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United Nations Environment Programme

World Health Organization

International Atomic Energy Agency

United Nations Industrial Development Organization

Inter-Agency Programme on the Assessment and Management of Health and Environmental Risks from Energy and Other Complex Industrial Systems

PROCEDURAL GUIDE FOR INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

DRAFT

United Nations Environment Programme

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PROCEDURAL GUIDE FOR INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

Volume I

Organization and Management of the Integrated Risk Assessment Study Process

v1.004

PROCEDURAL GUIDE

FOR

INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

VOLUME I

ORGANIZATION AND MANAGEMENT OF THE INTEGRATED RISK ASSESSMENT STUDY PROCESS

United Nations Environment Programme
World Health Organization
International Atomic Energy Agency
United Nations Industrial Development Organization

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- United Nations Industrial Development Organization
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PREFACE

There is a growing need to ensure that health environmental and safety issues are addressed as an integral part of social and economic development. This can be achieved through an integrated approach to environmental risk assessment and safety management where all elements of risk are identified and assessed and where priority management actions are formulated in an integrated way. Recognizing the emergence of such needs, the United Nations Environment Programme (UNEP) within the framework of its programme on Awareness and Preparedness for Emergencies at Local Level (APELL), the World Health Organization (WHO), the International Atomic Energy Agency (IAEA) and the United Nations Industrial Development Organization (UNIDO) have joined efforts to promote and facilitate the implementation of integrated risk assessment and management for large regional industrial areas. Such an initiative includes: the compilation of procedures and methods for environmental and public health risk assessment; and the transfer of knowledge and experience amongst countries in the application of these procedures. The preparation of a procedural guide on integrated environmental risk assessment and management is part of the initiative.

This Procedural Guide provides a reference framework for the undertaking of integrated environmental risk assessment for large industrial areas and for the formulation of appropriate safety and risk management strategies for such areas.

This guide is presented in four inter-related volumes: **Volume I** (this document) outlines the organization and management issues associated with the process of integrated risk assessment studies; **Volume II** presents the methods and procedures for health and environmental risk assessment; **Volume III** highlights the different elements of integrated risk management; and, **Volume IV** specifies the documentation requirements.

PROCEDURAL GUIDE FOR INTEGRATED ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

VOLUME I: ORGANIZATION AND MANAGEMENT OF THE INTEGRATED RISK ASSESSMENT STUDY PROCESS

VOLUME II: METHODS AND PROCEDURES FOR HEALTH AND ENVIRONMENTAL RISK ASSESSMENT

VOLUME III: ELEMENTS OF INTEGRATED RISK MANAGEMENT FOR LARGE INDUSTRIAL AREAS

VOLUME IV: DOCUMENTATION REQUIREMENTS FOR INTEGRATED RISK ASSESSMENT STUDIES FOR LARGE INDUSTRIAL AREAS

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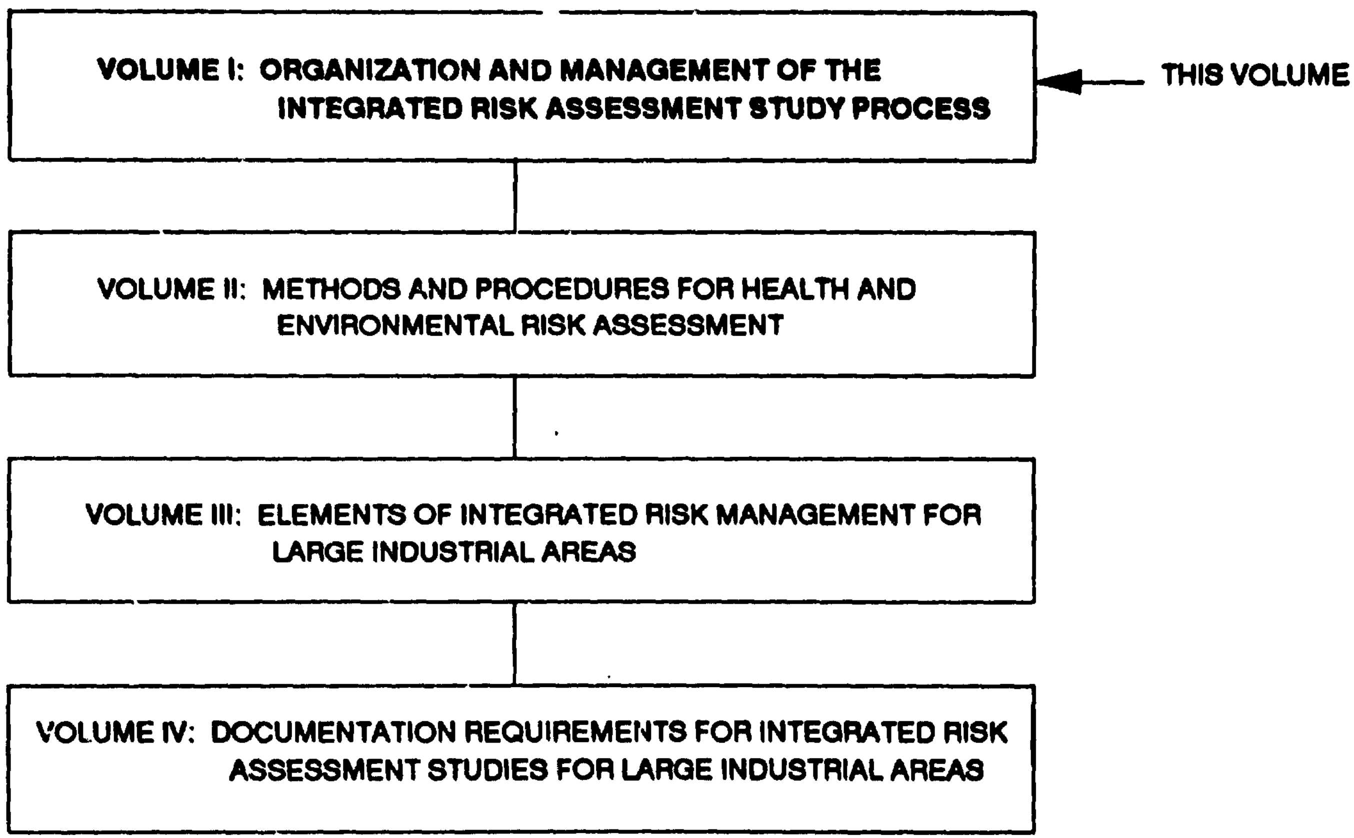
PROCEDURAL GUIDE FOR INTEGRATED ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS



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CHAPTER 1

INTRODUCTION AND SCOPE OF GUIDE

Chapter 1. INTRODUCTION AND SCOPE OF GUIDE

1.1 Introduction

There is a growing worldwide awareness and concern by government, community and industry about the risk to people and the environment from the location and operation of hazardous and polluting industries, including those involved in the production of energy. The identification, assessment and management of environmental risk* are now recognized as essential elements for orderly economic and social developments.

Three important emerging issues are particularly significant, concerning environmental risk management:

- The optimum allocation of resources in the environmental risk management process. That is, the need to prioritize all relevant risks and directing management strategies towards achieving the highest benefits from the resource expenditures in the environmental control and management processes.

- The need to ensure, that all elements of environmental risks are considered: risks to people and to the environment; risks from continuous emissions as well as those from accidents; risks from the operations of fixed installations as well as those associated with support activities such as transportation and disposal of wastes.

- The integration of all elements in the environmental management strategy: locational, technical, organizational, legislative, social and economic. These elements are complementary and each cannot be considered in isolation. The need for a wholistic approach to environmental risk management is evident in most situations.

These issues are particularly significant when dealing with an extended region with conflicting demands and pressures for industrial developments and urbanization. There are a large number of such areas worldwide, both in developing and developed countries.

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* In the context of this guide, 'environmental risk' includes both health and physical and natural environment. Health considerations are therefore implied wherever environmental risks are referred to.

Recognizing the emergence of such needs, the United Nations Environment Programme (UNEP) within the framework of the Awareness and Preparedness for Emergencies at Local Level (APELL) programme, the World Health Organization (WHO), the International Atomic Energy Agency (IAEA) and the United Nations Industrial Development Organization (UNIDO) have joined efforts to promote and facilitate the implementation of integrated risk assessment and management for large regional industrial areas. Such an initiative includes: the compilation of procedures and methods for environmental and public health risk assessment; and the transfer of knowledge and experience amongst countries in the application of these procedures. The preparation of a procedural guide on integrated environmental risk assessment and management is part of this initiative.

1.2 Purpose of Procedural Guide and Areas of Application

The main purpose of this procedural guide is to provide practical guidance and a reference framework for the undertaking of integrated environmental and health risk assessment studies; and, formulate and implement co-ordinated environmental management strategies for large industrial areas including those that accommodate energy producing facilities. This purpose is achieved by presenting an outline of the methodologies and procedures to enable an appreciation of the techniques and processes involved. It is noted, that there are a number of published guideline documents dealing with various aspects of environmental and risk impact assessment. It is not the aim to duplicate these documents. The integrated risk assessment approach, however, necessitates a wholistic cumulative approach for all emission sources, over the entire cycle of production for a number of industries and associated operations including transportation and waste generation. The integrated risk environmental management approach also necessitates the formulation of overall co-ordinated strategies involving multidimensional elements including technical, locational, social and economic considerations. These aspects require specialized methodologies. The procedural guide therefore relies on existing guidelines where appropriate but further integrates and provides specialized guidance to address the wholistic integrated risk assessment approach on an area/region wide basis.

The methods and techniques of integrated environmental risk assessment and management presented in this guide are best applied to geographical areas that accommodate a number of industrial and related activities of a hazardous and/or polluting nature, also being areas of regional or national significance in terms of social and economic developments. Two situations may apply: The study area may experience existing safety and environmental problems; or it may be the subject of conflicting demands for developments and environmental protection, particularly in terms of future environmental and land use planning. Within that context, major areas of applications include:

- Assessment of existing health and environmental risks in a large industrial region, including the prioritization of those risks that need to be managed or reduced;
- The formulation of integrated environmental risk management strategies, including the prioritization of implementation measures and of resources;
- Environmental planning of future industrial developments; population and land use safety planning; and, the formulation of appropriate assessment criteria to guide orderly economic and social developments;
- Transportation planning of hazardous substances;
- Licensing of hazardous and polluting industries;
- Emergency planning;
- Institutional and legislative applications for hazardous and polluting industry.

1.3 Scope of the Procedural Guide

The Procedural Guide is organized in four inter-related volumes.

(a) Volume I: Organization of the Integrated Risk Assessment Study Process

This volume introduces the guide and its purpose. It particularly provides an outline of the overall framework, structure, procedural and organizational steps to be followed when undertaking an integrated environmental and health risk assessment study. Topics covered include:

- Overall Scope of Manual and Areas of Application;
- Management and Organization of the Risk Assessment Study.

(b) <u>Volume II:</u> <u>Health and Methods and Procedures for Environmental Risk Assessment</u>

This volume outlines the main methods and tools for environmental risk assessment. Topics covered include:

- Identification of the Study Area and Prioritization of an Assessment Scheme.
- Analysis and Assessment of Continuous Emissions
- Analysis and Assessment of Major Accidents
- Assessment of Hazardous Wastes
- Transportation Risk Analysis
- Socio-Economic Analysis
- Integrated Health and Environmental Risk Assessment.

(c) <u>Volume III:</u> <u>Elements of Integrated Risk Management For Large Industrial Areas</u>

This volume addresses the various technical, operational, organizational and legislative components of integrated risk management. Topics covered include:

- Operational Safety Management and Controls
- Technical and operational environmental and safety controls
- Emergency Planning and Response
- Waste and Transportation Infrastructure Risk Management
- Institutional and Strategic Risk Management
- Integrated Risk Management.

(d) Volume IV: Documentation Requirements for Integrated Environmental Risk Assessment Studies for Large Industrial Areas.

The keeping and update of necessary documentation are essential components of the environmental risk assessment and management process. This volume outlines the range and nature of the required documentation.

PROCEDURAL GUIDE FOR INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

VOLUME I

ORGANIZATION AND MANAGEMENT OF THE INTEGRATED RISK ASSESSMENT STUDY PROCESS

CHAPTER 2

FRAMEWORK OF INTEGRATED ENVIRONMENTAL RISK ASSESSMENT AND MANAGEMENT STUDIES FOR LARGE INDUSTRIAL AREAS

Chapter 2. FRAMEWORK OF INTEGRATED ENVIRONMENTAL RISK ASSESSMENT AND MANAGEMENT STUDIES FOR LARGE INDUSTRIAL AREAS

2.1 The Concept of Integrated Environmental Risk Assessment and Management.

Decision makers are often confronted with of complex issues concerning economic and social development; industrialization and associated infrastructure needs and population and land use planning. Such issues have to be addressed whilst ensuring that public health will not be endangered by continuous or accidental hazardous emissions, that important ecological systems will not be disrupted and that land, soil, water and air will not be irreversibly destroyed for future generations. Only decisions made in such a way can support a sustainable development of a region.

The case may also be that serious risks to people and the environment already exist in a region and that decisions have to be made about the prioritization of the risks to be reduced, consistent with available resources.
Another important objective is to produce a well documented decision making procedure, which gives the community insight into the risks to which they are exposed, the hazards which were assessed and the basis of the assessment process. Insight into the methods by which risks were identified, estimated and assessed increases the opportunity for a rational discussion and acceptance of the recommended risk management strategy by the community. Ad hoc decisions, on the other hand, which consider only some of the risks, neglecting others, may lend themselves to opposition. The decision making process may also be ill-founded if certain risks are ignored. Many accidents and environmental catastrophes were caused by a narrow approach to risk assessment and management.

The **integrated risk assessment** approach is based on the notion that all health and environmental risks within a region should be systematically identified, analyzed and assessed in such a way that rational choices could be made about which risks should be reduced, weighing the social and economic costs of such risks, the benefits of risk reduction and associated costs and formulating the basis of an integrated environmental and safety management.

The **integrated risk management** approach is based on the notion that all options of risk management: locational, preventative, mitigating, protective and institutional should be explored in a wholistic way and used as complementary so that the resources committed in the safety management process are optimized.

Although the integrated environmental risk assessment and management approach necessitates the consideration of all risks, the level of details in such considerations may vary depending on pre-assigned priorities. The methods for setting risk priorities for further analysis are described in subsequent sections of the guideline.

Integrated risk management also necessitate efficient co-ordination between the different parties involved in the risk management process: government, industry and community. Co-ordination between the various government institutions involved in risk management is also essential. Liaison and co-ordination should preferably be formalized at an early stage of the risk assessment study process and continued as an integral part of developing the safety management strategy and its implementation.

2.2 Nature and Dimensions of Environmental and Health Risks

2.2.1 Types and Sources of Risk

All human activities are possible sources of risk. In the context of an integrated regional risk assessment and management, the following constitute the most relevant types and sources of risk to be considered:

- **Continuous emissions** to air, water and land from industry and associated activities.

- **Accidental releases** of hazardous materials from industrial installations have caused serious harm to the public and the environment. Fires, explosions and the release of toxic substances from the handling, processing and storage of hazardous substances are relevant type of risks to be considered.

- **Transportation systems** constitute a source of continuous emissions. The transportation of hazardous materials can also cause serious accidents with severe consequences for the public and the environment. In this context, transportation includes the transfer of material by rail, road, pipeline and ship.

- The interaction of **natural hazard sources** such as earthquakes, storms, flooding and volcano eruptions with man-made sources, such as industrial installations and urban developments may increase the risks of the latter, requiring additional safety measures to reduce the overall risks. Natural hazards may therefore constitute an important source of risk to be considered in the assessment process.

- **Large scale agricultural activities** form a potential serious risk to the environment and to the public health. Fertilizers, insecticides and herbicides may contaminate groundwater, rivers and soils. Large scale agricultural activities may also consume large amounts of water, causing droughts and soil erosion.

- **Urbanization** itself and its associated infrastructures are a source of environmental risk, including surface water contaminated runoff, air pollution from transportation systems in particular and waste generation and disposal.

2 Targets of Risks

Targets for the risks are, firstly, the people living in the study area under consideration. Very young and old people and people with different allergies and illnesses may be much more sensitive to certain contaminants than the general public. However, people outside the study area may also be at risk, due to transportation of contaminants through the air, by waterways or by contamination of agricultural products.

Secondly the ecological systems in the study area or within the influence sphere of the study area may be at risk. The extermination of one or two species may disrupt a whole ecological food chain.

Thirdly economic resources can be at risk. An accident at any industrial installation can destroy many others in its neighbourhood. Acid emissions may destroy forests, fisheries, historical buildings and monuments and pollution may have significant economic consequences to the tourist industry of a region.

2.2.3 Dimensions of Health and Environmental Risk

An integrated approach necessitates considerations of the different categories of risks and nature of impacts. Figure 2.1 outlines the broad categories of risk to assess the health and environmental impacts of different industrial operations and associated activities.

- In all cases it is necessary to assess (separately) both the risks to the environment and to human health;
- Risks from routine operations should be differentiated from those that could result from major accidents.

In relation to **health impacts**, occupational and public health risks should be treated separately. Two categories of risk apply as a result of direct or indirect impacts:

- Fatal effects, either immediate (resulting from direct exposure or accidental situation) or delayed (resulting from chronic exposure to hazardous substances);
- Non-fatal effects (injuries, diseases) of either an immediate or delayed nature.

In relation to environmental risk, categorization of risks can be made on the basis of extent: local, regional and global; and on the duration of the effect: short or medium term and long term.

Some environmental effects are of such a long term nature that they are irreversible. The complete destruction of vegetation and soil cover in certain

Fig. 2.1 Categorization of Health and Environmental Risk

Health risk

Source	People at risk	Exposure	Effects
Routine or accidents	Workers and public	Short or medium and long term	Fatal and non-fatal Immediate/delayed

Environmental risk

Source	Effects	
	Duration	Extent
Routine or accidents	Short or medium and long term	Local, regional and global

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mining operations is one such example; widespread loss of species in an area is another.

2.3 Broad Outline of the Study Process

Figure 2.2 provides a broad outline of the integrated regional risk assessment study process. Figure 2.3 is an example of the application of this process, including the prioritization of the different risk reduction strategies.

The study process may be divided into four broad components:

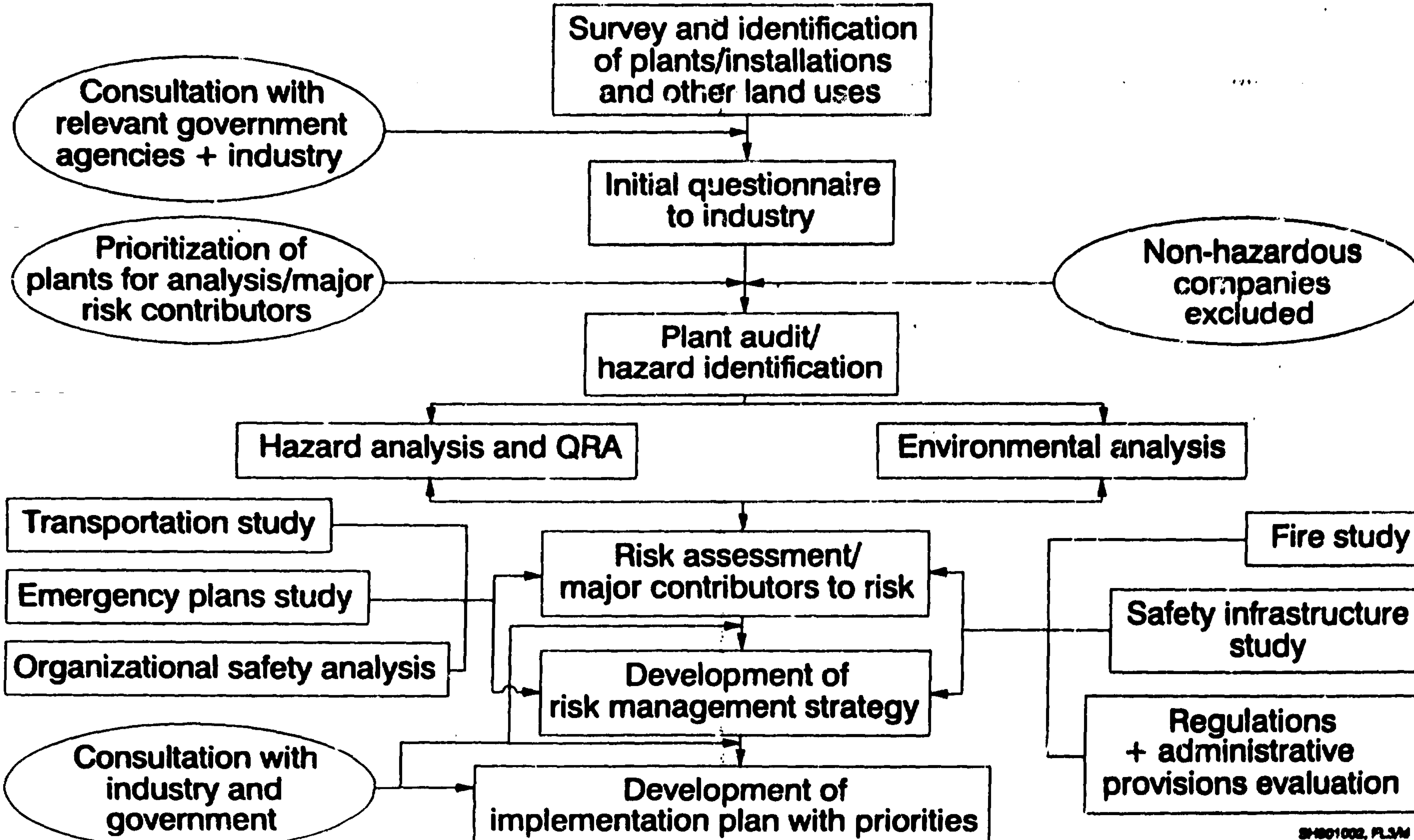
Step 1: **Establishment of a Database for the Study Area and Prioritization of Activities for Analysis:** including the delineation of the study area, the identification of various land uses, nature and type of industrial and other activities, the identification of priority activities for analysis and the establishment of key environmental and safety issues. An initial hazard identification scheme in order to determine those facilities for further analysis may be adopted (see Volume II).

Step 2: **Environmental and Health Risk Analysis Studies,** including: Quantified Risk or Hazard Analysis (QRA) for major accidents; analysis of continuous emissions and quantification of environmental impacts from emissions into air and water; analysis of hazardous waste generation; transportation risk analysis.

Step 3: **Infra-structure and Organizational Safety Analysis,** including analysis and evaluation of emergency planning and provisions; fire safety with emphasis on the availability and applicability of fire media, prevention and protection facilities off-site and on-site; environmental monitoring infrastructure in the area; review and analysis of institutional and regulatory provisions.

Step 4: **Formulation of Integrated Management Strategies with Associated Actions Plans,** including the establishment of cost/benefit allocations for the various risk contributors and the prioritization of implementation measures. The components of the risk management should cover the technical, operational, organizational and locational.

Fig. 2.2 OUTLINE OF REGIONAL RISK ASSESSMENT STUDY PROCESS



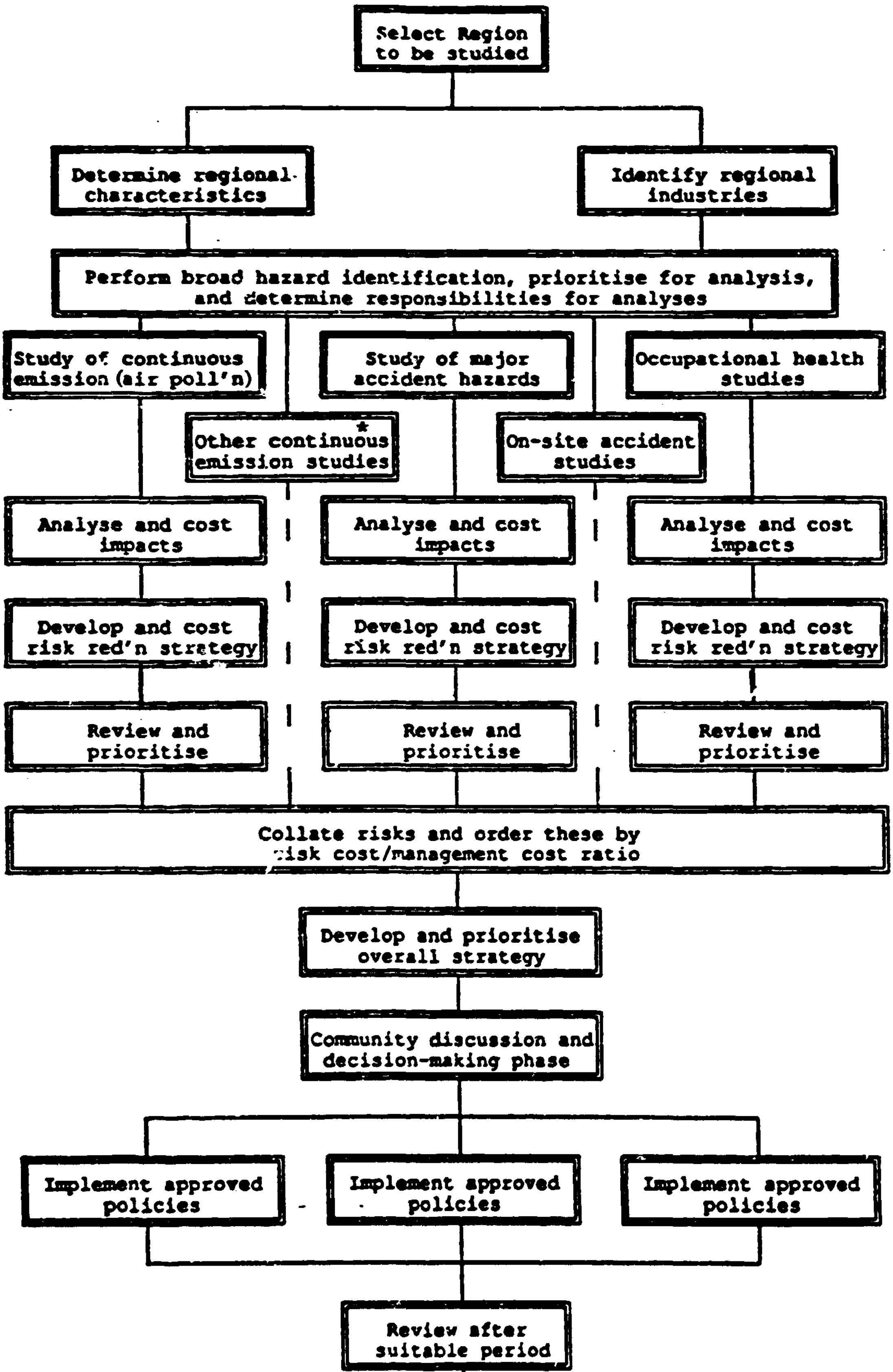


Fig. 2.3 Possible strategy for regional risk assessment

* water, solid wastes, noise

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VOLUME I

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CHAPTER 3

MANAGEMENT AND ORGANIZATION OF THE INTEGRATED REGIONAL ENVIRONMENTAL RISK ASSESSMENT AND MANAGEMENT STUDY

Chapter 3. MANAGEMENT AND ORGANIZATION OF THE INTEGRATED REGIONAL ENVIRONMENTAL RISK ASSESSMENT AND MANAGEMENT STUDY

There are a number of areas in which an integrated regional risk assessment project differs from other projects. The number of parties involved is relatively large. Therefore, a description of the project and the organizational and management aspects thereof required particular attention. Usually, the project deals with complex issues that could be socially and politically sensitive. Debate may ensue as to the results of the assessment and the proposed risk management recommendations; extra care is therefore required in formulating both. The uncertainty associated with the end results may be great, since assessment of the environmental and public health risks relies on a number of assumptions, the quantified results should be interpreted with care and all the uncertainties exposed, therefore, to ensure orderly and efficient progress of the study a number of procedural steps should be followed.

3.1 Procedural steps

The following procedural steps are suggested:

(a) The organization that intends to undertake the study should formulate the objectives and draft a project proposal, including the timetable, the manpower, and the financial and other resource requirements.

(b) The initiating organization should ensure that all the relevant organizations, industry and institutions are involved, on the basis of the draft project proposals. These organizations should decide on the conditions under which they wish to participate and on whether the proposed objectives and the draft study proposal require any modifications to fit their needs. They should also decide on the practical forms in which they are prepared to participate, be it manpower, information sources or funds. Should any adjustments applicable to the objectives of the study be made, joint agreement must be reached by all the participating organizations. They may also establish a joint co-ordinating committee.

(c) A steering committee for the project should be established by the participating organizations, specifying its responsibilities and terms of reference. For complex and sensitive projects, a supervisory steering committee (with political representatives) may be formed, again specifying its duties and responsibilities.

(d) The steering committee should establish working groups. The steering committee should formulate the project proposal into a detailed working project plan and establish working groups to carry out the various analyses. If external consultants are necessary, the steering committee should make tenders for the work and choose the bets person for the job. The working groups should undertake the various analyses associated with the project.

(e) The steering committee should accept, if necessary after some modification the final report of the working groups and prepare its own covering report, including the conclusions and recommendations.

(f) The participating organizations should receive the reports and decide on: (1) the final conclusions and recommendations, (2) the policy changes to be implemented, and (3) which of the proposed actions should be carried out, including final prioritization and action plans for implementation.

The participating organizations should put their decisions into effect, ensuring that the responsibilities and procedures are properly arranged to monitor and evaluate the implementation process. They should evaluate, together or separately, the results of their risk management policy, implemented on the basis of the results of the study.

The organizational arrangements for such a study are shown in Figure 3.1.

3.2 Formulating the Objectives and Study Proposals

In most cases, the **main objective** of the study is to formulate a regional completetly integrated environmental risk management strategy for a complex industrial area based on cumulative assessment of the health and environmental risks in that area. Emphasis placed on a definite objective (i.e. whether in terms of assessment of particular types of risk or in the environmental or safety management of particular activities within the region) will vary, depending on the precise needs of the particular region. Other objectives directly or indirectly related to the main objective may also arise, including development of methods and procedures for integrated risk assessment and management which could be applied to other regions in the country; development of local knowledge and capabilities in the field; and review and refinement of institutional or legislative provisions in the country.

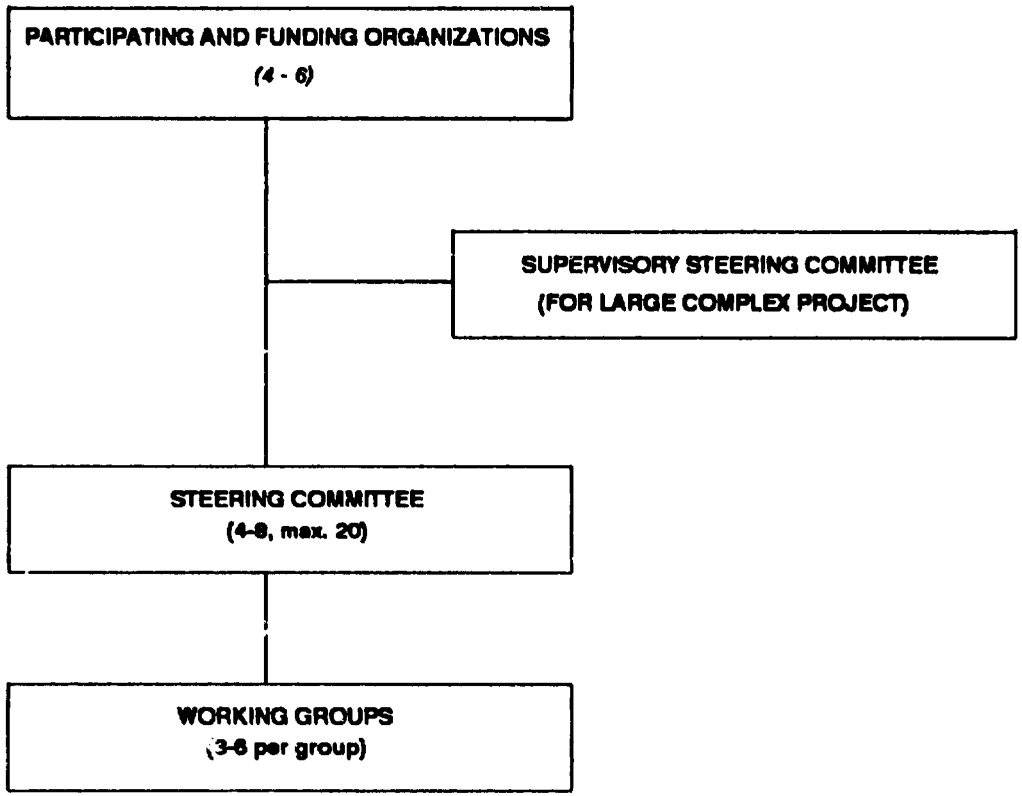
Annex 1 outlines the main elements to be included **in formulating a proposal for the integrated risk assessment and management study.** Such elements include:

- A clear statement on the objectives of the study and its expected output and results.

- A description of the study area and the main safety, environmental, social and economic issues of relevance to the study.

- A detailed description of all the activities to be undertaken, including the time schedule, milestones and flow charts.

Fig. 3.1 ORGANIZATIONAL ARRANGEMENTS FOR INTEGRATED RISK ASSESSMENT STUDY



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- The financial, manpower, equipment and other resources needed to undertake the study.

- An organizational chart for project implementation, including management/ co-ordination responsibilities and liaison mechanisms. The project description should stipulate the nature and type of documentation that is to be produced during the course of the project, including progress reports, revised time schedules and budget reports.

3.3 Selection of Participating Organizations

FACTORS:
. Objectives of the study . Expertise, knowledge and statutory capability . Resources
POSSIBLE PARTICIPATING ORGANIZATIONS:
. Government authorities (at national, regional and local levels as applicable) . Industrial organizations . Universities, research institutes . Labour organizations . Environmental/community groups

There are three main factors that guide the selection of organizations for participating in the study: the objectives of the study the required knowledge and expertise, and the necessary resources.

Because of the integrated objective of the risk assessment and management process, it is essential that all to those relevant organizations concerned with the implementation process participate in the study. In all cases both industry and representatives from relevant government authorities must participate.

For example a university or scientific institute without any legislative power is the initiating organization and all the legislative bodies refuse to participate, then only a risk assessment study with recommendations on the risk management policy to be implemented, is possible, however, there is less possibility of such a policy, actually being implemented.

When a local or regional authority or a national ministry is the initiating organization, it usually has the authority to implement the risk management policy for some forms of environmental and public health risk. The integrated approach, however, requires co-operation amongst several authorities; those are responsible for different forms of environmental and other legislation. It is always necessary for local or regional authorities to co-operate in, or at least to be aware of the project. Because of the size and importance of the project, it is appropriate that one or more national government authorities participate.

Another criterion is the contribution made by an organization in the form of finances, expert manpower or information. Often large government authorities, industrial organizations and international organizations can supply funds and manpower more easily. The necessary expertise usually resides in industry. Important information sources are frequently only available from specific authorities and from those organizations which own the industrial installations, pipelines, ships, trains and trucks. Therefore, it may be necessary and fruitful, to foster co-operation between those industrial organizations representing the industries to be studied and government authorities. In such cases one or more representatives of these organizations or industries should also be members of the steering committee.

The final objective of the project is to develop better decision making on those environmental and public health problems of particular concern to the public in general and the environmental and community groups in the area. It may be appropriate to involve one or more representatives of such groups in the project.

Whilst there may be many reasons for involving a relatively large number of participating organizations in an integrated risk assessment and management study, e.g. for reasons of efficiency, it may be more appropriate to limit the number of organizations with direct responsibility/participation to, say, four or six organizations each of which makes substantial contributions of money and manpower.

Where more organizations are interested in the project than can be accommodated, then the participating organizations and the steering committee should keep them informed by means of regular progress reports and by distributing the final report. It may also be useful to organize a discussion group in which all the organizations are represented.

3.4 Necessary Manpower, Finances and Other Resources

Only when the objectives and extent of the study project are defined, is it possible to provide estimates of the manpower, financial and other resources needed. Other requirements may include computers, software and environmental measuring and monitoring facilities. Manpower is usually more easily available from the participating organizations than from hired expertise, this should be encouraged in order to develop and extend the knowledge and capabilities. Manpower resources from within the participating organizations should therefore be given preference to hired consultants. However, in some cases it may be necessary to hire external experts. The role of such experts should in all times be to advise personnel from the local participating organizations rather than to undertake tasks in isolation.

