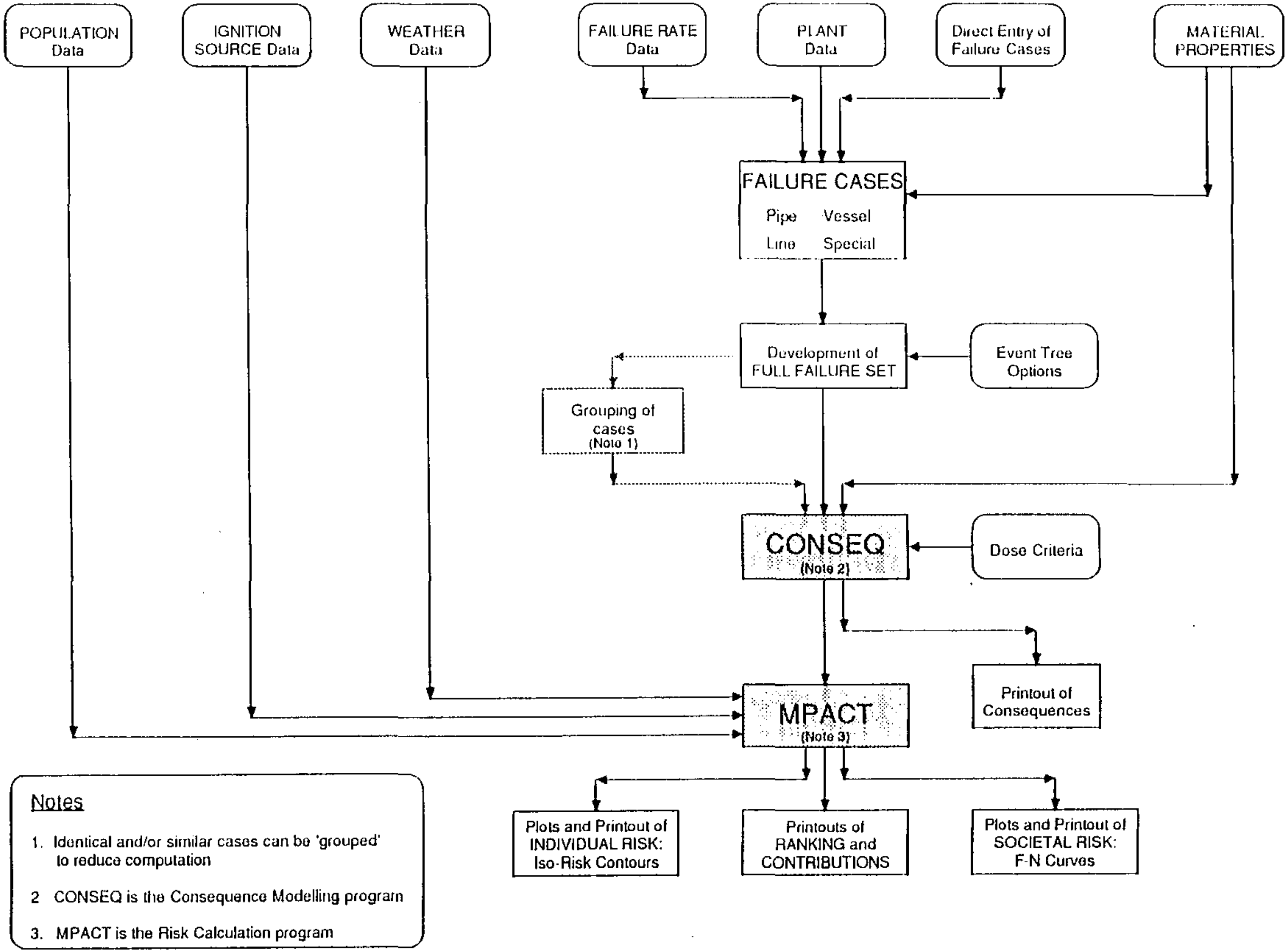
A subset of the full list of cases can be selected for further processing using program SELEDF.

The programs required for the remaining stages of the analysis (Consequence Modelling and Risk Calculation) are shown in Figure V.3. This figure also shows the other programs involved in preparing the remaining data required: POPXTR for population, IGNXTR for ignition sources, RAWMET and METXTR for meteorology. These are described below (Section V.3).

The consequence modelling (program CONSEQ) consists, for most types of release, of two stages. First, the atmospheric dispersion of the released material is calculated to derive concentrations as a function of downwind and crosswind distances; then the consequences, which are the doses received and the effect zones, are evaluated. The program then combines these two; the models and procedures used are further described in Section V.6 below.

Finally, the programs used for presentation of the risk results are shown in Figures V.4. and V.5. These programs allow the graphic representation of risk in the form of individual risk contours and F-N curves together with tabular rankings of the contributing events.

FIGURE V.1: OVERVIEW OF THE SAFETI PACKAGE FLOW STRUCTURE



Notes

1. Identical and/or similar cases can be 'grouped' to reduce computation
2. CONSEQ is the Consequence Modelling program
3. MPACT is the Risk Calculation program

FIGURE V.2: PLANT AND FAILURE CASE DATA HANDLING IN SAFETI

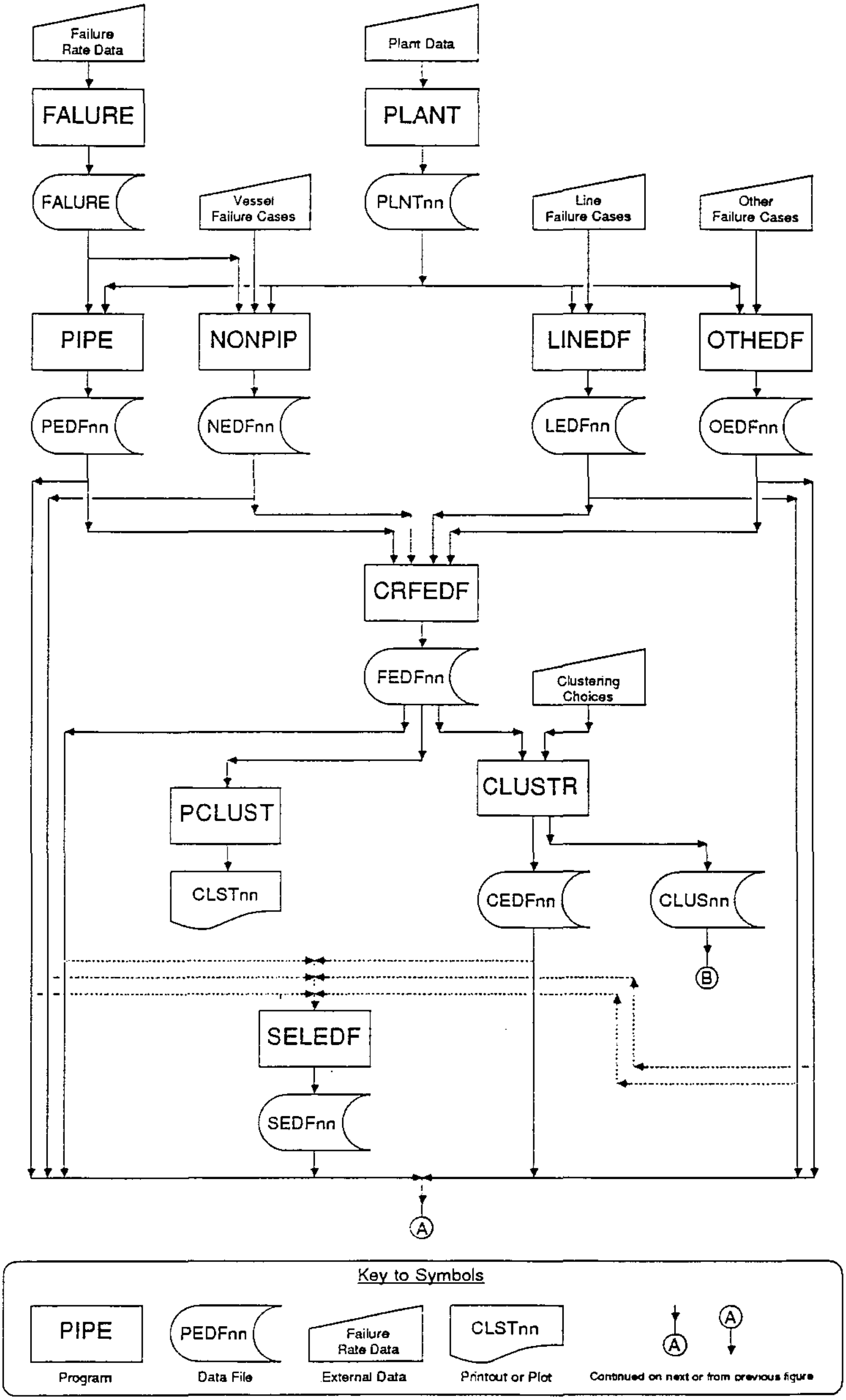


FIGURE V.3: CONSEQUENCE MODELLING, RISK CALCULATION AND BACKGROUND DATA IN SAFETI

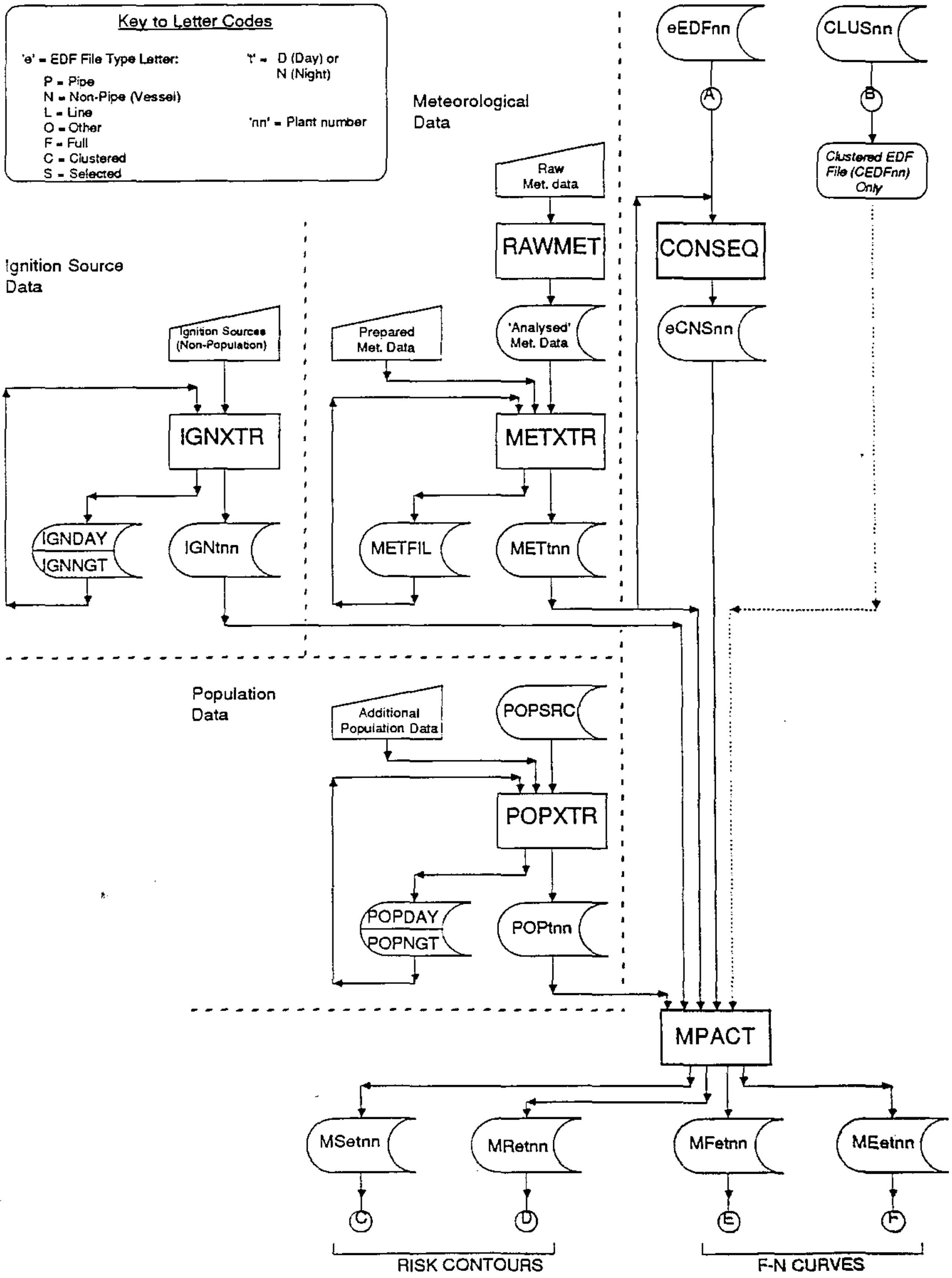


FIGURE V.4: PRESENTATION OF INDIVIDUAL RISK RESULTS

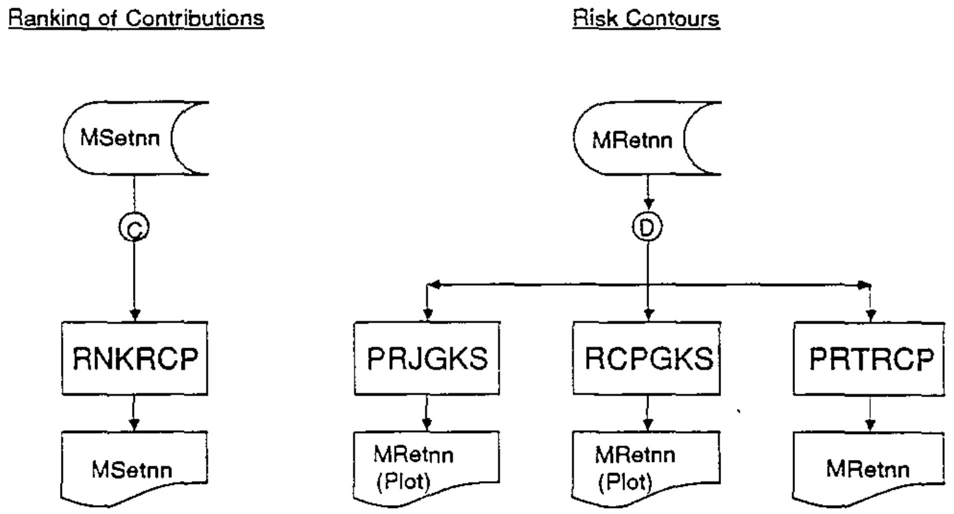
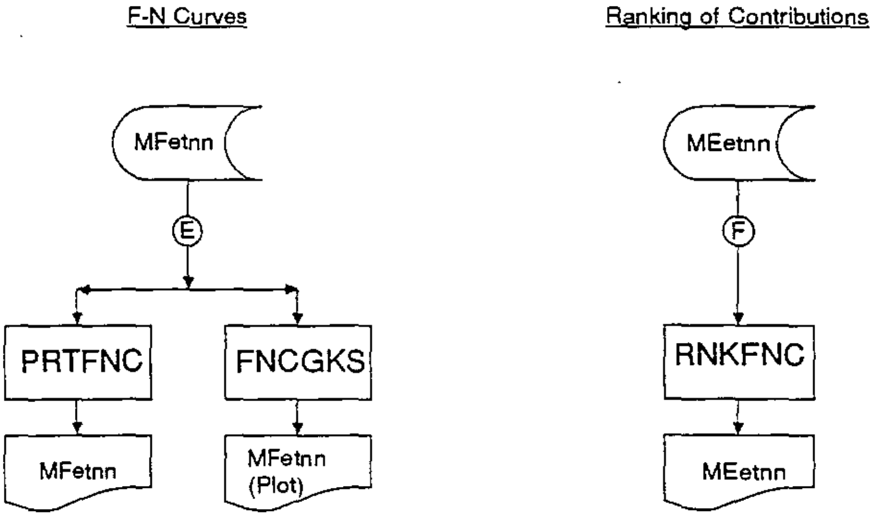