A project may run for a period longer than 1 year. Therefore it is essential that the financial and manpower resources are ensured for subsequent years. This also provides the opportunity of spreading the projectcosts over several years.

In most cases, it is not necessary to buy or hire new large main-frame computers for the purpose of the study. Usually it is sufficient to have one or two modern personal computers or work stations available. It is also not appropriate to purchase expensive measuring or monitoring equipment at the start of the study, because there is a real risk of deciding on inadequate or unnecessary equipment before the the real needs of the study have been determined. The risk assessment study itself should first show what important gaps in knowledge exist and then define the priority requirements. If no data nor measuring equipment are available, the purchase or loan of some equipment may be justified in order to obtain some objective data on the existing situation.

3.5 Steering Committee

The Steering Committee
<u>Selection of the Team:</u>
. 4 - 8 people (optimum), 20 people (maximum) . Broad knowledge and experience . Mandate to make decisions . Representative of different interests
<u>Terms of Reference:</u>
. Overall responsibility for the undertaking and progress of the study to completion . Steer the project in line with the agreed objectives . Make adjustments where necessary . Establish and guide working groups . Review working group reports . Prepare final strategy with recommendations . Ensure appropriate consultations

When the study project has been defined and the participating organizations have decided on its objectives and contents and have made decisions concerning manpower, funds and other resources, then responsibility for the execution of the study falls on the steering committee. Thereafter, the steering committee should make all further decisions and direct the course of the study. Interim reports may be presented by the steering committee to the participating organizations.

All participating organizations, especially those which contribute manpower, funds or valuable information, should be invited to take their place on the steering committee. The representatives should preferably be experts with wide experience or people that have been given a significant decision making mandate.

For very large and politically important projects there may be a need to establish a supervisory steering committee of senior decision makers or political representatives to which the steering committee reports.

The size of the steering committee should not be too large. The optimum number is four to eight people, the maximum 20 people. The steering committee should convene regularly, perhaps, every 4-8 weeks, to supervise progress, to make decisions on questions that have arisen and to review the interim and final reports.

Selection of the members of the steering committee should be done in such a way, that the steering committee can act with authority and expertise. The participating organizations must be able to rely on the steering committee for almost all the decisions to be taken during the course of the project. It should not be necessary for its members to consult the organizations they represent before taking decisions. Therefore, the representatives should be given ample mandate by their organizations.

Further, the steering committee must have sufficient experience and expertise amongst its members to be able to make a critical review of the work of the working groups and to formulate practical conclusions and recommendations. Thus people with broad knowledge and experience in the field of environmental sciences, technology, risk management and policy formulation should be made members of the steering committee. External experts, i.e. those that do not belong to one of the participating organizations, may be asked to assist when only a few specialists are available within the participating organizations. The chairman of the steering committee should be selected by consensus. He/she does not necessarily have to be an expert in the field of environmental sciences, but he/she should have some experience in leading major projects, chairing committees and formulating conclusions and recommendations.

The steering committee should also have a secretary with some knowledge of the environmental sciences, with experience in taking the minutes of complex meetings and in writing draft conclusions and reports. The secretary is charged with most of the practical work attached to the committee meetings.

3.6 Working Groups

The analysis and assessment of different issues should be carried out by one or more working groups under the guidance of the steering committee. For example, separate working groups may be established to undertake analysis of continuous emissions, the risk of accidents; legislative provisions, etc. The whole study, considered as a system, can often be divided into substudies that can be carried out by different working groups in their own specific operations. Possible subdivisions of the study are reflected in the various sections of this manual but other forms of subdivision of the total study are also possible.

When subdividing the work of the main study into substudies with a view allocating specific tasks to the different working groups, data collection should be organized as efficiently as possible in order to avoid the same information sources being consulted by one working group after the other.

The working groups should consist of technical experts in the particular fields required by the specific study. There is a wide range of expertise required for the specific substudies, e.g. as environmental sciences, biology, ecology, chemistry, chemical engineering, mechanical engineering, civil engineering, toxicology, epidemiology, safety science and risk analysis, meteorology, physical planning, economy, legislation, administration and political sciences etc.

Each working group should consist of three to six people. If more experts are needed, they can be consulted by the working group on an ad-hoc basis. The working group itself should remain small, to be able to work informally and efficiently. Larger topics of work, requiring more manpower and expertise should be further subdivided by the steering committee, so that they can be carried out by working groups of the size of three to six people.

3.7 Reporting

The steering committee is responsible for the execution of the study and should report on the final results of the study. Such a report should also contain the conclusions and recommendations to be discussed and agreed upon by the participating organizations at the end of the study. Interim progress reports from the steering committee should are only required for very large and complex studies. The writing and discussion of such progress reports involve time and resources which may be better spent on the main study and the final report. The steering committee briefs the working group(s) on the various steps of the study. The tasks of each working group should be divided into well defined steps which are then reported step by step to the steering committee. Such reporting does not always have to be done through formal progress reports; in most cases, it may be sufficient to have the main progresspoints written down. The general progress report can be made by way of verbal presentation to the steering committee. The purpose of such progress reports is to brief the members of the steering committee on the activities that have been carried out by the working group and of the direction the study is taking. All changes from the main project plan and all the preliminary decisions of the working group on questions that have arisen during the course of the study must be reported on, since it is the steering committee that has to decide on these matters.

The progress reports of the working group can be used as building blocks for the draft final report. In principle, the working groups are responsible for writing the draft final report of their activities, together with the appropriate recommendations. The steering committee evaluates the final report and writes its own covering report with a short account of the main steps of the study and its own conclusions and recommendations.

The covering report of the steering committee should be short. It should refer to the final report for all details, but should include the main conclusions and recommendations of the steering committee, to be approved by the participating organizations.

For complex studies with several working groups and final reports, the steering committee has to decide if it will collect these reports and send them with a covering report of the conclusions and recommendations to the participating organizations, or if it will send each report together with its own separate covering report, with, possibly, an extra integrated final report of the steering committee at the end of all the substudies.

3.8 Evaluation

Three forms of evaluation are recommended for an integrated area risk assessment study. During the course of the study, the steering committee should evaluate whether the work carried out by the working groups and by itself is in agreement with the stated objectives of the study.

The second form of evaluation relates to the results of the integrated risk assessment as a basis for formulating an integrated risk management strategy. In this case, the evaluation should focus on whether the results of the assessment process have provided the relevant basis for formulating management, policies and strategies.

The third form of evaluation relates to the total resources committed to the study and its subsequent risk management policy development. This evaluation should preferably be carried out some time after implementation of the policy. It can lead to a new, improved and adapted cycle of the whole study process, placing more emphasis on certain points, that were not covered well enough by the study, or which need to be updated.

ANNEX I

Guideline on Content of Case Study Proposal

This Annex provides general guidance concerning the range of information to be addressed when formulating the proposals for an integrated risk assessment study. The details of such information would vary for different situations and conditions.

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- Agencies
- Universities
- Research Organizations
- Consulting Engineering

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5. Milestones Flowchart

References

United Nations Environment Programme

World Health Organization

International Atomic Energy Agency

United Nations Industrial Development Organization

Inter-Agency Programme on the Assessment and Management of Health and Environmental Risks from Energy and Other Complex Industrial Systems

PROCEDURAL GUIDE FOR INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

Volume II

Methods and Procedures for Health and Environmental Risk Assessment

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PROCEDURAL GUIDE

FOR

INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

VOLUME II

METHODS AND PROCEDURES FOR HEALTH AND ENVIRONMENTAL RISK ASSESSMENT

United Nations Environment Programme
World Health Organization
International Atomic Energy Agency
United Nations Industrial Development Organization

Information and Clarification concerning this document may be obtained from the following organizations

- United Nations Environment Programme
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- World Health Organization
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  CH-1211, Geneva 27,
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- International Atomic Energy Agency
  Division of Nuclear Safety
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- United Nations Industrial Development Organization
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PREFACE

There is a growing need to ensure that health, environmental and safety issues are addressed as an integral part of social and economic development. This can be achieved through an integrated approach to environmental risk assessment and safety management where all elements of risk are identified and assessed and where priority management actions are formulated in an integrated way. Recognizing the emergence of such needs, the United Nations Environment Programme (UNEP) within the framework of its programme on Awareness and Preparedness for Emergencies at Local Level (APELL), the World Health Organization (WHO), the International Atomic Energy Agency (IAEA) and the United Nations Industrial Development Organization (UNIDO) have joined efforts to promote and facilitate the implementation of integrated risk assessment and management for large regional industrial areas. Such an initiative includes: the compilation of procedures and methods for environmental and public health risk assessment and the transfer of knowledge and experience amongst countries in the application of these procedures. The preparation of a procedural guide on integrated environmental risk assessment and management is part of the initiative.

This Procedural Guide provides a reference framework for the undertaking of integrated environmental risk assessment for large industrial areas and for the formulation of appropriate safety and risk management strategies for such areas.

This guide is presented in four inter-related volumes:
Volume I outlines the organization and management issues associated with the process of integrated risk assessment studies; **Volume II** (this document) presents the methods and procedures for health and environmental risk assessment; **Volume III** highlights the different elements of integrated risk management; and, **Volume IV** specifies the documentation requirements.

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VOLUME I: ORGANIZATION AND MANAGEMENT OF THE INTEGRATED RISK ASSESSMENT STUDY PROCESS

VOLUME II: METHODS AND PROCEDURES FOR HEALTH AND ENVIRONMENTAL RISK ASSESSMENT

VOLUME III: ELEMENTS OF INTEGRATED RISK MANAGEMENT FOR LARGE INDUSTRIAL AREAS

VOLUME IV: DOCUMENTATION REQUIREMENTS FOR INTEGRATED RISK ASSESSMENT STUDIES FOR LARGE INDUSTRIAL AREAS

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PROCEDURAL GUIDE FOR INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

VOLUME II

METHODS AND PROCEDURES FOR HEALTH AND ENVIRONMENTAL RISK ASSESSMENT

CHAPTER 1

HAZARDS IDENTIFICATION SCHEME FOR AREA RISK ASSESSMENT

PROCEDURAL GUIDE FOR INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

Volume II

Methodological Procedures for Integrated Risk Assessment for Large Industrial Areas

<u>Chapter 1:</u> <u>HAZARDS IDENTIFICATION SCHEME FOR AREA RISK ASSESSMENT</u>

The delineation of the study area and identification and prioritization of the most relevant plants, processes and activities for hazard analysis, are critical first steps in the area risk assessment process. This chapter outlines the key factors and the associated procedures in that regard.

The contents of the chapters are based on information compiled by: Mr. E. Blokker (Netherlands), Mr. P. Dryden (Australia) and Mr. J. Clifton (United Kingdom).

The user should also refer to the method for risk classification and prioritization <u>'A Manual for Classification and Prioritization of Risk from Major Accidents in Process and Related Industries'</u> prepared for the Inter-Agency Organizations should also be consulted.

1.1 Key Factors to be Considered in the Selection of the Study Area

The crucial first step in the area risk assessment and management process is the delineation of an appropriate area. The appropriate basis for area selection will depend on the particular circumstances of each case. There cannot be any absolute rules. Any definition of study area will inevitably be arbitrary to an extent. However, several factors which should be considered can be suggested:

- The area should be selected for its physical and industrial / economic characteristics not on administrative boundaries.

- It should be defined on the basis of the facilites and systems of concern and the potential areas that can be directly affected.

- Hard boundaries should not be drawn before the initial hazard analysis as the area which may be affected will not have been identified.

- Outlying/stand alone activities within the same air or watershed should be considered for inclusion.

- Where an entire system, such as a coal-fired power station is to be included, components of the system, such as mines, may lie significantly outside the area. In such cases relevant generic information rather than specific analysis of that component may be more appropriate.

- As the ultimate aim of the exercise is risk management, it is important that as many of the authorities with risk management roles or relevant information be involved as possible.

- Transport systems used for the movement of hazardous materials to and from the area may need to be considered for some distance outside the core study area.

- Some risk sources will have potential for effects well beyond the immediate area. In such cases the analysis may need to take account of local effects and seperately of wider regional or global effects.

1.2 Basic Information on the Area

For the specific plant identification processes some background information is required. The desirable set of information includes:

(i) General Environmental Quality

- Air-Average and peak concentrations of SO_2, NO, CO, dust and any other pollutants of concern in industrial, urban and rural areas.

- Water-General water quality including drinking water

- Land-Deposits of acid, nitrates, fluorides, heavy metals

(ii) Geographical Information

- Demography, Population density and distribution
- Main transportation routes.
- Topography
- River systems and other waterways
- Climatic and meteorological data
- Actual and intended land use and zoning
- General location of industrial facilities

1.3 Types of Activities to be Considered

The following list, which is by no means exhaustive, gives an indication of the types of activities which should be considered for inclusion in the initial identification stage of the study. The initial list gives the types of activities to be considered, further details of each type of activity are then given to illustrate that a wide range of activities may pose a hazard. (Note: the types of activities are listed in alphabetical order and not in any order of priority.)

- Agriculture
- Biochemicals and pharmaceuticals
- Defence
- Explosives and Fireworks
- Food and Drink
- Gas Works
- Manufacturing
- Metal Production
- Mining and Quarrying Primary Products
- Other Nuclear
- Petrochemicals, Chemicals
- Pipelines
- Power Generation and Distribution
- Research
- Storage
- Transportation
- Waste Treatment Disposal
- Water Treatment

Agricultural Activities: intensive agricultural operation involving the use/application of chemicals and/or generation of significant quantities of problem wastes.

Biochemicals and Biotech and Pharmaceuticals: production and storage of biochemicals and pharmaceuticals is of concern as some of the materials used are highly biologically active and may be hazardous to people and other organisms. Combustion products may also be harmful. Chlorine, sulphur and solvents may be present in sufficient quantities to pose a hazard.

Defence: storage, manufacture and transport of ammunitions, explosives, fuels etc, and special transport systems including pipelines need to be considered.

Explosives and Fireworks: storage, handling and processing of industrial explosives, pyrotechnical devices and fireworks.

Food and Drink:

- Refrigeration plants in the food industry may use ammonia
- Distilleries will have flammables
- Breweries
- Edible Oil Processing (use of hexane)
- Food Processing (use of sulphur dioxide, formaldehyde, solvents)
- Dust Explosions (flour, sugar)

Gas Works: the main hazards here are those of explosions, fires and toxicity.

- Coal Gas production
- LNG facilities
- Gas distribution stations.

Manufacturing: manufacturing activities where the principle materials are not by themselves hazardous such as brickworks and glassworks may involve the storage of significant quantities of fuel, the utilisation of solvents and cleaning materials which are hazardous.

- Metal Works (carbonmonoxide, NO_x)
- Paint (hydrocarbons)
- Brickworks (fuel, fluorides)
- Glass Works (fluorides)
- Ship Yards (gases, acids)

Metal Production:

- Steel (CO, NO_x, SO_2)
- Aluminium (fluorides, cyanide wastes)
- Non-Ferrous Metals (solvents, trace metal emissions)

Mining, Quarrying other extraction and Primary Processing:

- Oil (explosions, fire,
- Gas air pollution,
- Coal waste,
- Metal use of explosives)
- Non-metallic Minerals

Other Nuclear:

- Processing/reprocessing plant
- Accelerators
- Irradiation plants (radioactive materials)
- Industrial uses
- Medical uses

Petrochemicals and Chemicals:

This category includes many products and processes such as distillation, halogenation, sulphurization. Some examples:

- Oil Refineries
- Plastics (ethylene, vinulchloride, acrylonitril)
- Solvents
- Biocides
- Fertilizer Production (ammonia, ammoniumnitrate, NO_x, hydrogen)
- Acids, Alkalis
- Detergents
- Bulk Chemical Production
- Ammonia Production
- Chlorine Production

Petrochemicals, Chemicals and related Installations

1. (a) Installation for the production of organic or inorganic chemicals using for this purpose, in particluar:
   - alkylation
   - amination by ammonolysis
   - carbonylation
   - condensation
   - dehydrogenation
   - esterification
   - halogenation and manufature of halogens
   - hydrogenation
   - hydrolysis
   - oxidation
   - polymerization
   - sulphonation
   - desulphurization, manufacture and transformation of sulphur-containing compounds
   - nitration and manufacture of nitrogen-containing compounds
   - manufacture of phosphorus-containing compounds
   - formulation of pesticides and of pharmaceutical products.

   (b) Installation for the processing of organic and inorganic chemical substances, using for this purpose, in particular:
   - distillation
   - extraction
   - sulphonation
   - mixing.

2. Installations for distillation, refining or other processing of petroleum or petroleum products.

3. Installations for the total or partial disposal of solid or liquid substances by incineration or chemical decomposition.

4. Installations for the production or processing of energy gases, for example, LPG, LNG, SNG.

5. Installations for the dry distillation of coal or lignite.

6. Installations for the production of metals or non-metals by a wet process or by means of electrical energy.

Pipelines: liquids, gases and possibly slurries (crude oil, gasoline, chlorine, ethyleneoxyde)

Power Generation and Distribution: SO_2 and NO_x emissions are of concern with conventional power plants. Also dusts and wastes containing heavy metals can form a hazard. Many plants store chlorine for the conditioning of cooling water. Electric generation systems are based on:

- Coal/Peat
- Oil
- Gas
- Nuclear

Transformer/Switchyards where transformer oils containing PCBs are involved could represent also a source of hazards.

Research Facilities: handling hazardous materials in significant quantities. Also natural or genetically engineered organisms, bacteria and viruses are of concern.

Storage: bulk and packaged storage of flammable, toxic and explosive gases, liquids and solids including materials with potential for production of toxic combustion products or dust explosions in tanks, silos, warehouses etc. For example:

- Bulk fuel
- Grain/flour silos (possibility of dust explosions)
- Biocides
- Plastics (combustion products)

Transportation of Hazardous Materials: trucks, trains and ships with hazardous materials pass often through densely populated areas. Transfer sites have often large quantities of such materials present. Road, rail, water(sea-going and internal) including transfer, marshalling yards, terminals, harbour facilities, isocontainer storage.

Waste Treatment and Disposal: hazardous wastes may be present at unsuspected waste treatment facilities. The waste can generate flammable gases.

- Landfill (methane, seepage of materials into ground water)
- Chemical, physical, thermal etc. treatment of wastes, incinerators
- Ship, tank cleaning etc. (rest contents of tanks, cleaning liquids)
- Waste water treatment (methane, hazardous liquids transported accidentally from a chemical plant)

Water Treatment: potential for bulk storage/use of water treatment chemicals especially chlorine.

1.4 Basic Information on Activities

In order to be able to identify possible hazards of the activities listed in the previous chapter, one must obtain information of a general nature for each activity:

(a) Fixed Facilities

- General description of the nature of activities at the site.
- Nature, type and quantity of substances being used (as main input and as auxiliary materials), processed, stored (including transportation vessels) and produced.
- What kind of materials are produced as waste, air emission and water emission: average and maximum quantities.
- Main methods of waste treatment and disposal.
- Transport of materials in and out (including pipelines).
- Number and type of transportation vessels with hazardous materials that can be present.
- Surrounding land use (activities, main roads and dwelling areas).

(b) Transport of Hazardous Materials

Use as the basis information to identify transported hazardous materials the UN list of hazardous materials. Identify the main modes and routes of transportation, if possible also main origins and main destinations. Road, rail, barge, ship, pipelines and conveyors as well as main transfer facilities should be considered. Special attention should be given to chlorine, ammonia, LPG and other liquified flammable gases; toxic gases; flammable liquids and gases.

1.5 Initial Hazard Identification

With the information collected in the previous steps an initial Hazard Identification can be carried out. For this the Table 1.1 should be filled in for each activity and for each hazard aspect. The hazard aspects are divided into two main categories. (i) hazards from accidents and other abnormal occurrences and (ii) hazards from normal operation. The subcategories of hazard are: acute fatalities, long term health effects, property damage and

	HAZARDS FROM ACCIDENTS AND OTHER ABNORMAL OCCURRENCES				HAZARDS FROM NORMAL OPERATION			
FACILITY| Activity	ACUTE FATALITIES	LONG-TERM Health	PROPERTY DAMAGE	BIOPHYS. AIR, WATER LAND	LONG TERM HEALTH	PROPERTY DAMAGE		BIOPHYS. AIR, WATER, LAND

Table 1.1

major economic damage, biophysical damage through the media air, water or land.

For each entry one should fill in one of the following labels: "yes", "no", or "maybe". Guidance for the factors to be considered for these choices is given hereafter.

The basic principles for initial hazard identification and prioritization of activities for further analysis are:

- Select the main activities for hazard analysis based on the quantity of hazardous materials handled, stored or transported. The criteria for quantities is the listing of notifiable installations in the Directive of the Council of the European Communities (CEC); and the Treshold quantities specified in the Dutch Labour Directorate.

- From the above, further prioritize activities for further analysis based on their location relative to populated areas. The criteria is a distance vs. quantity tabulation; and a hazard index approach.

1.5.1 Hazards from Accidents and other Abnormal Occurrences.

a) Acute Fatalities

Look at the total quantity of each hazardous material at the facility under investigation or in one transport unit.

Stationary Installations

Step 1. If the quantity is equal or greater than the quantity prescribed in the CEC Directive, use label "yes"; otherwise label "no". Appendix (1.1.) outlines the relevant information of the CEC Directive. If no, proceed to Step (2).

Step 2. Use a simplified classification based on the Dutch Labour Directorate treshold quantity values for different substances.

- Flammable substances > 10,000 kg
- Explosive substances > 1,000 kg
- Toxic substances: based on LC_{50}.

Table 1.5a provides the relationship between the treshold quantity and LC_{50}. Examples of toxic substances and threshold quantities are in table 1.5b.

If quantity of substance is equal or greater than the treshold quantity from above, label "may be", otherwise label "no".

Transport

Step 1. If the quantity is equal of greater than the treshold quantity indicated above, use label "yes". Otherwise use label "no".

b) Health and Long Term Effects

If specific categories of materials such as carcinogens, mutagens, teratogens, asbestos, combustion products are present use label "yes", otherwise, "no".

c) Property Damage and Economic Loss

If the following type of losses might occur fill in the following label "yes", otherwise "no".

- Structural damage/loss including corrosive and other effects on paints etc.
- Contamination
- Infrastructure loss/costs
- Factors of strategic significance, crucial plant loss
- Crops and stock losses.

d) Biophysical Damage (Air/Water/Land)

If the following type of damage could occur fill in one of the following labels: "yes", otherwise "no", in doubt "maybe".

- Possible destruction of large quantities of animals, plants or destruction of whole species
- Possible serious disruption or destruction of eco-systems
- Presence of materials such as biocides, PCBs, heavy metals,
- Possibility of crude oil spills etc.

1.5.2 Normal Operation

For normal operation the hazards are mainly caused by the regular emission of the hazardous materials to the air and water and by the disposal of waste.

Table 1.5a

MODEL-CALCULATION OF THRESHOLD-QUANTITY OF TOXIC SUBSTANCES

LC50 Ihl-rat, 1 hr mg/m3	Physical condition at 25 C	threshold quantity kg
LC ≤ 20 (4h)	not applied	1
20 <LC≤ 100	gas	3
	liquid (HV)	10
	liquid (MV)	30
	liquid (LV)	100
	solid	300
100 <LC≤ 500	gas	30
	liquid (HV)	100
	liquid (MV)	300
	liquid (LV)	1000
	solid	3000
500 <LC≤ 2.000	gas	300
	liquid (HV)	1000
	liquid (MV)	3000
	liquid (LV)	10000
	solid	- *)
2.000 <LC≤ 20.000	gas	3000
	liquid (HV)	10000
	liquid (MV)	- *)
	liquid (LV)	- *)
	solid	- *)
LC> 20.000	not applied	-

HV = high volatility, 25 C < boil.pt < 50 C
MV = medium volatility, 50 C < boil.pt < 100 C
LV = low volatility, boil.pt > 100 C

*)
Because of the combination of the dispersion possibilities and the acute toxicity no threshold quantity is determined.

Table 1.5b

EXAMPLES OF TOXIC SUBSTANCES AND THRESHOLD QUANTITIES

USED IN THE HAZARD INDEX SYSTEM

SUBSTANCE	THRESHOLD QUANTITY	TOXICITY-DATA	BOILING POINT
Acroleine	300	LC_{50} : 109.7 mg/m^3 1H	53
Acrylonitril	-	LC_{50} -1hour between 3 g/m^3 en 5 g/m^3	77
Aldicarb	1	LD_{50} ORL-RAT = 1mg/kg	indep.
Ammonia	3000	LC_{50} : 11590 mg/m^3 1H	-33
Arsine	30	LC_{50} : 369 mg/m^3 1H	-55
Azinphos-methyl	300	LC_{50} : 69 mg/m^3 1H	solid
Hydrogenbromide	3000	LC_{50} : 2858 ppm/1H	-67
Chlorine	300	LC_{50} : 293 ppm/1H	-34
Hydrogenchloride	3000	LC_{50} : 3124 ppm/1H	-85
Chromic acid	1000	LC_{50} : 0.35 g/m^3 1H	› 100
Hydrogencyanide	100	LC_{50} : 163 mg/m^3 1H	26
Dichloroethane /1.2-	-	LC_{50} : 28 g/m^3 1H	84
Dichlorovos	1	LC_{50} : 15 mg/m^3 4H	indep.
Dieldrin	1	LC_{50} : 3.8 mg/m^3 1H	indep.
Diethyl-S-ethionylmethyl-fosforthioaat /o.o-	1	LD_{50} ORL-RAT = 1mg/kg	indep.
Diethyl-S-(ethylthiomethyl)-thiofosfaat	1	LD_{50} ORL-RAT = 250 ug/kg	indep.
Dimefox	1	LD_{50} ORL-RAT = 1 mg/kg	indep.
Ethylchloroformiate	3000	LC_{50} : 145 ppm/1H	93
Ethyleneoxide	3000	LC_{50} : 10,95 g/m^3 1H	11
Fluor	30	LC_{50} : 185 ppm/1H	-188
Hydrogenfluoride	300	LC_{50} : 1276 ppm/1H	20
Formaldehyde	300	LC_{50} 1-uurs between 600 and 1000 mg/m^3	-21
Phosphine	30	LC_{50} : 361 mg/m^3 1H	-88
Phosgene	3	LC_{50} : 38 mg/m^3 1H	8
Furan	100	LC_{50} : 120 mg/m^3 1H	31
Methylchloroformiate	300	LC_{50} :88 ppm/1H	71
Methylisocyanate	1	LC_{50} : 5 ppm/4H	indep.
Mevinphos	1000	LC_{50} : 14 ppm/1H	solid
Monocrotofos	3000	LC_{50} : 162 mg/m^3 1H	125
Oxamyl	3000	LC_{50} : 170 mg/m^3 1H	solid
Ozon	1	LC_{50} : 4,8 ppm/4H	indep.
Parathion	1000	LC_{50} : 210 mg/m^3 1H	375
Pentaboraan	1	LC_{50} : 7 ppm/4H	indep.
Phoraat	1	LD_{50} ORL-RAT = 1 mg/kg	indep.
Promurit	1	LD_{50} ORL-RAT= 0,28 mg/kg	indep.
Nitrogendioxide	30	LC_{50} : 220 mg/m^3 1H	-21
Nitrogenmonoxide	300	LC_{50} : 924 mg/m^3 1H	-152
Nitrogentrifluoride	-	LC_{50} : 6700 ppm/1H	-129
Sulfurylfluoride	3000	LC_{50} : 3020 ppm/1H	-55
TCDD	1	LD_{50} ORL-RAT= 22,5 ug/kg	indep.
TEPP	1	LD_{50} ORL-RAT = 0,5 mg/kg	indep.
Tetraethyllead	10000	LC_{50} : 850 mg/m^3 1H	›100
Triethylenemelamine	1	LD_{50} ORL/RAT = 1 mg/kg	indep.
Sulphurdioxyde	3000	LC_{50} : 5,14 g/m^3 1H	-10
Carbonsulphide	-	A concentration of 20.5 g/m^3 during 1 hour no lethality	
Hydrogensulphide	300	LC_{50} : 898 mg/m^3 1H	-60
Sulphuric acid	-	LC_{50} : 3,6 g/m^3 1H	280

e) Long Term Health Effects

- Air: Major pollutant gases such as SO_x, NO_x, CO, O_3, NH_3, HCL, hydrocarbons, carcinogens such as benzene, toluene, fluorine, H_2S, dusts, particulates and fumes, CFCs and radioactive materials.

- Water: Biocides, heavy metals, phosphates, acids, nitrates, fertilisers, carcinogens, radioactive material

- Waste: hazardous waste disposal

If such emissions or waste are produced by the activity fill in the label "yes" for this entry, otherwise "no".

f) Property Damage

- Stock and crop loss including forests and fisheries

- Acid gas damage to buildings and monuments

- General quality of life, such as recreational activities (loss of access to beaches, fishing groundings).

If such damage may be caused by the emissions of the activity, fill in the label "yes", otherwise "no".

g) Biophysical Damage

- As for accident situation.

1.6 Setting Priorities for further Analysis

The completed table described in the previous section gives a first identification of the hazardous activities. **In principle all activities with label entries "yes" or "maybe" should be investigated further.** However, the number of such activities may in some cases be very large and it may be desirable to concentrate further only on some of the major activities. This section gives guidance for the selection and identification of the most important hazards for further analysis.

1.6.1 Accidents

a) Acute Fatalities

Step 1: If the activity falls within the distance corresponding to the different quantities, as indicated in table (1.6), label "yes". Otherwise label "may be" and proceed to step 2.

Step 2: For activities labelled "may be" from step 1 above, calculate the Potential Hazard Index (PHI) as a function of distance to the nearest population area. Figures (1.1a to 1.1c) indicate the relevant relationships to be applied.

If PHI(d) < 1 label "no"
If PHI(d) ≥ 1 label "yes"

All activities labelled "yes" should be further analyzed by way of quantified risk assessment.

b) Long Term Health Effects

Make the worst case accident scenario for the maximum number of people that can be affected, due to an accident.

c) Property Damage and Economic Loss

Make an attempt to quantify the possible damage by the worst case accident scenario.

d) Biophysical Damages

Make an attempt to quantify the area affected by the worst case accident scenario.

1.6.2 Normal Operation

Compare the ambient concentrations of major pollutants with the levels given in the WHO guides for air and water. Do this for industrial, urban and rural areas. If a level exceeds the concentration as given in the WHO guides, an important hazard has been identified.

Further, the total emission in the area can be calculated from the data of the number of emitters and the quantities each of them emits. Take the population density into account to determine approximately the number of people affected by too high ambient concentrations. For a worst case accident scenario assume extremely bad meteorological circumstances. Try a rough quantification of the damage per year by the different pollutants taken into analysis.

Potential Hazard Index

Quantities-Distance Calculations

Storage

Combustible

Installations in Buildings

$$PHI(d) = 10\ Q\ /\ d^{3}$$

PHI(d)-represents the Potential Hazard Index as a function of distance,d

Q-quantity of materials in kg,

d-distance to nearest populated area in meters

Fig. 1.12

Potential Hazard Index

Quantities-Distance Calculations

Storage

Explosive Materials

Installations in Buildings

$$PHI(d) = 100\ Q\ /\ d^3$$

PHI(d) - represents the Potential Hazard Index as a function of distance, d

Q - quantity of materials in kg,

d - distance to nearest populated area in meters

Potential Hazard Index

Quantities-Distance Calculations

Storage

Toxic Materials

Installations in Buildings

$$PHI(d) = 1000 \, (Q / Td^2)$$

PHI(d) - represents the Potential Hazard Index as a function of distance, d

Q - quantity of materials in kg,

d - distance to nearest populated area in meters.

T - the threshold quantity which varies with LC-50 (see Tables 1.5a and 1.5b)

Fig. 1.1c

TABLE 1.6 Suggested approximate separation distances for major hazard works

Substance	Largest tank size (t)	Separation distance (para. 7.3.) (m)
Liquefied petroleum gas, such as propane and butane, held at a pressure greater than 1.4 bar absolute	25- 40	300
	41- 80	400
	81-120	500
	121-300	600
	More than 300	1 000
	25 or more, only in cylinders or small bulk tanks of up to 5 te capacity	100
Liquefied petroleum gas, such as propane and butane, held under refrigeration at a pressure of 1.4 bar absolute or less	50 or more	1 000
Phosgene	2 or more	1 000
Chlorine	10-100	1 000
	More than 100	1 500
Hydrogen fluoride	10 or more	1 000
Sulphur trioxide	15 or more	1 000
Acrylonitrile	20 or more	250
Hydrogen cyanide	20 or more	1 000
Carbon disulphide	20 or more	250
Ammonium nitrate and mixtures of ammonium nitrate where the nitrogen content derived from the ammonium nitrate exceeds 28% of the mixture by weight	500 or more	See note [1]
Liquid oxygen	500 or more	500
Sulphur dioxide	20 or more	1 000
Bromine	40 or more	600
Ammonia (anhydrous or as solution containing more than 50% by weight of ammonia)	More than 100	1 000
Hydrogen	2 or more	500
Ethylene oxide	5-25	500
	More than 25	1 000
Propylene oxide (atmospheric pressure storage)	5 or more	250
(stored under pressure)	5-25	500
	More than 25	1 000
Methyl isocyanate	1	1 000
Classes of substances not specifically named		
1. Gas or any mixture of gases which is flammable in air and is held in the installation as a gas (except low-pressure gasholders)	15 or more	500
2. A substance or any mixture of substances which is flammable in air and is normally held in the installation above its boiling point (measured at 1 bar absolute) as a liquid or as a mixture of liquid and gas at a pressure of more than 1.4 bar absolute	25- 40	300
	41- 80	400
	81-120	500
	121-300	600
	More than 300	1 000
	25 or more only in cylinder or small bulk tanks or up to 5 te capacity	1 000
3. A liquefied gas or any mixture of liquefied gases which is flammable in air, has a boiling point of less than 0°C (measured at 1 bar absolute) and is normally held in the installation under refrigeration or cooling at a pressure of 1.4 bar absolute or less	50 or more	1 000
4. A liquid or any mixture of liquids not included in items 1-3 above which has a flashpoint of less than 21°C	10 000 or more	250

[1] For bagged ammonium nitrate stored in stacks of 300 t (maximum) a separation distance of 600 m is appropriate. For loose ammonium nitrate, the separation distance is given by–

$$600 \left\{\frac{\text{stack size (t)}}{300}\right\}^{1/3}.$$

Appendix 1.1
CEC Directive on Major Hazard

Indicative Criteria are given for the following classes of substances:

(a) very toxic substances:

- substances which correspond to the first line of Table 1.2;

- substances which correspond to the second line of Table 1.2 and which, owing to their physical and chemical properties, are, capable of producing major accident hazards similar to those caused by the substance mentioned in the first line.

(b) other toxic substances:

- are the substances showing the following values on line three of Table 1.2 of acute toxicity and having physical and chemical properties capable of producing major accident hazards:

(c) flammable substances:

(i) flammable gases (substances which in the gaseous state at normal pressure and mixed with air become flammable and the boiling point of which at normal pressure is 20° C or below);

Table 1.2

Toxicity / Case	LD_{50} (oral) mg kg body weight	LD_{50} (cutaneous) mg kg body weight	LC_{50} mgl (inhalation)
1	$LD_{50} \leq 5$	$LD_{50} \leq 10$	$LC_{50} \leq 0.1$
2	$5 < LD_{50} \leq 25$	$10 < LD_{50} \leq 50$	$0.1 < LC_{50} \leq 0.5$
3	$25 < LD_{50} \leq 200$	$50 < LD_{50} \leq 100$	$0.5 < LC_{50} \leq 2$

LD_{50} (oral) in rats
LD_{50} (cuteneous) in rats and rabbits
LC_{50} by inhalation (hours) in rats

(ii) highly flammable liquids (substances which have a flash point lower than 21° C and the boiling point of which at normal pressure is above 20° C);

(iii) flammable liquids (substances which have a flash point lower than 55° C and which remain liquid under pressure where particular processing conditions such as high pressure and high temperature may create major accident hazards).

(d) explosive substances

- substances which may explode under the effect of flame or which are more sensitive to shocks or friction than dinitrobenzene.

Isolated Storage; quantities given in Table 1.3 relate to each installation or group of installations belonging to the same manufacturer where the distance between installations is not sufficient to avoid, in foreseeable circumstances, any aggravation of major accident hazards; the distance between the installations is less than 500 metres.

Table 1.3

Substances or groups of substances *(Column 1)*	*Quantities (tonnes) ≤*	
	For application of Regulation 4 *(Column 2)*	*For application of Regulations 7 to 12* *(Column 3)*
Acrylonitrile	350	5000
Ammonia	60	600
Ammonium nitrate	500*	5000*
Chlorine	10	200
Flammable gases as defined in Schedule 1, paragraph (c)(i)	50	300
Highly flammable liquids as defined in Schedule 1, paragraph (c)(ii)	10 000	100 000
Liquid oxygen	200	2000*
Sodium chlorate	25	250*
Sulphur dioxide	20	500

*Where this substance is in a state which gives it properties capable of creating a major accident hazard.

The quantities given in Table 1.4 relate to each installation or group of installations belonging to the same manufacturer where the distance between the installations is not sufficient to avoid any aggravation of major accident hazards; the distance between the installations is less than 500 metres.

Table 1.4

Substance (Column 1)	*Quantity (for application of Regulations 7 to 12) (Column 2)*	*CAS number (Column 3)*	*EEC number (Column 4)*
Group 1-Toxic substances (quantity ≤ 1 tonne)			
Aldicarb	100 kilograms	116-06-3	006-017-00-X
4-Aminodiphenyl	1 kilogram	92-67-1	
Amiton	1 kilogram	78-53-5	
Anabasine	100 kilograms	494-52-0	
Arsenic pentoxide, Arsenic (V) acid and salts	500 kilograms		
Arsenic trioxide, Arsenious (III) acid and salts	100 kilograms		
Arsine (Arsenic hydride)	10 kilograms	7784-42-1	

Substance (Column 1)	*Quantity (for application of Regulations 7 to 12) (Column 2)*	*CAS number (Column 3)*	*EEC number (Column 4)*
Azinphos-ethyl	100 kilograms	2642-71-9	051-056-00-1
Azinphos-methyl	100 kilograms	86-50-0	015-039-00-9
Benzidine	1 kilogram	92-87-5	612-042-00-2
Benzidine salts	1 kilogram		
Beryllium (powders, compounds)	10 kilograms		
Bis (2-chloroethyl) sulphide	1 kilogram	505-60-2	
Bis (chloromethyl) ether	1 kilogram	542-88-1	603-046-00-5
Carbofuran	100 kilograms	1563-66-2	006-026-00-9
Carbophenothion	100 kilograms	786-19-6	015-044-00-6
Chlorfenvinphos	100 kilograms	470-90-6	015-071-00-3
4-(Chloroformyl) morpholine	1 kilogram	15159-40-7	
Chloromethyl methyl ether	1 kilogram	107-30-2	
Cobalt (powders, compounds)	100 kilograms		
Crimidine	100 kilograms	535-89-7	613-004-00-8
Cyanthoate	100 kilograms	3734-95-0	015-070-00-8
Cycloheximide	100 kilograms	66-81-9	
Demeton	100 kilograms	8065-48-3	
Dialifos	100 kilograms	10311-84-9	015-088-00-6
OO-Diethyl S-ethylsulphinylmethyl phosphorothioate	100 kilograms	2588-05-8	
OO-Diethyl S-ethylsulphonylmethyl phosphorothioate	100 kilograms	2588-06-9	
OO-Diethyl S-ethylthiomethyl phosphorothioate	100 kilograms	2600-69-3	
OO-Diethyl S-isopropylthiomethyl phosphorodithioate	100 kilograms	78-52-4	
OO-Diethyl S-propylthiomethyl phosphorodithioate	100 kilograms	3309-68-0	
Dimefox	100 kilograms	115-26-4	015-061-00-9
Dimethylcarbamoyl chloride	1 kilogram	79-44-7	
Dimethylnitrosamine	1 kilogram	62-75-9	

Substance (Column 1)	Quantity (for application of Regulations 7 to 12) (Column 2)	CAS number (Column 3)	EEC number (Column 4)
Dimethyl phosphoramidocyanidic acid	1 tonne	63917-41-9	
Diphacinone	100 kilograms	82-66-6	
Disulfoton	100 kilograms	298-04-4	015-060-00-3
EPN	100 kilograms	2104-64-5	015-036-00-2
Ethion	100 kilograms	563-12-2	015-047-00-2
Fensulfothion	100 kilograms	115-90-2	015-090-00-7
Fluenetil	100 kilograms	4301-50-2	607-078-00-0
Fluoroacetic acid	1 kilogram	144-49-0	607-081-00-7
Fluoroacetic acid, salts	1 kilogram		
Fluoroacetic acid, esters	1 kilogram		
Fluoroacetic acid, amides	1 kilogram		
4-Fluorobutyric acid	1 kilogram	462-23-7	
4-Fluorobutyric acid, salts	1 kilogram		
4-Fluorobutyric acid, esters	1 kilogram		
4-Fluorobutyric acid, amides	1 kilogram		
4-Fluorocrotonic acid	1 kilogram	37759-72-1	
4-Fluorocrotonic acid, salts	1 kilogram		
4-Fluorocrotonic acid, esters	1 kilogram		
4-Fluorocrotonic acid, amides	1 kilogram		
4-Fluoro-2-hydroxybutyric acid	1 kilogram		
4-Fluoro-2-hydroxybutyric acid, salts	1 kilogram		
4-Fluoro-2-hydroxybutyric acid, esters	1 kilogram		
4-Fluoro-2-hydroxybutyric acid, amides	1 kilogram		
Glycolonitrile (Hydroxyacetonitrile)	100 kilograms	107-16-4	
1,2,3,7,8,9-Hexachlorodibenzo-*p*-dioxin	100 kilograms	19408-74-3	
Hexamethylphosphoramide	1 kilogram	680-31-9	

Substance (Column 1)	*Quantity (for application of Regulations 7 to 12) (Column 2)*	*CAS number (Column 3)*	*EEC number (Column 4)*
Hydrogen selenide	10 kilograms	7783-07-5	
Isobenzan	100 kilograms	297-78-9	602-053-00-0
Isodrin	100 kilograms	465-73-6	602-050-00-4
Juglone (5-Hydroxynaphthalene-1,4-dione)	100 kilograms	481-39-0	
4,4'-Methylenebis(2-chloroaniline)	10 kilograms	101-14-4	
Methyl isocyanate	1 tonne	624-83-9	615-001-00-7
Mevinphos	100 kilograms	7786-34-7	015-020-00-5
2-Naphthylamine	1 kilogram	91-59-8	612-022-00-3
Nickel (powders, compounds)	100 kilograms		
Nickel tetracarbonyl	10 kilograms	13463-39-3	028-001-00-1
Oxydisulfoton	100 kilograms	2497-07-6	015-096-00-X
Oxygen difluoride	10 kilograms	7783-41-7	
Paraoxon (Diethyl 4-nitrophenyl phosphate)	100 kilograms	311-45-5	
Parathion	100 kilograms	56-38-2	015-034-00-1
Parathion-methyl	100 kilograms	298-00-0	015-035-00-7
Pentaborane	100 kilograms	19624-22-7	
Phorate	100 kilograms	298-02-2	015-033-00-6
Phosacetim	100 kilograms	4104-14-7	015-092-00-8
Phosphamidon	100 kilograms	13171-21-6	015-022-00-6
Phosphine (Hydrogen phosphide)	100 kilograms	7803-51-2	
Promurit (1-(3,4-Dichlorophenyl)-3-triazenethiocarboxamide)	100 kilograms	5836-73-7	
1,3-Propanesultone	1 kilogram	1120-71-4	
1-Propen-2-chloro-1,3-diol diacetate	10 kilograms	10118-72-6	
Pyrazoxon	100 kilograms	108-34-9	015-023-00-1
Selenium hexafluoride	10 kilograms	7783-79-1	
Sodium selenite	100 kilograms	10102-18-8	034-002-00-8
Stibine (Antimony hydride)	100 kilograms	7803-52-3	
Sulfotep	100 kilograms	3689-24-5	015-027-00-3
Sulphur dichloride	1 tonne	10545-99-0	016-013-00-X
Tellurium hexafluoride	100 kilograms	7783-80-4	
TEPP	100 kilograms	107-49-3	015-025-00-2
2,3,7,8-Tetrachlorodibenzo-*p*-dioxin (TCDD)	1 kilogram	1746-01-6	
Tetramethylenedisulphotetramine	1 kilogram	80-12-6	
Thionazin	100 kilograms	297-97-2	
Tirpate (2,4-Dimethyl-1,3-dithiolane-2-carboxaldehyde *O*-methylcarbamoyloxime)	100 kilograms	26419-73-8	
Trichloromethanesulphenyl chloride	100 kilograms	594-42-3	
1-Tricyclohexylstannyl-1*H*-1,2,4-triazole	100 kilograms	41083-11-8	
Triethylenemelamine	10 kilograms	51-18-3	
Warfarin	100 kilograms	81-81-2	607-056-00-0
Group 2-Toxic substances (quantity > 1 tonne)			
Acetone cyanohydrin (2-Cyanopropan-2-ol)	200 tonnes	75-86-5	608-004-00-X
Acrolein (2-Propenal)	200 tonnes	107-02-8	605-008-00-3
Acrylonitrile	200 tonnes	107-13-1	608-003-00-4
Allyl alcohol (2-Propen-1-ol)	200 tonnes	107-18-6	603-015-00-6
Allylamine	200 tonnes	107-11-9	612-046-00-4
Ammonia	500 tonnes	7664-41-7	007-001-00-5
Bromine	500 tonnes	7726-95-6	035-001-00-5
Carbon disulphide	200 tonnes	75-15-0	006-003-00-3
Chlorine	50 tonnes	7782-50-5	017-001-00-7

Table 1.4 cont.

Substance (Column 1)	Quantity (for application of Regulations 7 to 12) (Column 2)	CAS number (Column 3)	EEC number (Column 4)
Ethylene dibromide (1,2-Dibromoethane)	50 tonnes	105-93-4	602-010-00-6
Ethyleneimine	50 tonnes	151-56-4	613-001-00-1
Formaldehyde (concentration ≥ 90%)	50 tonnes	50-00-0	605-001-01-2
Hydrogen chloride (liquefied gas)	250 tonnes	7647-01-0	017-002-00-2
Hydrogen cyanide	20 tonnes	74-90-8	006-006-00-X
Hydrogen fluoride	50 tonnes	7664-39-3	009-002-00-6
Hydrogen sulphide	50 tonnes	7783-06-4	016-001-00-4
Methyl bromide (Bromomethane)	200 tonnes	74-83-9	602-002-00-3
Nitrogen oxides	50 tonnes	11104-93-1	
Phosgene (Carbonyl chloride)	20 tonnes	75-44-5	006-002-00-8
Propyleneimine	50 tonnes	75-55-8	
Sulphur dioxide	1000 tonnes	7446-09-5	016-011-00-9
Tetraethyl lead	50 tonnes	78-00-2	
Tetramethyl lead	50 tonnes	75-74-1	
Group 3 - Highly reactive substances			
Acetylene (Ethyne)	50 tonnes	74-86-2	601-015-00-0
Ammonium nitrate*	5000 tonnes	6484-52-2	
2,2-Bis(*tert*-butylperoxy)butane (concentration ≥ 70%)	50 tonnes	2167-23-9	
1,1-Bis(*tert*-butylperoxy) cyclohexane (concentration ≥ 80%)	50 tonnes	3006-86-8	
tert-Butyl peroxyacetate (concentration ≥ 70%)	50 tonnes	107-71-1	
tert-Butyl peroxyisobutyrate (concentration ≥ 80%)	50 tonnes	109-13-7	
tert-Butyl peroxy isopropyl carbonate (concentration ≥ 80%)	50 tonnes	2372-21-6	
tert-Butyl peroxymaleate (concentration ≥ 80%)	50 tonnes	1931-62-0	
tert-Butyl peroxypivalate (concentration ≥ 77%)	50 tonnes	927-07-1	

Substance (Column 1)	Quantity (for application of Regulations 7 to 12) (Column 2)	CAS number (Column 3)	EEC number (Column 4)
Dibenzyl peroxydicarbonate (concentration ≥ 90%)	50 tonnes	2144-45-8	
Di-*sec*-butyl peroxydicarbonate (concentration ≥ 80%)	50 tonnes	19910-65-7	
Diethyl peroxydicarbonate (concentration ≥ 30%)	50 tonnes	14666-78-5	
2,2-Dihydroperoxypropane (concentration ≥ 30%)	50 tonnes	2614-76-8	
Di-isobutyryl peroxide (concentration ≥ 50%)	50 tonnes	3437-84-1	
Di-*n*-propyl peroxydicarbonate (concentration ≥ 80%)	50 tonnes	16066-38-9	
Ethylene oxide	50 tonnes	75-21-8	603-023-00-X
Ethyl nitrate	50 tonnes	625-58-1	007-007-00-8
3,3,6,6,9,9-Hexamethyl-1,2,4,5-tetroxacyclononane (concentration ≥ 75%)	50 tonnes	22397-33-7	
Hydrogen	50 tonnes	1333-74-0	001-001-00-9
Methyl ethyl ketone peroxide (concentration ≥ 60%)	50 tonnes	1338-23-4	
Methyl isobutyl ketone peroxide (concentration ≥ 60%)	50 tonnes	37206-20-5	
Peracetic acid (concentration ≥ 60%)	50 tonnes	79-21-0	607-094-00-8
Propylene oxide	50 tonnes	75-56-9	603-055-00-4
Sodium chlorate*	250 tonnes	7775-09-9	017-005-00-9
Group 4 - Explosive substances			
Barium azide	50 tonnes	18810-58-7	
Bis(2,4,6-trinitrophenyl)amine	50 tonnes	131-73-7	612-018-00-1
Chlorotrinitrobenzene	50 tonnes	28260-61-9	610-004-00-X
Cellulose nitrate (containing > 12.6% nitrogen)	100 tonnes	9004-70-0	603-037-00-6
Cyclotetramethylenetetranitramine	50 tonnes	2691-41-0	
Cyclotrimethylenetrinitramine	50 tonnes	121-82-4	
Diazodinitrophenol	10 tonnes	7008-81-3	

Table 1.4 cont.

Substance (Column 1)	Quantity (for application of Regulations 7 to 12) (Column 2)	CAS number (Column 3)	EEC number (Column 4)
Diethylene glycol dinitrate	10 tonnes	693-21-0	603-033-00-4
Dinitrophenol, salts	50 tonnes		609-017-00-3
Ethylene glycol dinitrate	10 tonnes	628-96-6	603-032-00-9
1-Guanyl-4-nitrosaminoguanyl-1-tetrazene	10 tonnes	109-27-3	
2,2',4,4',6,6'-Hexanitrostilbene	50 tonnes	20062-22-0	
Hydrazine nitrate	50 tonnes	13464-97-6	
Lead azide	50 tonnes	13424-46-9	082-003-00-7
Lead styphnate (Lead 2,4,6-trinitroresorcinoxide)	50 tonnes	15245-44-0	609-019-00-4
Mercury fulminate	10 tonnes	20820-45-5 628-86-4	080-005-00-2
N-Methyl-*N*,2,4,6-tetranitroaniline	50 tonnes	479-45-8	612-017-00-6
Nitroglycerine	10 tonnes	55-63-0	603-034-00-X
Pentaerythritol tetranitrate	50 tonnes	78-11-5	603-035-00-5
Picric acid (2,4,6-Trinitrophenol)	50 tonnes	88-89-1	609-009-00-X
Sodium picramate	50 tonnes	831-52-7	
Styphnic acid (2,4,6-Trinitroresorcinol)	50 tonnes	82-71-3	609-018-00-9
1,3,5-Triamino-2,4,6-trinitrobenzene	50 tonnes	3058-38-6	
Trinitroaniline	50 tonnes	26952-42-1	
2,4,6-Trinitroanisole	50 tonnes	606-35-9	609-011-00-0
Trinitrobenzene	50 tonnes	25377-32-6	609-005-00-8
Trinitrobenzoic acid	50 tonnes	35860-50-5 129-66-8	
Trinitrocresol	50 tonnes	28905-71-7	609-012-00-6
2,4,6-Trinitrophenetole	50 tonnes	4732-14-3	
2,4,6-Trinitrotoluene	50 tonnes	118-96-7	609-008-00-4

Substance (Column 1)	Quantity (for application of Regulations 7 to 12) (Column 2)	CAS number (Column 3)	EEC number (Column 4)
Group 5 - Flammable substances			
Flammable substances as defined in Schedule 1, paragraph (c)(i).	200 tonnes		
Flammable substances as defined in Schedule 1, paragraph (c)(ii).	50,000 tonnes		
Flammable substances as defined in Schedule 1, paragraph (c)(iii).	200 tonnes	-	

*Where this substance is in a state which gives it properties capable of creating a major accident hazard.

Note (This note does not form part of Annex III to the Directive)

1. CAS Number (Chemical Abstracts Number) means the number assigned to the substance by the Chemical Abstracts Service, details of which can be obtained from the United Kingdom Chemical Information Service, University of Nottingham, Nottingham.

2. EEC Number means the number assigned to the substance by the Commission of the European Communities, details of which can be obtained from its office at 20 Kensington Palace Gardens, London W8 4QQ.

PROCEDURAL GUIDE FOR INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

VOLUME II

METHODS AND PROCEDURES FOR HEALTH AND ENVIRONMENTAL RISK ASSESSMENT

CHAPTER 2

ANALYSIS AND ASSESSMENT OF CONTINUOUS EMISSIONS

Chapter 2: ANALYSIS AND ASSESSMENT OF CONTINUOUS EMISSIONS

The purpose of this chapter is to highlight the main procedures for the assessment of health and environmental impacts from the continuous emissions of pollutants into air and water. The main procedural steps are supported by the most important methods of assessment as well as an overview of criteria and guidelines.

Information contained in the chapter is based on wide range of references, particularly contribution provided by the Biomedical and Environmental Assessment Division of Brookhaven National Laboratory, USA.

Complementary readings which are strongly suggested are: 'Management and Control of the Environment, WHO 1989' and 'Rapid Risk Assessment of Sources of Air, Water and Land Pollution, WHO 1982.

Chapter 2 - ANALYSIS AND ASSESSMENT OF CONTINUOUS EMISSIONS

2.1 Introduction

Continuous emissions include: air pollutants routinely emitted from smokestacks, tailpipes, and fugitive emissions from vents, open burning, etc.; water pollutants discharged to surface water from outfall pipes, routine overflow from waste ponds or lagoons, and non-point sources such as run-off from urban roadways; and emissions to ground water from landfill leachate, percolation from surface ponds and lagoons, leakage from pipelines, and discharges from injection wells.

Continuous emissions generally lead to exposures that create chronic, long-term risks. Acute health effects may also result. Extended meteorologic inversions, for example lead to acute exposures and acute effects from routine emissions. Continuous emissions to water more generally yield only chronic effects, but there can be exceptions. For example, contaminant concentrations built-up in river sediments over long periods may be released during storms that stir up sediments, resulting in acute, high-level exposure. Figure (2.1) outlines the general assessment framework.

The first step in analyzing continuous emissions is to identify their sources and to characterize their quantities and their physical and chemical properties. This is discussed in section 2.2.

The second step is to identify receptors and characterize the movement of pollutants from source to receptor, generally through the use of mathematical models. This is discussed in Sections 2.3 to 2.4. It requires that receptors, be they human populations or sensitive environments, be identified and located, and pathways from source to receptor be determined. Appropriate models are then established and exposures estimated. Ambient monitoring of pollution levels is helpful in guiding this process and in validating results of modeling. Modeling the transport of pollutants from source to receptor provides an estimate of exposure.

The next step is to identify or develop dose-response relationships between exposure and effects so that effects or risk may be determined. This is discussed in Section 4.5 for human health effects and in Section 2.6 for environmental effects. An overview of environmental guidelines and standards is given in Section 2.7.

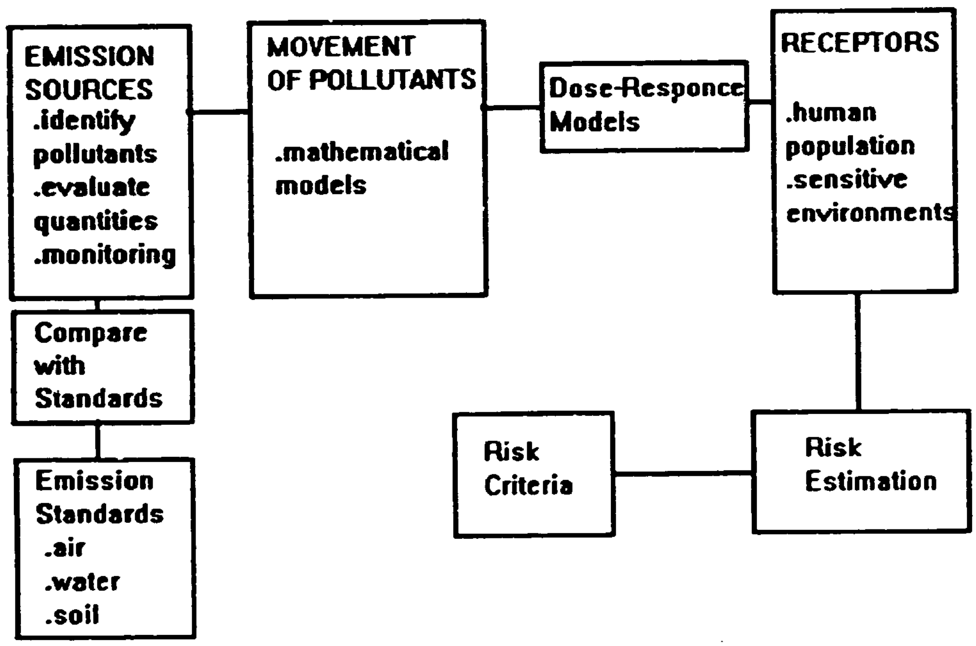

EMISSION
SOURCES
.identify
pollutants
.evaluate
quantities
.monitoring
MOVEMENT
OF POLLUTANTS
.mathematical
models
Dose-Responce
Models
RECEPTORS
.human
population
.sensitive
environments
Compare
with
Standards
Emission
Standards
.air
.water
.soil
Risk
Criteria
Risk
Estimation

Figure 2.1

2.2 Identification of Sources, Types and Quantities of Emissions

Estimates of sources, types, and quantities of gaseous, liquid, and solid emissions from industrial activities and energy systems are needed to evaluate their risks to health and the environment. Although there is a large compiled literature on a range of technologies and emission types (see Table 2.1), the World Health Organization (WHO 1983a; 1983b; 1988; 1989), the United Nations Environment Program (UNEP 1985) and others (e.g., OECD 1984) have found that in developing quantitative assessments of health and environmental effects, emissions data for a given technology in different countries vary. Principal reasons for these variations include differences in operating characteristics of fuel or material consuming devices, in fuel or material quality, or in regulatory-based pollution control requirements.

Table 2.1 Source Documents for Data on Emissions.

Citation	Title
Hittman 1974	Environmental Impacts, Efficiency and Cost of Energy Supply and End Use
Hubert et al., 1981	Les Impacts Sanitaires et Ecologiques de la Production D'Electricite - Le Cas Francais
Manthey et al. 1980	Energy Technology Data Handbook - Vol. I, Conversion Technologies
OECD 1984	Emission Standards for Major Air Pollutants from Energy Facilities in OECD Member Countries
The Aerospace Corporation 1981	Energy Technologies and the Environment
The Aerospace Corporation and Mueller Associates, Inc. 1983	Energy Technology Characterizations Handbook - Environmental Pollution Control Factors
The Science and Public Policy Program 1975	Energy Alternatives: A Comparative Analysis
UNEP 1985	The Environmental Impacts of Production and Use of Energy, Part IV: The Comparative Assessment of the Environmental Impacts of Energy Sources, Phase I: Data on the Emissions, Residuals and Health Hazards of Energy Sources
USEPA 1977	Compilation of Air Pollutant Emission Factors - Third Edition (Including Supplements 1-7)
USEPA 1980	Environmental, Operational, and Economic Aspects of Thirteen Selected Energy Technologies
USEPA 1986	Superfund Public Health Evaluation Manual
USEPA 1988	Superfund Exposure Assessment Manual
USEPA 1989	Risk Assessment Guidance for Superfund - Human Health Evaluation Manual Part A
WHO 1982	Rapid Assessment of Sources of Air, Water, and Land Pollution
WHO 1983a	Compendium of Environmental Guidelines and Standards for Industrial Discharges
WHO 1983b	Selected Techniques for Environmental Management - Training Manual
WHO 1988	Emissions, Environmental Transport, and Dose-Response Models: Guidelines for Case Studies
WHO 1989	Management and Control of the Environment

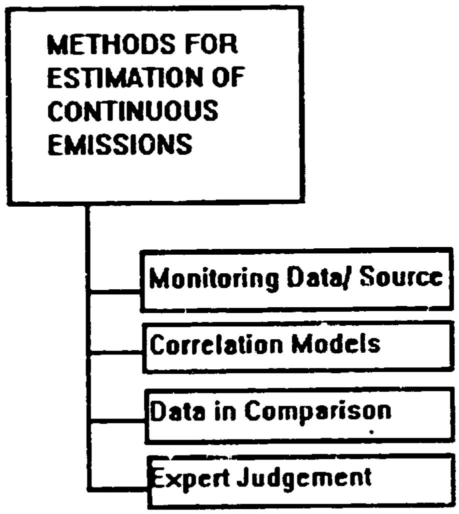

METHODS FOR ESTIMATION OF CONTINUOUS EMISSIONS
Monitoring Data/ Source
Correlation Models
Data in Comparison
Expert Judgement

Figure 2.2

Owing to these variations, country/technology specific emissions estimates are needed to increase the accuracy of any risk assessment effort. There are three principal approaches that can be used to develop estimates of routine or continuous emissions from a source; each has its own unique strengths and weaknesses (see Figure 2.2).

The **first method** consists of collecting monitoring data from an operational source. In such a case, monitoring equipments are used either on a continuous or intermittend bases to provide data specific to the process unit in question. Monitoring, however, requires substantial time and effort. Furthermore, if data are not collected over a long enough period of time, they may not be representative of the true emission characteristics because of time and process dependent variations. Monitoring may not be technically nor economically feasible in many cases.

A **second approach** is based on using theoretical or empirical equations correlating operating parameters to pollutant emissions rates. Stoichiometric estimates may be, however, erroneous because of inadequate specification or understanding of the process or knowledge.

The **third approach** is to use data compiled from other facilities and assume that the results are applicable to the facility in question. If coefficients are based on existing literature, questions will always remain about the accuracy and precision of the extrapolation.

The following Sections highlight information relevant to these methods.

The sections outline; data reporting protocols; potential information sources; sample emission coefficients for some energy processes; national emission standards in OECD member countries, and; demonstrate how to estimate coefficients of emissions.

Analysis and Assessment of Continous Emission

Step 1: Identify Sources of Continous Emission

Step 2: Characterize the Emission Source Inventory

2.1 If monitoring is available estimate pollution from different source terms by direct measurements.

2.2 If monitoring is not available or monitoring is not technically and environmentally feasible, then calculate emissions of different pollutant by means of conversion factors and the efficiency figures of the controlled polluation equipments.

2.3 If no measurement values are available, and monitoring not at hand use comparative values from similar situations in order to estimate emission values; check if the results of using these values are applicable to the facility under investigation.

Step 3: Select a pathway for analysis organized by a given receiving media; air, water, soil.

Step 4: Using models calculate dispersion values in the receiving media.

4.1 If air is the media where dispersion of pollutants occurs, then calculate concentration of pollutants under given weather conditions (see Para. 2.4.2) Go to step 5.

4.2 If water is the media where dispersion of pollutants occurs, then calculate concentration of different pollutants at some time instance and distance from the source of pollution (see Para. 2.4.3). Go to Step 6.

4.3 If soil is the media, evaluate the critical load and the exceedence of the pollutants in the given environment. Go to Step 6.

Step 5: For evaluating the concentration of pollutants as a time-distance function use atmospheric dispersion models.

5.1 For distances between on and about 50-80 km dispersion from a point source use simple Gaussian Plume Models (see Para. 2.4.2).

5.2 For complex meteorological conditions use Complex Gaussian Plume Models (see Para. 2.4.2).

Step 6: Use dose-response relationships to estimate the risk to the population; evaluate the health impacts.

Step 7: Use analytical methods or expert judgement for environmental impact assessment.

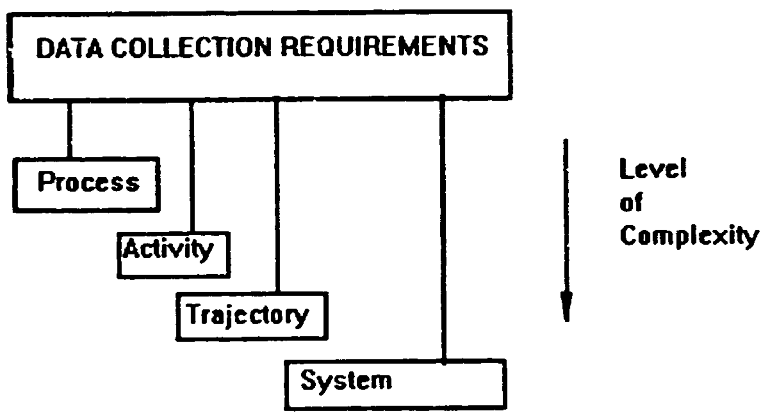

DATA COLLECTION REQUIREMENTS
Process
Activity
Trajectory
System
Level
of
Complexity

Figure 2.3

2.2.1 Data Reporting Protocols

Scope of Data

The scope of data to be compiled can vary by process and by pollutant. Processes being evaluated may need to be treated as one unified system, or as many independent subsystems. The degree of aggregation depends on the complexity of the facility in question, as well as on the degree of dependence among process operations. Facilities which tend to be more complex and composed of many semi-independent operations require more disaggregation than simple integrated operations. In general, this dichotomy parallels the difference between energy-related vs. industry-related activities. Energy-related activities tend to focus on the processing or combustion of a fuel in a unified way. Industrial operations, however, may include many loosely aggregated activities that must be evaluated independently.

As collection efforts are begun, some thought should be given to defining the system boundaries of interest (i.e., the back- and front-ends of the fuel and material supply cycles). In some instances, these contribute most of the emissions. Hence, the potential consequences of including or excluding them should be considered. As a general guide, complete cycles are often evaluated when systems are being compared, or when regional or national-scale analyses are being conducted.As the geographic or technologic scales of the analysis decrease, the value of including complete cycles diminishes.

Similarly, in assessing risks from these processes it might be appropriate to identify all pollutants from all alternatives. Practical limitations, however, quickly demand that effort be focused. Data collection could focus on any or all of the following (see Figure 2.3):

(i) pollutants for which there are acute (e.g., hydrogen sulfide) or chronic (benzo(a)pyrene) health effects;

(ii) pollutants that quantitatively dominate the waste streams (e.g., carbon dioxide from oil- or gas-fired steam electric power plants);

(iii) index pollutants (e.g., BOD or sulfur oxides);

(iv) pollutants for which there are environmental standards (e.g., lead in the atmosphere); and

(v) pollutants that are emitted routinely or accidentally (e.g., noble gases from nuclear steam electric power plant).

Emission coefficients may range from simple point estimates to complex models. In generating simple and complex coefficients for specific activities, many underlying predictors may need to be defined. In combustion-based systems, for example, the following types of information must often be specified:

(i) energy content of fuel;

(ii) moisture, sulfur, ash, and trace element (e.g., arsenic) content of fuel;

(iii) thermal efficiency of boiler;

(iv) temperature of exiting gases; and

(v) type and characteristics of pollution-control equipment applied.

In industrial-based systems, all the aforementioned information must be examined. In addition, rate of feedstock input and rate of product output may also need to be identified.

Format

In the technical literature, many formats are used to express emissions data for different processes:

(i) mass of pollutant per mass of fuel (g/kg);

(ii) mass of pollutant per mass of product (g/kg);

(iii) mass of pollutant per unit time (g/hr);

(iv) mass of pollutant per unit activity (g/km);

(v) mass of pollutant per unit of volume (g/m3); and

(vi) mass of pollutant per unit of energy input or output (g/J).

Reporting protocols differ, in part, for historical and regulatory reasons. In the U.S. and elsewhere (see OECD 1984), emissions are regulated as pollutant mass per unit of energy input (i.e., g/J) or as pollutant mass per unit of volume (g/m3). Emission standards for non-combustion sources associated with industrial activities span the range of reporting protocols listed above.

2.2.2 Data Sources

Information can be collected from government and private organizations, from compiled literature, from new engineering estimates, or from new measurements (see Figure 2.4). As noted by WHO (1982), "A major task of the study team is to locate all major government information sources and to extract the required data from them." Table 2.2 presents a partial list of possible sources of information. Undoubtedly, a sizeable portion of the required information available from these organizations will be in unpublished form. Therefore, some efforts will be needed to extract, process and classify useful information. The major difficulties with unpublished data are determining which are needed and then interpreting them. Often there is a danger of omitting important information if screening is not done carefully. But, complexity and resource requirements increase considerably if relatively unimportant data are retrieved and processed. Cross-checking collected data with information from other sources is often possible and highly desirable, since it is one way of insuring accuracy of the results. If important data from various sources are in significant disagreement, investigation of their original derivation often provides a good basis for formulation of the most accurate estimates.

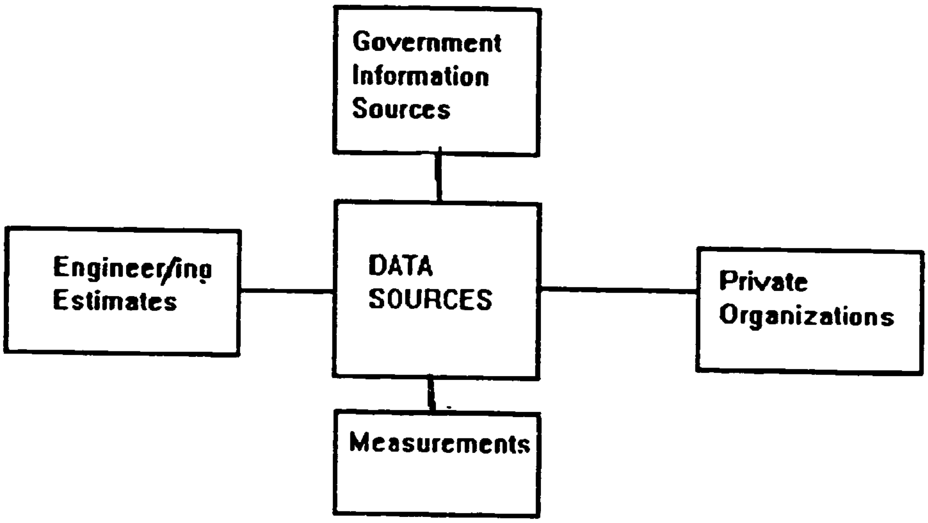

Government
Information
Sources
Engineering
Estimates
DATA
SOURCES
Private
Organizations
Measurements

Figure 2.4

Table 2.2 Possible Sources of Information [1]

Type of Data	Possible Sources
Industrial activity	Ministry of industry or commerce National planning/economic development agencies
Electric energy ministry, authority or company	Internal revenue agencies Local governments Industry associations Ministry of arimal production Air, water and solid waste pollution control authorities
Fuel consumption	Ministry of energy Ministry of industry Internal revenue agencies Refineries cr oil distribution companies
Rail & road traffic activity	Ministry of transportation
Air traffic activity	Airport authorities Ministry of transportation
Shipping activity	Port authorities Ministry of transportation
Water emissions	Oceanographic institute Ministry of health or environment River authorities Water pollution control authorities Ministry of fisheries Area planning agencies Local health departments Universities
Air emissions	Ministry of health or environment Air pollution control authorities Universities
Solid wastes	Local authorities Ministry of environment Private refuse disposal companies Area planning or development agencies
Occupational health	Ministry of health Local health departments Universities
Public health	Ministry of health Local health departments Universities

1. Modified from WHO 1982.

In the event that the agencies listed in Table 2 have not compiled the needed information, first-order approximations of the engineering and environmental characteristics for most energy systems and for most conventional air (e.g., PM, SOx, NOx) and water (e.g., TDS, BOD, pH) pollutants can be derived from several summary documents (see Table 2.1). Emission data on many industrial processes for conventional pollutants have been evaluated by WHO (1982) for the "Rapid Assessment of Sources of Air, Water, and Land Pollution" and by the U.S. Environmental Protection Agency (EPA) to establish air and water pollutant emission standards. Tables 2.3 and 2.4 summarize the industries and pollutants examined in the EPA efforts. EPA efforts have also focused on some toxic chemicals (Table 2.5).
More detailed characterization efforts may be required for any of the following reasons:

(i) development of site-specific case studies;

(ii) analysis of indigenous energy systems (e.g., peat or dung) or industrial activities that are not widely used; or

(iii) emission coefficients for nonconventional (e.g., toxic or hazardous) pollutants.