FIGURE V.5: PRESENTATION OF SOCIETAL RISK RESULTS



Key to Letter Codes

'e' = EDF File Type Letter:
  P = Pipe
  N = Non-Pipe (Vessel)
  L = Line
  O = Other
  F = Full
  C = Clustered
  S = Selected

't' = D (day) or N (Night)

'nn' = Plant number

V.3. Data input programs

V.3.1. Plant Data

The PLANT program is designed to allow input of plant layout, vessel, piping, material and operating data to the package. It contains all the elements of process equipment which are to be considered in the automatic failure generation process. The physical location of the plant is defined in terms of local coordinates which may be related in position and orientation to the National Grid. Each 'plant' is organised in terms of 'units', which are linked internally and externally by connecting 'pipes' to 'vessels' in each unit.

Vessels may be of four basis types:

(i) pressurised liquid (specify material, temperature and pressure)
(ii) pressurised gas (specify material, temperature and pressure)
(iii) pressurised gas and liquid (specify material, temperature or pressure)
(iv) unpressurised liquid (specify material, temperature and liquid head).

Connecting pipework is defined by the upstream and downstream vessels, by the diameter and by details of valves or other equipment in the line. Valves may be of three types:

(i) excess flow valve (specify maximum flow)
(ii) non-return valve
(iii) shut-off valve (specify total time for closure).

Other components in the pipe (e.g. pumps) may also be specified as these too are subject to failure.

The failure rate database contains typical failure rates for valves and other equipment items. These are used in the subsequent failure case generation together with other data to determine the likelihood, size and duration of a potential release.

V.3.2. Meteorological Data

All failure events leading to dispersion can be treated for a range of weather cases. Meteorological data are required in terms of the probabilities of occurrence of the range of weather types for each wind direction. Up to 10 (typically 6) weather types may be specified as atmospheric Pasquill Stability and wind speed pairs (e.g. F:1.5 m/s, D:5 m/s, etc.). The number of wind directions is usually 8, 12 or 16. Additionally, as daytime and night-time population and ignition source distributions often differ markedly, separate sets may be specified corresponding to these two periods.

A matrix of meteorological probabilities is specified in the form:

Element P_w (i,j,k) = probability of the wind in this condition

where i = wind direction (up to 8, 12 or 16)
j = weather type (up to 10)
k = day/night (up to 2)

$$\sum_i \sum_j \sum_k P_w(i,j,k) = 1.0$$

An example of such data, for daytime, is given in Figure V.6.

These data are entered using the program METXTR. Often, however, the data available give frequencies for stability and windspeed separately rather than in combined classes. Program RAWMET is used to enter this data, decide on the most appropriate weather types and group the frequencies into these types. The processed data can then be passed to METXTR for further treatment.

Where data are not available for a particular site, those from a nearby meteorological collection point may be adequate. Where stability data are not available, it can be estimated using standard tabulations of wind speed versus sky conditions (Gifford, 1976).

V.3.3. Ignition Data

For the analysis of flammable risks, the locations and effectiveness (i.e. strength) of ignition sources are crucial in determining the pattern and extent of the risk. Few flammable clouds will reach their full hazard extent if they must pass over a number of strong ignition sources.

The SAFETI package defines three types of ignition sources:

(i) Fixed point sources (e.g. furnaces, flares)
(ii) Line sources (e.g. roads, transmission wires)
(iii) Area sources (e.g. residential areas).

All these types are shown in Figure V.7: the sources to consider have been marked on a map of an example area being studied. From a map such as this the coordinates defining the boundaries of areas, the end-points of straight sections of lines and the locations of point sources are extracted.

Besides the source locations, the analyst must enter data for each source in terms of both a "presence factor" and an "ignition effectiveness". These are used to determine the probability of a flammable cloud being ignited as it passes over a source as follows:

$$P_I(t) = f\,[1 - \exp(-wt)]$$

where: $P_I(t)$ is the probability of ignition within time interval 0 to t seconds

f is the presence factor (fraction of time that an ignition source is active), in the range 0 to 1.0

w is the ignition source effectiveness (probability of ignition per unit of exposure time to a flammable cloud) in units s^{-1}

Area sources are determined from specified populated areas and the program does this automatically by scanning the population input data files. They may also be defined for other types of ignition source such as industrial sites where the locations of individual sources are not known.

The data are entered in the form required using program IGNXTR. Often the data available to the analyst are in a different form: program PIGN is provided to help him calculate the presence factor and ignition effectiveness from the data he has available.

V.3.4. Population Data

Population data are necessary for the calculation of societal risk. They are also used for area ignition source prediction and thus are relevant to individual risk as well, at least with regard to flammable releases.

Population may be specified on a 100m square grid (hectare blocks) for up to 10 km from the plant. Day and night variations may also be specified: these typically arise from the daytime movements of people out of residential areas to their workplace.

An example of a population map as produced by program POPXTR, with coastline and a river added by hand, is given in Figure V.8. A letter is used to represent the population in each 100m square. The precise populations are entered either for area blocks or points (which actually represent one 100m square).

The areas close to the river are industrial sites and wharves; ships on the river are also indicated. In some cases, the numbers of people on industrial sites were known, in other an average was used. Further away from the river most populated areas shown are residential: their populations were taken from census data.

FIGURE V.6: EXAMPLE OF METEOROLOGICAL DATA FOR USE IN A SAFETI ANALYSIS

WIND DIRECTION (degrees)	PERCENTAGE FREQUENCIES					
	3.0m/s B/C	1.0m/s D	4.0m/s D	9.0m/s D	3.5m/s E	1.0m/s F
341-010	1.451	0.256	1.691	5.762	0.587	0.654
011-040	2.141	0.226	2.183	8.451	0.678	0.573
041-070	1.556	0.316	2.113	3.768	0.608	0.519
071-100	1.117	0.356	2.208	3.600	0.594	0.703
101-130	1.164	0.311	2.264	5.871	0.506	0.655
131-160	1.401	0.281	2.745	5.888	0.468	0.478
161-190	1.352	0.382	2.204	4.134	0.302	0.430
191-220	1.154	0.186	1.399	4.398	0.148	0.220
221-250	1.116	0.156	1.072	3.568	0.172	0.182
251-280	1.151	0.211	1.055	2.419	0.116	0.227
281-310	1.152	0.156	0.988	1.399	0.176	0.235
311-340	0.874	0.236	0.844	1.343	0.295	0.408

FIGURE V.7: EXAMPLE OF AN IGNITION SOURCE MAP

KEY :

○	INDUSTRIAL CHIMNEYS
△	WELDING
—×—	OVERHEAD POWER CABLES
- - - - - -	HEAVY TRAFFIC
········	MEDIUM TRAFFIC
—·—·—	LIGHT TRAFFIC

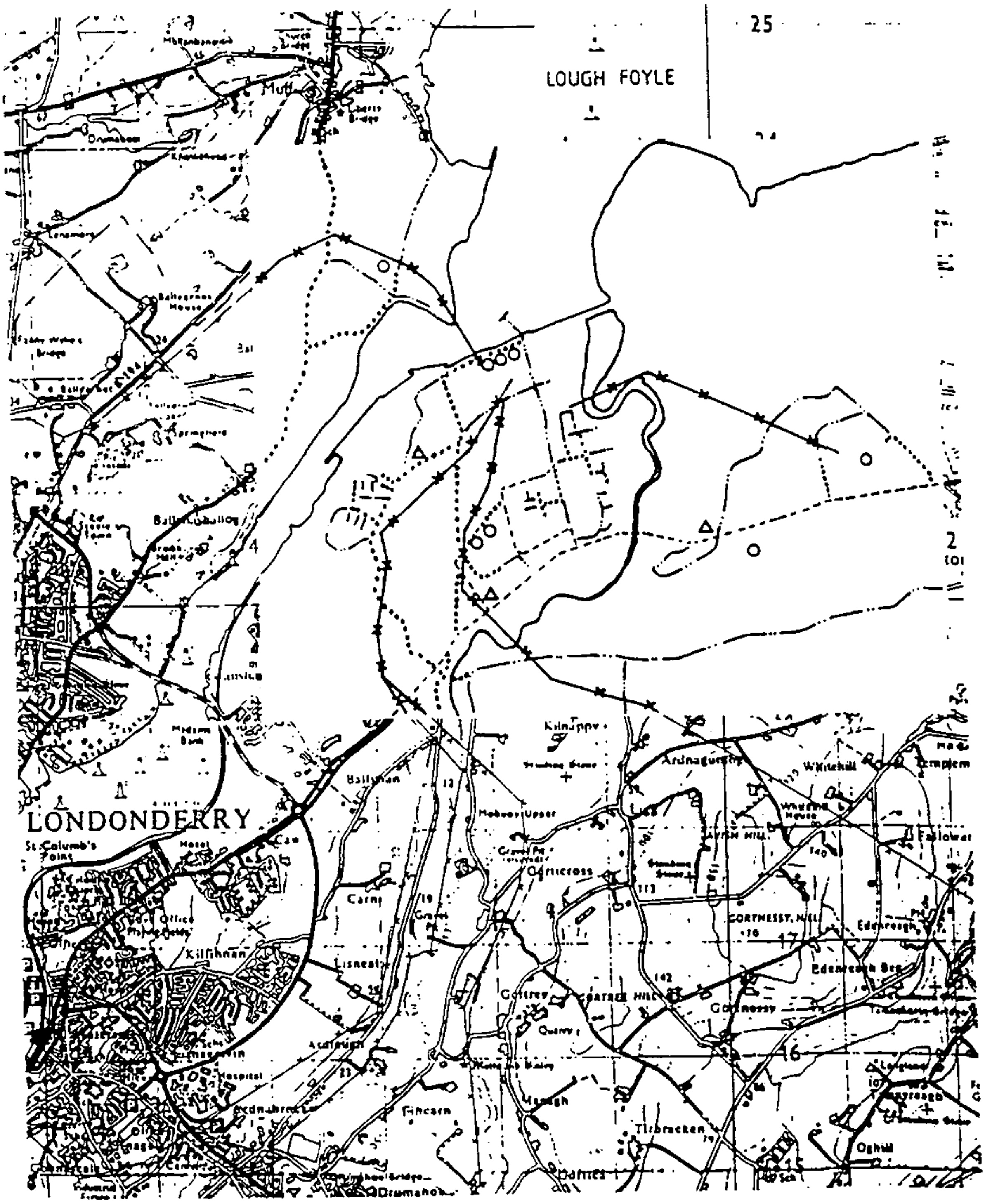
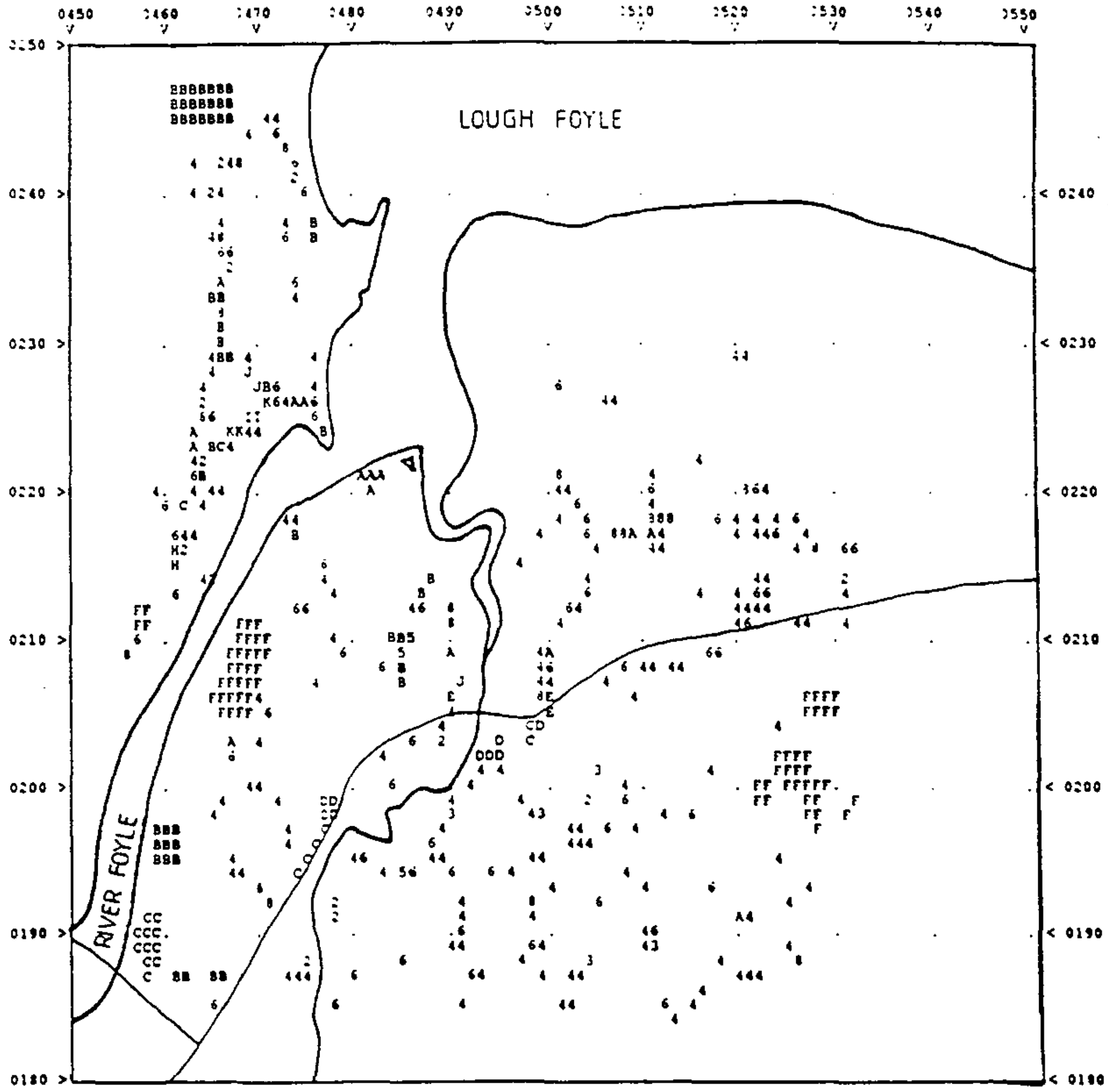


FIGURE V.8: EXAMPLE OF A POPULATION MAP

(Coordinates are for 100 m squares on National Grid.)



KEY

Population range	letter code
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
10	A
11 - 20	B
21 - 30	C
31 - 40	D
41 - 50	E
51 - 60	F
61 - 70	G
71 - 80	H
81 - 90	I
91 - 100	J
101 - 200	K

V.4. Failure Case Generation

The analyst has available a number of programs for failure case generation. Automatic generation is based on leaks from or full-bore rupture of pipework as defined in the Plant database; this is carried out by the PIPE program. Catastrophic ruptures of vessels are handled by program NONPIP, which is partly automated.

The analyst can bypass some or all of the automatic failure case generation and specify particular releases or events directly. This is useful early in a design when full details of pipework and vessels are not known. Similarly, failures due to special material properties or processing conditions can be entered this way. In this case the analyst uses programs OTHEDF (for failures at a point location) or LINEDF (for failures along a transport route).

Thereafter, these failure cases are treated similarly to those generated automatically.

The range of possible sizes of release for a given event (e.g. pipe leakage) covers a wide spectrum which it is both time-consuming and unnecessary to consider every part. Instead, **representative** failure cases are generated, termed Equivalent Discrete Failures (EDFs). They are representative in **both** magnitude **and** frequency. This is particularly appropriate to pipework failures, where the hole size can vary from pinhole to full-bore rupture, as will be discussed below.

The EDFs are defined by a set of general parameters identifying the release and a set of variables which describe the physical conditions pertaining. It is these physical variables which provide the initial conditions for the dispersion modelling.

The general parameters are:

Event number
Location (X- and Y-coordinates)
Event frequency
Brief description
Material released
Release type (as Table V.1).

The physical variables required for each of the release types are given in Table V.2. It should be noted that several of these are subdivided. The refrigerated/atmospheric releases may be either instantaneous or continuous. The pressurised releases may be Vertical or Horizontal (for flammable materials both cases may be considered) and at ground level or elevated (the latter is referred to in the table as a "Plume").

Failures occurring in pipework can be generated automatically using program PIPE. This considers in turn each connecting pipe defined in the Plant Data File. Releases based on both leakage and full-bore rupture are generated. In reality, leakages have many possible causes (e.g. corrosion, external impact, excess pressure, etc.) and hole sizes will exhibit a continuous probability distribution. The SAFETI program uses discrete hole sizes to represent this distribution; in the case of pipes it is 10% of diameter and full-bore rupture.

The alternative of Monte Carlo type selection was rejected as too numerically intensive and unnecessary.

The failure cases generated automatically consider the valving in the line and its probability of failure in assessing the total inventory that may be released and the duration of its release.

The physical conditions pertaining to each release are calculated from the conditions in the vessel upstream of the failure and other data using "release models" incorporated in the program. These models will be discussed in a subsequent intermediate report. The program also allocates to each failure case the general parameters required.

For catastrophic ruptures of vessels, the program NONPIP may be used. This takes the analyst through each vessel (as defined in the Plant database) in turn, prompting him to define how many and what failures occur. The frequencies are taken from the failure rate database, other general parameters from the Plant database. The analyst can define the pressure (or, for refrigerated vessels, liquid head), temperature and percentage of normal inventory released for each case. This enables him to define failure cases which are a result of excursions from normal operating conditions (such as pressure surges, temperature surges, or overfilled tanks). The program again uses release models to calculate the physical conditions of release.

To define other types of release, the analyst uses either OTHEDF for releases at point locations or LINEDF for releases which might occur somewhere along a transport route. The analyst enters the general parameters (except Event Number) directly; the physical conditions may also be entered directly if they are known. Frequently however the analyst only knows the source or vessel temperature and pressure/liquid head giving rise to the release. In this case, he can make use of the "release models" incorporated in these programs also to calculate the release conditions. For instantaneous releases, the source or vessel conditions are sufficient to model the release, calculating the expansion energy, final state and droplet size. For continuous releases, the analyst must decide whether the release is better modelled as flow through a sharp-edged orifice in the wall of the reservoir or a flow from the end of a pipe; he then enters the appropriate hole or pipe diameter (also, for pipe releases, the pipe length and other relevant data). The program then uses the models to calculate the flow rate, velocity, final state and size of any liquid droplets produced.

It should be noted that where the models are used the initial conditions are stored as part of the EDF definition; they are not however used by the consequence modelling.

TABLE V.1: CATEGORISATION OF RELEASES CASES IN SAFETI

RELEASE TYPE	ABBREV-IATION	DESCRIPTION	POSSIBLE OUTCOMES
Instantaneous pressurised release of flammable material	FIPR	Catastrophic failure of a pressure vessel	Dispersion Fireball Explosion
Continuous pressurised release of flammable material	FCPR	Prolonged release from pipe or vessel	Dispersion Jet Fire Explosion
Continuous elevated or vertical release of flammable material	FCPR	Prolonged release from stack or relief system	Dispersion Jet Fire Explosion
Refrigerated/atmospheric release of flammable material	FREF	Spill of liquid	Dispersion Pool Fire Explosion
Pool Fire	FIRE	Direct specification of pool fire	Pool Fire
Fireball or BLEVE	BLEVE	Direct specification of fireball or BLEVE	Fireball
Instantaneous pressurised release of toxic material	TIPR	Catastrophic failure of a pressure vessel	Toxic gas dispersion
Continuous pressurised release of toxic material	TCPR	Prolonged release from pipe or vessel	Toxic gas dispersion
Continuous elevated or vertical release of toxic material	TCPR	Prolonged release from stack or relief system	Toxic gas dispersion
Refrigerated/atmospheric release of toxic material	TREF	Spill of liquid	Toxic gas dispersion

TABLE V.2: EDF VARIABLES DESCRIBING THE PHYSICAL PARAMETERS OF THE RELEASE

RELEASE TYPE		SUB-DIVISION	PHYSICAL PARAMETERS							
			MASS/RATE	DURATION	STATE	"SPEED"	DROP SIZE	PRESSURE	TEMP.	"BUND"
1	BLEVE		Mass	-	-	-	-	-	-	-
2	FIPR		Mass	-	Temperature/ Liquid Fraction	Expansion Energy	Drop Size	Vessel Pressure	Vessel Temperature	Bund Size
3	FCPR	Vertical/ Horizontal/Both	Release Rate	Duration	Temperature/ Liquid Fraction	Velocity	Drop Size	Source Pressure	Source Temperature	Bund Size
4	FREF	Instantaneous	Mass	-	Temperature/ Liquid Fraction	Expansion Energy	Drop Size	Liquid Head	Storage Temperature	Bund Size
		Continuous	Release Rate	Duration	Temperature/ Liquid Fraction	Velocity	Drop Size	Liquid Head	Storage Temperature	Bund Size
5	FIRE		-	-	-	-	-	-	-	Pool Diameter
6	TIPR		Mass	-	Temperature/ Liquid Fraction	Expansion Energy	Drop Size	Vessel Pressure	Vessel Temperature	Bund Size
7	TCPR		Release Rate	Duration	Temperature/ Liquid Fraction	Velocity	Drop Size	Source Pressure	Source Temperature	Bund Size
8	TREF	Instantaneous	Mass	-	Temperature/ Liquid Fraction	Expansion Energy	Drop Size	Liquid Head	Storage Temperature	Bund Size
		Continuous	Release Rate	Duration	Temperature/ Liquid Fraction	Velocity	Drop Size	Liquid Head	Storage Temperature	Bund Size
9	FCPR	Vertical Plume/ Horizontal Plume	Release Rate	Duration	Temperature/ Liquid Fraction	Velocity	Drop Size	Source Pressure	Source Temperature	Release Height
10	FCPR	Vertical Plume/ Horizontal Plume	Release Rate	Duration	Temperature/ Liquid Fraction	Velocity	Drop Size	Source Pressure	Source Temperature	Release Height

Note: Abbreviations for Release Type as Table V.1.

V.5. Consequence Modelling

The SAFETI package completely separates the tasks of the general consequence modelling (CONSEQ program) from that of impact prediction (MPACT program) in the particular site environment.

SAFETI processes the failure cases by calculating the dispersion of the release for several weather types and then expressing the results of this dispersion in a tabulated file of effect zones. These results are further processed for toxic effects. The location of events and the relative probabilities of, for example, flash fire versus explosions, are not considered in the CONSEQ program. The dispersion results are calculated at regular steps downwind.

There are two main aspects to handling a release which act in parallel. The first of these might be called the "phenomenology" of the release, that is, whether liquid rains out or not, and whether it behaves as an instantaneous or continuous release. Secondly, there are the various dilution (air entrainment) regimes: turbulent jet, slumping dense cloud or passive tracer.

The release phenomenology can be quite complex and is based on a current understanding of important mechanisms occurring during and immediately after a release. This is shown in Figure V.9. This event tree, which operates automatically, considers at each downwind step the specific physical characteristics of each release to determine rain-out, evaporation, and other relevant conditions that must be considered. It then directs that release to be modelled in a particular way, as indicated in the figure by an arbitrary number.

For flammable materials, this modelling route includes information on all feasible outcomes of the release which directs the output to extract probabilities of each possible outcome from nominated standard event trees in the MPACT program. These event tree probabilities may be varied by the analyst.

The rain-out modelling is based on the predicted average aerosol droplet size and its settling velocity in air. Many pressurised releases of relatively low flash materials (e.g. ammonia) can result in virtually no rain-out and all the release remains in the cloud. The aerosol rapidly evaporates in the cloud as it disperses and dilutes. This modelling is based on recent experiments with pressurised releases (Emerson, 1987).

Liquid that rains out must still be considered in terms of dispersion and this is done in the re-evaporation models.

Dilution or entrainment of air is handled by a suite of dispersion models. These models simulate the four important regimes of dispersion:

(i) turbulent jet dispersion (initial kinetic energy dominates)
(ii) hybrid dispersion (joint turbulent and dense gas behaviour)
(iii) dense cloud dispersion (density effects dominates)
(iv) passive dispersion (atmospheric turbulence dominates)

Many releases pass through all four regimes, but this depends on the material and conditions of the release. A plan view of a release passing through all these stages is shown in Figure V.10.

For a ground-level or a horizontal elevated release, the initial turbulent jet dispersion phase is modelled by a jet of uniform concentration and square cross-section. It is an adaptation of well-known models for such jets based on an expression for the entrainment rate of air given in, for example, Ricou and Spalding (1962).

The transition to a dense cloud dispersion model is not made suddenly, but passes through stage (ii) above in which both turbulent and dense gas behaviour govern the air entrainment and cloud spreading rates.

For vertical elevated releases, the dispersion modelling procedure is different. The 'TECJET' model (Emerson, 1986a) has been incorporated in CONSEQ. This is also a turbulent jet dispersion model, but with a Gaussian concentration profile; far from the release point the cloud behaves as a passive plume. If the material released is dense, the plume will bend over and descend towards the ground; if it reaches ground level it can merge into the dense gas dispersion model.

The dispersion model for the dense gas cloud phase is based on the "box-model" of Cox and Carpenter (1980). This has had a number of enhancements (Emerson, 1986b). For instantaneous dense gas pressurised releases, the cloud is represented as a cylindrical cloud which slumps radially under gravity to a pancake shape while advancing with the wind. For a continuous pressurised release or for gas evaporating from a liquid pool, the model employs a plume of uniform concentration across a rectangular cross-section. When density effects no longer dominate, the model switches to a gaussian form with smooth matching of concentration at the transition.

Calculation of effects (as opposed to local impacts) is done with CONSEQ. For flammable releases this involves calculation of the dispersion cloud dimensions to the material lower flammable limit and mass in the cloud, either as steady-state (for a continuous release) or for each time step (for an instantaneous release).

The calculation for toxic materials is more complex, but an interesting simplifying technique has been developed, called the probability integral method (Emerson et al, 1988). This employs the probit method, summarised by Lees (1980), to predict the probability of death for a toxic gas exposure assuming a log-normal distribution of effect dose. The usual form of the probit relation for a toxic gas is:

$$Pr = A + B \ln (c^n t)$$

where: Pr = probit variable (normally-distributed with a mean of 5.0 and a variance of 1.0)

c = toxic gas concentration

t = duration of exposure

A,B,n = coefficients, specific to each toxic material.

The probability of death for any given exposure may be determined by reference to Probit tables (Lees, 1980) or to any Normal Distribution tabulation after subtracting 5.0 from the Probit variable.

The probability integral method integrates the probability of death calculated across a wind direction sector. Transient effects are considered by integrating the toxic load expression. The only information subsequently required in MPACT is a tabulation of cloud width and toxic probability integral. This makes data storage and computational requirements almost identical to flammable impact calculations, although the actual information included in the analysis is far more detailed than this. There is no element of approximation or loss of accuracy using this approach.