For these characterizations, data gathering efforts may need to focus on technical literature published by various research (e.g., U.S. Department of Energy) or regulatory organizations (e.g., U.S. Environmental Protection Agency), as well as by equipment manufacturers.

2.2.3 Compilation of U.S. Emission Factors

Table 2.6 gives emission coefficients for five conventional air pollutants (i.e., SOx, NOx, CO, HC, and TSP) for a range of energy systems. These are compiled from a report prepared for the U.S. Department of Energy (The Aerospace Corporation and Mueller Associates, Inc. 1983). Detailed documentation needed to define the bases for these numbers are contained in that report. Although these data provide some perspective on the coefficients for similar activities elsewhere, the true coefficients will differ, perhaps in major ways, for some or all of the following reasons:

(i) processes vary in their engineering characteristics (e.g., size, efficiency and temperature);

(ii) fuel supplies have different characteristics (e.g., heat, sulfur and ash content); and

(iii) pollution control equipment have different impacts (e.g., efficiency or on types of pollutants scrubbed).

Thus, extrapolation or direct application of these coefficients to other countries may introduce large errors unless these factors are examined.

Table 2.3 Industries for which U.S. Environmental Protection Agency New Source Performance Standards for Air Pollutants have been Developed.

Industry	Pollutants Regulated
Fossil-fueled steam generators	PM, SO2, NOx
Incinerators larger than 50 TPD	PM
Portland cement plants	PM, Opacity
Coal preparation facilities	PM, Opacity
Nitric acid plants	NOx, Opacity
Primary aluminum smelters	F, Opacity
Sulfuric acid plants	SOx, Acid Mist, Opacity
Asphalt concrete plants	PM, Opacity
Sewage sludge incineration	PM, Opacity
Iron and steel plants	PM, Opacity
Electric arc furnaces	PM, Opacity
Ferroalloy production facilities	PM, CO
Secondary brass and bronze ingot	PM, Opacity
Kraft pulp mills	PM, Total Reduced Sulfur
Petroleum refineries	PM, Opacity, CO, SO2
Storage vessels for petroleum	VOC
Secondary lead smelters and refining	PM, Opacity
Primary copper, lead and zinc	PM, SO2, Opacity
Phosphate fertilizer industry	F
Grain elevators	PM, Opacity
Ammonium sulfate manufacture	PM, Opacity
Lead acid battery manufacture	Pb, Opacity
Stationary gas turbines	NOx, SO2,
Glass manufacturing	PM
Phosphate rock plants	PM, Opacity
Synthetic organic chemicals	VOC
Pressure-sensitive tape and label coating	VOC
Auto and light truck surface coating operations	VOC
Asphalt processing and asphalt roofing manufacture	PM, Opacity
Rotogravure printing	VOC
Bulk gasoline terminals	VOC
Beverage can coating	VOC

Acronyms: PM = Particulate Matter; VOC = Volatile Organic Carbon

Table 2.4 Industries for which U.S. Environmental Protection Agency Pretreatment and Effluent Guidelines and Standards for Water Pollutants have been Developed.

Industry	Pollutants Regulated
Beet sugar	BOD, TSS, pH
Cane sugar	BOD, TSS, pH
Fiberglass insulation mfg.	Phenol, COD, BOD, TSS, pH
Sheet, plate and laminated glass	TSS, pH, O&G, P, F, Pb, Ammonia
Rubber processing	TSS, O&G, pH, BOD, COD
Asbestos mfg.	COD, TSS, pH
Meat products	BOD, TSS, O&G, Fecal Coliform, Ammonia
Phosphate mfg.	TSS, Phosphorus, As, pH, F
Fruit & vegetable processing	BOD, TSS, pH
Plastics & synthetics	BOD, COD, TSS, pH, Cr, Zn, Phenols, O&G
Nonferrous metals	TSS, F, Ammonia, Al, Cu, COD, pH, O&G, As, Cu, Pb, Cd, Se, Zn
Timber products	BOD, TSS, pH, Phenols, O&G, Cu, CR, As
Organic chemicals	COD, BOD, TSS, pH, Phenols, Cyanide
Leather tanning & finishing	BOD, TSS, O&G, Cr, pH, Sulfide
Petroleum refining	BOD, TSS, COD, O&G, pH, Phenols, Ammonia, Sulfide, Cr
Pulp, paper & paperboard mfg.	BOD, TSS, pH, Pentachlorophenol, Trichiorophenol, Zn
Builders' paper & roofing felt	BOD, TSS, pH, Pentachlorophenol, Settleable Solids, Trichlorophenol
Iron & steel mfg.	TSS, O&G, Ammonia, CN, Phenols, pH, Benzene, Naphthalene, Benzo(a)-pyrene, TRC, Pb, Zn, Ni, Cr, Tetrachloroethylene
Textiles	BOD, TSS, COD, O&G, Cr, pH, Phenol, Sulfide, Color, Fecal Coliform
Steam electric power plants	TSS, O&G, Cl, Cu, Fe, Cr
Paint formulating	No discharge of process waste
Ink formulating	No discharge of process waste
Paving & roofing materials	O&G, pH, TSS, BOD
Offshore oil & gas extraction	Produced water, deck drainage, Drilling muds, Drill cutting, Well treatment, Sanitary, Domestic, Produced sand
Mineral mining & processing	pH, TSS, F, Fe
Coal mining & processing	Fe, Mn, TSS, pH, Settleable Solids
Pharmaceutical mfg.	CN, COD, BOD, TSS, pH
Metal finishing	CN, Cd, Cr, Cu, Pb, Ni, Ag, Zn, TTO, O&G, TSS, pH
Coil coating	Cr, CN, Zn, Fe, O&G, TSS, pH, P, Mn, TTO
Porcelain enameling	Cr, Pb, Ni, Zn, Al, Fe, O&G, TSS, pH, Ammonia, Phenols, CN
Copper forming	Cr, Cu, Pb, Ni, Zn, O&G, TSS, F, pH, TTO, Cd, As
Aluminum forming	Cr, CN, Zn, Al, O&G, TSS, pH, TTO,
Ore mining & dressing	TSS, Fe, pH, Al, COD, As, Zn, Ra226, NH, U, Cd, Cu, Pb
Explosives mfg.	COD, BOD, TSS, pH, O&G

Table 2.4 (cont.)

Industry	Pollutants Regulated
Hospitals	
Gum & wood chemicals mfg.	BOD, TSS, pH
Photographic processing	Ag, CN, pH
Pesticide mfg.	COD, BOD, TSS, Organic Pesticides, pH
Electroplating	CN, Pb, Cd, Ni, Cr, Zn, Total Metals, TSS, pH Ag, TTO
Dairy processing	BOD, TSS, pH
Grain mills	BOD, TSS, pH
Canned & preserved seafood	BOD, TSS, O&G, pH processing
Cement mfg.	TSS, Temperature, pH
Feedlots	Fecal Coliform, BOD
Soap & detergent mfg.	BOD, COD, TSS, O&G, pH, Surfactants
Fertilizer mfg.	P, F, TSS, Ammonia, N
Phosphate mfg.	P, F, pH, TSS
Ferroalloy mfg.	TSS, Cr, Mn, pH, CN, Phenols, Ammonia
Asbestos products mfg.	TSS, pH, COD
Electrical & electronic components	TTO, F, pH, As, TSS
Inorganic chemicals	TSS, pH, Zn, Hg, Cu, Pb, Ni, Cl, TOC, CN, Cr, Fe, COD, Se, Ba, Sulfide, Ag

Acronyms: TSS = Total Suspended; COD = Chemical Oxygen Demand; BOD = Biological Oxygen Demand; O&G = Oil and Grease; TTO = Total Toxic Organics; TOC = Total Organic Carbon.

Table 2.5 Pollutants and Activities for which U.S. Environmental Protection Agency Hazardous Air Pollutant Emission Standards have been Developed.

Asbestos

- Asbestos mills
- Roadway surfacing
  - Manufacture of cloth, cord, wicks, tubing, tape, twine, rope, thread, yarn, roving, lap, or other textile materials, cement products, fireproofing and insulating materials, friction products, paper, millboard and felt, floor tile, paints, coatings, caulks, adhesives, plastics, rubber materials, chlorine, shotgun shells, and asphalt concrete
- Demolition and renovation

Beryllium

- Extraction plants, ceramic plants, foundries, incinerators, propellant plants, rocket motor test sites and machine shops

Mercury

- Stationary sources which process mercury ore to recover mercury, use mercury chlor-alkali cells to produce chlorine gas and alkali metal hydroxide, and incinerate or dry wastewater treatment plant sludge

Vinyl Chloride

- Plants which produce ethylene dichloride by reaction of oxygen and hydrogen chloride, vinyl chloride by an process, and or one or more polymers containing any fraction of polymerized vinyl chloride.

Benzene

- Fugitive emission source, coke by-product plants

Radionuclides

- DOE facilities, NRC-licensed facilities, elemental phosphorus plants

Inorganic Arsenic

- Low and high arsenic copper smelters

Table 2.6 Emission Coefficients for Criteria Air Pollutants from Various Energy Technologies.[1]

AIR POLLUTANTS, tons/1012 BTU

TECH. ACTIVITY	SOx	NOx	CO	HC	TSP	Comments
Nuclear						
Open Pit Uranium Mining	0.43	0.25	0.00	0.02	0.27	Open pit mining of ore for fuel
Underground Uranium Mining	0.02	0.32	0.19	0.03	0.01	Underground mining of ore for fuel
Uranium Milling	0.01	0.41			5.40	Milling ore to yellowcake (U308)
Hexafluoride Conversion	1.30	0.46	0.01	0.04		Yellowcake to UF6
Gaseous Diffusion	197.00	51.80	1.30	0.50	51.80	Enrichment to 4% U-235
Gas Centrifuge Enrichment	0.46	0.37	0.01		0.02	Enrichment to 2-4% U-235
Fuel Fabrication	1.10	0.28	0.01			UF6 to UO2 fuel elements
Commercial Waste Repository	0.27	0.42	0.38	0.03	0.02	Construction & Operations Emissions
Coal						
Eastern Underground Mining	0.03	0.31	0.08	0.02	0.02	With preparation plant; diesel emissions
Eastern Surface Mining	2.55	3.50	7.30	2.27	1.81	With preparation plant
Western Surface Mining	0.32	4.80	0.97	0.30	0.96	With prep. plant; TSP incl. fugitive dust
Beneficiation	0.01	0.60	0.20	0.20	0.90	Cleaning process
Dedicated Rail, eastern	3.70	3.20	3.40	2.50	102.90	4 diesels, 90 trips/yr.
Dedicated Rail, western	5.00	4.40	4.60	3.60	140.00	4 diesels, 90 trips/yr.
Conventional Rail, eastern	2.60	2.90	0.50	2.00	102.00	1 diesel, 20 trips/yr;(other cargo)
Conventional Rail, western	3.50	4.00	3.70	2.70	138.40	1 diesel, 20 trips/yr;(other cargo)
Barge Transport, eastern	0.52	7.71	1.68	0.62	0.55	1 diesel tug, 22040 miles/yr.
Barge Transport, western	1.47	22.03	4.79	1.76	1.57	1 diesel tug, 26889 miles/yr.
Truck Transport, eastern	0.29	1.87	2.95	0.47	35.16	1 trailer, 1.2 x 106 net ton miles
Fluidized Bed, bituminous	1440.	366.00	56.00	15.00	138.00	Steam plant with emission controls
Fluidized Bed, subbitum.	1700.	582.00	90.00	30.00	146.00	Steam plant with emission controls
Coal-Oil Power Plant	1297.	648.00	40.00	18.00	144.00	40/60 mix (by wt.) coal/oil
Coal-Fired Plant, eastern	850.00	850.00	60.00	18.00	42.00	Mine-mouth steam plant; emission controls
Coal-Fired Plant, western	600.00	850.00	90.00	30.00	40.00	Conv. steam plant; emission controls
Petroleum						
Primary Oil Extraction	13.60	18.60	0.50	10.60	3.50	Emissions from drilling/production
Enhanced Oil Recovery	207.00	71.00	4.00	2.00	24.00	Recovery via steam injection
Offshore Oil Extraction	11.79	31.92	6.91	2.55	2.28	18 platforms; 4000 bbl/day
Crude Oil Storage				2.27		Lined salt-dome caverns
Oil-Fired Power Plant	3720.	432.00	49.30	9.80	410.00	Steam plant with emission controls
Gas						
Onshore Gas Extraction	1425.	84.70	1.90	0.60	1.90	120 gas wells
Offshore Gas Extraction	300.00	0.15	0.06	0.01		18 well platform; 88.7 x 106 cu. ft/day
Natural Gas Purification	0.01	40.90	0.00	0.36	0.16	Treatment prior to transmission
Natural Gas Pipeline	0.01	4.00	1.52	0.28		600 mile underground pipe
Liquified Nat. Gas Tanker	7.42	5.84	0.41	0.52	2.44	63,460 dead-wt-ton tanker
Underground Gas Storage	0.19	136.98	3.92	9.45		5000 acres; 6 x 1010 scf/yr capacity
Gas-Fired Power Plant	0.79	930.00	22.40	0.03	42.90	Conventional steam plant
Solar						
Residential Wood Stoves	32.30	134.65	29.098	28.15	565.00	Transport and fuel gas emissions
Industrial Wood-Fired Boiler	70.00	162.00	1300	325.00	79.60	Steam boiler with emission controls

1. Compiled from The Aerospace Corp. and Mueller Associates, Inc. (1983).

2.2.4 Emission Standards for Energy Facilities in OECD Countries

Table 2.7 gives emission standards for electric generating plants for OECD countries (OECD 1984). The base reporting protocols for these coefficients vary among the different countries. As discussed by OECD, simply reporting the standards on one uniform basis (i.e., ng/J input) may introduce error because of underlying assumptions that must be made (e.g., temperature and moisture content of the flue gas). There may be other variations such as actual vs. normalized stack conditions, or weighted vs. rolling averages. Consequently, comparisons among the different coefficients should be made with caution.

Table 2.7 Comparison of National Emission Standards for Electricity Generating Plants.[1]

Fuel/Country	Pollutant (tons/10[12])			
	TSP	SOx	NOx	
Solid				
Australia		122		
Belgium		171		
Canada		50	299	299
Denmark		73		
Germany		24	172	386
Greece		65		
Japan	49	267	201	
Netherlands	23	267	313	
New Zealand	60			
Sweden		17	116	325
United Kingdom		56		
United States	15	603	302	
Liquid				
Australia				
Belgium			2146	
Canada		50	299	150
Denmark		42		
Germany		21	195	194
Greece		65		
Japan	21	235	115	
Netherlands				
New Zealand				
Sweden			116	
United Kingdom				
United States			394	244
Gas				
Australia				122
Belgium				
Canada		50	299	100
Denmark				
Germany		2	12	123
Greece		65		
Japan		17	191	43
Netherlands				
New Zealand				
Sweden				
United Kingdom				
United States		340	86	

1. Adapted from OECD 1984.

Sample Calculations to Develop Emissions from Coal-Fired Power Plants.

Sulfur Oxide (SO_x) Case - combustion in Furnace

Step 1: Calculate the Coal Feed Rate required on a Daily Basis for Electricity Production
$B = P.h.q$ [t/day]

where: B represents the coal feed rate [t/day]
P - average value for the installed power in operation [MW]
h - daily number of hours of operation at power P
q - specific energy consumption (q = 0.35 - 0.4) [kg c.e./kwh].

Step 2: Calculate the SO_x Emission Factor for the Bituminous Coal combustion without Control Equipment
$E_{sox} = 17.24\ S$ [kg/t coal]

where: S represents the sulfur content of the burnt fuel

Step 3: Calculate the Daily SO_x Emissions due to Coal Burning without Control Equipment
$S_u = E_{sox}.B.10^{-3}$ [t/day]

Step 4: Calculate the Daily Sulfur Emissions with Control Equipment
$S_c = S_u\ (1-a)$ [t/day]

where: a represents the scrubber efficiency

Numerical Example:

If: P = 400 MW; h = 24 hours
q = 0.37 [kg.c.e/kwh]
S = 3%; a = 0.8

then: B = 400 x 24 x 0.37 = 3552 [tons/day]
S_u = 17.24 x 3 x 3552 x 10^{-3} = 184 [tons]
S_c = 184 (1-0.8) = 36.8 [tons]

SAMPLE CALCULATIONS TO DEVELOP EMISSIONS FROM PULVERIZED COAL BOILERS IN POWER PLANTS

TSP - Pulverized - Coal Boilers

Step 1:	Calculate Particulate Emissions from the Pulverized - Coal Boilers E_p = 7.25 A {kg/t coal]
where:	A represents the ash content of the fuel
Step 2:	Calculate Daily Uncontrolled Pariculate Emissions $P_u = E_p B 10^{-3}$ [t/day]
Step 3:	Calculate Daily Controlled Particulate Emissons $P_c = (A/100) (A_f) (B) (1-e)$ [t/day]
where:	A - ash content of the coal A_f- fly ash fraction (the usual value is 0.80) e - efficiency of the control device (e.g. the electrostatic precipitation)

Numerical Example:

If:	B = 3552 [t/day]; A = 8; A^f = 0.8, e = 0.995
then:	$P^u = 7.25 \times 8 \times 3552 \times 10^{-3} = 206$ [t/day] P_c = (8/100) (0.8) (3552) (1-0.995) = 1.137 [tons]

2.3 Establishing Media and Modes of Environmental Transfers

To estimate human exposure to hazardous substances, one must establish:

- a credible source and mechanism of release to the environment;
- a medium of transport through the environment;
- a point of potential human contact with the contaminated medium; and
- an exposure route at the contact point.

For continuous emissions, the mechanisms of release and the receiving media are generally known or can readily be determined. The human activities and potential routes of exposure at each possible contact point (immersion, breathing, eating, drinking, etc.) define the pathways that must be evaluated between source and recipient.

Selection of pathways for analysis is aided by professional experience and judgment. As a rule, pathways are selected to provide estimates of population-average exposures and maximum individual exposures.

Each realistic pathway from source to recipient represents a unique mechanism of exposure. In selecting pathways, especially those following accidents, it is easy to become overwhelmed with considerations of "what-if" scenarios that postulate extreme combinations of unlikely pathways and events. But little is accomplished by analyzing potential pathways of exceedingly low probability. The most extreme pathway scenario normally evaluated for continuous emissions is that of the "fence-post" or the "maximum individual," a person who, for example, lives his whole life at the boundary of a facility, drinks water from a well there, grows all of his food on a farm there, etc. Such an analysis is useful only to demonstrate that the highest conceivable exposures are not harmful, provided this is, in fact, the case. It is not useful for estimating actual health risk, since no such person normally exists, and the results can cause unnecessary public concern if they demonstrate potentially harmful exposures under these unrealistic conditions.

Some form of analysis involving realistic "maximum individuals," particularly any classes of especially sensitive individuals, is appropriate and useful. But care is required that the maximum scenario is quantitatively meaningful (i.e., its probability or its consequences are high enough to be worthy of attention).

Table 2.8 shows some typical maximum exposure points that might be evaluated.

The media and mode of environmental transfer of pollutants depend on:

- the medium into which they are initially released;
- the physical and chemical properties of the pollutants; and
- the pathway of transport and available opportunities for transferring from one medium to another.

Table 2.8 Typical Contact Points for Determining Maximum Exposure from Continuous Emissions.

Medium	Exposure Point	Exposure Route
Air	Nearest residence	Inhalation
	Nearest population magnet (school, shopping area, etc.	Inhalation
	(occupied) point of highest concentration	Inhalation
Surface water	Withdrawal point for drinking	Ingestion, dermal, inhalation
	Withdrawal point for agriculture	Inhalation, ingestion (food), dermal
	Nearest point for swimming/ contact sports	Ingestion, dermal
	Nearest point for fishing	Ingestion, (food)
Ground water	Nearest potable well	Ingestion, dermal, inhalation
	Nearest agricultural well	Inhalation, ingestion (food),
	Nearest well for other uses	Inhalation, dermal
Soil	Onsite	Dermal, ingestion
	Immediately adjacent to site (if restricted)	Dermal, ingestion
	Nearest cropland	Ingestion (food)

The first two factors can be determined directly from the emission source inventory, which is normally organized by receiving medium (air, water, land). The physical and chemical characteristics of the pollutants determine their transferability among media. The specific transfers depend on the presence of opportunities for transfer along transport pathways -- points of direct contact between air and land, air and water, etc. -- which are characteristics of the surrounding environment.

The receiving medium is often technology-specific; one technology may release a substance to the air and another competing technology may release the same substance or a transformation product (e.g., scrubber wastes) to water or land. From emission to air, heavy particles deposit rapidly to nearby surfaces on land or water. Lighter particles travel farther and deposit at lesser rates. Gases may deposit slowly or rapidly, depending on their reactivity with the surfaces they encounter. Many reactive gases change chemical and/or physical form in transit, which can change their despositional characteristics.

Emissions to water seldom reach the air, except for volatile substances like organic solvents. Mostly, these emissions change medium by direct deposition in bottom sediments, by uptake up and/or decomposition in the aquatic food chain, or by changing chemical and physical form during transport.

Materials deposited on land routinely enter surface and ground waters by runoff and leaching, and enter the air through direct volatilization, chemical or biological transformation (fire, bacterial decomposition, etc.), or resuspension. Rates are determined by the chemical and physical properties of the materials and the characteristics of their environment (e.g., rainfall, wind, permeability of soils, and cover).

The physical and chemical characteristics that are important in determining transfers among media are usually available in the environmental literature and are often included as part of the characterization of source terms or incorporated in standard environmental transport models. Expert judgment is helpful in selecting appropriate rate constants for less common pollutants. Rate constants are often complex functions of environmental conditions and can not necessarily be transferred from one environment to another without careful evaluation.

Some care must be taken in cases where a single indicator chemical has been selected to represent a broader class of pollutants. Indicators are often developed for different purposes; sometimes they are just substances that are easy to measure. A particular indicator may be useful for quantifying the presence of a class of pollutants in a source term, but the physical and chemical characteristics of the indicator may not provide a good representation of the transport and fate of that class of pollutants in the environment or the health effects of exposure to them. Expert judgment is helpful in determining the usefulness of a particular indicator chemical in all stages of a risk assessment.

Transfers of materials from one medium to another are normally treated as a loss to the supplying medium and a source to the receiving medium.

Deposition and chemical transformation rates are usually incorporated directly into environmental transport models (see below), and models need only be appropriately linked at the loss-source term.

2.4 Environmental Dispersion Models

In the absence of direct measurements of exposures produced by specific emissions, quantification of the pathway from emissions to effects (see Figure 2.5) must be made with models that simulate transport and transformation of materials in the environment. These models can range from the simplest of calculations done on hand calculators to state-of-the-art super-computer systems that solve coupled partial differential equations governing transport and transformation of pollutants.

Characteristics that must be considered in selection of a model for estimating pollution dispersion include:

- conditions under which materials are released;
- chemical and physical characteristics of the materials released;
- medium of transport;
- geophysical characteristics of the pathway;
- chemical and physical changes during transport;
- matching of model output to information needed in the application; and
- availability and cost.

Transport medium and materials released are major and obvious determining factors in the selection of appropriate models. Conditions of release include an important differentiation between routine-continuous and short-term accidental releases, which determine the time scale required for modeling and needs for probabilistic analysis.

For risk assessment, model selection is driven by the type of calculation required for estimating the effects under consideration. An application such as estimating environmental insults to a lake requires estimates of long-term (hours to seasons) average concentrations. Others, such as determining whether or not an explosive limit might be exceeded, require an estimate of peak concentration over a short time, perhaps seconds. Still others may require estimates of the area over which a regulatory contamination limit is exceeded. In some cases, estimates of coexisting concentrations of more than one pollutant may be required.

The conditions of release that must be considered cover a wide range, including physical and chemical form of the material, height of release and plume rise, smooth airflow or turbulence from nearby buildings or topography, still or flowing bodies of water, etc. These source conditions determine the initial dilution of the materials, maximum impacts, and constrain possibilities for mitigating effects.

Chemical transformations during transport can alter a toxic material from one form to another, to a harmless form, or from a harmless form to a toxic one. Analysts must determine whether this is important before models are selected. Similarly, removal mechanisms during transport can be significant and these mechanisms must be included in the capabilities of the selected models. Removal from one medium to another constitutes a source to the receiving medium and may expand needs for modeling to ensure comprehensive treatment.

Final and nontrivial considerations in selection of models for risk assessment are the practical ones of availability, costs of use, timeliness of results, etc.

There are cases in which scientific knowledge or resources available are inadequate to support a complete analysis. In such cases, analysts must use whatever limited information is available in estimating risks, including using models that must be extended beyond their normal range of validity. These kinds of uncertainty must be identified clearly.

2.4.1 General Types of Models

Risk assessment requires careful selection of suitable models for description of natural phenomena and effects of pollution exposure. Choice of models sometimes depends heavily on available data and the purpose of the analysis. Highly sophisticated models combined with inadequate data are surely the worst combination.

Keeping in mind the main goal of risk management, the final product must be a list of corrective measures that are feasible, rational and in line with social and economic objectives. It is the spatial and technological harmony of solutions within an all-encompassing rational plan that must be the base for efficient risk reduction.

In selecting risk assessment models, analysts should include evaluation of their ability to address key problems, such as:

- assessment of routine and accidental effects;
- establishing relationships between local, short-term effects and long-term goals;
- simultaneous evaluation of several different sources of risk according to different attributes;
- assessment of risks over time and the problem of discounting future risks and benefits;
- uncertainty analysis; and
- synergistic effects.

Various environmental dispersion or transport models are available. Some are based on purely ecological principles; others favor a balance between economic parameters and the corresponding ecological risk. They fall into three general categories based on transport medium:

- short- and long-range air quality models;
- water quality models of various types and scales; and
- terrestrial and aquatic food-chain models.

Selection of a suitable code must depend on the aims of the case study in which it will be used, and on an in-depth evaluation of the code's models, parameters, and implementation requirements, as well as verification of the adequacy of predicted results.

2.4.2 Atmospheric Dispersion Models

The goal of atmospheric dispersion modeling is to predict concentrations of pollutants as a function of time since release and position with respect to the release point. The initial release and its characteristics are called the "source term." The final outputs of dispersion models are derived from atmospheric concentrations and dispersion conditions, but they can be quite different according to the nature of the problem.

Meteorological dispersion models can be reduced to simple mathematical formulae. They can be lists of equations to be calculated by hand, single codes working on microcomputers, or more complex codes normally run on mainframe computers. Some even more complex codes require powerful super-computers, and considerable skill to run them. These complex codes are not normally available for routine risk assessment.

Selection of appropriate meteorological dispersion models depends in part on the relative proportion of large point sources of emissions to the total regional emissions. Dispersion within 50-80 km of one to a few large point sources is normally simulated with some form of plume model and results for these few sources are added. If there are many large point sources or widely distributed smaller sources, plume models are not appropriate and regional average dispersion models must be used. The U.S. Environmental Protection Agency has an especially useful guide for selecting appropriate air quality models from among a broad range of models that are in the public domain and available free as down-loadable code on a computer bulletin board system (SCRAMS) or at modest cost from the U.S. National Technical Information Service.

Simple Gaussian Plume Models. Over distances between one and about 50-80 kilometers dispersion from a point source can be described by Gaussian plume models. These models are derived from mathematical descriptions of the physical characteristics of dispersion in wandering plumes, and they produce an estimate of the concentration distribution throughout a plume as a function of a few source and meteorological characteristics. They require as inputs only a source term, an atmospheric stability category, and wind speed and direction. Estimated dispersion is governed by an increase in standard deviation with distance or by an increase in transfer time. Gaussian plume models assume the pollutant to be passive; they do not account for topography or changes in meteorological conditions. But they can accept exogenous variables such as release height, deposition parameters, and transformation kinetics. These models can be reduced to simplified nomograms giving dilution factors at various distances and they are available in easy-to-use microcomputer software packages.

One solution to the Gaussian equation yields the location and magnitude of maximum ground-level concentration, which is useful for estimating potential maximum exposure from a single source.

Elevated Point Source Dispersion

The Gaussian Dispersion Model used both in horizontal and vertical axes evaluates the dispersion of emissions from an elevated point source (it is assumed that no ground absorption or reaction take place) is given by:

$$C = \frac{Q}{2\pi\sigma_y\sigma_z u}\left[\exp\frac{-y^2}{2\sigma_y^2}\right]\left[\exp\frac{-(z-H)^2}{2\sigma_z^2} + \exp\frac{-(z+H)^2}{2\sigma_z^2}\right]$$

where: C - represents the ground level concentration on the centre line of the plume [kg/m^3], at location of coórdinate x,y,z

Q - gas release rate [kg/s]
H - height of source above ground level plus plume rise [m]
u - wind velocity [m/s]
σ_y, σ_z - horizontal and vertical dispersion coefficient respectively [m]
x,y,z - distance from source [m]
(x - downwind, y - crosswind, z - vertical)

For the urban D stability class conditions the parameters σ_y and σ_z as a function of x (in meters) are calculated with the following relations:

$\sigma_y(x) = 0.16\ (1 + 0.004\ x)$* * (-0.5)
$\sigma_z(x) = 0.14\ (1 + 0.0003\ x)$ * * (-0.5)

In case of different stability categories to determine the horizontal and vertical dispersion coefficients σ_y and σ_z as a function of distance from source one can use the monograms givenin Figures 2.6 and 2.7. The characteristics of different stability categories are given next.

Figure 2.6
Horizontal Dispersion Coefficients

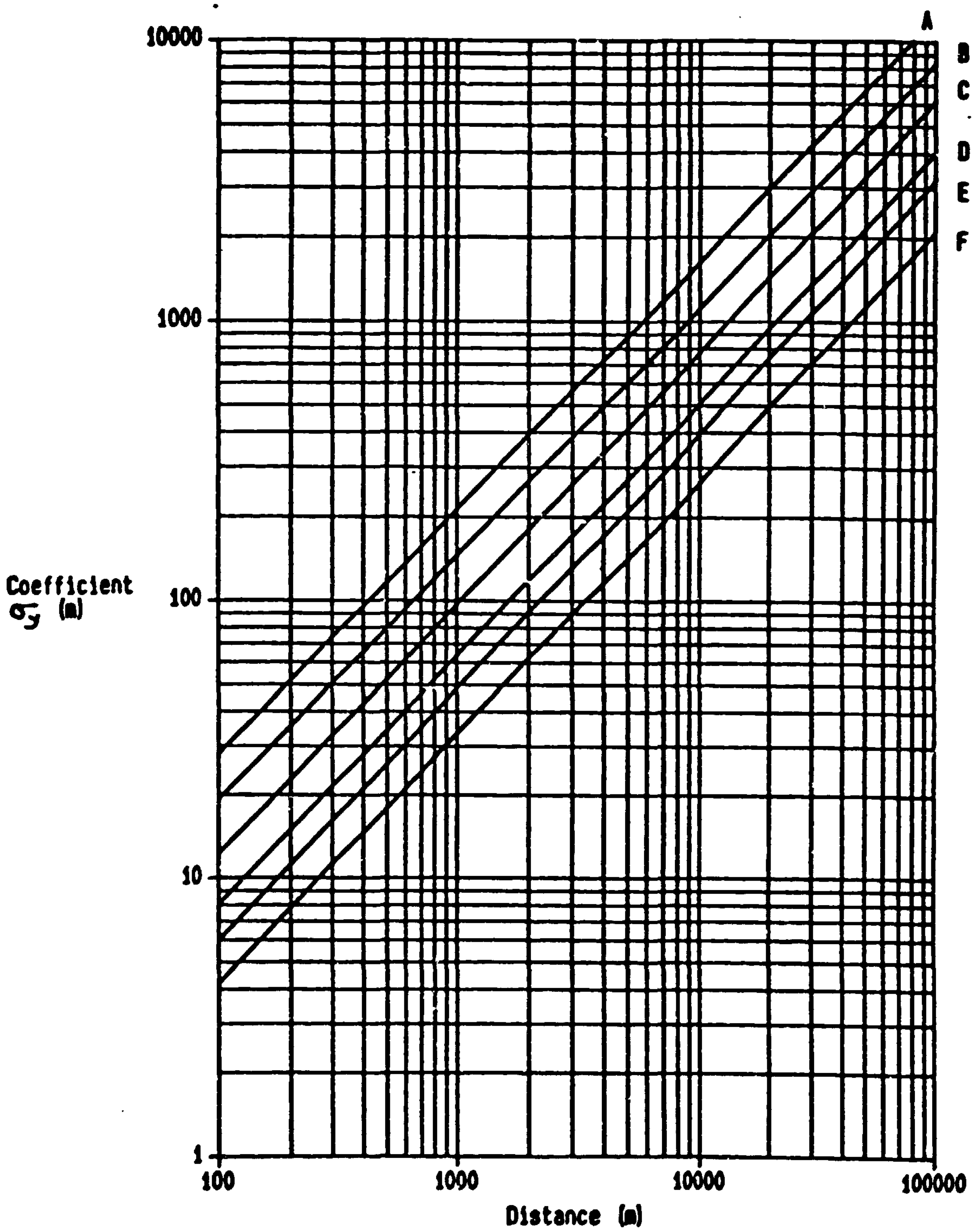
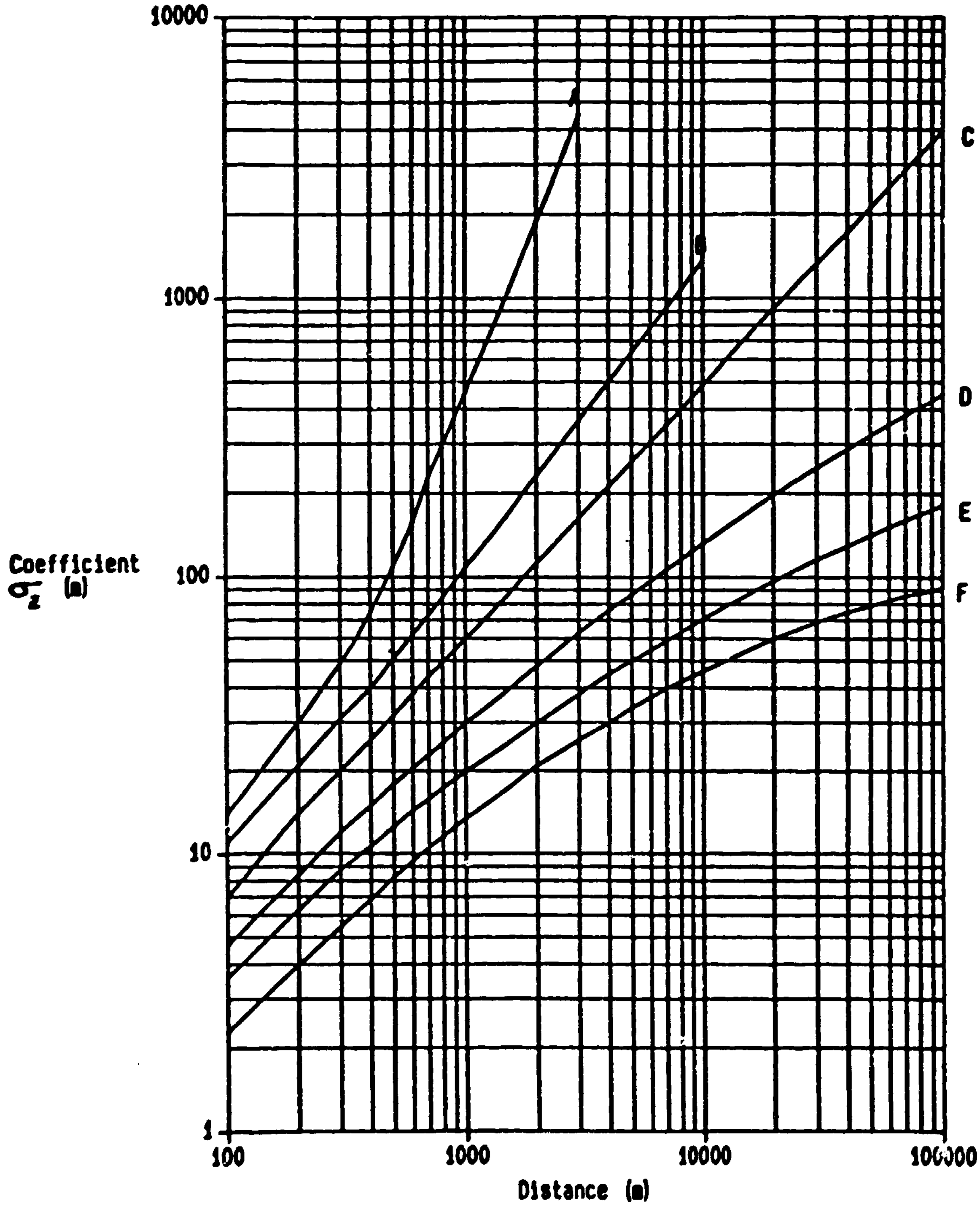


Figure 2-7
Vertical Dispersion Coefficients



Stability Categories

Stability Category	Wind Speed m/sec	Typical Description
A	1	very sunny and warm day
B	2	sunny and warm
C	5	partially cloud during day
D	5	overcast (day and night)
E	3	partially cloud during night
F	2	clear night

Elements of the Stability Categories

Surfaces wind speed (at 10m) meters/second	Heating from Sun			Sun	Sun
	Strong	Moderate	Slight	Thinly overcast or more than half low cloud	Clear up to half low cloud
< 2	A	A-B	B	-----	-----
2 - 3	A-B	B	C	E	F
3 - 5	B	B-C	C	D	E
5 - 6	C	C-D	D	D	D
6	C	D	D	D	D

Complex Gaussian Plume Models. These Gaussian plume models generally represent pollutants as puffs or a succession of puffs that are transported by wind trajectories within a varying meteorological field. The puffs expand in Gaussian fashion about a center, which is transported by local winds. Meteorological conditions and resulting puff expansion and transport are recomputed at fixed time intervals. Such models can account for orography, meteorological changes, and multiple sources (assuming additivity).