The dispersion models represent the bulk of the consequence computations, however a number of other models are included to predict the effects of various incident outcomes. These models include:

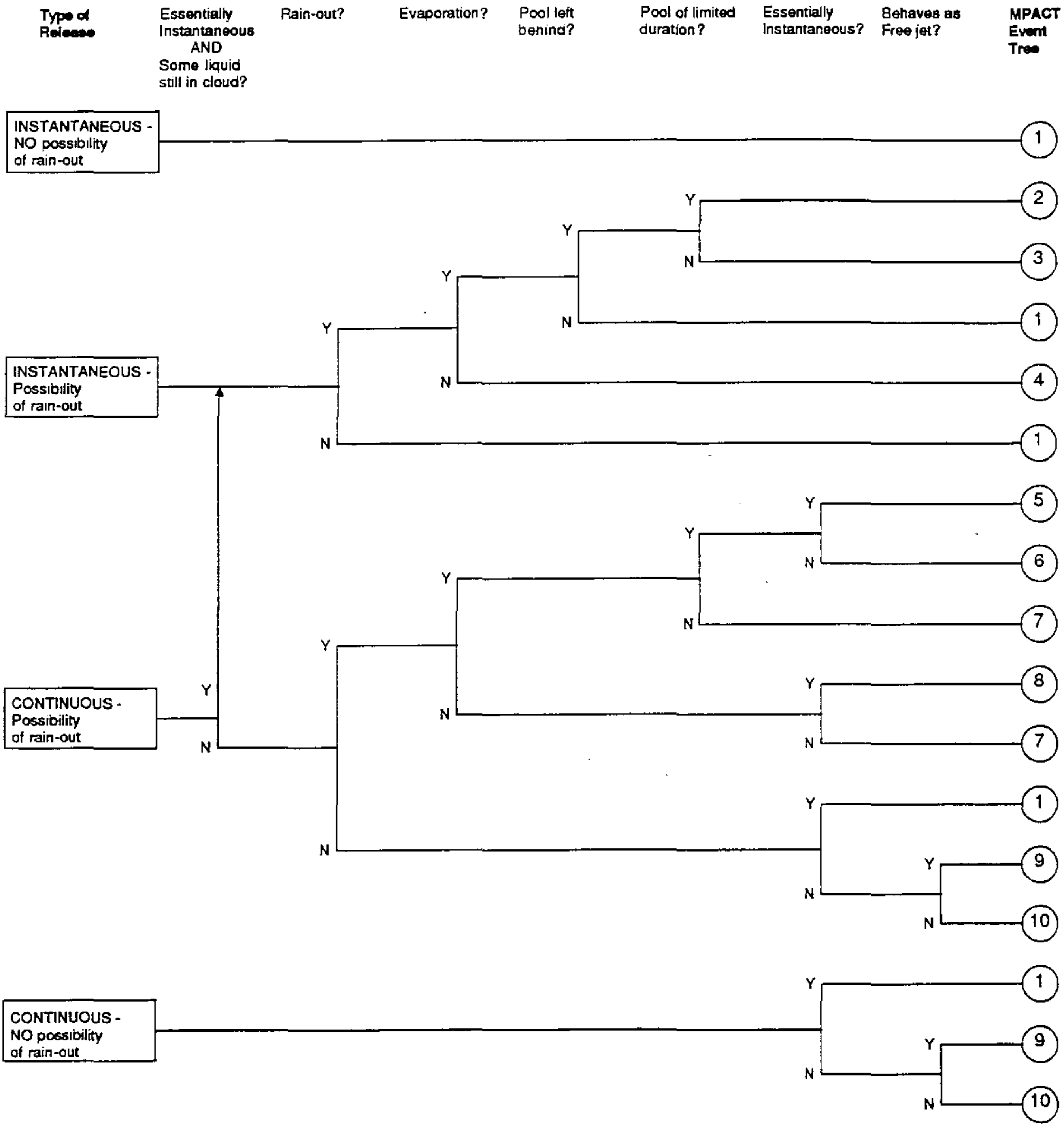
Pool Evaporation: The model of Shaw and Briscoe (1978) is used as the basis of modelling the spreading and subsequent evaporation of a liquid pool formed by rainout. Three evaporation mechanisms are allowed for: boiling due to heat conduction from the ground, evaporation due to ambient convective heating and diffusive mass transfer arising from the wind blowing over the pool. There will usually be some evaporation even for materials with a boiling point above ambient temperature.

Vapour Cloud Explosion: The correlation model developed by TNO (Opschoor, 1979) is employed to predict blast overpressure and distance relations.

Fireball, Pool Fire, Jet Fire: The models used are taken from several sources; they are referenced and described in a paper by Cook, Bahrami and Whitehouse (1990).

Flash Fire: The package does not employ a flash fire model as such. The dimensions of the flammable cloud are used at the time of ignition increased by a small fixed amount to account for thermal effects beyond the cloud. Fatalities within the cloud are assumed.

FIGURE V.9: CONSEQUENCE MODELLING EVENT TREE

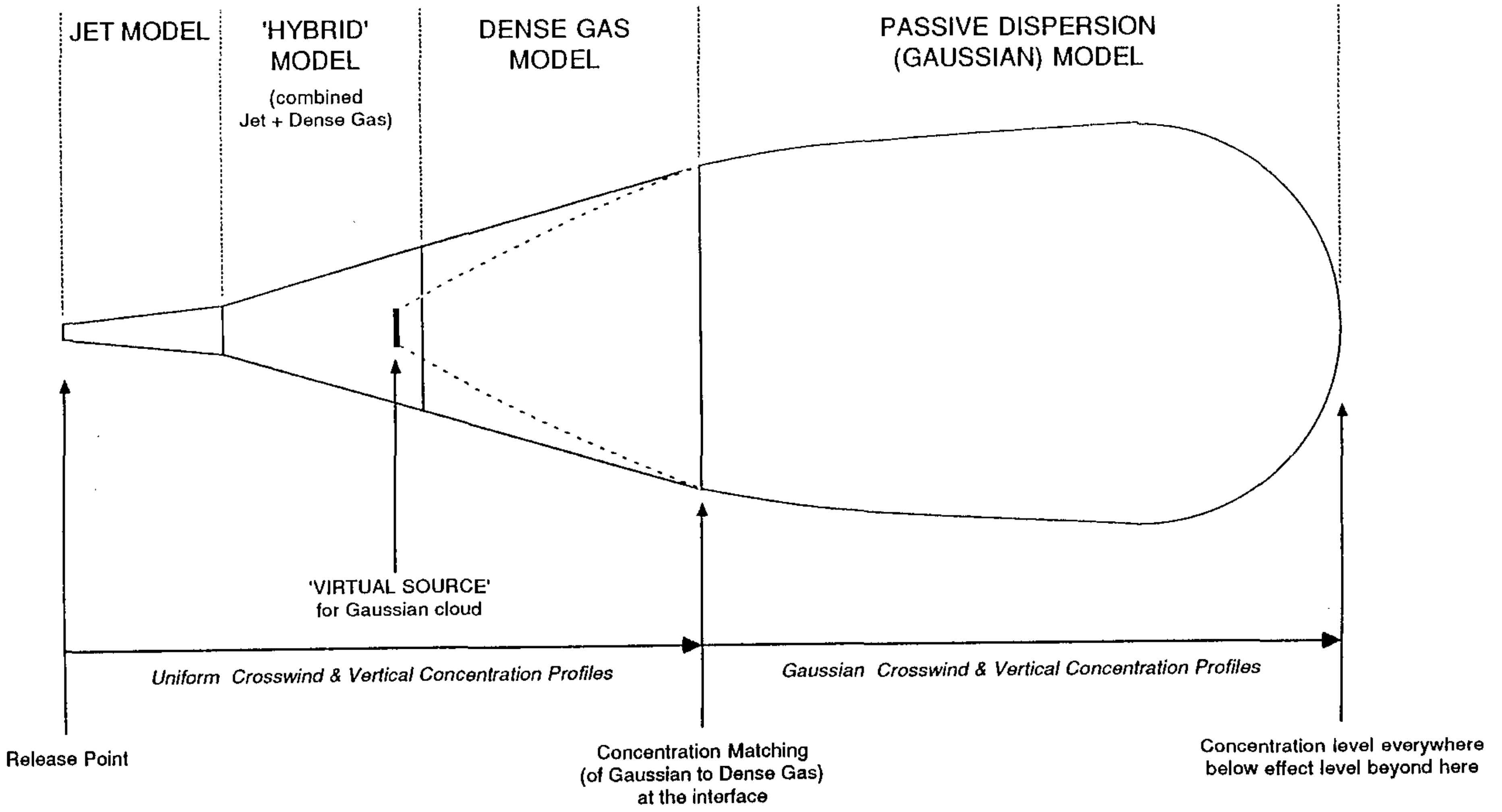


Notes

"Essentially Instantaneous" means that although the release is continuous its duration is short such that it is modelled more accurately as an instantaneous release.

The "MPACT" Event Tree numbers refer to event trees determining the different possible outcomes for releases of FLAMMABLE materials, e.g. Flash Fire, Pool Fire, Explosion.

FIGURE V.10: PLAN VIEW OF IDEALISED CONTINUOUS GAS CLOUD, SHOWING DISPERSION MODEL TRANSITIONS



V.6. Calculation of Risk

The calculation of risk is done within the MPACT program. This package is a highly flexible program that can accept a wide variety of problem definitions (weather types, wind rose directions, grid size, etc.).

Each failure case is analysed to determine its impact. Frequency information is extracted from the failure case description and combined with meteorological probabilities and any event tree conditional probabilities leading to that particular outcome. Both individual risk at every grid point and societal risk for each incident can be determined.

Toxic impacts are more straightforward as the consequence model results (in terms of probability integrals) can be used directly in combination with the actual population data to determine impact. The toxic envelope is, in effect, laid over the population map for every weather type for every wind direction.

Flammable impacts are more involved. This is because there are many possible final outcomes from a release and ignition may occur at several places. Instantaneous flammable releases are analysed at every time step with respect to likelihood of ignition. Such incidents can either flash fire or explode. Frequencies of these events are determined using the conditional probabilities in the MPACT event trees. Continuous releases are treated similarly.

The impact of other release case possible outcomes (jet fire, pool fire, fireball) are analysed in terms of their effects on surrounding population.

In general terms, for individual risk it is assumed that the population is out of doors and does not shelter or escape. For societal risk, it is possible to include mitigation by sheltering or by evacuation.

The evaluation of the individual risk even at a single point involves a large number of calculations, especially for releases of flammable materials. Calculations must be performed for each release case and weather type, and for each wind direction which would include that point inside the effect zone. The steps involved are shown in Figure V.11. Often however the required result is not the risk at one point but over an area, in the form of "iso-risk contours". To obtain these, the point risk calculations must be repeated at a large number of grid points within the area of interest. MPACT uses a grid of 200 x 200 points.

Figure V.12 shows a typical individual risk contour plot. The annotations to one side show the plant numbers considered in the analysis, whether the contribution is day or night, and whether the plant is being added or subtracted. Subtraction is used for plant modification exercises: an old design is subtracted and the replacement is added in.

To calculate the societal risk, the total number of people killed for each release case, weather type and wind direction must be calculated: this will usually be spread over a number of grid squares. Finally the frequencies of all those combinations contributing to the same number of fatalities must be summed. The procedure is illustrated in Figure V.13. The results are typically presented as an F-N societal risk curve such as that shown in Figure V.14, which corresponds to the individual risk contour plot of Figure V.12. This plot also identifies the contributions from several plants.

MPACT also produces a table showing the overall ranking of incidents in terms of their importance.