Another approach for estimating long-term pollutant exposure is to combine estimates of concentrations from Gaussian plumes over average conditions represented by wind roses showing annual distributions of wind speed, stability class, and frequency for points of the compass.

Puff Emissions

For the puff emissions the Gaussian formula for ground level concentration has the following form:

$$C = \frac{M}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z}\left\{\exp\left[-\frac{(x-ut)^2}{2\sigma_x^2}-\frac{y^2}{2\sigma_y^2}\right]\right\}\left[\exp\frac{-(z-H)^2}{2\sigma_z^2}+\exp\frac{-(z+H)^2}{2\sigma_z^2}\right]$$

where: M represents the amount released [kg]
t -time elapsed after release [s]

Puff emissions could develop different spreading characteristics; continuous plumes models have greater uncertainty. Because of lack of data, it is often assumed $\sigma_x = \sigma_y$

The above equations are applied to ideal point sources from which the vapors are released. More comples relationships are available in the literature. Simplified relationships to calculate the ground level concentration from an elevated point and for puff emissons are given next.

Situation	Relationship
1. Elevated Point Situation	$c = QF/\pi\sigma_y\sigma_z u$ c - ground level concentration on the centre line of the plume [m^3/m^3] F = exp (H**2/2σ_z** 2) F - stack correction factor H - height of stack or height of source above ground [m]; Q - gas release rate [m^3/s] σ_y, σ_z - horizontal/vertical dispersion coefficient [m] u = wind speed [m/s]
2. Puff emissions	$c = 2\,Q/\pi^{1.5} \cdot a_y\, a_z\, D^{(3-1.5n)}$ c - centerline concentration (m^3/m^3) Q - volume of gas release (m^3/m^3) a_y, a_z - diffusion coefficients of the gas dependent on weather/conditions n - turbulence parameter n.b. - concentration is independent of wind speed

Weather Category	A	B	C	D	E	F
a_y	.4	.37	.25	.21	.133	.105
a_z	.25	.21	.15	.12	.076	.06
n	.15	.2	.25	.25	.333	.5

These approaches have given rise to a series of models, some of which are available as microcomputer software packages and others of which are run only on mainframe computers. The latter are generally more flexible, and "tailored-to-fit" runs can be made for specific conditions of release and local meteorology and topography. These models can also cope with complex, time-dependent release patterns. It is still impossible, however, to include highly detailed site characteristics and to reconstruct exact trajectories for specific puffs.

Simplified Relations for Concentrations at Cloud Centre

Instantaneous Point Emissions (Short Bursts or Puffs)

a)	Lapse Condition (stability category A-B)	$c = 45Q/(ut)^{2.74}$
b)	Neutral Condition (stability category C-D)	$c = 131Q/(ut)^{2.62}$
c)	Inversion (stability category E-F)	$c = 493Q/(ut)^{2.47}$

t-represents time following emissions [sec]
Q-total quantity instantaneously released [m^3/m^3]
u-mean wind speed [m/s]
c-concentration at cloud centre [m^3/m^3]

Regional Air Quality Models. The simplest air quality models assume some linear relationship between regional average emissions and regional average concentrations.Coefficients are estimated during a monitoring period and applied to some future period when emissions are different.

The first of these was the Linear Roll-back Model used in the early days of air quality assessment to estimate the effect on regional air quality of regulating specific sources. This model assumed that all sources in a region contributed to measured regional average pollution concentration in direct proportion to their relative contribution to total regional emissions. Information on emissions from all sources was used to estimate an overall coefficient for concentration per unit emission from any source, and this coefficient was then used to estimate the change in concentration that would be produced by a change (increase or decrease) in emissions from each source. This modeling approach can be expanded to yield coefficients for seasons or for different meteorological conditions, but the basic idea remains the same.

These models require simple data and are exceedingly easy to use, but are useful only over a small range of changes from the observations and only for pollutants without complex atmospheric chemistry that makes the emission-concentration relationship non-linear. They contain no causal mechanisms that can be adjusted for new conditions.

The regional air quality model of the International Institute for Applied Systems Analysis (IIASA) is more sophisticated than linear roll-back, but is still easy to use. This model consists of an array of coefficients to be entered into a dispersion equation that is a simple function of the size of the area modeled. The coefficients were derived as generalizations of results from repeated runnings of more complex mathematical models under a broad range of representative conditions. The resulting equation yields ground-level concentration per tonne emission for:

- source height categories -- low, medium, and high; and
- meteorological conditions -- unstable, neutral, and stable, at windspeeds:

very low	<2 m/s
low	2-5 m/s
moderate	5-7.5 m/s
high	>7.5 m/s

The total emissions are apportioned out into each height and meteorological category by their relative frequencies, the appropriate coefficients are applied to the resulting array, and the results are added.

Other coefficients are provided for ratios between regional average concentration and peak concentration for a uniform emission density, for areas without pronounced centralization, and for areas with pronounced centralization of activities. These can be used to estimate maximum exposures. Default coefficients are provided for the three emission height categories to use for approximations in the absence of the necessary data on the frequency of meteorological conditions.

A broad range of more complex Lagrangian and Eularian regional wind-trajectory models is available from various government agencies and packaged in user-friendly formats by private computer software firms. These models are data-intensive, require considerable knowledge and experience to operate properly, and their relative applicability is problem-specific. Analysts should seek advice on these from experienced meteorological modelers.

2.4.3 Aquatic Dispersion Models

The aquatic environment can be divided into a number of sub-regimes, each requiring a different kind of model:

- surface waters
  seas, lakes and reservoirs
  estuaries
  rivers and canals
  surface runoff of rain

- subsurface waters
  stationary
  flowing

Except for the simplest of water bodies, modeling water quality is sufficiently complex that it must be computerized. Many models are available as general-purpose computer software packages that can be configured by users for specific bodies of water. A few simple screening-type models are available that can estimate maximum allowable loadings of important conservative and non-conservative pollutants, but can not estimate concentrations as a function of source strength. These are described below.

Surface Models. Models of surface water contamination are either steady state or time-dependent. They vary in complexity, containing two or three dimensions, with or without convection, and with or without sinks. The simplest models are no more than solutions to simple equations that use mixing ratios (perhaps time dependent) and some removal constants. These are usually sufficient only for routine effluents, and can lead to gross estimation errors even in simple cases. Table 2.9 summarizes examples of available models used to assess exposure to radionuclides listed from simple to complex.

Table 2.9 **Examples of the Range of Models used to Evaluate Changes in Concentration of Radionuclides in Aquatic Environments.**

Type	Comments	Application	Assumptions
Box Models	Lakes Impoundments	Used to predict ^{90}Sr in Great Lakes	Completely mixed above and below Thermocline
Time Dependent Box	Lakes	Used to predict Pu in Great Lakes	Completely mixed sith sediment interaction
Models	Rivers	Used to describe pesticides in rivers ^{137}Cs on Clinch river	Assumes river can be divided into a series of well-mixed compartments, includes equilibrium with suspended sediments
Simple Flow Models	Rivers	Applied to ^{3}H releases into Savannah River	Calculate dilution factors and radioactive decay
		Behaviour of ^{137}Cs	Estimates fraction absorbed to sediments
Two Dimensional Flow Models	Rivers	Applied to Missouri River water quality	Mixing with vertical variation in concentration and velocity averaged
		>>> Complicated Flow Models <<<	
One Dimensional	Rivers, Estuaries	Diffusion is not considered, since the cross-sectional area of the river is considered constant	Steady, one-dimensional convection equation with decay and source/sink terms
		Uses KD to simulate first-order exchange between sediment and water	Simulates transport of trace contaminants in dissolved form and on particles
		Couples water transport using three sub-models and has been used to simulate the behavior of ^{137}Cs, ^{90}Sr in Clinch River (see text)	Combines Wisconsin hydrologic transport model with a sediment transport model
Two Dimensional		Applied to canyons in Los Alamos National Laboratory to simulate migration of ^{239}Pu	Simulates transport of sediment and Dimensional contaminants with interactions
		Handles linear or quadratic transport and interaction of velocity and depth with sediment approximations disruption so as to be compatible with other hydrodynamic models	Finite element model including sediment of contaminant

	Has been used to predict migration of ^{238}Pu, Kepone	Includes advection and dispersion, longitudinal and lateral wave motion to resuspend sediments and sediment cohesion, sediment deposition and resuspension, sediment sources, and mixing
Three Dimensional	Applicable to cases of non-steady state flow particularly in estuaries; used to estimate bacteria distribution in the NY Bight	Numerical model that computes a velocity field from vertically integrated two-dimensional equation of mass and momentum conservation which then becomes advective mechanism
	Has been used to predict migration of ^{137}Cs in the Hudson River Estuary with K_D changing with salinity	Finite difference computing unsteady distribution of flow, water temperature salinity, sediment, dissolved contaminants and particulate contaminants

Unlike atmospheric dispersion models, many water quality models are not readily adjustable to conditions different from those for which they were designed. They tend to be highly site-specific. Thus, accommodating site-specific conditions may require gross revisions of existing models or use of models specifically designed to be general-purpose and easily configured by users.

Relatively simple, straightforward models are available for estimating concentrations in rivers and streams. More complex models are needed for lakes, reservoirs, and estuaries, because they are readily stratified and large enough to support complex patterns of flow. Subsurface models are simple in concept, but complicated in execution because of the potential complexity of the subsurface structures.

River models. Rivers are modeled as linked segments between nodes where there are important changes, such as a large discharge, a large intake, entry of a tributary, or a large change in the physical characteristics of the river. Within segments, all conditions are assumed constant except for the flow-controlled time of transit to the next downstream node. Non-conservative substances, such as decomposing organics and the associated oxygen uptake, pathogens, radionuclides with short half-lives, and substances with high deposition, biological accumulation, or chemical reaction rates, are estimated as a function of time while in each segment. Conservative substances accumulate between sources.

Some river pollution problems, for which maximum concentration is of special concern (such as heat), are modeled as plumes for short distances downstream of the discharge point.

Organic and nutrient loading of rivers are particularly important, and a broad range of helpful equations and models is available to assist in determining the self-purification capacity of a river and the maximum organic loading that can be accommodated while maintaining dissolved oxygen levels at specified minimum levels. Fair, et al., for example, have produced a useful nomograph from which allowable loading can be read directly.

Lake Models. Lakes are generally classified as oligotrophic (low nutrients, always oxygenated) and eutrophic (high nutrients, can become anoxic). Oligotrophic lakes tend to be nutrient limited and therefore do not support abundant growth of plants. Within limits, these lakes can absorb exogenous nutrients and oxidize organic material without damage.

Eutrophic lakes have large amounts of nutrients which support abundant growth of algae and other aquatic organisms. Dead plants and animals sink to the lower levels of these lakes, where decomposition by microorganisms depletes or eliminates oxygen, with associated killing of oxygen-dependent species. Eutrophic lakes cannot absorb large quantities of exogenous nutrients and organic materials without damage.

Oligotrophic lakes are usually phosphate-controlled. Vollenweider has developed a simple equation that can be used to estimate the loading of nutrient

LAKE MODELS

Model for Critical Phosphorus Loadings.

Phosphorus concentration is an important parameter which characterizes the oligotrophic lakes. Critical phosphorus load [mg P/m^2 yr] above which eutrophication conditions may begin to develop is given by:

$$L_c = 10^* q_s + [1 + \sqrt{Z/q_s}]$$

where: L_c - critical phosphorus load
q_s = Q/A - overflow rates [m/yr]
Z - lake mean depth [m]
Q - annual inflow rate [m^3/yr]
A - lake area [m^2]

Eutrophic conditions may be expected when the actual phosphorus load L equals 2 to 3 times L_c.

The maximum annual discharge of phosphorus B [t/yr] into the lake, above which eutrophic conditions may begin to develop is:

$$B = 10^{-6} L_c A$$

Value of B has to be used along with inventory results yielding the total anticipated phosphorus input load into the lake.

RIVER MODELS

Modelling the microbial pollution in streams is done by using an indicator organism such as coliform. A simple model used is:

$$N = N_o * \exp(-k^* t)$$

where: N represents the number of coliforms per 100 ml;
N_c - initial number of coliforms per 100 ml;
k - die - off rate constant per day (k = 1.0 .... 1.8 in medium sized ones at 10° C);
t - time [days]

The correction equation for a given temperature is:

$$k = (k)_{20} * 1.075 ** (T-20).$$

phosphates that can be added to an oligotrophic lake without reaching a critical level: eutrophications can be expected when phosphorous loading reaches two to three times the critical level.

Conservative substances in lakes can be modeled simply by assuming complete mixing and using a materials-balance equation.

Subsurface Models. Contamination of subsurface aquifers is modeled in two phases:

- vertical transport through the unsaturated zone; and
- plume-like spreading and transport through the aquifer.

Vertical transport of pollutants through the unsaturated zone above an aquifer is a function of the physical and chemical characteristics of the pollutant and the percolation characteristics of the soil. Many organic pollutants are relatively nonpolar and hydrophobic, so they tend to sorb into soils and migrate more slowly than polar pollutants. Inorganic chemicals can precipitate out. Some low-density organics can even float. Soils differ greatly in their physical and chemical characteristics and their interactions with specific pollutants.

Similarly, once in the aquifier, pollutants form plumes by diffusion and transport in gravity-driven water flow. Again, the rates of movement are controlled by the physical and chemical characteristics of the pollutant and the geohydrology of the aquifer. Modeling movement in sand is simple; modeling movement in fractured rock or solution cavities is orders of magnitude more complex.

Potentially important characteristics affecting subsurface movement of pollutants are shown in Table 2.10.

These characteristics are incorporated into models by combining a ground-water flow equation and a chemical mass transport equation. There are separate models for unsaturated and saturated zones, but they are often linked in comprehensive computer codes.

Table 2.10 Potentially Important Characteristics Affecting Subsurface Movement of Pollutants.

Boundary conditions	
	Distribution of hydraulic head
	Recharge and discharge points
	Locations and types of boundaries
Material constants	
	Hydraulic conductivity
	Porosity
	Transmissivity
	Extent of hydrogeologic units
Attenuation mechanisms	
	Adsorption-desorption
	Ion exchange
	Chemical complexting
	Nuclear decay
	Ion filtration
	Generation of gases
	Precipitation-dissolution
	Biodegradation
	Chemical degradation
Molecular diffusion and hydrodynamic dispersion	
	Transverse
	Longitudinal
	Vertical
Pollutant concentration	
	Initial and background
	Boundary conditions

So ground-water modeling would appear to be relatively straightforward. But the problem is the data.

It is common that the geophysical and hydrological characteristics that must be modeled vary by large amounts over short distances. And because sampling requires expensive drilling programs, data are often sparse.

Oil refineries placed on-shore sometimes on large industrial areas are the cause of environmental impacts due to normal or accidentatl conditions. Sources of effluents due to production activities are represented in Figure 2.8.

The impurities in effluent water are of the following sort:

- in solution (e.g. soluble salts and organic compounds)
- insoluble material (e.g. higher-molecular-weight oil fractions and suspended solids).

The mechanism of the fate of oil in the marine environment is represented in Figure 2.5 - certain elements of this mechanism are:

- evaporation
- dissolution
- adsorption
- entry into sediments
- hydrocarbons in marine lists.

Data gathering and applying associated models for this problem requires specialized information and knowledge.

These problems with data quality, plus the long time spans involved in ground-water movements, have hindered verification of models for ground-water transport. Most are not fully verified. The reliability of model results therefore depends heavily on site-specific conditions and analysts' ability to account for them adequately in the coefficients supplied to the models. Much professional judgment is required.

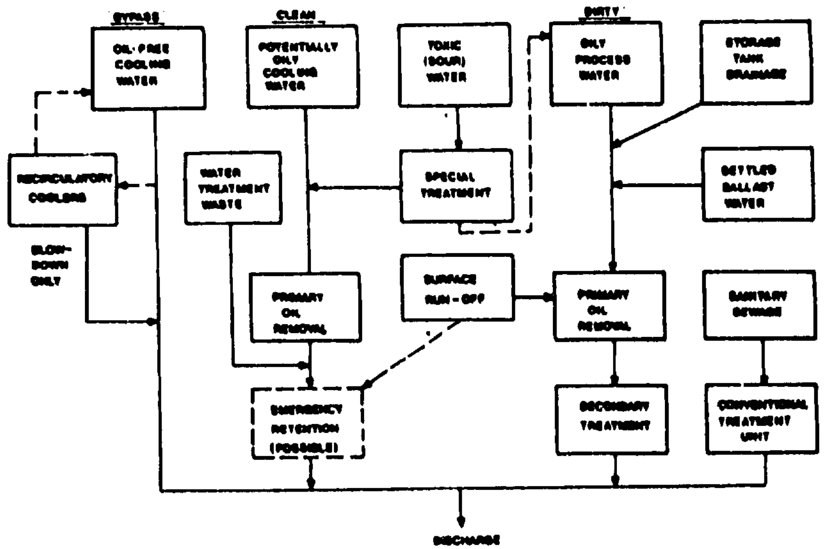

BYPASS
OIL-FREE COOLING WATER
CLEAN
POTENTIALLY OILY COOLING WATER
TOXIC (SOUR) WATER
DIRTY
OILY PROCESS WATER
STORAGE TANK DRAINAGE
RECIRCULATORY COOLERS
WATER TREATMENT WASTE
SPECIAL TREATMENT
SETTLED BALLAST WATER
BLOW-DOWN ONLY
PRIMARY OIL REMOVAL
SURFACE RUN-OFF
PRIMARY OIL REMOVAL
SANITARY SEWAGE
EMERGENCY RETENTION (POSSIBLE)
SECONDARY TREATMENT
CONVENTIONAL TREATMENT UNIT
DISCHARGE

Figure 2.8

2.4.4 Food Chain Models

Food chain pathways that should be evaluated can be determined from examination of diets, local sources of food, and the likely pathways for contamination of these foods. One special "food" that should be considered is ingestion of soil, which is common in children two through six years of age.

A large number of conceptual models and computer codes were developed recently for assessing human exposures to radionuclides in foods. Most of these models could also be adapted relatively easily to assess exposures to heavy metals, but not as easily to assess organic compounds or other pollutants metabolized or transformed in biological systems. Some care is required in adapting them. Many are specifically designed to model special circumstance, such as accumulation of strontium-90 in milk, and do not contain the necessary structure to model other circumstances.

Although food-chain models are usually categorized as terrestrial or aquatic, they do not differ in concept. All are based on an assumption of equilibrium transfer rates among "compartments" representing different parts of an ecosystem.

They differ only in their relative complexity -- the number of compartments included, and the number of variables influencing each compartment, including multiple interconnections with other compartments. They range from simple transfer coefficients or bioaccumulation factors expressing the proportion of contamination deposited to water or ground that is ingested by humans (single-compartment) to complex ecosystem models with multiple transfers among many ecosystem compartments. Bioconcentration factors can be derived from field measurements or they can be generalized from results of more complex modeling of the contaminant through the food chain under representative conditions.

These models were developed primarily for assessing long-term releases. They can be applied to short-term accidental releases, but at considerable increases in uncertainty associated with the values of model parameters. Their scale is necessarily medium-range; small-scale contamination is easily prevented from reaching the food-chain and long-range dilution reduces exposures to insignificance.

In general, the more complex the models, the more site-specific data they require. The most complex are so site-specific that the effort required to adapt them to other sites is generally not justifiable.

2.4.5 An Environemtal Decision Support System for Air and Water Pollution Simulation and Control

During recent years complex models have been developed for the simulation of the air or/and water pollution due to industrial activities.

CLAIR/CLEW is an Environmental Decision Support system for Air and Water Pollution Simulation and Control.

The CLAIR/CLEW System developed by IIASA is a software designed for decision support in problems of atmospheric and water protection for industrial risk management and planning on national, regional (sectoral) and enterprise levels. The model can be used within areas up to 400x400 km. The system has been developed and extended by IIASA; initial versions of it where validated in 30 case studies for the different climatic conditions and types of industries.

Features of the system make it useful in different applications related to integrated risk management, mainly for the case of continuous emissions (not accidents):

- regional stationary pollution sources data base;
- technological measures data base (e.g. optimal pollution control systems, fuels emission sources liquidation, etc.);
- industry and each particular emission source impacts on the atmosphere and aquatic systems;
- ecological and economical multicriteria effectiveness analysis of the industrial innovations;
- optimized investments allocations for the air and water quality protection;
- maximum resources calculation which are required for the atmospheric and water protection options;
- multicriteria air pollution minimization within the given value of expenditures;
- effective set of the measures definition which could be applied to each source of emission;
- surface water protection.

The solution from the simulation process could be given for a set of pollutants simultaneously. the computer model requires minimal data input for its runs, taking into consideration the application environments in the developing countries. Default data are provided in CLAIR/CLEW model.

2.5 ESTIMATES OF DOSE-RESPONSE RELATIONSHIPS

2.5.1 Background

The need to quantify dose-response curves is more recent and is tied directly to quantitative risk assessment. To aid in rational planning and decision making, it is necessary to estimate health risks associated with new developments or review of existing situations. The method of approach generally adopted consists of hazard identification, followed by parallel steps of exposure assessment and dose-response assessment, which are brought together in risk characterization (NAS, 1983). This section is concerned with dose-response assessment, the evaluation and quantitative characterization of the relationship between level of exposure and health-related response (CCERP, 1985). It differs from other parts of risk assessment in that it often is developed independently of the application on which the risk assessment focuses, using data from other sources. A single dose-response assessment may be applicable to many risk assessment applications.

Toxicity is related to dose. A "toxic" agent is observably toxic at some dose level. Below that level it is apparently safe, and may even be beneficial. Depending on the mechanism of effect, there may be a threshold level below which the agent is truly safe, or there may be no threshold. In the latter case, with decreasing dose, the level of effect approaches the level of spontaneous occurrence of the same effect so that the effect signal becomes lost in the natural variation of the effect. It is then impossible to detect the presence of an effect in a particular experimental design, even if it exists. In theory, one can detect effects, if they exist, at lower and lower dose levels by going to more powerful experimental designs, but there are practical limits. There will always be dose levels below which one cannot observe effects directly.

It is statistically impossible to distinguish between a true threshold of effect and a continuing effect which disappears into the background noise of spontaneously occurring disease. Decisions on (a) whether to treat a dose-response relationship as threshold or no-threshold and (b) the form of equation that should be used for the dose-response function should be based on an understanding of the underlying mechanism of disease, not on the data of a single experiment. In the hazard identification process, screening experiments are often used to determine if an effect can be observed. The standard animal tumor bioassay of the National Toxicology Program (NTP, 1984), for example, is used to determine if a chemical is a carcinogen. This generally consists of exposing animals at three dose levels: the maximum tolerated dose (the highest dose that is not acutely toxic), half the maximum tolerated dose, and a zero-dose control. The question to be answered is basically, "Do the exposed animals have a higher tumor incidence than the control animals?" This is a different question to ask of a data set than, "What is the quantitative relationship between exposure and response?" In cancer risk assessment, the process is generally a two-step process. First, ask if the substance is a carcinogen. If the answer is "yes", then determine the quantitative dose-response relationship for use in risk assessment. Other situations have been handled as a one-step process and the quantitative dose-response relationship is determined directly. Since the determination that the substance is a carcinogen is made at a high-dose level, the confidence limits of the dose-response function may include zero effect at low doses.

Detailed risk assessments are unnecessary if environmental agents are routinely present at levels which are clearly toxic to any substantial group of people; if such an exposure occurred, it could be brought under control by regulatory authority. Dose-response functions in this clearly toxic range are useful primarily to assess effects of accidental exposures. Risk assessment of routine, low-level exposures almost always involves dose-response functions in the fuzzy range below the point where effects are clear. As dose-response functions are extrapolated from high doses (where the data have been collected) to low doses, uncertainty increases.

Effects model can influence space and time resolution in a given dispersion model. In case of non-stochastic effects, which manifest themselves at high exposure levels, there is certainty that harm will occur sometimes above some threshold level of exposure. In this case the harm will be a monotonically increasing function of the exposure (see Figure 2.9).

Stochastic effects are those in which there is always a probability of harm from any exposure to a contaminant, no matter how small. This situation is given by a dose-response relationship (see Figure 2.10).

For the case of near field of exposure, peak concentrations are relevant. In the far field one has to define the long-term exposures in order to estimate both the individual and collective exposure risks.

Mathematically, a dose-response function can be extrapolated down to infinitesimally small doses. Practically, limits must be considered. First, at what level does the risk become so low as to be of no practical concern to either society or the individual? This is often referred to as a de minimus level. If the criterion is individual risk, a de minimus level can be determined from the dose-response function directly. If the criterion is the population risk, however, the decision goes beyond dose-response assessment and also depends on the size of the population exposed and the level of exposure. Second, at what level does the dose-response relationship become too tenuous to justify its application? As the dose level of concern extends further from the range for which experimental or observational data are available, uncertainty increases. In general, either a threshold is established or a decision is taken to assume a continuous dose-response function to zero dose.

The most important current problem in the interpretation of dose-response functions and the risk assessments using them is that of including an appreciation of uncertainty and of individual risk levels in the final risk estimates. Typically, the size of the population at risk and the uncertainty in the dose-response function increase with decreasing exposure levels. It is difficult to judge the importance of estimates of high population risk when large populations are exposed to low doses without a clear understanding of the uncertainty.

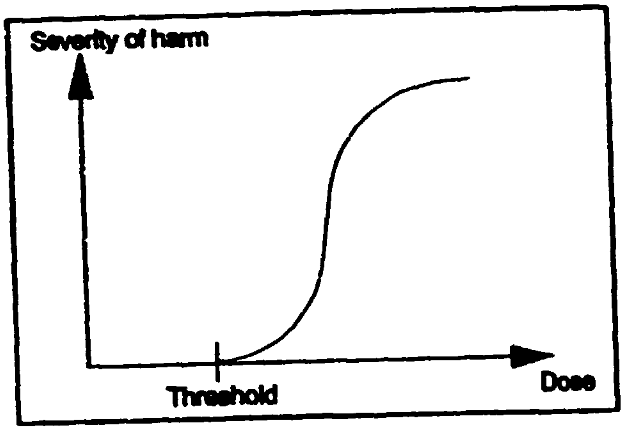


Figure 2.9 Dose-effect relationship.

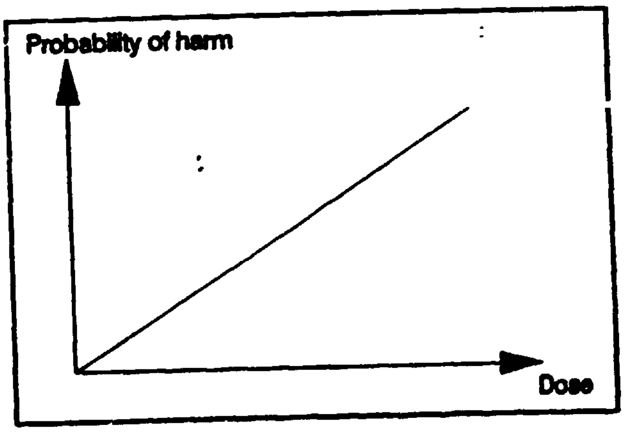


Figure 2.10 Dose-response relationship.

2.5.2 Kinds of Exposures: Dose-Response Implications

Exposure and Dose. An understanding of dose-response assessment and its use in risk assessment requires a clear distinction between exposure and dose. Exposure is the concentration (or amount) of pollutant in the environment to which a person is exposed, (e.g., 25 Mg/m3) in the air one breaths or (e.g., 50 ppb) in the water one drinks. Dose is the amount of pollutant reaching the organ, tissue, or specific cell of interest. Interposed between the two are simple factors such as breathing rate (e.g., an exercising person has a faster breathing rate and thus inhales more pollutant than the sedentary person with the same exposure) as well as complex metabolic and pharmacokinetic processes (NAS, 1987). The dose of concern may not even be the same material as the exposure but a chemically altered metabolite.(e.g., the actual cancer-producing agent in an exposure to benzo[a]pyrene is its metabolite 7b, 8a-dihydroxy-9a, 10a-epoxy-7,8,9,10-tetrahydrobenzo[a]pyrene).

The term dose-response function most commonly means exposure-response function. Risk assessments must deal with multi-media exposures including air, water, and food-chains (see Figure 2.11).

The same level of exposure in different environmental media can lead to vastly different doses at the tissue level. The exposure-response function is thus highly dependent on how the person was exposed. For example, while the exposure-response function for lung cancer from benzo[a]pyrene in air may be substantial, the exposure-response function for lung cancer from benzo[a]pyrene in food may be zero. The true dose-response function for the lung is independent of how the person was exposed or how the pollutant reached the lung. The true dose-response function may be difficult to determine, however, since the actual dose to the target organ is difficult to measure. The target tissue itself may be unknown or in question. Is the target tissue the whole lung or the basal cells of the bronchial epithelium?

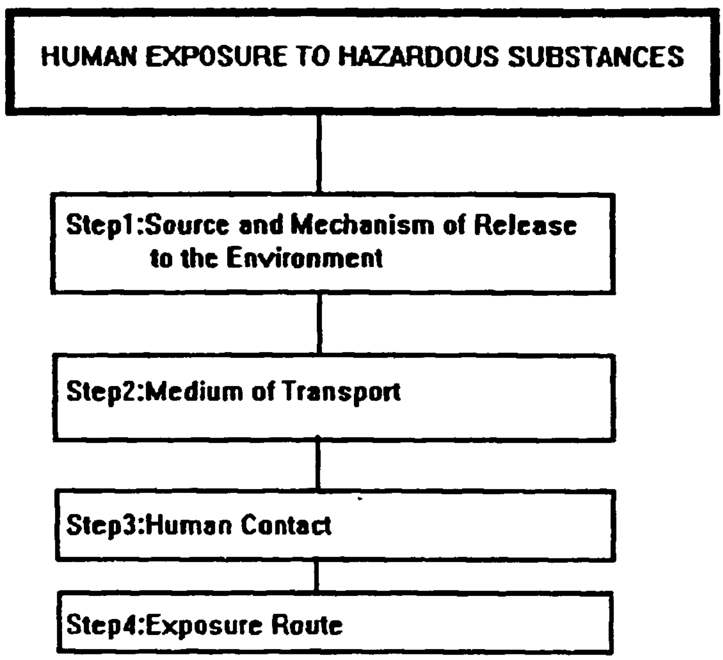

HUMAN EXPOSURE TO HAZARDOUS SUBSTANCES
Step1:Source and Mechanism of Release to the Environment
Step2:Medium of Transport
Step3:Human Contact
Step4:Exposure Route

Figure 2.11

An exposure-response function thus incorporates the metabolic, pharma-cokinetic, and other processes which intervene between the initial point of exposure and the tissue of interest. These processes are often poorly understood, and, from what is known, can be highly non-linear and involve substantial interspecies variation.The current trend is to couple physiologically based pharmacokinetic models, which predict organ or tissue dose, with dose-response models which predict health effects from biologically relevant dose. Unless the relationship between exposure and dose can be quantified, one must exercise care in using a dose-response function based on ingestion in a risk assessment involving an inhalation exposure or even in extrapolating from high doses to low doses.

Averaging Time. Concentrations of pollutants in air vary over time and space. A person standing in one spot receives a continually varying exposure. People moving through their daily activities are exposed to even wider variations in exposure. Averaging times for exposure measurements range from seconds to 24 hours or longer. For acutely toxic materials, a single breath exposure may be an appropriate measure, although the more conventional approach is a 30-minute exposure. The latter defines the level immediately dangerous to life or health or IDLH (NIOSH-OSHA, 1981). For some pollutants (e.g., ozone, nitrogen oxides), peak exposures seem to be important in causing effects, although the role of the time-distribution of the peak or the interval between peaks is not well understood. For yet other pollutants, particularly those which accumulate in the body (e.g., lead, cadmium), long term averages are more appropriate measures. In deriving dose-response functions, the importance of exposure averaging time is often neglected. In many cases, lack of data on effects at the desired averaging time force the analyst to rely on less suitable data. For example, data from short-term occupational or accidental exposures may be used as surrogates for population dose-response functions. Consideration should always be given to the match between the averaging time of the dose-response function (presumably that from the underlying experiment) and that of the exposure data in the risk assessment. When they do not match, assumptions must be made about the relationship between average and peak exposures.

Time-Regimen of Exposure. Uncertainties are introduced in risk assessments by applying dose-response functions based on animal experiments in which the animals were exposed 5-days per week, or from occupational epidemiological studies in which the workers were exposed for 8-hours per day, 5-days per week, to general populations with continual exposures (although varying in magnitude). A correction factor is used to pro-rate the exposure on the assumption that only the long-term average is of importance. But, is there a recovery factor over the weekend? Does this make a difference when carried through to a low-dose extrapolation? Quantitative answers are seldom available to such questions, but some qualitative information, based on knowledge of the action of the chemical, may be available.

Complex Mixtures. No one is exposed to a single pure chemical. Dose-response functions, on the other hand, are always expressed in terms of single chemicals, sometimes in a pure state (usually derived from animal experiments), sometimes as an index of a mixture (usually derived from epidemiological studies). The index-based dose-response function presumably would overestimate the risk in this situation. In general, the state-of-the-art precludes more than simple assumptions of independence of action in most cases, but further information is available in Calabrese (1990), Gray et al. (1987), NAS (1988).

Measurement Techniques. Technical considerations in measuring exposure, dose, or effect are often ignored. A dose-response function is developed from a study in which both exposure and response were measured. It is then applied in a risk assessment in which only exposure is measured (or estimated with models). This is particularly true for composite indices such as "fine particles" or "total organics". Although this is not the principal source of error in risk assessments, one must give some consideration to the compatibility of the exposure measures in the risk assessment and the dose-response function. From the standpoint of dose-response, there is, thus, an obligation to provide adequate documentation on the basis of the exposure.

Ambient concentrations may not be the same as exposure. Environmental measurements are made for many different purposes and in many different ways. Those made in conjunction with dose-response studies must be designed to provide estimates of exposure to people. Surprisingly, only in the past decade has it become commonly considered in air-pollution epidemiology and risk assessment that people spend the majority of their time indoors, and that outdoor measurements may be poor indicators of exposure (Morgan and Morris, 1977). Personal monitoring; monitoring of micro-environments, including indoor monitoring and monitoring in vehicles; and personal activity pattern analyses are now almost a sine qua non in air pollution health effects studies. Recent studies are following the concept of "total exposure" (Wallace, 1987).

2.5.3 Kinds of Effects: Implications for Dose-Response

There are many health end-points for which dose-response functions are available or might be desirable for risk assessment. Commonly used end-points depict diseases which are of greatest concern, e.g., cancer, heart disease, or reproductive effects. They also include injury, mortality, and effects on future generations. These end-points have obvious social significance that can be understood easily by the decision maker. For example, a risk assessment which concludes that a given action will produce ten additional cancers per year fits easily into a decision process. If desirable, such results can readily be translated into monetary terms to allow calculation of benefit-cost ratios in like units. There is some feeling that such end-points may over-simplify the risk, reducing it to "body counts" that are often artificial. This is particularly pertinent in the case of low-level effects spread over a large population. The numbers may be a useful index to the analyst but have quite a different meaning to the public.

Two recent advances in the study of health effects are a focus on sensitive subgroups in the population and on early biological and biochemical markers of disease.

Sensitive Populations: Important effects may be missed in large population studies if they occur only in sensitive subgroups that are not identified and examined separately or in sufficient numbers.

Early Markers of Disease: Parallel to the increasing use of biochemical markers of dose, research efforts have recently begun to focus on early biochemical indicators of disease, rather than the disease itself. These may or may not have direct significance themselves and so are more difficult to incorporate in a risk assessment.

Morbidity: Morbidity is the recognized presence of disease. It is generally expressed as incidence (number of new cases developing annual per 1000 people in a population) or prevalance (number of cases extant per 1000 people in a population at a given time). The former is more appropriate for dose-response relationships. Dose-response relationships usually relate exposure to a specific pollutant with a specific disease. For example, sulfur dioxide with respiratory disease, lead with neurotoxic diseases, cadmium with kidney disease. Special subcategories of morbidity are reproductive and developmental effects. The former is associated with preconceptual exposure to the mother or father while the latter is associated with exposures (through the mother) to the fetus. Risk assessment applications of these effects are discussed in NAS (1986).

Mortality: Total mortality is frequently used as an end-point in dose-response functions. An important consideration for risk assessment in mortality studies has been the length, quality, or value of life lost. Expressing the response in terms of years of life lost would help solve the problem regarding the length of life lost. The mortality rate equation developed on a linear multiple regression for the case of an industrialized urban area (Seoul) when CO and SO_2 pollutants are taken into consideration, is of the following form (Kwi-Gon, 1991):

$$\text{Mortality} = -0.29065\times10^{-5} \times CO\ [kg] - 0.39953 \times 10^{-5} \times SO_2\ [kg] + 4.96441$$

The results of linear multiple regression analysis are not consistent with the hypothesis that air pollution increases the mortality rate. Mortality rates presumably reflect the influence of technology (e.g. medical improvements) a great many environmental and time factors. However, this analysis does not account for factors other than pollution.

2.5.4 Data Sources and Their Implications

Data for dose-response functions come from three basic sources: (1) studies of human populations, both epidemiological and clinical; (2) toxicological studies on whole animals, generally mammals; and (3) laboratory studies on human or animal cells or tissues or on lower life forms such as bacteria.

Any study which is to provide the basis of a dose-response function must include information on both exposure (or dose) and the health response.

Before attempting to derive a dose-response relationship from basic data, however, the risk analyst should seek relationships already developed and available in the literature. Suitable quantitative relationships are available for many pollutants along with considerable background analysis and discussion. For other pollutants, qualitative or semi-quantitative reviews may be available. The U.S. Environmental Protection Agency has developed numerous quantitative dose-response functions, especially for carcinogens. These are available in computerized form, along with other dose-response information, in EPA's Integrated Risk Information System (IRIS). IRIS includes some on-line documentation, but cites appropriate source reports. Other useful sources include WHO's series on Environmental Health Criteria and the publications of the International Agency for Research on Cancer. Numerous commercial publications compile available dose-response functions or supplementary information. These include Calabrese and Kenyon (1990), Cothern et al. (1988), Howard (1989), Lappenbusch (1989), Lioy and Daisey (1987), Sittig (1985), and Weiss (1986).

2.5.5 Deriving the Dose-Response Relationship

A dose-response relationship specifies a quantitative increase in a specific health effect associated with an increase in exposure to a pollutant. The effect may be in absolute terms (number of increased cases per 1000 people per unit of exposure) or in relative terms (percentage increase in background rate per unit of exposure). Dose-response relationships are usually derived through the application of a mathematical model to data from epidemiological, toxicological, or clinical studies. Mathematical models simplify the underlying biological mechanisms and often include assumptions that are not experimentally verifiable.

Mathematical and statistical methods of deriving quantitative dose-response relationships from a toxicological or epidemiological data set are well known. Almost never is a single study sufficient to determine the form of the dose-response function. In fact, for extrapolations to the low-dose region, there is seldom sufficient information on which to select a functional form; it must be assumed. Ideally, the form of the function (i.e., the shape of the dose-response curve), be it linear, quadratic, exponential, threshold or no-threshold, is based on the entire body of knowledge available on the mechanisms involved in producing the observed effects from the kind of agent of concern.

A dose-response function can take several forms. Qualitatively, as dose increases, different effects of increasing severity occur within an individual. Carbon monoxide, for example, at low levels of exposure causes measurable (though not noticeable) visual impairment and decreased manual dexterity; at increasingly higher exposure levels the progression of symptoms includes headache, dizziness, nausea, vomiting, collapse, coma and ultimately death. Because of differences in individual susceptibility, the threshold for each level of effect will differ among individuals. Quantitatively, the distribution of these thresholds describes a population dose-response function for that individual effect. That is, at increasing levels of dose, the particular effect will occur in an increasing number of people. This is called a statistical or tolerance distribution model. This is an appropriate form for threshold phenomona, and is the basis of classical toxicology in which dose-response functions are often represented as probit curves.

In some cases, detailed dose-response function equations are themselves incorporated into risk assessments. More frequently, however, results of such dose-response modeling are reduced to a single coefficient, the slope of a linear portion of the dose-response curve. This coefficient is then simply multiplied by the exposure to yield the effect on the population. While the state of knowledge may not warrant a more complicated approach, it is important to be aware of the assumptions behind this. It assumes a linear dose-response function, at least within the range of exposures in the population of interest. Equally important, it assumes a dose-response function in one variable, excluding any effect of concurrent exposures or population-based factors such as age or susceptibility.

Consider a dose-response function for the exposure of interest (F_i) is unknown, but there is a potency estimate (P_i). For a similar exposure, both the dose-response function (F_s) and the potency estimate (P_s) are known. In the most simple form, the desired dose-response function is estimated as:

$$F_i = F_s (P_i/P_s)$$

This is an example of combining different kinds of health effects information to produce a dose-response function for which insufficient information was available from a single kind of information.

It is generally recognized that drawing on all the information available is more likely to provide a better dose-response function than one based on a single study. While information from other studies is often used to support the dose-response function based on a single study, there is no generally recognized analytical method to mathematically combine data from several sources to form a combined dose-response function, although such integration of results is obviously done subjectively.

2.5.6 Levels of Aggregation: Population at Risk

Each individual responds uniquely to an environmental exposure, but it is impracticable to make environmental risk assessments at the individual level. Instead, the population must be divided into groups with similar characteristics. The degree of detail in grouping depends primarily on information available for exposure and dose-response. Thus, the more detail available in the dose-response function, the more flexibility for grouping is available in the risk assessment. It is always possible for the risk assessment to be conducted at a more aggregated level than the dose-response function, but seldom possible to meaningfully work at a more detailed level. There are basically three classes of grouping:

(1) demographic factors, (e.g., age, sex, and race);

(2) constitutional factors, (e.g. genetic predispositions, pre-existing disease, constitutional susceptibilities resulting from earlier disease, and susceptibilities or sensitivities resulting from previous exposures); and

(3) exposures, especially the exposure level of the particular agent of interest but also others, including smoking, diet, and concurrent occupational or environmental exposures.

Some of these factors can easily be included in a dose-response function and used in a risk assessment. These include the demographic factors and many exposure factors. Others are more difficult. Information on genetic susceptibility, for example, may be impossible to obtain. Often, surrogate factors such as socio-economic level are used as indicators, too.

2.5.7 Uncertainty

Dose-response functions, particularly for low-level exposures, are inherently subject to considerable uncertainty. If this uncertainty is not explicitly incorporated in the dose-response function, results derived from using the dose-response function can be misleading. Several reports provide useful information on the characterization of uncertainty in dose-response functions and their application in risk assessments (Morgan et al., 1985; Griffiths, 1985; Niehaus et al., 1985; Cothern et al., 1986)

Crump (1984) lists five areas in quantitative risk assessment which have important uncertainties. First is in high- to low-dose extrapolation. This can apply to dose-response functions derived from occupational as well as animal studies. Second is animal to man extrapolation. Third is extrapolation from long-term to short-term exposures. In the case of carcinogens, the studies from which dose-response functions are drawn must be long-term; the application of these dose-response functions to short-term exposures introduces uncertainties. In other situations, dose-response functions developed from short-term studies might be extrapolated to long-term exposures, also introducing uncertainty.

Fourth is the subject's age at the time of exposure, and fifth the extrapolation from one route of exposure to another.

In any situation in which a model is used, two basic sources of uncertainty must be considered:

(1) uncertainty in the appropriateness of the functional form of the dose-response model;

(2) uncertainty in specifying the parameters of that model, which has to do with the validity of data and the stochastic nature of events.

Because use of 95% confidence levels are so ingrained in science, and because risk assessment draws heavily on science, 95% confidence levels are often used in risk assessments. The degree of uncertainty in risk assessment, and especially in dose-response assessment, is usually so great that estimating 95% confidence bounds requires assumptions about the shape of probability distributions that are unwarranted. Much better to present 67% or 80% confidence bounds in which one has confidence than 95% confidence bounds that may be misleading.

The ideal, and generally practicable solution, in the case of dose-response functions, is to explicitly include sufficient uncertainty information so that decision-makers (who may be the public), who are in a better position to judge the appropriate level of confidence fcr a particular analysis, can draw their own conclusions.

2.5.8 Guidance Note

All quantitative dose-response functions involve considerable uncertainty at low-dose levels. If this uncertainty can be adequately characterized and expressed, however, quantitative dose-response functions can be usefully applied in health risk assessments to guide planning and policy.

Dose-response functions, in general, represent biological relationships which are common world-wide. The same dose-response function can thus be used in risk assessments in different settings and cultures. In any case, however, even in situations seemingly similar to that in which the dose-response function was derived, the specific applicability of the dose-response function should be investigated. Areas of particular importance to assure compatibility include characteristics of exposure and of the population at risk. Are the exposure measurement techniques, concurrent exposures to other materials, and the relationship between the overall complex mixture to the index compound in the risk assessment compatible with those from which the dose-response function was derived? Is the effect associated with particularly sensitive subgroups of the population or does it depend on a particular distribution of sensitivity in the population? Ideally, dose-response functions should be disaggregated in such a way that dependencies on characteristics of the population at risk are explicit.

2.6 Environmental guidelines

Voluntary guidelines and legally enforceable standards for contaminants in air and water are needed by analysts attempting to determine the hazards presented by environmental contamination, and the benefit of applying different pollution control strategies. Guidelines and standards for various substances are frequently determined by environmental agencies or by ministries of environment. In the absence of such sources, voluntary guidelines published by international agencies such as the World Health Organization (WHO) should be consulted. Therefore, the environmental guideline values for specified contaminants in air and water which were published by WHO are presented (WHO, 1984; 1987). In developing these guidelines, a consistent process of assessment was used. The primary aim of these guidelines is to provide a basis for protecting public health from the adverse effects of air and water pollution and for eliminating or reducing those contaminants that are known or likely to be hazardous to human health and welfare. The guideline values should not be considered standards in themselves. Standards, which have to be determined by scientists and administrators making risk management decisions, should be consistent with these guideline values, taking into account also other factors such as specific environmental, social, ecomomical conditions.

WHO clearly indicates that numerical values are to be regarded as indications; they are proposed in order to help avoid major discrepancies in reaching the goal of effective protection against recognized hazards. The guideline values should be used and interpreted in conjunction with the scientific informations that are at their basis.

2.6.1 Guidelines for air quality

Tables 2.11-2.16 show air quality guideline values or carcinogenic risk estimates for organic and inorganic substances recommended by WHO for Europe [1]. The emphasis in the guidelines is based on exposure. The starting point for the derivation of guideline values based on effects other than cancer (Tabs. 2.11 and 2.12) was to define the lowest concentration at which adverse effects are observed. On the basis of the body of scientific evidence and judgments of protection (safety) factors, the guidelines were established (WHO, 1987). For some of the substances, a direct relationship between concentrations in air and possible toxic effects is very difficult to establish, because ingestion could highly contribute to the body burden (e.g. Cr and Pb). WHO has made an attempt to develop guidelines which would also prevent those toxic effects of air pollutants that resulted from uptake through both ingestion and inhalation. The averaging times of exposure that have been chosen for the guidelines are based on the characteristical effects of the substance. Compliance with proposed guideline values does not guarantee the absolute exclusion of effects at lower levels owing to the existence of highly sensitive groups, especially those impaired by concurrent diseases or other physiological limitations.

Carcinogenic risk estimates were made by WHO for substances which, according to the International Agency for Research on Cancer (IARC), are considered proven human carcinogens or probable human carcinogens with at least limited evidence of carcinogenicity in humans and sufficient evidence for carcinogenicity in animals. In these guidelines the risk associated with lifetime exposure to a certain concentration of a carcinogen in the air has generally been estimated by linear extrapolation, assuming no-threshold dose (Tabs. 2.13 and 2.14). The carcinogenic potency is expressed as the incremental unit risk estimate, defined as "the additional lifetime cancer risk occurring in a hypothetical population in which all individuals are exposed continuously from birth throughout their lifetimes to a concentration of 1 $\mu g/m^3$ of the agent in the air they breathe" (WHO, 1987; US EPA, 1985).

Table 2.15 (WHO, 1987) shows the rationale and guideline values based on sensory effects or annoyance reactions, using an averaging time of 30 minutes. The aspects and respective levels considered by WHO in the evaluation of sensory effects where the intensity, where the detection threshold level is defined as the lower limit of the perceived intensity range; the quality (recognition threshold level); and the acceptability and annoyance, where the nuisance threshold level is defined as the concentration at which less than 5% of the population experience annoyance for less than 2% of the time.

Table 2.16 shows WHO guideline values for individual substances based on effects on terrestrial vegetation which occur at concentrations below those known to be harmful to humans. It is to be mentioned that WHO guidelines regard only few of the pollutants that are harmful for the ecosystem and that only the effects to the vegetation are considered.

WHO guidelines are for individual chemicals (except that for sulphur dioxide and suspended particulates). Pollutant mixtures can yield differing toxicities, but data for synergistic effects are at present insufficient for establishing guidelines.

2.6.2 Guidelines for water quality

Table 2.17 shows WHO guideline values for various substances or contaminants in drinking water (WHO, 1984). WHO states that, if properly implemented, the guidelines will ensure the safety of drinking-water supplies. Although the guideline values describe a quality of water that is acceptable for lifelong consumption, the establishment of these guidelines should not be regarded as implying that the quality of drinking-water may be degraded to that recommended level. In this context, the specified guideline values have been derived to safeguard health on the basis of lifetime exposure. Short term exposure to higher contaminant levels that might occur following an accident may be tolerated, but should be examined on a case-by-case basis. In developing the guideline values, WHO took into consideration the total intake of each contaminant from air, food and water. For the majority of the substance evaluated, the toxic effect in man is predicted from studies with animals.

Furthermore, because of the uncertainties in applying animal data to humans, and because of the doubts about the reliability of extrapolating from high doses to low doses, arbitrary safety factors ranging from 100 to 1000 were applied.

The actual methods of extrapolating data from animal to man deal with exposures to single substances; therefore, effects from exposure to mixtures are not considered. Guideline values are also proposed for carcinogenic substances, taking into account appropriately conservative risk factors.

In the case of radioactive substances, the term guideline value is used in the sense of "reference level" as defined by ICRP. The values shown in Tab. 2.18 for gross alpha and gross beta activity are to be referred to all sources of radioactivity, natural and man-made. These values were calculated so that the associated dose corresponds, according to ICRP data, to a total risk in the range 10^{-7}-10^{-6} per year (WHO, 1984).

2.6.3 Health effects of various pollutants

It is useful to include short informations on the health effects of exposure to various concentrations in air of some pollutants. Tables 2.18 - 2.22 (UNEP, 1987) regard health effects of sulphur dioxide and sulphate, sulphur dioxide and particulate matter, nitrogen oxides, carbon monoxide and ozone. Tables 2.23 and 2.24 (OECD, 1991) show the major health effects of selected toxic trace air pollutants, respectively organic compounds and metals, without specifying the dose absorbed and the exposure time.

Table 2.11 WHO Air Quality Guidelines Values for Individual Substances Based on Effects Other than Cancer or Odor/Annoyance.

Substance	Time-weighted average	Averaging time
Cadmium	1-5 ng/m^3	1 year (rural areas)
	10-20 ng/m^3	1 year (urban areas)
Carbon disulfide	100 μg/m^3	24 hours
Carbon monoxide	100 mg/m^3 [a]	15 minutes
	60 mg/m^3 [a]	30 minutes
	30 mg/m^3 [a]	1 hour
	10 mg/m^3	8 hours
1-2, Dichloroethane	0.7 mg/m^3	24 hours
Dichloromethane	3 mg/m^3	24 hours
Formaldehyde	100 μg/m^3	30 minutes
Hydrogen sulfide	150 μg/m^3	24 hours
Lead	0.5-1.0 μg/m^3	1 year
Manganese	1 μg/m^3	1 year
Mercury	1 μg/m^3 [b]	1 year
Nitrogen dioxide	400 μg/m^3	1 hour
	150 μg/m^3	24 hours
Ozone	150-200 μg/m^3	1 hour
	100-120 μg/m^3	8 hours
Styrene	800 μg/m^3	24 hours
Sulfur dioxide	500 μg/m^3	10 minutes
	350 μg/m^3	1 hour
Tetrachloroethylene	5 mg/m^3	24 hours
Toluene	8 mg/m^3	24 hours
Trichloroethylene	1 mg/m^3	24 hours
Vanadium	1 μg/m^3	24 hours

[a] Exposure at these concentrations should be for no longer than the indicated times and should not be repeated within 8 hours.

[b] The value is given only for indoor pollution.

Table 2.12 Guideline values for combined exposure to sulfur dioxide and particulate matter[a]

	Averaging time	Sulfur dioxide (μg/m³)	Reflectance assessment: black smoke[b] (μg/m³)	Gravimetic assessment: Total suspended particulates (TSP)[c] (μg/m³)	Gravimetic assessment: Thoracic particles (TP (μg/m³)
Short term	24 hours	125	125	120[e]	70[e]
Long term	1 year	50	50	—	—

[a] No direct comparisons can be made between values for particulate matter in the right- and left-hand sections of this table, since both the health indicat and the measurement methods differ.

[b] Nominal μg/m³ units, assessed by reflectance. Application of the black smoke value is recommended only in areas where coal smoke from domestic fires the dominant component of the particulates. It does not necessarily apply where diesel smoke is an important contributor.

[c] TSP: measurement by high volume sampler, without any size selection.

[d] TP: equivalent values as for a sampler with ISO-TP characteristics (having 50% cut-off point at 10μm), estimated from TSP values using site-speci TSP/ISO-TP ratios.

[e] Values to be regarded as tentative at this stage, being based on a single study.

Table 2.13 Carcinogenic Risk Estimates Based on Human Studies.

Substance	Unit Risk[a]
Acrylonitrile	2×10^{-5}
Arsenic	4×10^{-3}
Benzene	4×10^{-6}
Chromium (VI)	4×10^{-2}
Nickel	4×10^{-4}
Polynuclear Aromatic Hydrocarbons (PAH)[b]	9×10^{-2}
Vinyl Chloride	1×10^{-6}

[a] Cancer risk estimates for lifetime exposure to a concentration of 1 $\mu g/m^3$.

[b] Expressed as benzo[*a*]pyrene.

Table 2.14 Risk estimates for asbestos

Concentration	Range of lifetime risk estimates	
500 F*/m³ (0.0005 F/ml)	$10^{-6}-10^{-5}$	(lung cancer in a population where 30% are smokers)
	$10^{-5}-10^{-4}$	(mesothelioma)

Note. F* = fibres measured by optical methods.

Table 2.15 Rationale and guideline values based on sensory effects or annoyance reactions, using an averaging time of 30 minutes

Substance	Detection threshold	Recognition threshold	Guideline value
Carbon disulfide in viscose emissions			20 µg/m³
Hydrogen sulfide	0.2-2.0 µg/m³	0.6-6.0 µg/m³	7 µg/m³
Styrene	70 µg/m³	210-280 µg/m³	70 µg/m³
Tetrachloroethylene	8 mg/m³	24-32 mg/m³	8 mg/m³
Toluene	1 mg/m³	10 mg/m³	1 mg/m³

Table 2.16 Guideline values for individual substances based on effects on terrestrial vegetation

Substance	Guideline value	Averaging time	Remarks
Nitrogen dioxide	95µg/m³ 30µg/m³	4 hours 1 year	In the presence of SO_2 and O_3 levels which are not higher than 30µg/m³ (arithmetic annual average) and 60µg/m³ (average during growing season), respectively
Total nitrogen deposition	3 g/m²	1 year	Sensitive ecosystems are endangered above this level
Sulfur dioxide	30µg/m³ 100µg/m³	1 year 24 hours	Insufficient protection in the case of extreme climatic and topographic conditions
Ozone	200µg/m³ 65µg/m³ 60µg/m³	1 hour 24 hours averaged over growing season	
Peroxyacetylnitrate	300µg/m³ 80µg/m³	1 hour 8 hours	

Table 2.17 **WHO Drinking-Water Quality Guidelines for Inorganic and Organic Contaminants of Health Significance.**

Contaminant	Guideline Value
Aldrin and Dieldrin	0.03 μg/l
Arsenic	0.05 mg/l
Benzene	10 μg/l [a]
Benzo[*a*]pyrene	0.01 μg/l [a]
Cadmium	0.005 mg/l
Carbon Tetrachloride	3 μg/l [a]
Chlordane	0.3 μg/l
Chloroform	30 μg/l [a]
Chromium	0.05 mg/l
Cyanide	0.1 mg/l
2,4-D	100 μg/l [b]
DDT	1 μg/l
1,2-Dichloroethane	10 μg/l [a]
1.1-Dichloroethene	0.3 μg/l [a]
Fluoride [c]	1.5 mg/l
gamma-HCH (lindane)	3 μg/l
Gross alpha activity	0.1 Bq/l
Gross beta activity	1 Bq/l
Heptachlor & heptachlor epoxide	0.1 μg/l
Hexachlorobenzene	0.01 μg/l [a]
Lead	0.05 mg/l
Mercury	0.001 mg/l
Methoxychlor	30 μg/l
Nitrate	10 mg/l (N)
Pentachlorophenol	10 μg/l
Selenium	0.01 mg/l
Tetrachoroethene	10 μg/l [a]
Trichloroethene	30 μg/l [a]
2,4,6-Trichlorophenol	10 μg/l [a,b]

[a] These guideline values were computed from a conservative hypothetical mathematical model which cannot be experimentally verified and values should therefore be interpreted differently. Uncertainties involved may amount to two orders of magnitude (i.e., from 0.1 to 10 times the number).

[b] May be detectable by taste and odour at lower concentrations.

[c] Local or climatic conditions may necessitate adaptation.

Table 2.18 HEALTH EFFECTS OF SULFUR DIOXIDE AND SULFATE

Concentration			Health Effect
SO_2 (ug/m^3	Sulfates ug/m^3	Averaging Time	
300-400	NA	24 hours	Increased mortality
365	8-10	24 hours	Aggravation of symptoms in elderly
180-250	6-10	24 hours	Aggravation of asthma
220	11	Annual mean	Decreased lung function in children
90-100	9	Annual mean	Increased acute lower respiratory disease in families
95	14	Annual mean	Increased prevalence of chronic bronchitis
106	15	Annual mean	Increased acute respiratory disease in families
NA	13	Annual mean	Increased respiratory disease-related illness, absence in female workers

Source: U.S. Environmental Protection Agency, 1974.

Table 2.19 SYNERGESTIC EFFECTS OF SULFUR DIOXIDE AND SUSPENDED PARTICULATE MATTER

Concentration			Adverse Effect
SO_2 (ug/m^3	SPM (ug/m^3	Averaging Time	
500	500	daily average	Excess mortality and hospital admissions
500-250	250	daily average	Deterioration of patients with pulmonary disease
100	100	annual arithmetic mean	Respiratory symptoms
80	80	annual geometric mean	Visibility and/or human annoyance effects

Source: 'Health Hazards of the Human Environment', WHO, Geneva, 1973.

Table 2.20 HEALTH EFFECTS OF NITROGEN OXIDES

Average NO_2 Concentration (ug/m^3)	Health Effect	Population Studied
300-1130	Decrease in several measures of pulmonary function as compared to controls	Japanese railroad workers
150-280	Borderline decrease in lung function test	Chattanooga school-children, aged 7-8
100 vs. 80	No differences in various measures of pulmonary function	Central City vs. suburban policeman in Boston
96 vs. 43	No differences in various measures of pulmonary function	Seventh Day Adventists in Los Angeles vs. San Diego
20—70	Twofold excess in acute respiratory disease compared to unexposed group	Czechoslavakian children, aged 7-12
10	Excess in acute respiratory disease ranging from 11 to 27%	U.S.S.R. adolescents in chemical and fertilizer plants
580—1120	Forty-four percent increase in physician visits for respiratory visual, nervous system and skin problems	Individuals living within 1 km of a U.S.S.R. chemical plant
150—280	Excess in acute respiratory disease: 1-17% in children, 9-33% in adults	Families in Chattanooga, Tennessee
150—280	Infants exhibited 10-58% excess of acute bronchitis; children 6-9 years showed 39-71% excess of acute bronchitis	Infants and children 6-9 in Chattanooga

Source: U.S. Environmental Protection Agency, 1976.

Table 2.21 **HEALTH EFFECTS OF CARBON MONOXIDE**

CO Concentration (ug/m^3)	Health Effects
0 - 4,250	No Symptoms
4,250 - 12,750	Slight headache, tightness across forehead, shortness of breath with vigorous exertion, dilation of cutaneous blood vessels
12,750 - 21,250	Slight to moderate headache, and throbbing in temples, shortness of breath with moderate exertion
21,250 - 34,000	Decided to severe headache, weakness, dizziness, dimness of vision, nausea, vomiting, and collapse; irritable, judgement disturbed
34,000 - 51,000	Same as previous item with more possibility of collapse and syncope, especially with exertion and increased respiration and pulse; slight confusion
51,000 - 76,500	Fainting, increased respiration and pulse, coma with intermittent convulsions, and irregular respiration
76,500 - 119,000	Coma with intermittent convulsions, depressed hearing action and respiration, and possible death
119,000 - 204,000	Weak pulse and slow respiration, respiratory failure, and death
204,000	Rapidly fatal
204,000	Immediately fatal

Source: 'Medical Aspects of Air Pollution'. Society of Automotive Engineers, Inc., Michigan, 1971.

Table 2.22 RELATIONSHIP OF OZONE AND PHOTOCHEMICAL OXIDANT EXPOSURE TO HUMAN HEALTH EFFECTS AND RECOMMENDED ALERT AND WARNING SYSTEM LEVELS

Recommended Episode Levels	Ozone and Photochemical Oxidants (ppm)	Duration of Exposure	Health Effects
Emergency	0.70	2.0 hr.	Soreness of upper respiratory tract; tendency to cough while taking deep breaths; significant increase in breathing difficulty. These conditions were made worse by 15 minute of light exercise.
	0.50	2.75 hr.	Measurable biochemical changes in blood sera enzyme levels and in red blood cell membrane integrity; some subjects became physically ill and unable to perform normal jobs for several hours.
	0.37	2.0 hr.	Impairment of pulmonary function in young adults probably due to a decreased lung elastic recoil, increased airway resistance, and small airway obstruction.
	0.37	2.75 hr.	Significant biochemical changes in blood sera enzyme levels and in red blood cell membrane integrity, but less severe than at 0.50 ppm; some subjects became physically ill and unable to perform normal jobs for several hours.
Red alert	0.30	—	Precipitous increase in rates of cough and chest discomfort in young adults.
	0.25	—	Greater number of asthma attacks in patients on days when daily maxima equalled or exceeded 0.25 ppm during a 14-week period.
	0.25	2.75 hr.	Biochemical changes in blood sera enzyme levels.
Yellow alert	0.10	1 hr.	Breathing impaired
	0.10	—	Tokyo elementary school children had significantly reduced respiratory function associated with ozone levels less than 0.1 ppm during a long-term epidemiologic study. Beginning of headache without fever in young adults; median age 18.6 years.
Watch	0.07	2 hr. average	
	0.065	—	Impairment of performances of student athletes during running competition.
	0.05	15-30 min.	Threshold of respiratory irritation.
	0.005	—	Decreased electrical activity of the brain.

Source: E.J. Calabrese, 'Pollutants and High-Risk Groups', Wiley-Interscience, New York, 1978.

Table 2.23 **HEALTH EFFECTS OF SELECTED TOXIC TRACE AIR POLLUTANTS, Organic compounds**

Pollutant	Major health effects
Acrylonitrile ($CH_2-CH-C-N$)	Dermatitis; haematological changes; headaches; irritation of eyes, nose and throat; lung cancer
Benzene (C_6H_6)	Leukemia; neurotoxic symptoms; bone marrow injury incl. anaemia, chromosome aberrations
Carbon disulfide (CS_2)	Neurologic and psychiatric symptoms, incl. irritability and anger; gastro-intestinal troubles; sexual interferences
1,2 Dichloroethane ($C_2H_2Cl_2$)	Damage to lungs, liver and kidneys; heart rhythm disturbances; effects on central nervous systems, incl. dizziness; animal mutagen and carcinogen
Formaldehyde (HC HO)	Chromosome aberrations; irritation of eyes, nose and throat; dermatitis; respiratory tract infections in children
Methylene chloride (CH_2Cl_2)	Nervous system disturbances
Polychlorinated bi-phenyls (PCB) (coplanar)	Spontaneous abortions; congenital birth defects; bioaccumulation in food chains
Polychlorinated dibenzo-dioxins and -furans	Birth defects; skin disorders; liver damage; suppression of the immune system
Polycyclic Organic Matter (POM) [incl. benzo(a)pyrene (BaP)]	Respiratory tract and lung cancers; skin cancers
Styrene ($C_6H_5-CH-CH_2$)	Central nervous system depression; respiratory tract irritations; chromosome aberrations; cancers in the lymphatic and haematopoietic tissues
Tetrachloroethylene (C_2Cl_4)	Kidney and genital cancers; lymphosarcoma; lung, cervical and skin cancers; liver dysfunction; effects on central nervous system
Toluene ($C_6H_5-CH_3$)	Dysfunction of the central nervous system; eye irritation
Trichloroethylene (C_2HCl_3)	Impairment of psychomotoric functions; skin and eye irritation; injury to liver and kidneys; urinary tract tumors and lymphomas
Vinyl chloride (CH_2-CHCl)	Painful vasospastic disorders of the hands; dizziness and loss of consciousness; increased risk of malformations, particularly of the central nervous systems; severe liver disease; liver cancer; cancers of the brain and central nervous system; malignancies of the lymphatic and haematopoietic system

Source: OECD

Table 2.24

HEALTH EFFECTS OF SELECTED TOXIC TRACE AIR POLLUTANTS, Metals

Pollutant	Major health effects
Arsenic (As)	Lung cancer; dermatological disorders, incl. ulcerative dermatitis; haematological effects, incl. anaemia
Beryllium (Be)	Dermatitis; ulcers; inflammation of mucous membranes
Cadmium (Cd)	Acute and chronic respiratory disease; renal dysfunction; animal carcinogen
Chromium (Cr)	Lung cancer; gastro-intestinal cancers; dermatitis
Lead (Pb)	Interference with bloodforming processes; liver and kidney damage; neurological effects
Mercury (Hg)	Effects on nervous system, incl. deficits in short-term memory, disturbance of sensory and co-ordination functions; kidney failure
Nickel (Ni)	Respiratory illnesses, incl. asthma; impairment of respiratory defence system; birth defects and malformations; nasal and lung cancers
Thallium (Tl)	Bioaccumulation; toxic to plants and animals
Vanadium (V)	Respiratory irritation; asthma; nervous disturbances; changes in the blood formula

Source: OECD

2.7 Assessment of Continuous Emissions Impacts to the Environment

Assessment of environmental impacts is more complex than that of human health impacts, because of the large variety of species and physical entities involved, availability of toxicological data on only a few, and the need to consider competition, predation, and other ecological interactions. To make the task manageable, effects are usually addressed in terms of aggregate indices (total biomass or species diversity) or assessment is limited to key species.

Four key issues in its ecological risk assessment programme are relevant:

1. Which ecological resources are at risk? What are the characteristics of these ecosystems and how do they respond to pollution? What are the best indicators and endpoints to determine the condition of these ecosystems? What are the best methods for screening and characterizing pollutants in these ecosystems?

2. What is the condition of the environment and how is it changing? What are the baseline characteristics that define a healthy ecosystem against which to measure change? How are the affected ecosystems changing? Which pollutants are contributing to ecosystem deterioration? How accurately can ecosystem exposure and effects models predict reality?

3. To what levels of pollutants are the ecosystems exposed? What pollution levels exist in the environment? What biological, chemical or physical processes form and transform complex pollutants and how are they taken up in the environment? What are the most accurate and sensitive biomarkers of pollution exposure?

4. How do pollutant exposures affect ecosystems? What structural properties of chemicals predispose them to be biologically active and what are the best methods for predicting their effects? How can we predict effects of long term, indirect, or cumulative exposures of ecosystems to pollutants? How can laboratory data be extrapolated to ecosystem effects? How can effects seen in one species, population, or community be extrapolated to others?

2.7.1 Endpoints

The diversity of possible endpoints requires that they be divided into classes.

Biome: Biomes represent large types of environment: tundra, deciduous forest, grassland, and desert. Many specific processes of environmental impact and ecological models through which those processes are quantified to explain impacts or estimate risk are biome specific.

Structure and Function: The health of ecological communities can be evaluated by parameters measuring their structure and function. Species diversity is a frequently used measure. The greater the diversity of species in a community, the stronger that community is ecologically.

Physical support entities: Air, water, and soil are the basis of the environment. While environmental impact assessment often focuses on the biosphere, the biological inhabitants of the physical world, the term environmental quality itself usually refers to the physical state of air, water, and soil. While in health effects assessment, degrading environmental quality is addressed in terms of potential risks to human health, in environmental assessment it is addressed both in terms of its own merit and for its implications for the biosphere. In some cases the latter relationships are sufficiently well established that physical environmental parameters can be used as indices of ecological damage. For example, the relationship between acidification of freshwater lakes and the resulting impacts on aquatic life is sufficient that the latter is often indexed solely on the basis of predicted changes in pH of the lake water.

2.7.2 Assessment Methods

Matrix approach: This is essentially a checklist approach, widely used in environmental impact assessment. It helps assure completeness, but, in itself, is not sufficient for environmental risk assessment.

Thresholds: There are often specific levels of environmental quality parameters (e.g. pH in lakes) that represent the threshold of ecological change. A series of such thresholds can represent a progression of stages in ecological decline. Thresholds may also be toxicological benchmarks such as LC50.