FIGURE V.11: DETAILED PROCEDURE FOR CALCULATING INDIVIDUAL RISK AT A POINT

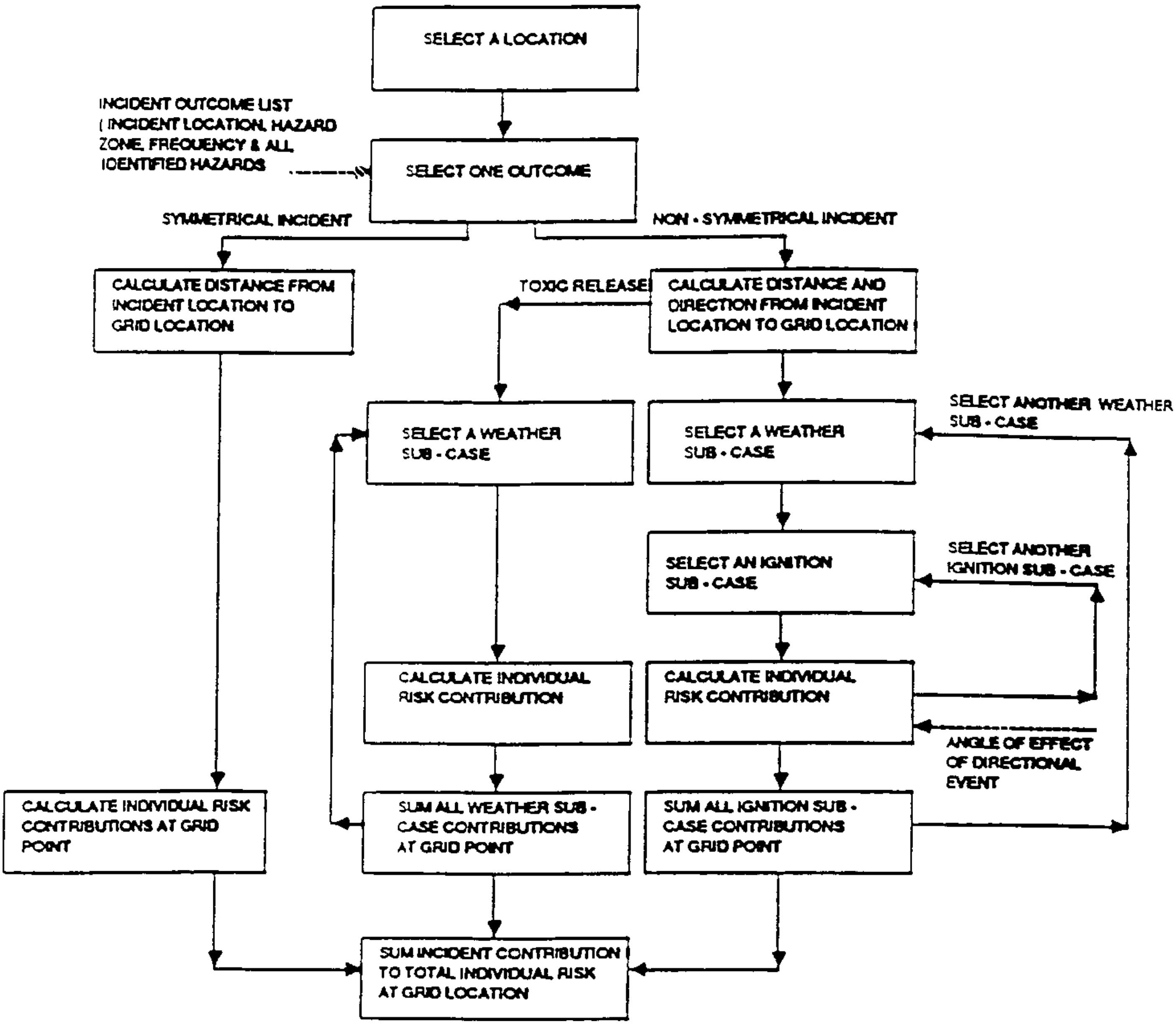
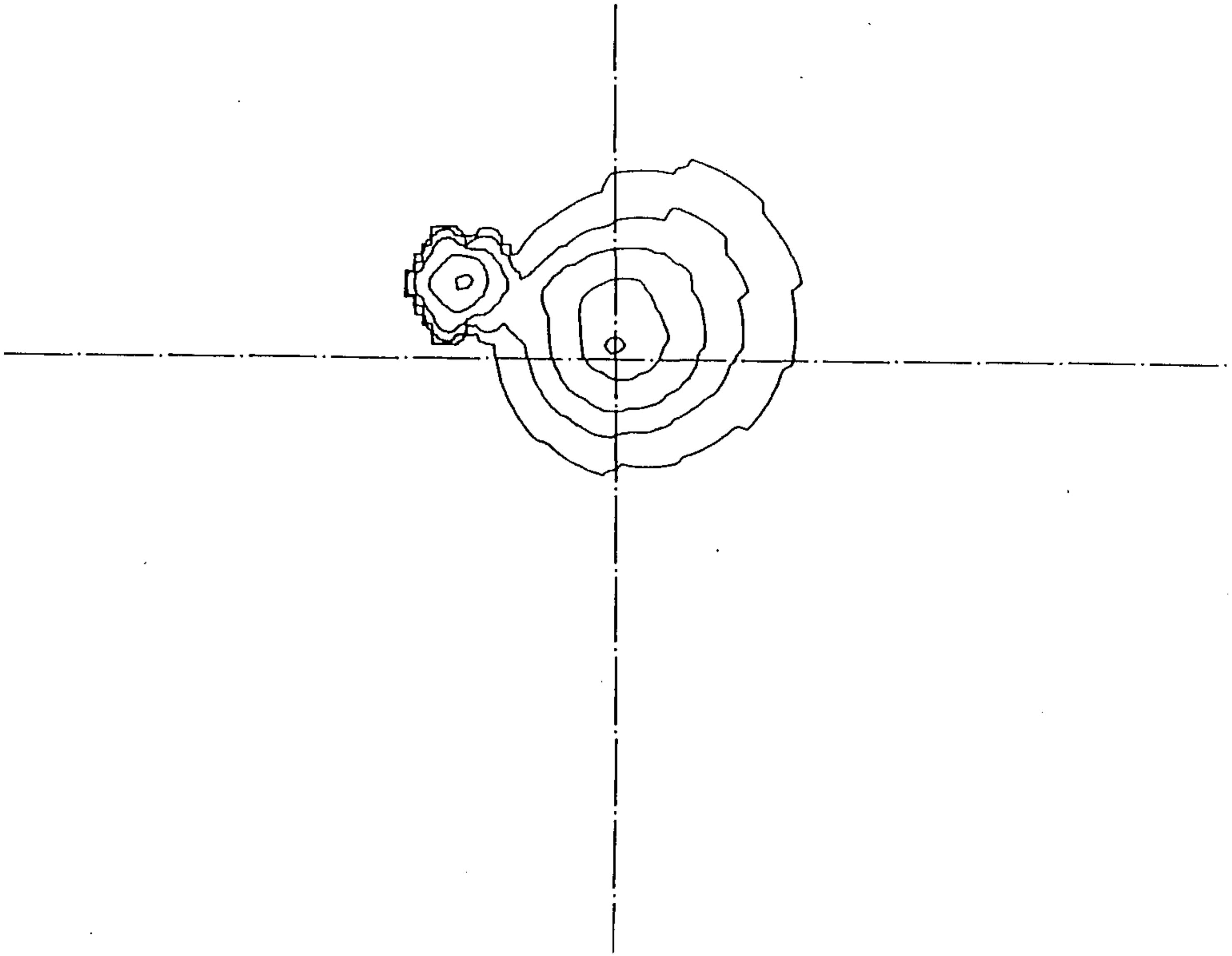


FIGURE V.12: EXAMPLE OF AN INDIVIDUAL RISK CONTOUR PLOT PRODUCED BY SAFETI



Run on 6-APR-88 at 09:46:04

Scale : 1/ 50000

Plot Centre : X: 84000
Y: 34000

Actual minimum risk value: 1.86E-16
Actual maximum risk value: 1.81E-04

ALL PLANTS COMBINED

Plant	EDF	Day/ Night	Daytime factor	Add/ Subt
41	C	D	1.00	+
42	C	D	1.00	+
43	C	D	1.00	+
44	C	D	1.00	+
45	C	D	1.00	+
23	0	D	1.00	+
23	0	D	1.00	+
21	0	D	1.00	+
22	0	D	1.00	+
24	0	D	1.00	+
33	C	D	1.00	+
99	0	D	1.00	+
98	0	D	1.00	+
34	0	D	1.00	+
35	0	D	1.00	+
87	0	D	1.00	+
88	0	D	1.00	+
89	0	D	1.00	+
86	0	D	1.00	+

Risk Level:

1.0×10^{-4}

1.0×10^{-5}

1.0×10^{-6}

1.0×10^{-7}

1.0×10^{-8}

FIGURE V.13: DETAILED PROCEDURE FOR DRAWING F-N CURVES

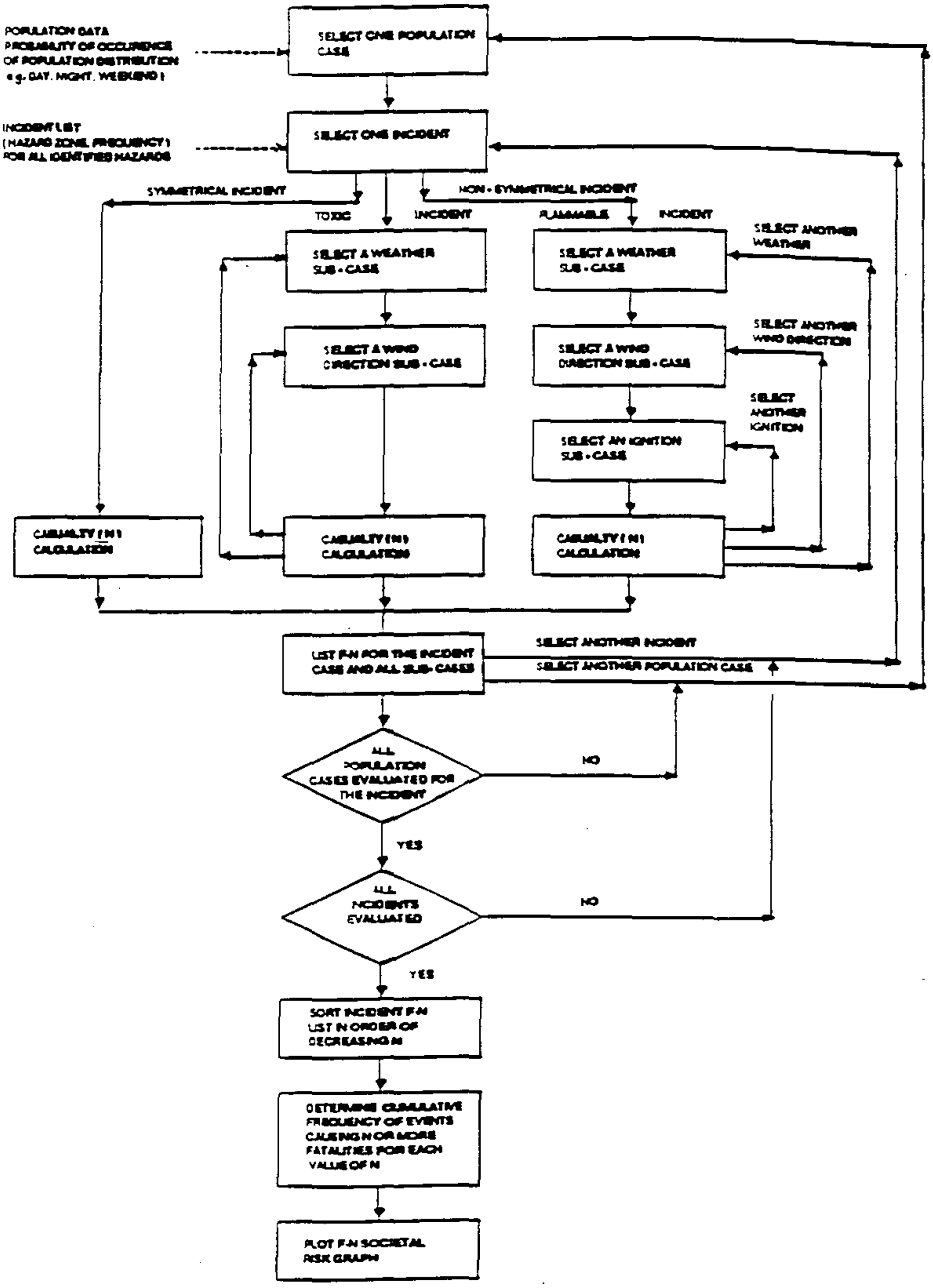
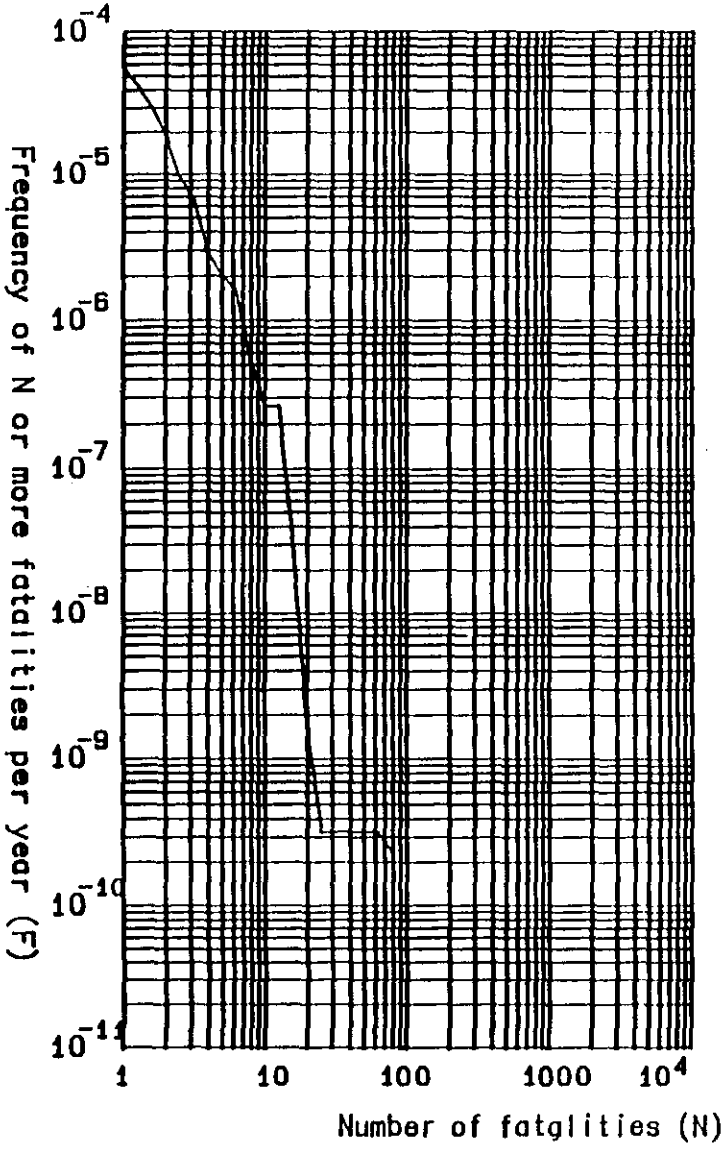


FIGURE V.14: EXAMPLE OF A SOCIETAL RISK (F-N) PLOT PRODUCED BY SAFETI



```
Curve   Plant   EDF   Day/   Daytime   Add/
                      Ngt    Factor    Sub
-----------------------------------------------------------
1        41      C     D      1.00      A
         42      C     D      1.00      A
         43      C     D      1.00      A
         44      C     D      1.00      A
         45      C     D      1.00      A
         23      0     D      1.00      A
         23      0     D      1.00      A
         21      0     D      1.00      A
         22      0     D      1.00      A
         24      0     D      1.00      A
         33      C     D      1.00      A
         99      0     D      1.00      A
         98      0     D      1.00      A
         34      0     D      1.00      A
         35      0     D      1.00      A
         87      0     D      1.00      A
         88      0     D      1.00      A
         89      0     D      1.00      A
-----------------------------------------------------------
```

V.7. Material Properties

Both the release modelling and the consequence modelling require various thermophysical properties for the materials released. These are held in a database which forms part of the package along with programs to interrogate it and modify the data in it.

The properties database is supplied with data for over 60 hazardous materials, both toxic and flammable. The user can add further materials to the database.

The database contains, for each material, both constant properties (such as critical temperature) and temperature dependent ones (such as saturated vapour pressure). For toxic materials it also contains probits values. The mathematical models access the database directly; the user may optionally do so to find out property values of interest.

V.8. References

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APPENDIX VI

CONSEQUENCE ANALYSIS

CONTENTS PAGE

APPENDIX VI. CONSEQUENCE ANALYSIS

VI.1 Screening of Cases

Potential vapour releases arising from process failures (in particular from the incinerator) and from inadvertent mixing of incompatible substances have been 'screened' to eliminate those which will not present any offsite risk. This has been done by determining a threshold release rate for each of the materials concerned: only release rates calculated as likely to be larger than the threshold were analysed further.

The method of screening was deliberately conservative so that no case should be eliminated which might contribute to offsite risk. The steps involved were as follows.

1. Determine threshold ground level concentration. This was taken as LC_{10} for 30 minutes' exposure.

2. Determine threshold flow rate required to give this concentration at 50 m from the release point (taken as being a typical distance to the nearest site boundary) under stability F, wind speed 1 m/s.

Step 2 was carried out for different release conditions and heights. These were:

Case 1: Vertical release from top of stack (76.2 m above ground) at temperature of 400 K - equivalent to toxic gas not eliminated by incinerator.

Case 2: Horizontal release from near the ground (1 m above ground level) at temperature of 400 K - equivalent to leak from incinerator.

Case 3: Vertical release from vent above reception tank (5 m above ground level) - equivalent to accidental mixing in tank venting direct to atmosphere.

The LC_{10} values were determined from the probit equation for each gas considered. Dispersion of releases defined by the cases above was then modelled for each gas. The LC_{10} values and threshold release rates determined are given in the following table.

TABLE VI.1: THRESHOLD CONCENTRATIONS FOR RELEASES

MATERIAL	LC_{10} (ppm): 30 MINUTES EXPOSURE	THRESHOLD RELEASE RATE (kg/s)		
		CASE 1	CASE 2	CASE 3
Hydrogen Sulphide	365	-	-	0.03
Hydrogen Cyanide	91	Buoyant	-	0.02
Hydrogen Chloride	980	Buoyant	0.05	-
Hydrogen Fluoride	267	Monomer Buoyant	0.08	-
Sulphur Dioxide	265	2.0	0.01	-
NO_x	125*	1.0	0.005	-

Note

* Not directly available: probit for **chlorine** used instead.

The values in the table above provide a ready means of determining whether flow rates as calculated below are likely to be significant.

VI.2 Development of Failure Cases

VI.2.1 Storage Failures

Since all storage is under atmospheric conditions and is of materials which are liquids at these conditions, releases from storage will be in the first instance a liquid spill. Releases of organic liquids sufficiently volatile to be likely to generate significant amounts of vapour were modelled explicitly as **instantaneous releases** (catastrophic ruptures) or **continuous releases** (leaks). It was assumed that these tanks were **50% full**, using this to determine the liquid head and the mass available for release.

Releases of relatively non-volatile organic liquids were simply modelled as pool fires with a diameter corresponding to a circle of identical area to the bund in which the fire occurs.

No storage of inorganic materials was identified as a potential hazard within the terms of this study.

The full specification of each failure case as an EDF requires determination not only of mass released (instantaneous releases) or mass release rate and duration (continuous releases) but also other parameters determining the kinetic and thermodynamic state of the release, as identified for the different EDF types in Appendix V, Table V.2. SAFETI contains models to determine these parameters given the conditions pertaining in the storage tank, the ambient conditions and the hole size (the latter applies only to continuous releases). The relevant input data are given in the following table. Release durations for leaks are determined from the mass of liquid in the tank and the modelled flow rate. Although the flow rate would in reality decrease with time as the tank emptied, the assumption that the initial rate is maintained for the duration of the release is acceptable within the accuracy of the study.

TABLE VI.2: INPUT DATA FOR RELEASES FROM STORAGE

MATERIAL AND SITE PLAN AREA (See Figure 3.7)	MASS OF LIQUID IN TANK (kg)	LIQUID HEAD (m)	HOLE SIZE(S) (mm)	BUND AREA (m^2)
Methanol (Area 6)	63 000	4.3	10 100	475
Carbon Tetrachloride (Area 6)	127 600	4.3	10 100	475
Oil/water (Area 6)	-	-	-	475
Non-MARPOL or fuel oil (Area 7)	-	-	-	300
MARPOL (Area 1)	-	-	-	950

VI.2.2 Packaged Waste Storage Fire Failure Case

It is anticipated that 64 000 tonnes per annum of packaged waste will be received at the CWTF. This is equivalent to 1280 tonnes per week. Building 16 is to have the capacity to hold one week's deliveries although in normal operations the stored inventory should be substantially lower than this. For the purposes of this analysis, it is assumed that the maximum of one week's storage is present and that the breakdown of packaged wastes is the same as for the total waste receivings. In this case some 25% of it will be organics, a large proportion of which will be combustible or flammable. This equates to 320 tonnes. If it is assumed that two-thirds of the organics are combustible or flammable, then the maximum amount of this material will be approximately 210 tonnes. Some of this material will be toxic and could contribute to the offsite hazard by being dispersed in the plume from a fire in Building 16. Another contribution to offsite hazard could come from toxic products of combustion in the plume. A further assumption is that the material considered in this section is stored on one floor of Building 16. Finally, it is assumed that the burning period for the fire is 3600 s. This is a typical value for warehouse fires.

Toxic Material Discharge

In order to determine the concentration of toxics in the plume from a Building 16 fire, it is important to know the rate at which fuel is being consumed by the fire and the change in rate at which hot gases are evolved from the fire area. Based on the conservative estimate of 50% of the combustible and flammable material being classed as toxic or very toxic, the maximum inventory of toxic or very toxic material available to a fire is estimated to be approximately 110 tonnes. For the purposes of this analysis, the terms toxic and very toxic are assumed to encompass a group of materials whose toxicity is in the range LD_{50} (rat) = 100 mg/kg.

An examination of Table I.4, Forecast Waste Arisings, suggests that less than 1% of wastes will be solid. Assuming this ratio of solid to liquid applies also to the toxic material, the estimated solid toxic material available to the fire is 1100 kg.

It has been estimated from a previous Technica study of fires in warehouses that approximately 90% of toxics are destroyed in a fire. This means that approximately 11 tonnes of toxic or very toxic material would remain to be drawn into the plume from the fire and dispersed offsite.

In the previous study, Technica derived a formula for a composite representative molecule based on the inventories and elemental compositions of a very wide range of materials stored. This formula is:

$$C_{404}H_{551}O_{473}N_{81}S_5Cl_5F_2$$

In order to derive the stoichiometry for the combustion of this composite, the hypothetical molecule $C_8H_{11}O_{10}$ has been used to represent the stoichiometry of the fuel. The combustion reaction has beencalculated on the basis of 1:1 fuel:oxygen stoichiometry. The combustion is taking place in an enclosed space so that the stocheiometry may be leaner in oxygen at the centre of the fire and richer near the periphery where air can be drawn in through external openings.

The combustion reaction at 1:1 stoichiometry can be represented by:

$$C_8H_{11}O_{10} + 23/2\ O_2 + x\ N_2 \rightarrow 8\ CO_2 + 11/2\ H_2O + x\ N_2$$

96+11+160	368	1472	372	99	1472
267 kg fuel			1933 kg gases		
22.5 kg/s fuel			162.89 kg/s gases		

Toxic Liquid Discharge

Assuming 90% destruction of combustible material in the fire, there will be approximately 10,000 kg of toxic liquid inventory left for dispersion in the plume. This corresponds to a mas evolution rate of 2.5 kg/s.

Breakdown Products Discharge

The true output of materials in the plume from a fire in Building 16 would contain an extremely complex mixture of oxides and other molecules. It is beyond the scope of this study to determine the exact nature of this mixture. In order to render the analysis manageable the conservative assumption has been made that the materials burning in the fire break down to the simplest combustion products.

Although the equation for combustion above has ben based on 1:1 stoichiometry, typically approximately 2% of the available carbon would be expected to be evloved as carbon monoxide. A carbon monoxide evolution rate has been based on this asumption.

The worst case assumption is made that all the available nitrogen in the toxic material would be converted to HCN, NO_2, NO and N_2O rather than more complex molecules. Table VI.3 shows the mass production rates of the products of combustion of the toxics.

Nitrogen mass in one mole of composite molecule is 81 x 14 / 14 316 = 0.079 g. In breakdown products, nitrogen is distributed among 5 molecular destinations. Therefore the mass evolution rates (MER) for the nitrogen-containing molecules can be calculated from:

$$\text{MER} = \text{fuel burning rate} \times 0.079 \times M(\text{Product})$$

Similar calculations can be made for the products from the sulphur, chlorine and fluorine components of the composite molecule.

Toxic Particulate Discharge

Based on an anlaysis of the forecast wastes arisings, it is estimated that not more than approximately 5% of the combustible inventory will be present as solid. Assuming that 90% of this is destroyed by combustion, the amount of toxic material to be dispersed by the plume is approximately 550 kg. This corresponds to a mass evolution rate of 0.137 kg/s.

TABLE VI.3 COMBUSTION PRODUCTS AND EVOLUTION RATE FROM BUILDING 16 FIRE

COMBUSTION PRODUCT	MASS EVOLUTION RATE (kg/s)
CO	0.35
NO_2	1.168
NO	0.7617
N_2O	1.117
HCN	0.6855
SO_2	0.74
HCl	0.286
HF	0.63

VI.2.3 Solvent Recovery Failures

Assumptions

(i) Rupture in the bottom half of the vessel leads to a pool of liquid only

(ii) Rupture in the top half of the vessel leads to hot vapour escaping

(iii) Loss of containment will result in feed being automatically shut off

(iv) Capacity of the vessel and associated pipework is 4 m^3, of which up to half is liquid

(v) Area around the unit is bunded

Consequences

If the feed is shut off immediately, only material in the vessel will escape. This is estimated to be up to 4 m^3 of vapour at about its flash point, or 2 m^3 of liquid.

The release could be of either halogenated or non-halogenated solvent. Non-halogenated liquid solvent would drain into the surrounding bund and is assumed to cause a pool fire if ignited; a release of halogenated solvent vapour is modelled as a toxic release.

VI.2.4 Incinerator Failures

Assumptions

- (i) The feed is shut off by one of the automatic protection systems
- (ii) Sulphur content of incinerator fuel is 0.5%
- (iii) Feed rate of waste is 500 kg/hr (from mass balance flow sheet)
- (iv) Feed rate of fuel is the same ie 500 kg/hr.

Consequences: Case I11

Rupture of the line between the incinerator unit and the scrubber/stack would release warm waste gases that would normally be discharged through the stack.

Sulphur dioxide would be present from combustion of sulphur in the fuel feed. For 0.5% sulphur content the rate of generation of sulphur dioxide is 5 kg/hr.

Consequences: Case I12

Hydrogen chloride is produced in different amounts, depending on the composition of the feed. The highest rate of production of this would result from the combustion of a chlorinated compound. The only chlorinated compounds present in bulk are chlorinated solvents, represented here by carbon tetrachloride.

If an equivalent, by chlorine amount, of 6% of the waste feed is carbon tetrachloride, then combustion of this will form 30 kg/hr of hydrogen chloride.

Consequences: Case I21

In the event of a flame-out in both the primary and secondary burners, and failure of the protection systems to cut off the feed, unburnt waste may vaporise in the hot interior of the furnace. This waste could then pass out of the stack into the atmosphere.

The most hazardous waste involved in a scenario like this would be carbon tetrachloride, the most toxic of the burnable wastes. On the basis of the preceding calculations, if all this waste were to vaporise, the release rate of carbon tetrachloride (from the top of the stack) would be 30 kg/hr.

Consequences: Cases I31 and I32

Scrubber failure would cause release of acid gases from the stack. Rates would be the same as in cases I11 and I12.

VI.2.5 Mixing Failures

Case M11

Assumptions

(i) Vessel is 50% full of liquid i.e. 6 m^3

(ii) Waste contains 10% cyanide i.e. 100 g/litre

(iii) Acid reagent, 10% acid, delivered at 1 m/s through a 40 mm pipe

(iv) Error not detected for 5 minutes, when reagent shut off

(v) Failure of both scrubber and incinerator

Consequences

The rate of production of hydrogen cyanide is determined by the rate of addition of acid. Up to 37.5 kg acid is added, which results in the liberation of 40 kg of HCN over 5 minutes.

Case M12

Assumptions

(i) Acid dosing control failure to allow pH to go below 7.0

(ii) Incinerator failure

(iii) Waste contains 10% sulphide i.e. 100 g/litre

(iv) Acid reagent, 10% acid, delivered at 1 m/s through a 40 mm pipe

(v) Error not detected for 5 minutes, when reagent shut off

(vi) Failure of both scrubber and incinerator

Consequences

The rate of production of hydrogen sulphide is determined by the rate of addition of acid.

Up to 37.5 kg acid is added, which results in the liberation of 48 kg of HCN over 5 minutes.

VI.2.6 Reception Failures

The input data required to specify the failures in reception associated with bulk tankers bringing in solvent/oil waste and trucks carrying drums of chlorine and sulphur dioxide for use in the treatment processes are specified in the following tables. Release durations for leaks are determined from the mass of liquid in the tanker or drum and the modelled flow rate. Although the flow rate would in reality decrease with time as the vessel emptied, the assumption that the initial rate is maintained for the duration of the release is acceptable within the accuracy of the study.

TABLE VI.4a: INPUT DATA FOR RELEASES AT RECEPTION OF UNPRESSURISED BULK TANKERS

MATERIAL	MASS OF LIQUID IN TANKER (kg)	LIQUID HEAD (m) AND [PUMP RATE] (kg/s)	HOLE SIZE(S) (mm)	BUND AREA (m^2)
Methanol	4725	2.0 [7.6]	10	1250
Carbon tetrachloride	9570	2.0 [7.5]	10	1250
Oily waste	c. 6000	-	-	1250

TABLE VI.4b: INPUT DATA FOR RELEASES AT RECEPTION OF PRESSURISED DRUMS

MATERIAL	MASS OF LIQUID IN TANK (kg)	PRESSURE (BAR)	HOLE SIZE(S) (mm)	BUND AREA (m^2)
Chlorine	1000	7.5	3 8	NA
Sulphur dioxide	1000	3.7	3 8	NA

VI.2.7 Transport Failures

The input data required to specify the failures associated with transport by bulk tankers of solvent/oil waste and trucks carrying drums of chlorine and sulphur dioxide for use in the treatment processes are specified in the following tables. Although the flow rate would in reality decrease with time as the vessel emptied, the assumption that the initial rate is maintained for the duration of the release is acceptable within the accuracy of the study.

The incident involving failure of 6 drums of chlorine (Case T32M) is modelled in the same way as an 8 mm leak from a single drum, with the flow rate being multiplied by 6.

For the bund diameter, it is assumed that a liquid pool formed will be limited in extent by buildings or topography to either side of the road.

TABLE VI.5a: INPUT DATA FOR FAILURES IN TRANSPORT BY UNPRESSURISED BULK TANKERS

MATERIAL	MASS OF LIQUID IN TANKER (kg)	LIQUID HEAD (m)	HOLE SIZE(S) (mm)	BUND AREA (m^2)
Methanol	4725	2.0	10	1250
Carbon tetrachloride	9570	2.0	10	1250
Oily waste	c. 6000	-	-	1250

TABLE VI.5b: INPUT DATA FOR FAILURES IN TRANSPORT BY PRESSURISED CYLINDERS

MATERIAL	MASS OF LIQUID IN TANK (kg)	PRESSURE (BAR)	HOLE SIZE(S) (mm)	BUND AREA (m^2)
Chlorine	1000	7.5	3 8	NA
	6 X 1000	7.5	8	
Sulphur dioxide	1000	3.7	3 8	NA

VI.3 Hazard Effects Modelling Results

In this section, maximum hazard effect distances are tabulated for each event and weather class modelled.