Functions: Where decline is continuous, without clear thresholds, continuous damage functions may be available. Such functions have been developed for the impact of air pollution on agricultural crops, for example. Ideally, functions include extrapolation error, the appropriate uncertainty factors associated with extrapolation from laboratory test organisms to field observations.

Simulation Models: Thresholds or formulae, while often useful for environmental assessment, are generally limited in the kinds of impact they can represent and are always a simplification. Analysis of complex ecosystems usually requires more detailed models that can integrate the combined effect of multiple relationships. Models have often proven to be powerful guides for studying and understanding ecological relationships, but less useful as predictors of future effects. Nonetheless, they can serve as a useful comparative measure of the possible impacts of different policy options. Added detail in highly complex models may improve predictability, although too much detail can introduce crippling problems of parameter estimation and error propagation. In some cases, simplified models may be preferred even when detailed data are available. The status of ecological models has been summarized as (DOE, 1987):

Long-term predictability remains an elusive target. There are severe limits to how long into the future the behavior of complex systems with many feedbacks can be projected. What must replace these are short-term predictive schemes coupled with monitoring and adaptive management approaches that incorporate both modeling and monitoring.

Probabilistic Models: Probabilistic models explicitly take into account the variability and uncertainty in natural systems. These include analysis of extrapolation error (mentioned above), fault-tree analysis applied to elucidate causal linkages between pollutants and endpoints, and ecosystem uncertainty analysis using Monte Carlo simulation and ecosystem models to extrapolate from laboratory toxicological data to estimate risks to populations and ecosystems (Barnthouse et al., 1982).

Expert judgement: Few, if any, needs for environmental risk assessment will be able to be met satisfactorily with ecological models within the foreseeable future. While these models may provide valuable guidance, they must be used in an integrated way with expert judgment. Methods of eliciting expert judgment are described by Morgan and Morris (1981). Judgments can be applied to policy making using techniques such as decision theory or analytical hierarchy method. Environmental applications of the latter are described by Barnthouse et al. (1982).

PROCEDURAL GUIDE FOR INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

VOLUME II

METHODS AND PROCEDURES FOR HEALTH AND ENVIRONMENTAL RISK ASSESSMENT

CHAPTER 3

ANALYSIS AND ASSESSMENT OF MAJOR ACCIDENT RISKS

Chapter 3: ANALYSIS AND ASSESSMENT OF RISKS FROM MAJOR ACCIDENTS

This chapter provides guidance information on the methods and procedures for the identification and analysis of hazards; and the quantification and assessment of risks from major accidents in the process industry.

The methods outlined are based on a large number of sources included in the reference listing.

Further reading should particularly focus on relevant publications by UNEP, WHO, IAEA, UNIDO (see list of further reading) particularly in the recent UNEP publication: 'Hazard Identification and Evaluation in a Local Community' and IAEA reports on 'Procedures for the conduct of Probabilistic Safety Assessment (PSA) of NPP's'. The Role of PSA and PSC in NPP Safety', to be published in the IAEA Safety Series.

Section 3.2 of this chapter is based on information provided by Mr. J. Clifton (United Kingdom).

Chapter 3: ANALYSIS AND ASSESSMENT OF RISKS FROM MAJOR ACCIDENTS

3.0 Overview

Government, industry and the community now recognize the need to identify, assess and control the risks to both people and the environment which come from potentially hazardous industries. Appropriate siting and comprehensive risk assessment and safety management are therefore essential in ensuring orderly development and at the same time the safety of people and the environment.

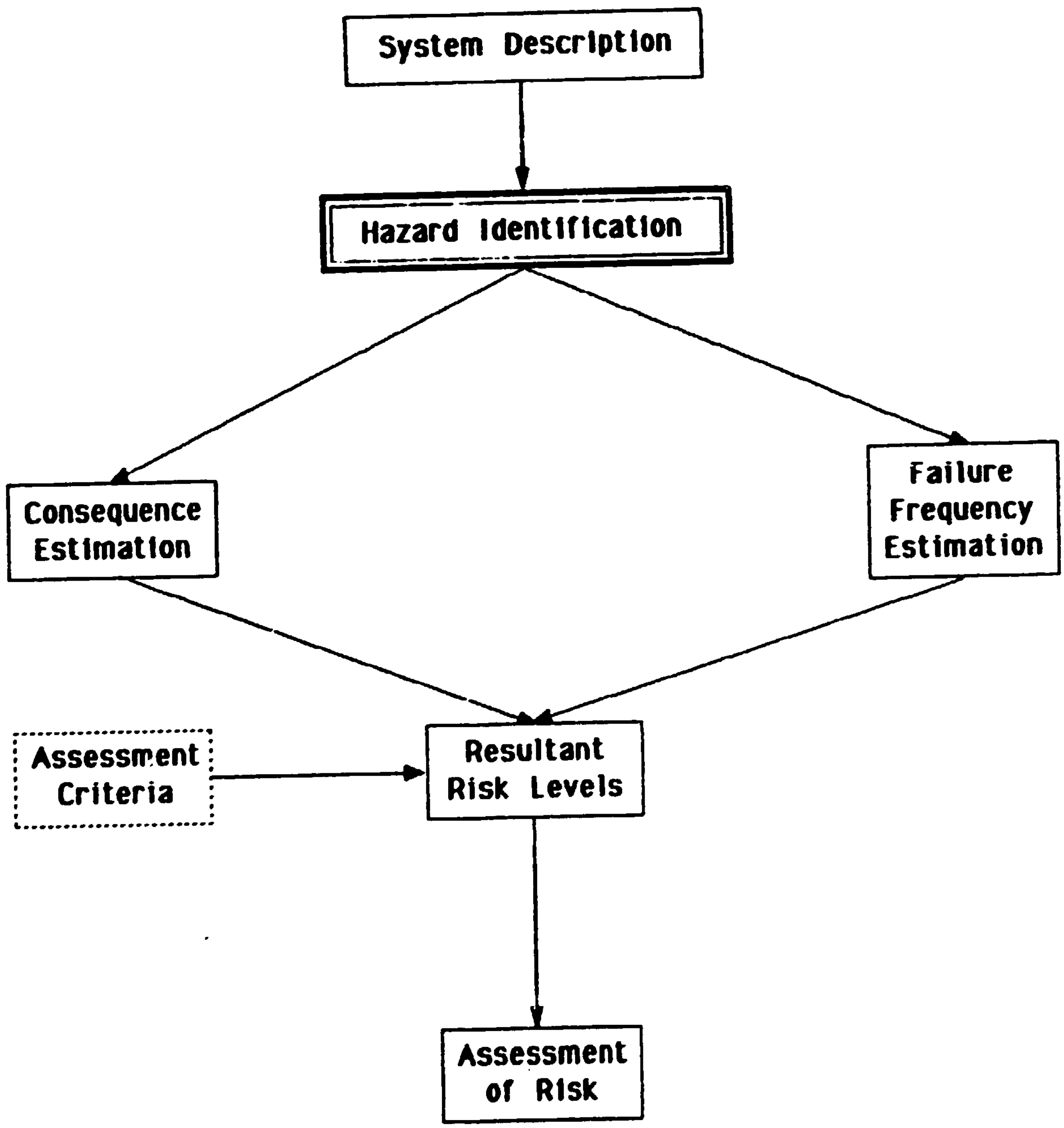
Good industry safety practices, engineering safety codes and standards, design and operating procedures remain at the core of safety management. The increase awareness of hazards and of the accidents that may result in significant loss of life and property, have led to the development and application of systematic approaches, methods and tools for risk assessment. These methods termed hazard analysis or quantified risk assessment are hazard evaluation tools. Figure 3.1 is an overall scheme of the risk assessment process, which involves: system description, the identification of hazards and the development of accident scenarios and outcomes events associated with a process operations or a storage facility; the estimation of the effects or consequences of such hazardous events on people, property and the environment; the estimation of the probability or likelihood of such hazardous events occurring in practice and of their effects - accounting for the different operational and organizational hazard controls and practices; the quantification of ensuing risk levels, outside the plant boundaries, in terms of both consequences and probabilities; and, the assessment of such risk levels by reference to quantified risk criteria.

The process of quantified risk assessment is probabilistic in nature. It recognizes that accidents are rare but possible events and that risk cannot be entirely eliminated. Because major accidents may or may not occur over the entire life of a plant or a process, it is not appropriate to base the assessment process on the consequences of accidents in isolation. The likelihood or probability or such accidents to actually occur should be taken into account. Such probabilities and resultant risk levels should reflect the level of design, operational and organizational controls available at the plant.

There are a number of uncertainties associated with the quantification of risk. Amongst the most important sources of such uncertainties are the mathematical models in estimating the consequences of major accidents including dose-effect relationships and the setting of probabilities for different accident scenarios and for the probability effects of such accidents. Significant procedural and methodological advances have been developed in order to address and reduce the effect of such uncertainties. The risk assessment process should in all cases expose and recognize such uncertainties.

Figure 1.1

OVERVIEW OF QUANTITATIVE RISK ASSESSMENT PROCEDURE



It is to be noted, that the main value of the quantified risk assessment process should not rest with the numerical value of the results (in isolation). Rather, it is the assessment process itself which provides significant opportunities for the systematic identification of hazards and evaluation or risk. The most significant advantages in this regard relate to the optimum allocation of priorities in risk reduction in that the assessment process provides for the clear identification and recognition of hazards and as such enable the allocation of relevant and appropriate resources to the hazards control process. The quantified risk assessment process also provide a useful tool for risk communication.

3.1 Hazard Identification

3.1.1 Introduction

Subsequent to the compilation of process plant information (system description) required for risk assessment, the first and most essential step in any risk assessment is the identification of all relevant hazards applicable to a particular plant or operation, as basis for further analysis. In all cases, it is necessary to establish:

- what dangerous situations exist within a plant or a process operation; and
- how these situations may come about.

This component of the analysis, termed 'Hazard Identification', involves consideration of all situations in which the potential for harm may exist in order to identify those which are hazardous, followed by a systematic analysis of the sequence of events which could transform this potential into an accident. Once an accident scenario has been establisned, the likelihood of such an accident occurring in practice (accounting for design operational and organizational safeguards) and its consequence (impact effect) should it occur, can be estimated. Figure (3.1) indicates the context of hazard identification within the overall risk assessment process.

This section provides guidance on the role of the hazard identification process,the tools and techniques available to undertake hazard identification and the relevance and scope of application of these techniques. The review presented here is intended to provide a basic procedural framework to assist in undertaking hazard identification for both existing and new proposed plants. It does not intend to duplicate the extensive body of reference material available on the subject. A list of the most relevant references which should be consulted is included.

It must be particularly noted that there is not a fixed golden rule as to which particular technique should be adopted. There are, however, useful and important guidelines. It may be necessary to use a variety of approaches to improve the hazard identification process. Techniques may also be used in isolation or in complement to each other.

3.1.2 Objectives of Hazard Identification

Hazard identification is the corner stone in the assessment of the safety of an installation. It is essential to have clear understanding of the type and nature of hazardous incidents associated with the operations of a plant and of the initiating and contributing events that can lead to such hazardous incidents. Without such an understanding the formulation and implementation of any risk management strategy is in many cases not possible and certainly inefficient. The main objectives for identifying hazards at an early stage of the assessment process are basically:

(a) Providing the basis for the design and operation of appropriate operational (hardware) and organizational (software) safety mechanisms. Safeguards must be appropriate and relevant to each type of hazards, and unless such hazards are identified and recognized, safeguards may be irrelevant or sub-optimal.

(b) Risk quantification and evaluation. Estimations of likelihood and consequences of hazardous incidents cannot be undertaken unless each hazard has been identified in the first instance.

(c) Accidents can be prevented by anticipating how they may occur. A systematic understanding of the major contributors to hazardous incidents and of the interaction of contributing events (concurrently or sequentially) enable the formulation of appropriate mitigating measures (e.g. shut-off systems) that may prevent such events escalating into major hazards.

(d) Prioritization of hazards for further analysis and control. Systematic identification of hazards enables the formulation of risk management strategies based on optimum resources allocation on a priority control/management basis.

(e) Hazard identification may also be used for safety training purposes, as a tool for communicating safety information to the general public and as a basis for emergency procedures and emergency planning.

3.1.3 Hazard Identification Techniques

The procedures for identifying hazardous situations which may arise in process plants and equipment are generally considered to be the most developed and well established element in the assessment process of hazardous installations. The techniques have been reviewed in a number of documents notably Lees (1980), CONCAW (1982), AICHE (1985), IAEA (1991)*, EFCE (1985) and SRD (1986).

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* to be published

It must be recognized that:

(a) The procedures and techniques vary in terms of comprehensiveness and level of detail from comparative checklists through to detailed structured logic diagrams.

(b) The procedures may apply at various stages of project formulation and implementation. From the early decision making process to determine the location of a plant, through to its design, construction and operation.

Techniques for hazard identification essentially fall into three categories. The following indicates the most commonly used techniques within each category.

Category 1: Comparative Methods

- Process/System Checklist
- Safety Audit/Review
- Relative Ranking: Dow and Mond Hazard Indices
- Preliminary Hazard Analysis

Category 2: Fundamental Methods

- Hazard Operability Studies (HAZOP)
- 'What if' Analysis
- Failure Mode and Effect Analysis (FMEA)

Category 3: Logic Diagrams Methods

- Fault Tree Analysis
- Even Tree Analysis
- Cause Consequence Analysis
- Human Reliability Analysis

The reference list provides detailed information on each of these methods. Summary paragraphs on each and a summary table are presented for guidance purposes. Safety Audit/Review and Event Tree Analysis and Hazard Operability are discussed in more details as they represent prevailing trends in applications.

- **Process/Safety Checklists:** checklists are used to identify hazards and examine compliance or otherwise with standard procedures. Checklists are limited to the experience base of the checklist author(s). Qualitative results from this hazard evaluation procedure vary with the specific situation, including the knowledge of system or plant; they lead to a "yes-or-no" decision about compliance with standard procedures.

- **Safety Audit/Review:** a walk-through on-site inspection can vary from an informal routine function that is mainly visual, with emphasis on housekeeping, to a formal comprehensive examination by a team with appropriate background and responsibilities. When a comprehensive review is undertaken, it is referred to as safety audit/review, process review or loss prevention review. In addition to providing an overall assessment of the safety of the plant both operationally and organizationally such reviews intend to identify plant conditions or operating procedures that could lead to an accident and significant loss of life or property. The review includes systematic on-site examination of process plants, equipments and safety systems as well as interviews with different people associated with plant operations, including: operators, maintenance staff, engineers, management, safety and environmental staff and personnel. An examination of accident records, maintenance procedures, emergency plans, etc. is also undertaken.

  Various hazard evaluation techniques are used including checklists, 'what-if' questions. An integrated auditing survey system is appended. (Appendix 3.I).

- **Relative Ranking (Dow and Mond Indices):** the method assigns (i) penalties to process materials and conditions that can contribute to an accident and (ii) credits based on plant features that can mitigate the effects on an accident. An index for a relative ranking of the plant risk is derived from the combined penalties and credits. The method gives also qualitative information on equipment exposed to possible damage through accident propagation.

- **Preliminary Hazard Analysis** (see Figure 3.2): the method is designed to recognize early hazards and it focuses on the hazardous materials and major plant elements since few details on the plant design are available, and there is likely no information available on procedures. The method consists of formulating a list of the hazards related to available design details, with recommendations to reduce or eliminate hazards in the subsequent plant design phase. The results are qualitative, with no numerical estimation or prioritization.

- **Hazard Operability Studies (HAZOP - see figures 3.5(a), 3.5(b), 3.6):** A systematic review of the plant, including piping and instrumentation, section by section, using a series of guide words to identify possible deviations and establish necessary action to cope with such deviations. HAZOP studies are both hazard identification as well as safety management tools. The techniques are described in detail in volume 3 of this guide.

- **"What If" Analysis:** the main purpose of the method is to consider carefully the result of unexpected events that would produce an adverse consequence, by a detailed examination of possible deviations from the design, construction, modification, or operating intent. It identifies the hazards, consequences, and perhaps potential methods for risk reduction.

- **Failure Mode, Effect, Analysis (FMEA):** is a tabulation of the system/plant equipment, their failure modes as a description of how equipment fails (open, closed, on, off, leaks etc.), the effect of failure mode (e.g. system response of accident resulting from the equipment failure). FMEA requires knowledge of system/plant function; it does not apply to a combination of equipment failures that lead to accidents.The result of using the method is qualitative and consists in a systematic reference listing of system/plant equipment, failure modes, and their effects.

- **Fault Tree Analysis (FTA)** (see Figure 3.4): identifies combinations of equipment failures and human errors that can result in an accident event. It can be used in the design phase of a plant to uncover hidden failure modes that result from combination of equipment failures or in the operation phase when operator and procedure characteristics can be used to study an operating plant. Results are qualitative, with quantitative potential when probabilistic data are available.

- **Accident Scenario Modelling/Event Tree Analysis** (see Figures 3.3, 3.3 (a), 3.3 (b), 3 (c)): in many cases a single incident can lead to many distinct outcomes. The process of developing possible accident scenarios is an essential element in the risk assessment process. The event tree technique provides a logic framework for the determination and quantification of a sequence of events which can result in the occurrence of potential accidents. Event trees used inductive logic (normally binary) and have been widely used in risk analysis of chemical and nuclear industries.

  Two distinct applications can be identified which lead to the development of pre and post-accident event-trees. The basic steps of event tree analysis include:

  - identification of initiating events (hazard identification);
  - identification of functions or factors which can influence the sequence propagation;
  - development of all possible outcomes;
  - classification of outcomes in categories of similar consequences for further experience estimation;
  - quantification of probabilities of each branch (using fault tree models, expert judgement, operational records on other means);
  - quantification of sequences (combining frequence or initiating event and sequence branch probabilities).

  Pre-accident event trees can be used to evaluate effectiveness of plant protective systems and operator actions against the occurrence of an accident initiator (Figure 3 (c)). Post-accident event trees can be used to evaluate types of accident outcomes that might arise from a release of hazardous materials. Post-accident event trees can be appended to those branches of pre-accident event trees which led to unsafe plant states.

- **Cause-Consequence Analysis:** is a blend of fault tree and event tree analysis for evaluating potential accidents and the basic causes of these accidents. It can be used as communication tool by using cause-consequence diagram which displays the interrelationships between the accident outcomes and their basic causes. Results are qualitative, with quantitative potential. Knowledge of safety systems or emergency procedures that can influence the outcome of an accident is required.

- **Human Error Analysis:** the method consists in a systematic evaluation of the factors that influence the performance of human operators, maintenance staff, and other personnel in the plant and identifies error-likely situations that can cause of lead to an accident. It includes identification of system interface affected by particular errors and relative ranking of errors based on probability of occurrence or severity of consequences. Results are qualitative and quantitative and include a systematic listing of the types of errors likely to be encountered during normal or emergency operation.

Techniques of Hazard Identification	General Description	Data and Requirements	Output
* Process/System Checklist	Standard list to indicate: type of hazards for various plant items and operations; compliance or otherwise with codes and standards	- Need knowledge of system or plant and its operations - Manual of operating procedures - One or more experienced persons should prepare the checklist. An experienced manager/engineer should review the checklist results.	Qualitative results usually in the form of 'yes-or-no' decision about compliance with standard/codes
* Safety Audit/Review	Walk through the plant recording possible hazards, nature and conditions of plant equipment. Interview operators and plant managers. Examine maintenance procedures, organisational safety systems, emergency procedures.	- For a complete review, team need access to plant descriptions, piping and instrumentation diagrams, flow charts, monitoring procedures and all related safety documentation. - Depending on scale of operations, 2-5 personnel may be required to undertake the audit. The audit team should preferably be independent from local operations management.	Safety audit report which identifies nature/type of hazards, outlining (qualitatively) nature and extent of impact and where appropriate recommend safety measures.

Techniques of Hazard Identification	General Description	Data and Requirements	Output
* Relative Ranking - Dow and Mond Hazard Indices	Use standard indices charts to assign penalties and credits based on plant features and safety controls. These are combined to derive and index that is a relative ranking of the plant risk.	- Plot plans - Understanding of process flows - Nature/type of materials handled and processed and of site inventories - Process and material data sheets - Experienced engineer with support from senior plant operators would be most suited to undertake the identification process.	Relative ranking of plant process units based on degree of risk. Qualitative evaluation of people and equipment risk exposure.
* Preliminary Hazard Analysis	Examine preliminary design to determine hazards related to materials and processes, components and interfaces as well as organisational safety.	- Preliminary design specifications and information on nature of processes and of process conditions. - One to two experienced personnel (depending on scale)	Qualitative listing of potential incidents and hazards. Word diagrams useful presentation tool. (See figure 3.2)

Techniques of Hazard Identification	General Description	Data and Requirements	Output
* Failure Mode and Effect Analysis (FMEA)	List all conceivable failure malfunctions; describe intermediate and ultimate effects of failure on other equipment or rest of system; rank each failure mode and its effect by failure mode's severity. Include worst case consequences of single point failure.	- Knowledge of equipment and plant/system function. - Plot plants, piping diagrams, flow charts. - Listing of plant items and inventories. - Ideally two analysts should be involved.	Systematic list of failure modes and potential effects.
* Fault Tree Analysis	Construct a diagram to show the combination of faults and failure (including human errors) that will contribute/ lead to an accident event. The inter-relationship between components, causes and the accident are shown. Frequency of failure may be included if a quantitative analysis is being undertaken.	- A detailed understanding of how the plant/ process work. - Knowledge of failure modes and their effects. - Process information and plans. - Understanding of the relationship between inter process components. - One analyst to be responsible for analysis. Consultation plant operators and managers highly desirable.	A diagramatic representation of equipment/process component failure that leads to an overall malfunction/accident. Can be qualitative or quantitative to derive frequency of failure. (see figure 3.4)

Techniques of Hazard Identification	General Description	Data and Requirements	Output
* Event Tree Analysis	Construct a decision tree that shows sequence of accident and chronological relationship between initiating and subsequent events accounting for safety systems. The probability of events may be used for quantitative analysis.	- Knowledge of equipment failures and system upsets. - Knowledge of safety systems including emergency shut-off mechanisms. - Normally a team of 2-4 experienced personnel preferred.	Event sequence that results in accidents (in a diagramatic format) with expected probability of the sequences of events if quantitative analysis needed. (See figure 3.3)
* Cause-Consequence Analysis	Combination of fault and event tree analysis. Construct a diagram that displays the relationship between the causes of an accident and its outcome. The frequency of occurrence of an accident may be included if quantitative analysis undertaken.	- Knowledge of equipment failure and of safety systems. - Best performed by a team of 2-4 people of varying experience.	Potential accidents identified and related to their causes. May be quantitative to derive probability of accidents.

Techniques of Hazard Identification	General Description	Data and Requirements	Output
* Hazard Operability (see Chapter 1, Vol 3, for details)	A systematic review of the plant design, section by section, using a series of guide words to identify possible deviations and establish necessary action to cope with such deviations.	- Piping and Instrumentation and process flow sheets and diagrams. - HAZOP relies on brainstorming amongst team of design/operational personnel (see Figures 3.5 (a) and 3.5 (b)).	A comprehensive identification of possible deviations, their consequences, causes and suggested actions (see Figure 3.6).
* 'What If' Analysis	Systematic exmanation of a process of operation, using 'what if' prompt to suggest an initiating event, a failure from which an undesirable event sequence could occur (see Figures 3.7 (a-c).	- Process flow sheets, pilot plans, PIDs; - two qualified analysts.	An identification of deviations with their consequences and recommended actions.

Techniques of Hazard Identification	General Description	Data and Requirements	Output
* Human Reliability Analysis	Examine plant operations and procedures to establish those events initiated or mitigated by humans. Determine if event is related to response. May involve determining the the cause of a human error.	- Plant procedures, interviews with operators, knowledge of plant layout/ function/task. - One experienced analyst in liaison with senior plant operators and management.	List of events where human interaction contribute significantly to risk, including type of errors and factors contributing to such errors.

Figure 3.2 - Hazard Identification Word-Diagram

TYPE OF FACILITY	POSSIBLE INITIATING EVENTS	POSSIBLE RESULTS AND COMMENTS
Flammable liquids (e.g. oils, petrol, etc.) Storage	Rupture of tank roof (or failure of floating roof system) followed by ignition.	Fire of entire tank roof surface. Unless cooling is applied to adjacent tanks. potential for fire to spread to them if very close (Rare event).
	Leak into bund followed by ignition in bund.	Large bund fire. Very rare event. Because of large surface area, the height of the flame is greater than for a tank fire, so radius of effect on surroundings would be greater.
Flammable liquid processing	Leak from process vessels or piping, followed by ignition.	Fire. Such a fire may be very damaging to the plant involved and, if interplant spacing is inadequate may spread to neighbouring plant. However, the radius of damage to surroundings is usually very limited.
		Blast and vapour cloud explosion. Only possible if the flammable liquid is processed at a temperature significantly above its normal point.
Flammable liquids Transportation - Tanker loading bays	Tanker driving off while still coupled, or other leak, followed by ignition.	Fire. Mostly local effect on loading bay.
	Tank liquid leak to the surrounding area.	Large fire. Extremely unlikely because of secondary containment.
- Processing Plant	Leak followed by ignition.	Fire or blast or vapour cloud explosion or plant fire. As for liquified flammable gas pressurised storage, with the following differences: lower potential consequences as inventories in process are generally less and higher potential likelihood owing to the extra complexity of pipework and so opportunity for mechanical damage and/or failure leading to leaks.
Toxic gas manufacture or storage	Leak.	Toxic gas cloud. Significant inventories of toxic gases are normally protected to prevent leaks and to enable rapid isolation.
Storage or processing of materials with toxic combustion products.	If engulfed in fire, would result in smoke containing toxic combustion products.	Toxic effects.
Highly reactive materials - processing or storage.	Process or storage conditions deviating from standard, with the result of reaction run-away or decomposition.	Fire and explosion toxic fumes. Dependent on the nature of the highly reactive material.
		Most of the quantities processed at any time are sufficiently small to ensure that the effect of reaction run-away would be mostly local.
- Road transport	Vehicle collision or other cause resulting in a leak, followed by ignition.	Fire. The area of effect of the fire is largely determined by where the liquid drains to, and the time taken till fire fighting can start.
- Drum stores containing flammable liquids, etc.	Leak and ignition.	Fire. Local effect mostly.
	Fire engulfing intact drums.	Drums bursting. sheets of flame of short duration.
Liquified flammable gas - Pressurised storage	Leak, igniting promptly.	Fire. Potent. to cause blast, otherwise of local effect.
	Fire (e.g. from leak) heating and weakening containment vessel until it ruptures and contents escape and ignite almost instantaneously.	Blast (fireball) of potentially large impact.
	Leak, mixing with air before delayed ignition.	Vapour cloud explosion (only if vapour cloud before) or flash fire. Radius of blast effect can be large.
		Main damage confined to area covered by cloud. at time of ignition.
- Refrigerated storage at atmospheric pressure.	Leak from plant pipework.	Fire. If suitably designed, such leaks should be small and quickly isolated.
	Release of vapour from relief valves, followed by ignition.	Fire.
	Overpressure in tank or under-pressure in tank followed by rupture of tank roof.	Large fire confined to area of tank.
Flammable powder processing.	Ignition of dust-filled air.	Dust explosion. Mostly localised to the dust-filled buildings or plant.
Transfer pipelines - Liquified flammable gas.	Leak, mostly due to one of the following causes: - mechanical damage due to accidentalexcavation, soil subsidence. - Corrosion followed by ignition.	Fire. Flash fire. Vapour cloud explosion. The effect of any incident depends on the diameter and process conditions in the pipeline, the speed of leak detection and isolation and the delay before any ignition.
- Flammable liquid	Leak, due to causes such as above, followed by ignition.	Fire. The extent of the effect of any such incident depends on factors listed above, plus the area covered by the leaked material when ignited.
Port operations involving flammable liquids or liquified flammable gas.	Ship collision with other ship or fixed object, rupture of tanks, leakage, ignition.	Fire, possibly explosion.
	Shipboard pipework or plant leakage, and fire.	Fire, possibly explosion.
	Wharf incident - leak from loading/ unloading line.	Fire, possibly explosion. The nature and severity of the result depends on the nature of the material leaking and the delay before ignition.

Source: NSW Department of Planning, Sydney, Australia

Figure 3.3

SIMPLIFIED EVENT TREE EXAMPLE

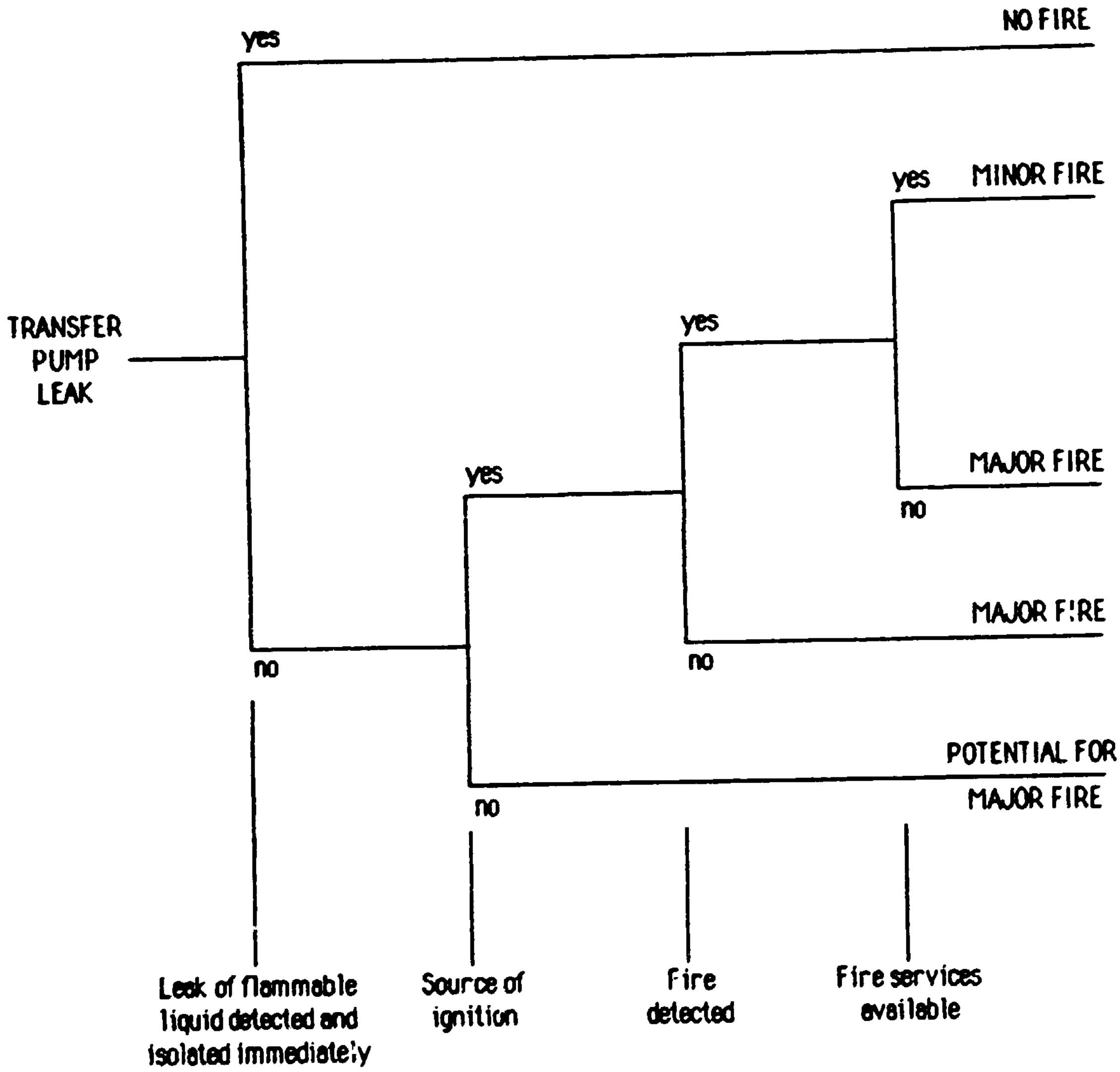
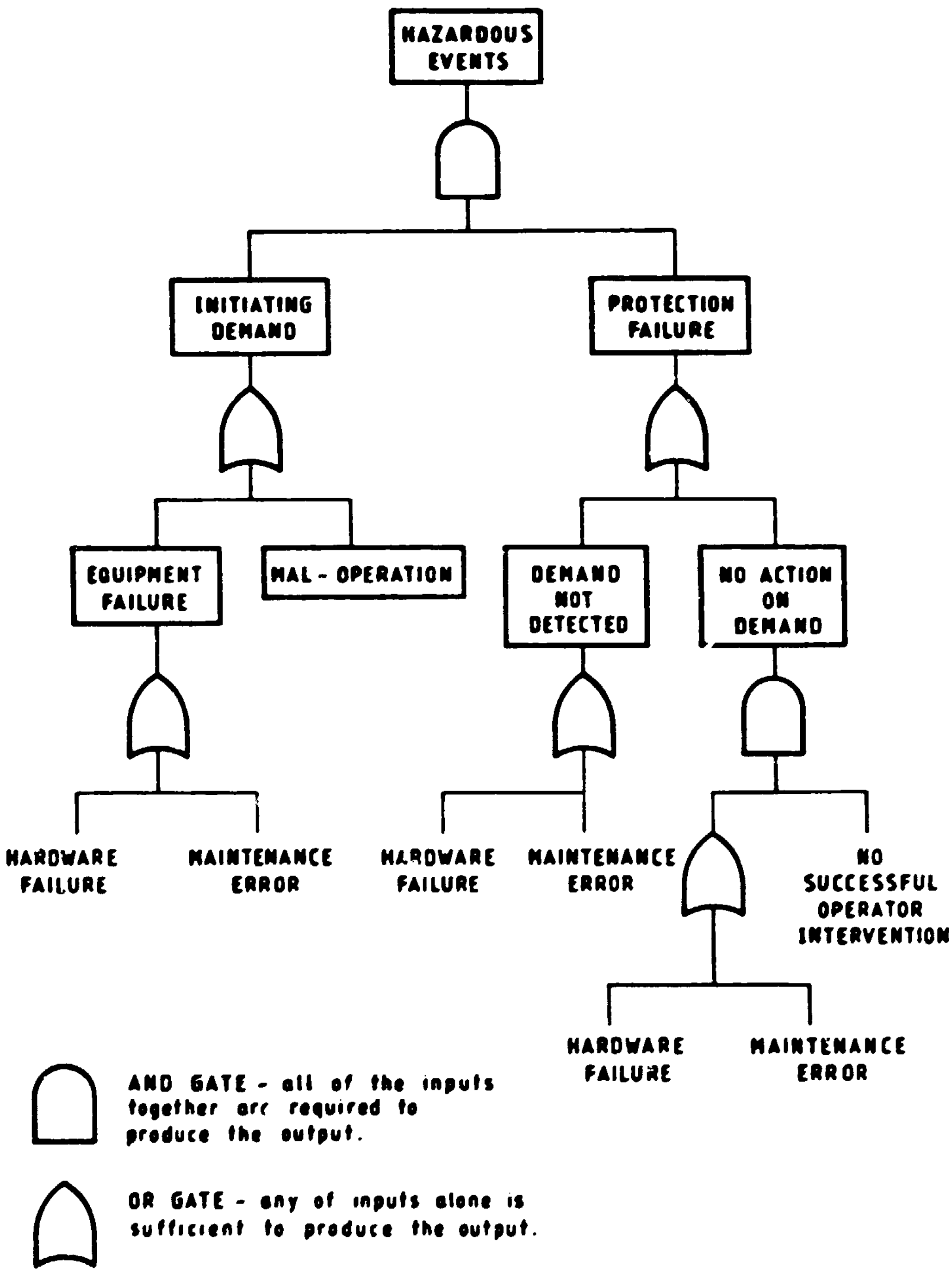
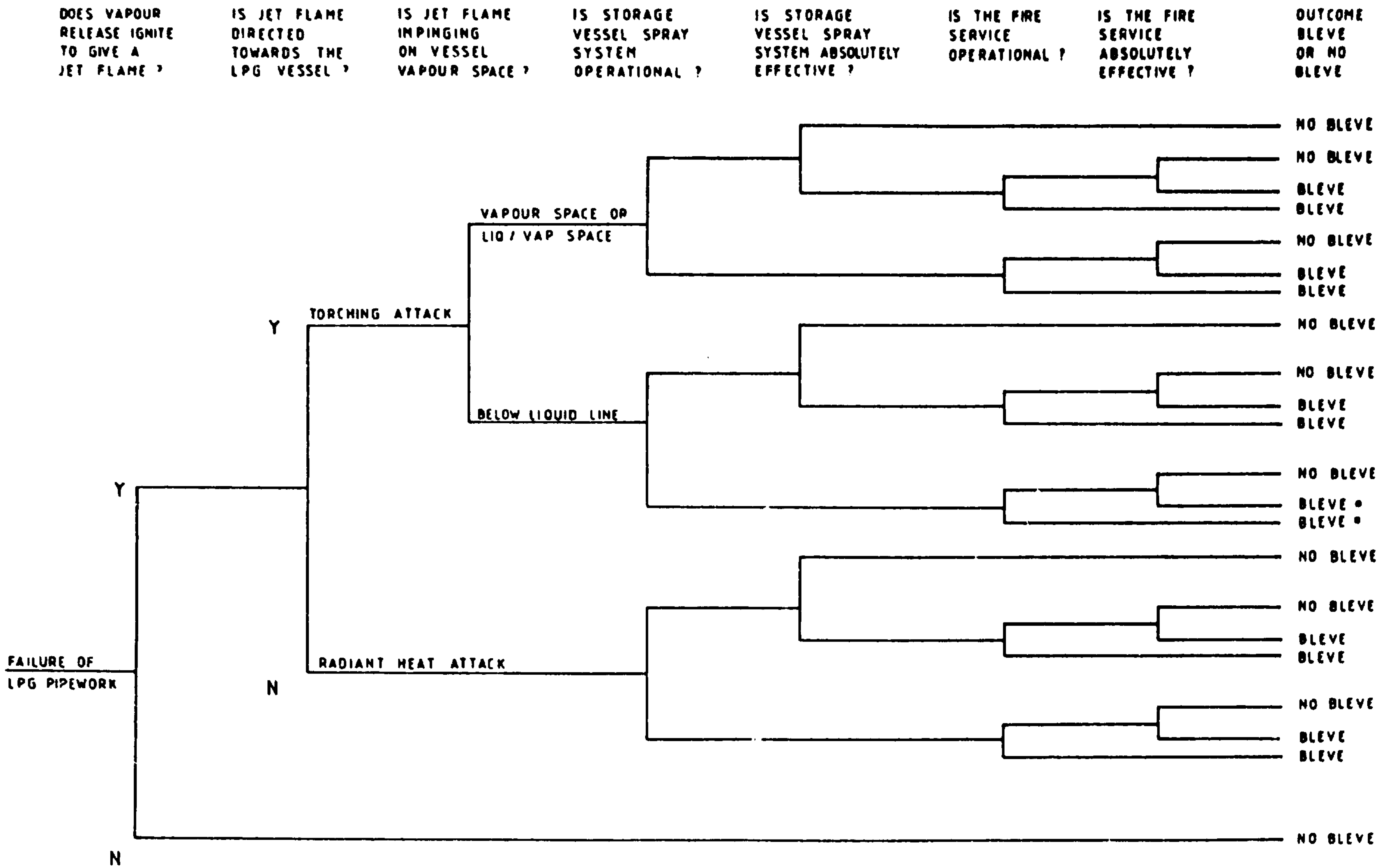