VI.3.1 Dispersion of Toxic Clouds

Dispersion of toxic clouds is modelled to a maximum effect distance corresponding to a toxic does equivalent to LD_{001}, i.e. a probability of death of 0.001, on the cloud centreline. The maximum distances are given in Table VI.6 below; distances less than 50 m are not given explicitly, since these events are assumed not to have any consequences beyond the site boundary (50 m being a typical distance to this).

The dispersion of the toxic plume produced by a warehouse fire (Case S41) does not give rise to significant concentrations at ground level since the plume is very buoyant and hence rises rapidly. In all cases the concentration drops below that corresponding to LD_{001} within 550 m.

VI.3.2 Dispersion of Flammable Clouds

Dispersion of flammable events is modelled down to the LFL concentration of the material concerned; this is also taken as the boundary of a flash fire and the zone within which this would cause fatalities. The releases modelled are all of liquids at ambient temperature; the dispersion results presented here pertain to evaporation from the liquid pool formed by the spill. The maximum distances are given in Table VI.7 below; distances less than 50 m are not given explicitly, since these events are assumed not to have any consequences beyond the site boundary (50 m being a typical distance to this).

VI.3.3 Thermal Radiation from Pool Fires

The pool fire effect zone is modelled by an elliptical contour of thermal radiation of 12.5 KW/m^2. The maximum distances from the centre of the pool or bund to this level of radiation are given in Table VI.8 below; since pool fires are more likely to present an onsite hazard and can lead to more serious consequences from knock-on failures, all distances are given even if these are within the 50 m limit defined above.

TABLE VI.6: MAXIMUM DISTANCE TO LD_{001} DOSE FOR TOXIC RELEASES (Sheet 1 of 2)

FAILURE CASE GROUP	CASE IDENTIFIER	WEATHER CLASS					
		2.5 m/s B	1.0 m/s D	3.5 m/s D	7.0 m/s D	3.0 m/s E	1.0 m/s F
Storage	S21T	90	154	150	125	175	225
	S22T	300	775	275	175	325	1025
	S23T	< 50	88	100	75	113	113
Reception	R21T	50	75	75	50	100	113
	R22T	125	400	113	75	150	500
	R23T	< 50	75	75	50	100	88
	R31	513	1041	965	752	1044	1300
	R32	75	300	125	78	225	400
	R33	50	225	75	50	150	275
	R41	465	761	743	730	796	912
	R42	50	200	100	50	150	250
	R43	< 50	100	50	< 50	75	125
Process	P12	< 50	75	< 50	< 50	< 50	88

TABLE VI.6: MAXIMUM DISTANCE TO LD_{001} DOSE FOR TOXIC RELEASES (Sheet 2 of 2)

FAILURE CASE GROUP	CASE IDENTIFIER	WEATHER CLASS					
		2.5 m/s B	1.0 m/s D	3.5 m/s D	7.0 m/s D	3.0 m/s E	1.0 m/s F
Transport	T21T	50	75	75	50	100	113
	T22T	125	400	113	75	150	500
	T31	513	1041	965	752	1044	1300
	T32S	200	800	400	225	675	1025
	T32M	550	1750	1125	650	1800	2325
	T33	75	350	125	75	200	450
	T41	465	761	743	730	796	912
	T42S	75	300	150	75	250	400
	T43	< 50	125	50	< 50	75	150

TABLE VI.7: MAXIMUM DISTANCE TO LFL FOR FLAMMABLE RELEASES

FAILURE CASE GROUP	CASE IDENTIFIER	WEATHER CLASS					
		2.5 m/s B	1.0 m/s D	3.5 m/s D	7.0 m/s D	3.0 m/s E	1.0 m/s F
Storage	S11	< 50	< 50	< 50	< 50	< 50	< 50
	S12	< 50	< 50	< 50	< 50	< 50	< 50
	S13	< 50	< 50	< 50	< 50	< 50	< 50
Reception	R11	< 50	< 50	< 50	< 50	< 50	< 50
	R12	< 50	< 50	< 50	< 50	< 50	< 50
	R13	< 50	< 50	< 50	< 50	< 50	< 50
Transport	T11	< 50	< 50	< 50	< 50	< 50	< 50
	T12	< 50	< 50	< 50	< 50	< 50	< 50

TABLE VI.8: MAXIMUM DISTANCE TO THERMAL RADIATION LEVEL OF 12.5 KW/m^2 FOR POOL FIRES

FAILURE CASE GROUP	CASE IDENTIFIER	WIND SPEED				
		1.0 m/s	2.5 m/s	3.0 m/s	3.5 m/s	7.0 m/s
Storage	S11	38	42	42	42	41
	S12	38	42	42	42	41
	S13	38	42	42	42	41
Reception	R11	32	35	35	35	36
	R12	32	35	35	35	36
	R13	32	35	35	35	36
Process	P11	11	17	18	19	24
Transport	T11	32	35	35	35	36
	T12	32	35	35	35	36
	T51	13	16	17	17	21

APPENDIX VII

GENERIC FAILURE FREQUENCY DATA

CONTENTS PAGE

APPENDIX VII. GENERIC FAILURE RATE DATA

VII.1 Atmospheric Storage Tanks

VII.1.1 Tank Failures

Failures of atmospheric storage tanks containing toxic materials or flammable materials which do not ignite to give tank fires are also important in this study. Frequencies for large leaks and catastrophic ruptures of atmospheric storage tanks rather than roof and rim failures are given in the COVO study (1982). These are shown in Table VII.1 below.

TABLE VII.1: FAILURE FREQUENCIES OF ATMOSPHERIC STORAGE TANKS

TYPE OF FAILURE	FAILURE FREQUENCY (per tank year)
Large Leak (50mm)	1×10^{-4}
Catastrophic Rupture	6×10^{-6}

VII.1.2 Pool Fires

A recent study by Technica, (C1998, April 1990), reviewed in detail tank fire incidents involving atmospheric storage tanks containing flammable and highly flammable materials. This review has enabled an analysis of atmospheric tank fire frequencies to be completed for covered fixed cone roof tanks and both rim seal and surface fires for floating roof tanks.

Two types of tank are considered, namely Floating Roof Tanks and Cone Roof Tanks (which have fixed roofs). The study analysed a limited selection of worldwide data and a special survey for Singapore.

The data sources were:

- The API Risk Analysis Tank Force (Document No. 1 May 1977). Source data was for the period 1969 to 1977.
- USA Refinery and Petrochemical Data from a confidential Operating Source covering the period 1965 to 1975.
- Savel Kronenburg bv database for the period 1981 to 1984 covering worldwide experience with tanks installed with their extinguishment systems.
- Scottish North Sea Terminals Data for 461 tank years.
- Singapore Data since 1945.

In the same study it was shown that approximately 40% of floating roof tank fires escalate beyond the original tank. It is assumed that half of these escalate to a fire equivalent to a full band fire and half can be modelled as single tank fires. Hence, 20% of the above frequency must be reallocated to full band fires including boilovers.

The different flammabilities of different materials must also be taken into account. For this study, materials which can be stored at atmospheric temperature and pressure have been classified as **Flammable** or **Highly Flammable**. Flammable materials are classified as liquids having a flash point between 22.8°C and 66°C, highly flammables as liquids having a flash point below 22.8°C, (BS:CP 3013(1974)). The API data indicate a fire frequency for materials with a flash point under 100°F as about 11 times greater than materials with a flash point above 200°F. Thus, by assuming that highly flammable materials are ten times more likely to be ignited than flammable the frequency can be distributed appropriately between tanks containing materials in the two classes. Therefore, the mean fire rate is doubled for highly flammable materials, while one-fifth of the mean rate is used for flammable materials.

The resulting pool fire frequencies are given in Table VII.2.

TABLE VII.2: POOL FIRE FREQUENCIES

TYPE OF FIRE	FREQUENCY (per tank year)	
	HIGHLY FLAMMABLE MATERIALS	FLAMMABLE MATERIALS
Roof Fire	4.8×10^{-4}	4.8×10^{-5}
Bund Fire	1.2×10^{-4}	1.2×10^{-5}

It should be noted that for bunds containing more than one tank, the total band fire frequency is the sum of the appropriate frequencies for all the tanks in the bund.

VII.2 Process Pipework

VII.2.1 Pipe Failures

For welded piping, a confidential Technica source (unpublished data from a major chemical company) gives general pipe leak frequency data as shown in Table VII.3. This is considered to be the best data on pipe failures which has been identified and hence is the basis for the data used in this study.

TABLE VII.3: HISTORICAL PIPE LEAK FREQUENCIES

TYPE	% OF CROSS SECTIONAL AREA	FREQUENCY (per year)
Small Leaks		2.8×10^{-7} L/D
Big Leaks	5	1.2×10^{-7} L/D
Catastrophic Leaks	20	5.0×10^{-8} L/D
Rupture	100	2.2×10^{-8} L/D
TOTAL		4.72×10^{-7} L/D

L = Piping Length
D = Pipe Diameter

Based on this table, leak frequencies for varying pipe sizes can be calculated for a section of the pipe. For the purpose of this report a **section of pipe is considered to be 10m in length.** The resulting leak frequencies calculated are given in Table VII.4.

TABLE VII.4: FAILURE RATES FOR PROCESS PIPES

PIPE DIAMETER (inches)	PIPE DIAMETER (mm)	MEAN FAILURE RATE (per section year)
0.5	13	3.7×10^{-4}
0.75	19	2.5×10^{-4}
1	25	1.9×10^{-4}
1.5	40	1.2×10^{-4}
2	50	9.3×10^{-5}
3	80	6.2×10^{-5}
4	100	4.6×10^{-5}
6	150	3.1×10^{-5}
8	200	2.3×10^{-5}
10	250	1.9×10^{-5}
12	300	1.5×10^{-5}
14	350	1.3×10^{-5}
16	400	1.2×10^{-5}
18	450	1.0×10^{-5}
20	500	9.3×10^{-6}
24	610	7.7×10^{-6}
36	900	5.2×10^{-6}
48	1200	3.9×10^{-6}

The hole size distribution for pipe failures with respect to cross sectional area and pipe diameter is presented in Table VII.5. For the purpose of this study, "small" leaks are considered to have a representative hole size of 1% of the pipe cross sectional area.

TABLE VII.5: HOLE SIZE DISTRIBUTION FOR PIPE LEAKS

HOLE SIZE AS A % OF :- CROSS SECTIONAL AREA (a/A)	HOLE SIZE AS A % OF :- PIPE DIAMETER (d/D)	PROPORTION OF FAILURES (%)
1	10	60
5	22	25
20	45	10
100	100	5

This hole size distribution is shown graphically in Figure VII.1. It is used for all pipes up to 10" diameter. Above that the distribution for pressure vessels has been used because this is considered more appropriate where the line sizes are large.

The resulting frequencies for generic pipe failure are calculated for the different hole size ranges by using the graph in Figure VII.1 to measure the fraction of failures that occur over the given hole size range. This is then simply multiplied by the total frequency of failure given in Table VII.2 for each pipe size. These resulting frequencies are given in Table VII.4. It should be noted that all large holes relative to the pipe diameter are considered to be full bore ruptures of the pipe. This is a valid assumption because most larger holes will tend to propagate to full bore ruptures due to the stresses in the pipework.

It is impossible to determine accurately lengths of pipe sections between equipment without either isometric drawings or a piping model and considerable time consuming effort. However, it is not necessary at this level of analysis to know these lengths exactly, and typical "sections" of 10m are used as a basis for the frequency analysis presented in Table VII.6 for pipes up to 250mm diameter. For pipe lengths of less than 10m it is acceptable to consider these as single sections rather than attempt to calculate the actual lengths. However, for a line greater than 10m, it is considered better to represent it as one "section" for each 10m length.

FIGURE VII.1: <u>HOLE SIZE DISTRIBUTION FOR PROCESS PIPING</u>

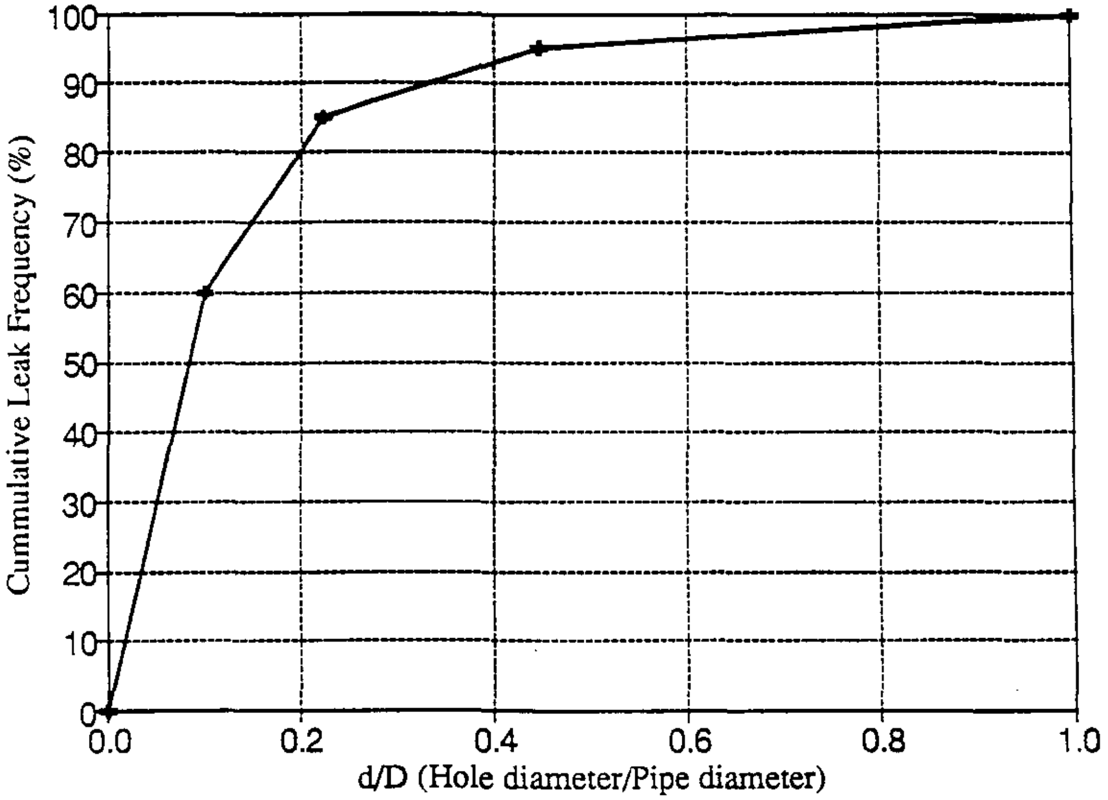

TABLE VII.6: PIPE FAILURE FREQUENCIES BY HOLE SIZE

PIPE DIAMETER		HOLE SIZE CATEGORY (mm)	FREQUENCY (per 10m section-year)
(in)	(mm)		
0.5	13	5 (0-10)	3.7 x 10^{-4}
		Full bore (10+)	7.1 x 10^{-6}
.75	19	5 (0-10)	2.4 x 10^{-4}
		Full bore (10+)	1.1 x 10^{-5}
1	25	5 (0-10)	1.7 x 10^{-4}
		Full bore (10+)	1.4 x 10^{-5}
1.5	40	5 (0-10)	1.1 x 10^{-4}
		Full bore (10+)	1.7 x 10^{-5}
2	50	5 (0-10)	7.4 x 10^{-5}
		Full bore (10+)	1.9 x 10^{-5}
3	80	5 (0-10)	4.1 x 10^{-5}
		25 (10-50)	1.9 x 10^{-5}
		Full bore (50+)	1.9 x 10^{-6}
4	100	5 (0-10)	2.7 x 10^{-5}
		25 (10-50)	1.7 x 10^{-5}
		Full bore (50+)	2.1 x 10^{-6}
6	150	5 (0-10)	1.2 x 10^{-5}
		25 (10-50)	1.6 x 10^{-5}
		Full bore (50+)	3.2 x 10^{-6}
8	200	5 (0-10)	6.9 x 10^{-6}
		25 (10-50)	1.3 x 10^{-5}
		100 (50-150)	2.7 x 10^{-6}
		Full bore (150+)	5.5 x 10^{-7}
10	250	5 (0-10)	4.4 x 10^{-6}
		25 (10-50)	1.0 x 10^{-5}
		100 (50-150)	3.1 x 10^{-6}
		Full bore (150+)	6.9 x 10^{-7}

A breakdown of failure causes is given in Table VII.7. The classification scheme has been adapted from the original (Atomic Energy of Canada) report.

This classification is used so that the individual elements, where appropriate, can be modified to allow for specific operating conditions. The breakdown differs markedly from that for pressure vessels. Notably, there are no cases listed under operational overload.

TABLE VII.7: PIPEWORK FAILURE CAUSES

FAILURE MECHANISM	% OCCURRENCE
Design Error*	36
Material/Construction Defect	23
Mechanical Wear	-
Fatigue	4.5
Corrosion	23.5
Corrosion Fatigue	-
Thermal Fatigue	8.0
Creep	3.8
Operational Overload	Not Stated
Unknown	1.2

* Includes material selection faults.

VII.2.2 Flange Failures

For flanges, industrial sources give figures covering the range of 4 x 10^{-4} to 7 x 10^{-6} failures per year. Since the quality of pipe flanges varies enormously with application, (the more reliable figures relate to ammonia plants), it seems sensible to regard this range as a reflection of flange and gasket quality.

In this study the flange quality is reflected by using a failure frequency of 1 x 10^{-5} per year. This represents the failure frequency for high quality flanges (for example, raised face, ring type or greylock flanges).

An analysis of flange failure hole sizes shows them to be small. A confidential source shows that the maximum equivalent hole diameter for a flange leak from a 6 inch pipe is 12mm. For this study it has been assumed that 10% of all flange leaks contribute to leaks in the range of 10-50mm (with a representative hole size of 25mm) regardless of pipe diameter. Smaller leaks are taken to fall into the range of 0-10mm (ie. 5mm holes) and comprise the remaining proportion of failures.

VII.3 Pump Failures

The NPRDS Annual Reliability Report (1981) gives the most detailed leak data records for pumps. It also covers one of the largest operational time spans, covering 3258 pump-years operational experience. Table VII.6 summarises the analysis of this data set. Most of the pump failures (63%) were detected whilst the system was in service, and only this fraction of failures are used below. 59% of the pump failures are leaks, which are in line with data given by a confidential source stating 60%.

Due to the relative rarity of diaphragm pumps being used in process situations, due to a number of reasons, data pertaining to their failure are relatively rare. There have been eight failures of these type of pump in 35 operating years. If a statistical process is applied to these data, we may conclude that the probability of a major failure is 0.1 times that of a minor failure. (The statistical analysis is use of a Poisson distribution, with 50% confidence, on observed minor failure data). It should, however, be noted that the statistical sample is not very large and therefore the probabilities may show some uncertainty.

The pump leak frequencies used in this risk analysis are summarised in Table VII.9.

TABLE VII.8: LEAK FREQUENCIES FOR PUMPS

PUMP TYPE	RUPTURE FREQUENCY (per item year)
Diaphragm	2.6×10^{-6}

TABLE VII.9: FAILURE MODE DISTRIBUTIONS FOR PUMPS IN NUCLEAR INDUSTRIES

TYPE OF PUMP	**FAILURE MODE**						**TOTAL FAILURES**	**OPERATIONAL/ CALENDER TIME (yr)**
	LEAK	**CRACK**	**BREACH**	**COLLAPSE**	**FRACTURE /BREAK**	**OTHER**		
AXIAL	1					2	3	66 / 230
CENTRIFUGAL	158	18	3	2	10	143	334	2139 / 6007
DIAPHRAGM	2					6	8	35 / 105
GEAR	1						1	70 / 313
RECIPROCATING	259	11	1	1	26	40	338	196 / 521
RADIAL						2	2	14 / 37
ROTARY	7				1	20	28	138 / 443
VANE						8	8	28 / 60
JET						4	4	492 / 586
OTHER						4	4	74 / 227
UNDEFINED							0	6 / 35
TOTAL	428	29	4	3	37	229	730	3258/8564

VII.4 Road Transport

VII.4.1 Unpressurised Bulk Tankers

Failure cases can occur in either the transport of materials, when the vehicle is moving, or at reception and unloading, where the vehicle is stationary or manoeuvring.

When the vehicle is moving, there is a probability that the vehicle will be involved in a road traffic accident. This may result in a spill of material; this spill may be either major or insignificant. In addition, failures may occur due to structural failure of the vessel, independent of whether the vehicle is travelling or not.

Reception failure cases can occur due to structural failure, as outlined previously, and due to failure of the unloading system (ie hose rupture).

Transport

The best available road accident frequencies for road tankers are the UK statistics for heavy goods vehicles (Technica, 1987), but data are available for Hong Kong which give a frequency of 7.7×10^{-7} accidents/vehicle km for heavy and medium goods vehicles (Hong Kong Traffic Department Accident Statistics (1987)).

The release probability for an unpressurised (eg. gasoline) tanker given that such an accident has occurred is available from three sources:

- Belgian hazardous cargo accident data, from which a compatible release probability of 0.1 has been estimated (Technica, 1987) given a road accident. Multiplying this probability by the accident frequency given above gives a frequency for a release of 6.7×10^{-8}.

- Canvey study (HSE, 1978) for which a spill frequency of 1.6×10^{-8} per km was roughly estimated. Dividing by the above accident rate gives a release probability of 0.02 given a loaded accident. This figure was estimated for petroleum tankers but used for LPG tankers.

- UK spill statistics, from which a spill frequency of 4.2×10^{-8} per loaded vehicle km has been derived. Dividing by the UK accident rate of 6.7×10^{-7} per vehicle km gives a release probability of 0.06, given a loaded accident. This value is considered to be the most reliable and will be used for the purpose of this study. The breakdown of spill sizes is given in Table VII.10. The resulting frequencies are given in Table VII.11; catastrophic failures, or their equivalent, are assumed to comprise 10% of all major releases.

TABLE VII.10: SPILL SIZES FROM UNPRESSURISED ROAD TANKERS

SPILL SIZE (kg)	PROPORTION OF FAILURES
< 15	0
15-150	0.33
150-1500	0.17
> 1500	0.50
TOTAL	1.00

TABLE VII.11: SPILL FREQUENCIES FROM UNPRESSURISED ROAD TANKERS IN HONG KONG

SPILL SIZE	SPILL FREQUENCY (per truck km)
Catastrophic failure	1×10^{-8}
Major leak	9×10^{-8}

Spills of less than 1.5 tonnes have not been considered because these are considered to have a negligible effect. Spills due to causes other than road accidents account for a significant proportion of a spills, but all of those reported (Technica, 1987) were of less than 1.5 tonnes, and have therefore been ignored.

Frequencies of catastrophic rupture or major release due to structure are outlined in the section on reception, below, but these are insignificant during transport.

Reception

As discussed above, failures during reception are due to either hose rupture, or structural or equipment failure of the tanker. The frequency derivation of hose rupture is outlined in Section VII.5 below.

Frequencies for "failure of body material and equipment" (ie not due to Road Traffic Accident) are derived from the SRD/UKPIA database which recorded that seven minor failures had occurred in the recorded period. This provides a frequency of 1.68×10^{-8}/tanker km.

A typical journey time for contributors to the SRD/UKPIA database is one hour; assuming a mean speed of 60 kph, the failure rate is equivalent to 1×10^{-6} /hr. This is independent of whether the tanker is loading, in transit or discharging and hence can be applied to failures both en route to and at the facility.

By applying the statistical technique of Poisson's Distribution on these seven cases, we may forecast that the probability of a major event occurring given a failure is 0.1. Of this, 10%

will be equivalent to a catastrophic failure. The resulting frequencies are shown in Table VII.12.

Table VII.12 FREQUENCIES OF MAJOR RELEASES FROM UNPRESSURISED TANKERS

SPILL SIZE	SPILL FREQUENCY (per hour)
Catastrophic failure	1×10^{-8}
Major release	9×10^{-8}

VII.4.2 Pressurised Drums

Frequencies and probabilities for incidents involving the transport of pressurised drums are taken from Technica's Risk Assessment of Liquid Chlorine Transport for the Hong Kong Water Supplies Department (1990). These frequencies are specific to Hong Kong, and are shown in Table VII.13. Table VII.14 shows the failure cases resulting from these accidents.

TABLE VII.13: SUMMARY OF ACCIDENT FREQUENCIES OF PRESSURISED DRUMS

CAUSE OF FAILURE	EVENT FREQUENCY	FAILURE PROBABILITY
Failures in road traffic accidents		
Rollover	3.3×10^{-7} per truck km	0.20
Crushed at rear	3.3×10^{-7} per truck km	1.1×10^{-2}
Crushed at side	3.3×10^{-7} per truck km	6.2×10^{-3}
Vehicle fire	3.3×10^{-7} per truck km	1.8×10^{-3}
Tanker fire	3.3×10^{-7} per truck km	4.5×10^{-5}
Other failures on the road		
Spontaneous	1.3×10^{-7} per container hour	1.00
Load-shedding	8.3×10^{-7} per truck km	0.47
Truck fire	4.0×10^{-9} per truck km	1.00

TABLE VII.14: SUMMARY OF FAILURE CASES OF PRESSURISED DRUMS

CAUSE OF FAILURE	PROPORTION OR NUMBER FAILING	PROBABILITY OF		
		SMALL LEAK	LARGE LEAK	CATASTROPHIC FAILURE
Failures in road traffic accidents				
Rollover	1	0.69	0.31	
Crushed at rear	1	1.00		
Crushed at side	1	1.00		
Vehicle fire	1		100%	
Tanker fire	100%		100%	
Other failures on the road				
Spontaneous	1	0.54	0.42	0.04
Load-shedding	1		0.90	
Load-shedding	100%		0.10	
Truck fire	100%		1.00	

The frequencies for the individual events can then be summed. The frequency of spontaneous events must, for transport incidents, be converted into a rate per truck kilometre from a rate per year; this is achieved by dividing the rate per hour by the estimated truck speed. Case studies in Hong Kong suggest an average speed of 60 kph for trucks.

For stationary trucks, during the reception of the materials at the plant, spontaneous failures and hose failures are considered; the latter are dealt with in Section VII.5 below; the spontaneous frequencies are expressed per hour.

Event frequencies are shown in Table VII.15.

TABLE VII.15: SUMMARY OF FAILURE FREQUENCIES OF PRESSURISED DRUMS

	SMALL LEAK	LARGE LEAK		CATASTROPHIC FAILURE
		1 DRUM	6 DRUMS	
Frequency /truck km on road	3.08×10^{-6}	3.78×10^{-5}	3.90×10^{-8}	7.80×10^{-10}
Frequency /hr at reception	7.02×10^{-8}	5.46×10^{-8}		5.20×10^{-9}

VII.5 Transfer Failures

Transfer failure rates leading to fuel leaks from arms or hoses, suitable for application to road tankers, are given in Table VII.16 from the COVO study (1982), drawn in turn largely from the WASH-1400 study.

TABLE VII.16: LOADING ARM AND HOSE FAILURE RATES

EVENT	FREQUENCY (Events/hour)
Loading arm leak Loading arm rupture	3×10^{-6} 3×10^{-8}
Hose (pressurised) rupture Hose (unpressurised) rupture	4×10^{-5} 4×10^{-6}

For failures of the hoses used to discharge chlorine and sulphur dioxide drums to process, data based on Hong Kong Water Supplies Department experience can be used. There have been two connection pipe failures over a 25 year period. The average annual trade over this period is estimated to have been 910 drums (*Risk Assessment of Liquid Chlorine Transport*, Technica 1990). This gives a failure frequency of 8.8 x 10^{-5} /drum-year. It is considered most likely that hose failures - which include leaks due to connection failures - are directly related to the number of times hose connections are made and unmade. This in turn depends on the number of drums used. The above failure frequency is used in the present study.

VII.6 Packaged Waste Fires

Statistics specific to fires in warehouses designed for or given over to the storage of hazardous chemicals are not generally available and so frequencies must be based on fires in more general warehouses. Two studies [Baldwin, R., The Analysis of Fire Safety, Accident Analysis and Prevention 6 205-222, 1974; HSE private and confidential communication to Technica] give values of frequency close to 1 x 10^{-2} per year. As chemical storage warehouses form only a small part of the total warehouse population, a smaller figure for frequency of fires in these warehouses is appropriate. A conservative value of 3 x 10^{-3} per year has been assumed for warehouses with little or no fire detection and alarm systems. This can be reduced further for the CWTF which will have a sophisticated fire detection, alarm and suppression system in Building 16.