Fig. 3.3 (a) **EXAMPLE USED TO ILLUSTRATE THE CONSTRUCTION OF A FAULT TREE**

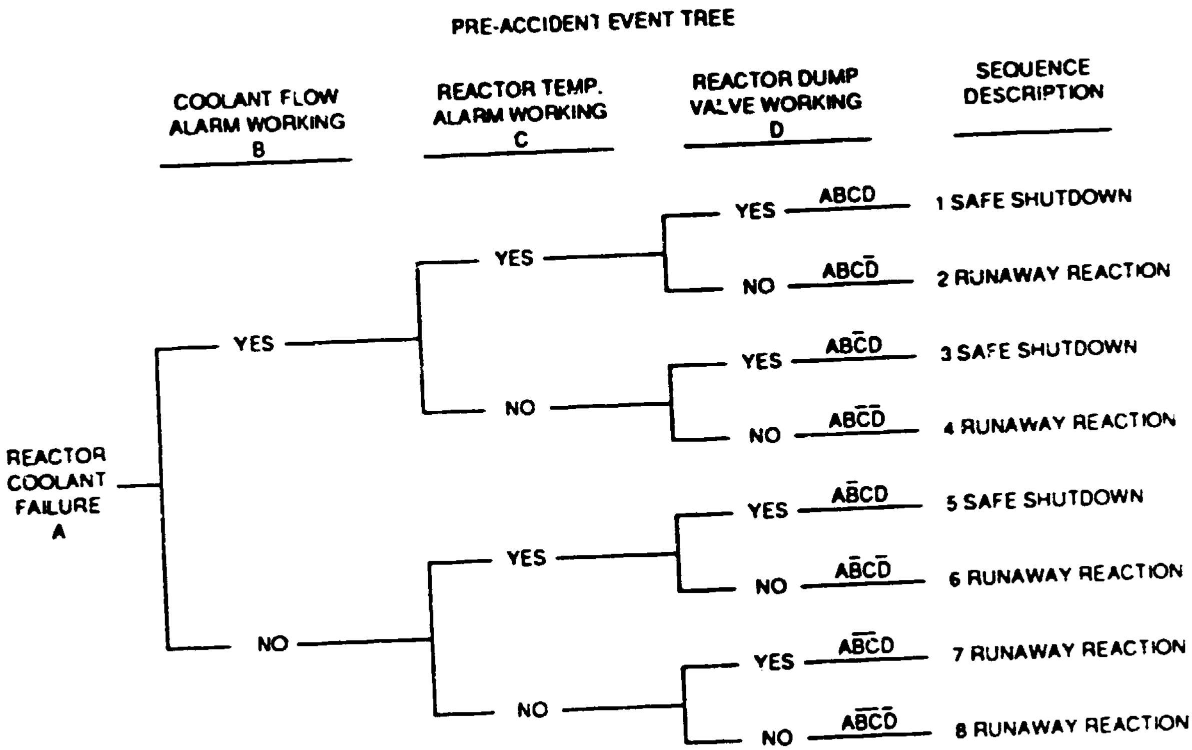




BLEVE (ACRONYM FOR BOILING LIQUID EXPANDING VAPOUR EXPLOSION)

* This situation arises when liquid level drops below torch point

Fig. 3.3. (b) EVENT TREE INDICATING HOW THE FAILURE OF LPG VAPOUR PIPEWORK CAN DEVELOP TOWARDS A BLEVE OF AN LPG STORAGE VESSEL



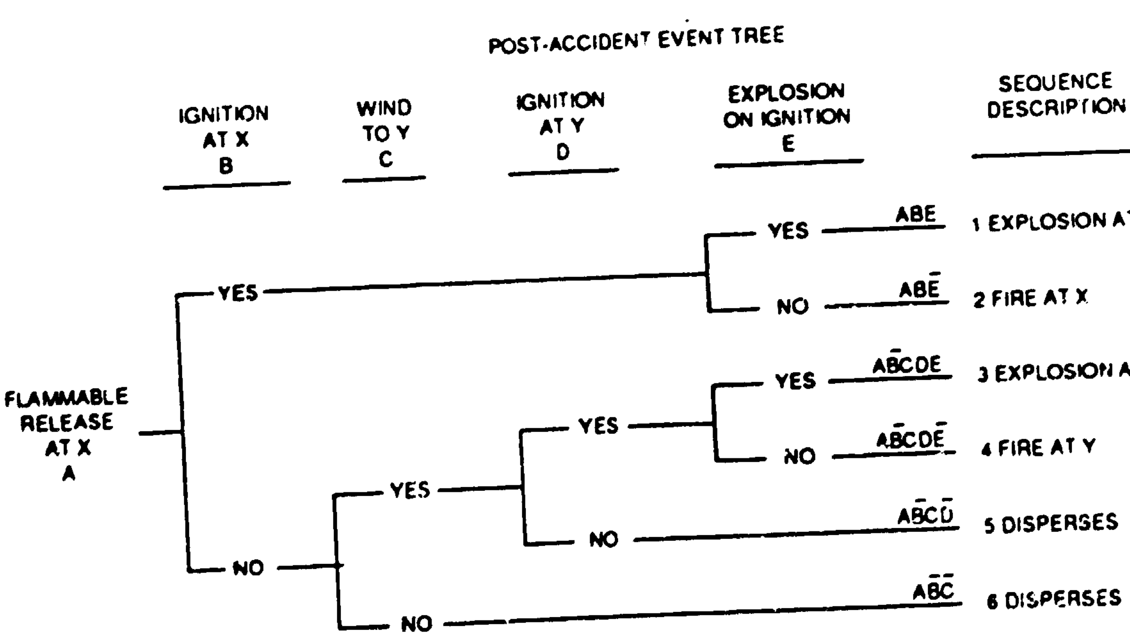
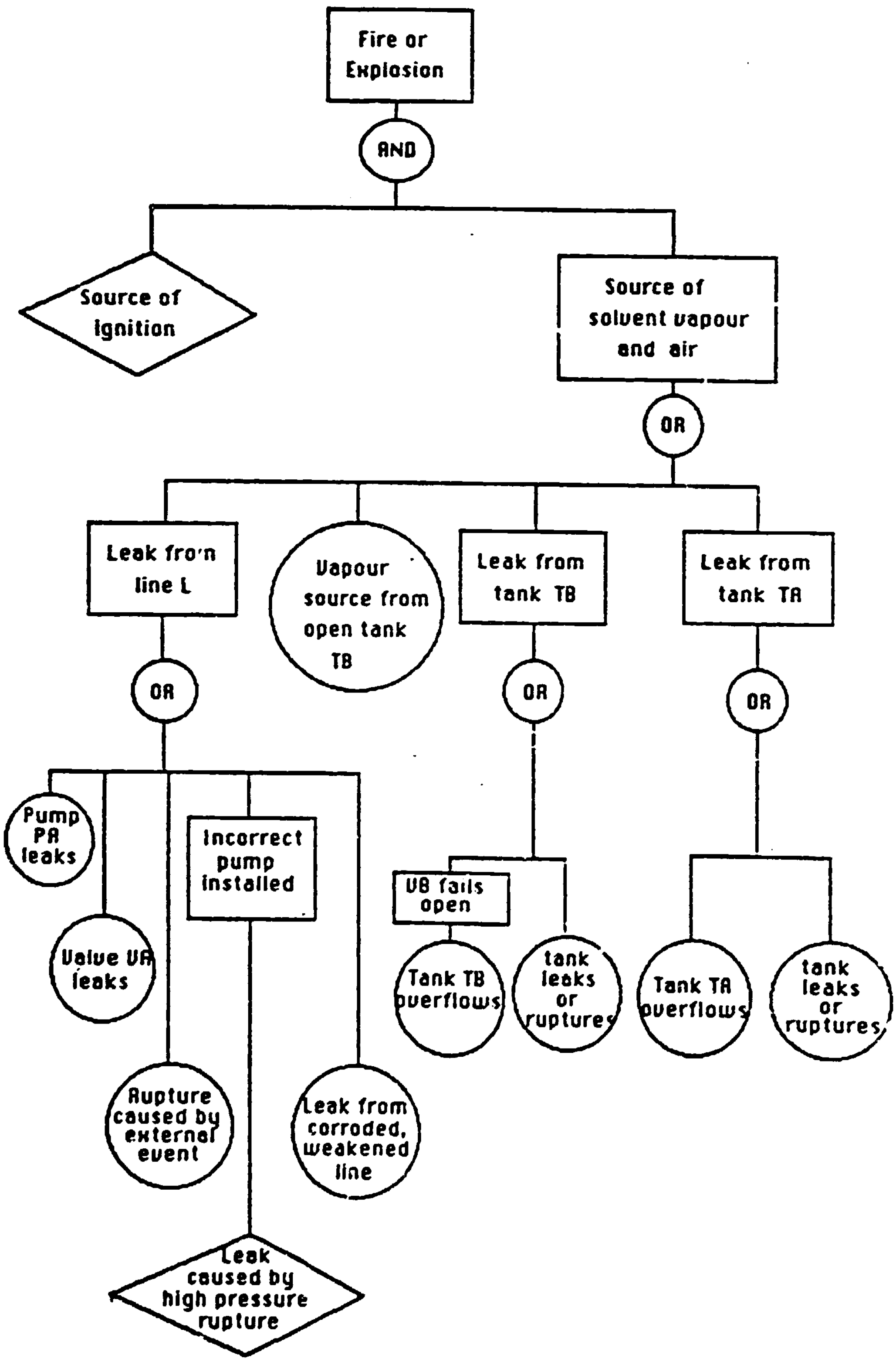


Fig. 3.3 (c) Examples of pre-incident and post-incident event trees. From EFCE (1985).

Figure 3.4

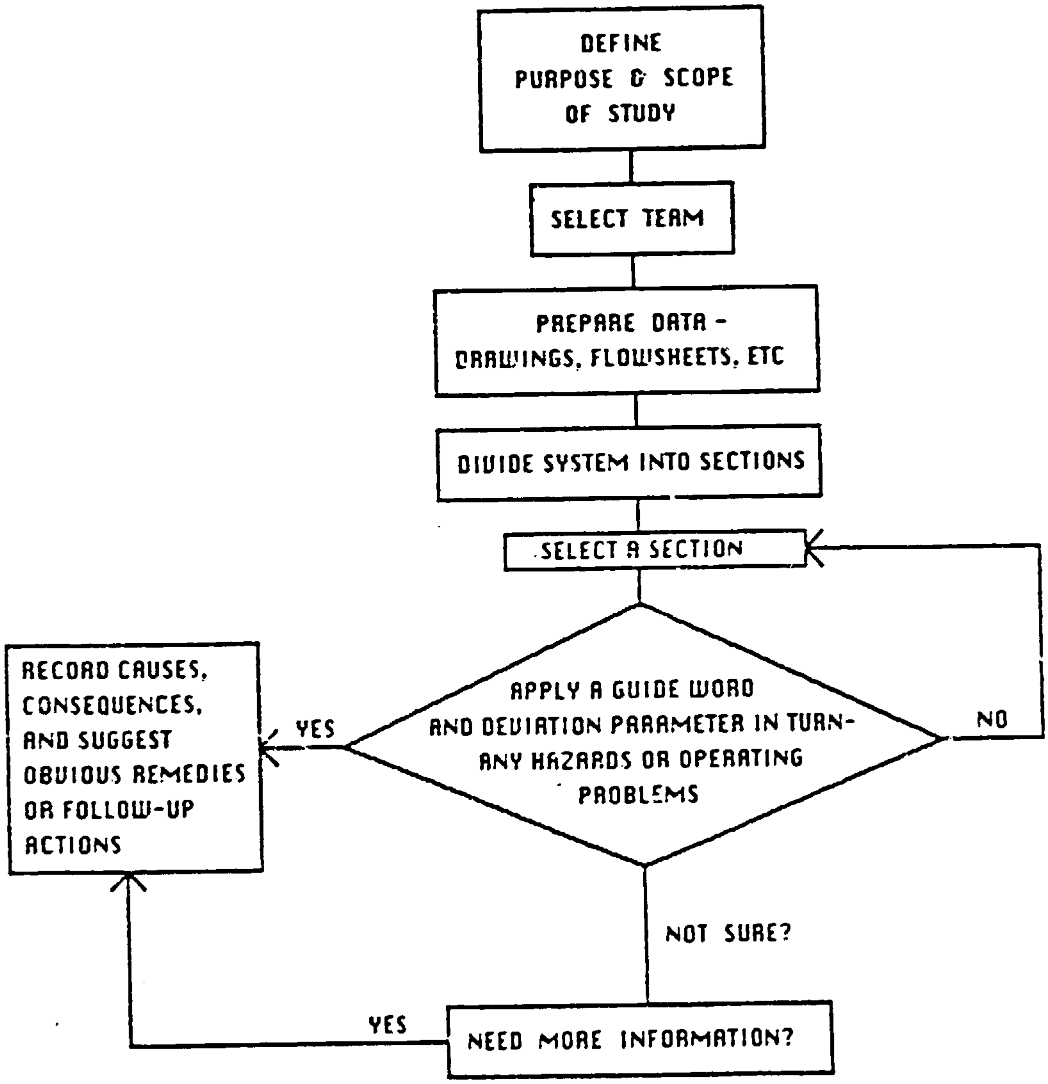
FAULT TREE EXAMPLE



Source: Warren Centre, Sydney University
NSW, Australia

FIGURE 3.5 (a)

HAZOP PROCEDURE



Source: Warren Centre, Sydney University NSW, Australia

HAZOP GUIDE WORDS

FIGURE 3.5 (b)

GUIDE WORDS	MEANINGS
NO or NOT	COMPLETE NEGATION
MORE LESS	QUANTITATIVE INCREASE QUANTITATIVE DECREASE
AS WELL AS PART OF	QUALITATIVE INCREASE QUALITATIVE DECREASE
REVERSE OTHER THAN	LOGICAL OPPOSITE COMPLETE SUBSTITUTION

DEVIATION PARAMETERS

PARAMETERS
FLOW PRESSURE TEMPERATURE LEVEL IMPURITIES MULTI PHASE VISCOSITY AND SO ON

Source: Warren Centre, Sydney University, NSW, Australia

Process Unit: DAP Production

Node: 1 Process Parameter: Flow

GUIDE WORD	DEVIATION	CONSEQUENCES	CAUSES	SUGGESTED ACTION
No	No Flow	Excess ammonia in reactor. Release to work area.	(1) Valve A fails closed	Automatic closure of valve B on loss of flow from phosphoric acid supply
			(2) Phosphoric acid supply exhausted	
			(3) Plug in pipe; pipe ruptures	
Less	Less Flow	Excess ammonia in reactor. Release to work area, with amount released related to quantitative reduction in supply. Team member to calculate toxicity vs. flow reduction.	(1) Valve A partially closed (2) Partial plug or leak in pipe	Automatic closure of valve B on reduced flow from phosphoric acid supply. Set point determined by toxicity vs. flow calculation
More	More Flow	Excess phosphoric acid degrades product. No hazard to work area.	--	--
Part of	Normal flow of decreased concentration of phosphoric acid	Excess ammonia in reactor. Release to work area, with amount released related to quantitative reduction in supply.	(1) Vendor delivers wrong material or concentration	Check phosphoric acid supply tank concentration after charging
			(2) Error in charging phosphoric acid supply tank	

Figure 3.6 SAMPLE OF HAZOP WORKSHEET

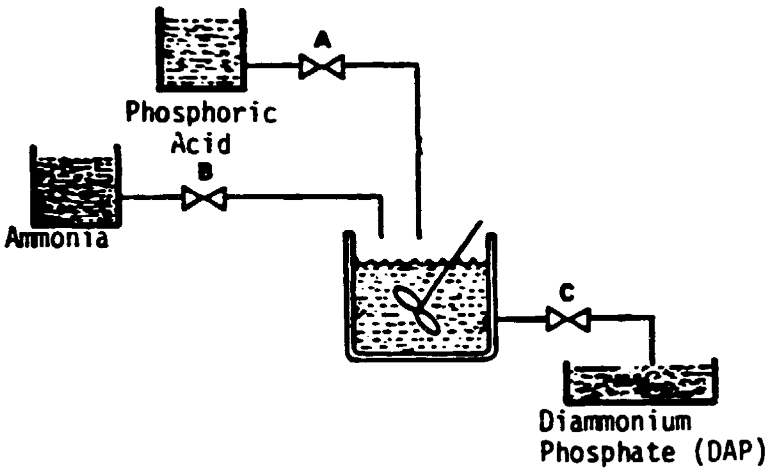


FIGURE 3.7(a)CONTINUOUS PROCESS EXAMPLE FOR "WHAT IF" TECHNIQUE

Figure 3.7(b) WHAT IF" QUESTIONS

"What If"

1. Wrong product is delivered instead of phosphoric acid
2. Phosphoric acid is wrong concentration
3. Phosphoric acid is contaminated
4. Valve A is closed or plugged
5. Too high a proportion of ammonia is supplied to reactor
6. Vessel agitation stops
7. Valve C is closed

What If	Consequence/Hazard	Recommendation
Wrong product is delivered instead of phosphoric acid	None likely	
Phosphoric acid is wrong concentration	Ammonia is not used up and is released to work area	Verify phosphoric acid concentration after filling vat prior to operation.
Phosphoric acid is contaminated	None likely	
Valve A is closed or plugged	Ammonia unreacteo, released to work area	Alarm/shutoff of ammonia (valve B) on low flow from valve A into reactor.
Too high a proportion of ammonia is supplied to reactor	Excess ammonia released to work area	Alarm/shutoff of ammonia (valve B) on high flow from valve B into reactor
. . .	. . .	. . .

FIGURE 3.7(C) SAMPLE "WHAT IF" WORKSHEET FOR DAP PLANT

3.1.4 Guidance on Implementation

The appropriateness and relevancy of any one particular technique of hazard identification largely depend on the purpose for which the risk assessment is being undertaken. The primary principle is to first examine the plant or operations from the broadest viewpoint possible and systematically identify possible hazards. Elaborate techniques as a primary tool may cause problems and result in missing some obvious hazards.

The objectives of the analysis must be clearly established at an early stage. It may also be necessary to adopt more than one technique depending on the level of detail required and whether the facility is a new proposed installation or an existing operation. For example, a preliminary hazard analysis or a generalized 'What if' analysis may be appropriate for a proposed new facility to assist in establishing a suitable location and when only preliminary design information is available. This could be followed by a detailed HAZOP at the design stage and then periodic safety audits and reviews at the operational stage. For an existing plant, HAZOP may be limited to when modifications are contemplated with safety audits and fault and event tree analysis undertaken as part of evaluating safety measures. The following provides a guidance framework to assist the most appropriate techniques for various situations.

Table 3.1 Guidance Table on Implementation of Hazard Identification Techniques

	Site selection/ early design stage	Design stage of new plants	Operational stage of new and existing plants	Modifications to existing plants
Process system checklist	B	B	A	B
Safety Audit/Review	C	C	A	C
Dow and Mond Hazard Indices	C	B	A	C
Preliminary Hazard Analysis	A	C	C	A
Hazard Operability Studies	C	A	B	A
'What if' Analysis	A	C	B	A
Failure Mode and Effect Analysis	C	A	A	B
Fault tree Analysis	C	A	A	B
Event tree Analysis	C	A	A	B
Cause-Consequence Analysis	C	B	A	B
Human Reliability Analysis	C	A	A	B
A- Best suited	B- Could be used	C- last suited (not advised)		

3.2. METHODS OF CONSEQUENCE ANALYSIS FOR ACCIDENTAL EMISSIONS

3.2.1. Introduction

Although there is no single authoritative source of acceptable definitions of the terminology used in probabilistic risk assessment (PRA), it is widely accepted that the term risk implies the consideration of the measure of some form of loss in terms of both the likelihood and the magnitude of that loss. This section presents the various methodologies and procedures used to calculate or estimate the unwanted consequences, effects, impacts or outcomes of severe accidents involving substances of a hazardous nature.

These outcomes may cause death, injury, property damage or permanent damage to the environment and can be considered under the broad headings of fire, explosion, toxic effects and missiles. The process of estimating quantitatively the effects of such outcomes is termed consequence analysis.

Before presenting the various methodologies and procedures for the estimation and calculations of the consequences of severe accidents a number of past accidents will be described. These will be used to illustrate the type and effect of Major Hazard that can occur at installations handling hazardous materials.

3.2.2. Major Hazard Incidents

Major disasters are not new – natural disasters have been recorded throughout history. The potential for man-made disasters has grown with technological achievements. In the context of this document a Major Hazard Incident has been taken to mean an accident involving one or more hazardous materials that has an impact in terms of death, injury or evacuation of people, damage to property or lasting harm to the environment. This type of impact can be caused by an explosion, high levels of thermal radiation or by exposure to a toxic material. It is acknowledged that other (lesser) effects could be caused by ionising radiations, asphyxiants, very cold substances (cryogens) and corrosive substances, however it is not intended to consider these in the context of the guideline document.

Table 3.2 [a] is a summary listing of major chemical accidents/incidents during the period 1950-1988.

Table 3.2

Major chemical accidents/incidents, 1950-1988

Year	Country	Location	Type of accident/incident	Chemical(s) involved	Outcome Deaths	Injuries[a]	Evacuated[b]
1950-1960	Japan	Minamata Bay	Foodstuff contamination (fish)	Methyl mercury	439	1,044	
	Japan	Toyama	Foodstuff contamination (rice)	Cadmium	0	200	
1955-1959	Turkey		Foodstuff contamination (seed)	Hexachlorobenzene	400	3,500[c]	
1956	UK		Foodstuff contamination (flour)	Endrin	0	59	
1959	Morocco		Foodstuff contamination (oil)	o-Cresyl-phoshate (OCP)	0	2,000[c]	
1960	India	Bombay	Foodstuff contamination (oil)	o-Cresyl-phosphate (OCP)	0	58	
1965	UK	Epping	Foodstuff contamination (flour)	4,4'-Methylenedianiline	0	84	
1968	Japan	Fukuoka	Foodstuff contamination (oil)	PCBs	0	200[c]	
1970	Japan	Osaka	Explosion	Gas	92		
1971-1972	Iraq		Foodstuff contamination (seed)	Methylmercury	459	6,071	
1972	USA	St. Louis	Rail accident (fire)	Propylene		250	
1973	USA	Market Tree	Rail accident	LPG			2,500
		Fort Wayne	Rail accident	Vinyl chloride			4,500
		Michigan	Foodstuff contamination (livestock)	PBBs	0	333	
		Greensburg	Rail accident	Chlorine		8	2,000
1974	UK	Flixborough	Plant (explosion)	Cyclohexane	28	89	3,000
	USA	Decatur	Rail accident	Isobutane	7	152	
		Wenatchee	Rail accident (explosion)	Monoethyl ammonium	2	112	
		Houston	Rail accident (explosion)	Butadiene	1	235	
1975	German Dem. Rep.	Helmstetten	Warehouse	Nitrogen oxide			10,000
	Netherlands	Beek	Road accident (explosion)	Propylene	14	104	
	USA	Eagle Pass	Road accident	LPG	17	34	
		Niagra Falls	Rail accident	Chlorine	4	176	
	Italy	Seveso[d]	Chemical plant (explosion)	Dioxin (TCDD)/2,4,5-T	0	193	730
	Jamaica		Foodstuff contamination (flour)	Parathion	17	62	
	USA	Houston	Road accident	Ammonia	6	178	
		Deer Park	Rail accident	Ammonia	5	200	
		Baton Rouge	Plant (explosion)	Chlorine			10,000
1976	German Dem. Rep.	Regensburg	Factory fire	Nitrogen oxide	0	40	2,000
	Italy	Manfredonia	Plant	Ammonia			10,000
	Mexico	Xilatopec	Road accident (explosion)	Gas	100	150	
		Huimanguille	Explosion (pipe)	Gas	58		
	Spain	Los Alfaques	Transport accident	Propylene	216	200	
	UK	Oxford	Road accident	Chlorine		99	
	USA	Youngstown	Rail accident (leak)	Chlorine	8	114	3500
1979	Canada	Mississauga	Rail accident	Chlorine/propane/butane/toluene			220,000
	China, Taiwan	Yucheng	Foodstuff contamination (oil)	PCBs/PCDFs	0	1900[c]	
	USA	Three Mile Island	Reactor failure	Radionuclides			200,000
		Crystal City	Warehouse	Pesticides			6,000
		Crestview	Rail accident	Ammonia/chlorine		14	4,500
		Memphis	Storage	Parathion	0	0	200
	USSR	Novosibirsk	Plant accident		300		
1980	India	Mandir Asod	Plant explosion	Explosives	50		
	Malaysia	Port Kelang	Explosion/fire	Ammonia/oxyacetylene	3	200	3,000
	Spain	Ortuella	Explosion	Explosives	51		

Table 3.2

Continued

Year	Country	Location	Type of accident/incident	Chemical(s) involved	Outcome Deaths	Injuries[a]	Evacuated
1980	UK	Barking	Plant fire	Sodium cyanide		12	3,500
	USA	Muldraugh	Rail accident (derailment)	Vinyl chloride		4	6,500
		Sommerville	Rail accident	Phosphorous trichloride		343	23,000
		Garland	Rail accident (derailment)	Styrene	0	5	8,600
		Newark	Rail accident (fire)	Ethylene oxide			4,000
1981	Mexico	Montana	Rail accident (derailment)	Chlorine	29	1,000	5,000
	Puerto Rico	San Juan	Rupture in factory	Chlorine		200	2,000
1981-1983	Spain	Madrid	Food contamination (oil)	As yet uncharacterized	340	20,000[c]	
1981	USA	Geismar	Plant	Chlorine		140	
		Castaic	Plant	Propylene		100	
	Venezuela	Tacoa	Explosion	Oil	145	1,000[c]	
	Viet Nam	Saigon	Contaminated product (talcum powder)	Warfarin	177[e]	564[e]	
1982	Canada		Rail accident	Hydrofluoric acid	0	0	1,200
	USA	Livingston	Rail accident	Fuel oil			3,000
		Vernon	Plant	Methyl acrylate		355	
		Fitchburg	Factory	Vinyl chloride	0	0	3,000
		Taft	Explosion	Acrolein			17,000
	Venezuela	Caracas	Tank explosion	Explosives	101	1,000	
1983	Nicaragua	Corintc	Tank explosion	Oil			23,000
	USA	Denver	Rail accident	Nitric acid		43	2,000
1984	Brazil	Sao Paulo	Pipeline explosion	Gasoline	508	3	
	India	Bhopal	Chemical plant (leakage)	Methyl isocyanate	2,500	50,000[c]	200,000
	Mexico	St. J. Ixhuatepec	Tank explosion	Gas	452	4,248	31,000
		Matamoras	Fertilizer factory	Ammonia		200	3,000
	Pakistan	Garhi Dhoda	Explosion (gas-pipe)	Natural gas	60		
	Peru	Callao	Pipeline explosion				3,000
	USA	Middleport	Plant	Methyl isocyanate		110	
		Saugel	Plant	Phosphorous oxychloride		125	
		Linden	Plant	Malathion		161	
1985	India	Bombay	Industrial accident (pipe burst)	Chlorine	1	110	
		New Delhi	Industrial accident (leakage)	Sulphur trioxide	1	350	100,000
	Mexico	Guadalajara	Rail accident (leakage)	Sulphuric acid	0	49	5,000
	USA	Institute	Fire	Aldicarbe oxime		140	
		Peabody	Plant	Benzene	1	125	
1986	Ukranian SSR	Chernobyl[d]	Nuclear reactor (explosion)	Radionuclides	31	300	135,000
1987	China	Guangxi province		Methyl alcohol	55	3,600	
		Shanxi	Drinking water contamination	Ammonium bicarbonate	0	15,400	
	USA	Wilson county	Rail accident	Sulphuric acid	0	0	3,000
		Nanticote	Factory fire	Sulphuric acid	0	0	18,000
		Ohio	Road accident	Phosphorous trichloride	0	6	2,000
		Confluence	Rail accident	Propane gas	0	0	1,000
1988	USSR	Yaroslavl	Rail accident		0	34	2,000

Table 3.2

Continued

- [a] Or affected in cases of poisonings.
- [b] Majority of data are approximations
- [c] Approximation.
- [d] Accompanied by widespread contamination of livestock and crops.
- [e] Infants.

Accidents/incidents listed are those which have caused 50 or more deaths and injuries and/or 1,000 evacuated.
Accident/incidents associated with the *use* of pesticides or drugs are not included.
Figures for numbers of injuries do *not* include numbers of deaths.
Incidents need not be of accidental origin and commonly result from ignorance or malpactrice (e.g. uncontrolled chemical waste disposal or misuse of chemicals)

Sources:

Buffler, P.A., Crane, M. and Key, M.M 1985 Possibilities of detecting health effects by studies of populations exposed to chemicals from waste disposal sites, *Environmental Health Perspectives*, 62, 423-456
Krishna Murti, C.R. 1988 A systems approach to the control of chemical disasters. In: *Risk Assessment of Chemicals in the Environment*, M.L. Richardson (Ed.), Royal Society of Chemistry, UK.
OECD 1987 *Environmental Data Compendium 1987*, Organisation Economic Co-operation and Development, Paris.
Umweltbundesamt 1983 *Materialien 5/83*, Erich Schmidt Verlag, Berl
UNEP 1985-1988 *UNEP NEWS, Environmental Events Record*, Unit Nations Environment Programme, Nairobi.
WHO 1987 *Environmental Epidemiology - Bibliography on Hea Effects of Environmental Hazards in Developing Countries*, World Hea Organization, Geneva.

3.2.2.1 Explosions

These can be dense-phase explosions, confined or unconfined vapour cloud explosions, boiling liquid expanding vapour explosions (BLEVE) or dust explosions. All of these can lead to blast overpressures. Other causes of less destructive explosions are large vessel rupture through internal overpressure, runaway chemical reactions or explosions resulting from contact of a hot non-volatile body such as molten iron with water.

(i) Dense-phase explosions

A dense-phase explosion occurs when a liquid or solid is suddenly converted to a gaseous form. The rapid increase in volume, results in a pressure wave which radiates from the source at a velocity greater than the speed of sound in air. This pressure wave can be very destructive. One of the most destructive explosions of this type which involved an industrial (rather than a military) hazardous material occurred at Oppau in Germany in 1921. A mixture of ammonium nitrate and ammonium sulphate was stored in the open in a large heap before being made into fertiliser. This mixture tended to become somewhat solid and it became the practice to break it up using explosive charges - a technique that had been carried out a large number of times. On this particular occasion it appeared that some 4500 t of the material exploded with devastating effects. The explosion killed 561 people, 4 of whom were 7 km away in the town of Mannheim. 1500 persons were injured and 75% of the buildings in the nearby town of Oppau were demolished. A total of around 1000 houses were destroyed. All buildings within a range of between 250 and 300 m were demolished and a 10 metre deep crater roughly 100 m in diameter was formed. Damage to buildings up to 45 km away was reported.

(ii) Vapour Cloud Explosions

The requirement for this type of explosion is a large pre-mixed cloud of flammable vapour and air within the flammable range. The combustion processes of large vapour clouds are still not fully understood, however the effects are strongly affected by the degree of confinement encountered, the size of the cloud and the degree of turbulence experienced. An example of a vapour cloud explosion was that which occurred at Flixborough in the UK in 1974. As part of its process the plant reacted cyclohexane (a flammable material with a boiling point of 81°C) with air at a temperature of 145°C at a pressure of about 8 bars gauge in a series of reactors. Due to a fault with one of the reactors it had been taken out of service and a temporary pipe in the shape of a 'dog-leg' installed in its place. Some time later this temporary pipe failed and hot liquid was released which flashed into a mixture of vapour and entrained liquid. A large vapour cloud was formed which contained approximately 50 t of cyclohexane. Ignition occurred within a minute and a massive explosion resulted. The plant and on-site buildings were destroyed and 28 plant personnel, most of them in the nearby control room, were killed. Nearby houses suffered heavy damage and some windows were broken up to 15 km away.

(iii) Boiling Liquid Expanding Vapour Explosions (BLEVE)

A BLEVE describes the sudden rupture of a vessel containing liquefied flammable gas under pressure due to flame impingement. The pressure burst and the flashing of the liquid to vapour creates a blast wave and potential missile damage. The immediate ignition of the expanding mixture of fuel and air leads to intense combustion and the creation of a fire-ball. The majority of BLEVES have occurred during the transport of pressurized liquefied gases but a number have occurred at fixed installations. Most probably the worst occurred at Mexico City in 1984. A release of gas occurred during the early morning at a large LPG distribution plant. The initiating event was possibly a leak on a pipeline bringing LPG in from a refinery. A cloud of vapour was formed and ignited. There were several violent explosions (7 or 8) and numerous smaller ones. These explosions and the fires that followed killed at least 500 people, injured more than 7000 others and about 60000 persons had to be evacuated. Out of the original 48 'bullet' type storage vessels only 4 remained on their supports. One of these weighing about 20 t was found 1200 m away. There were also 6 spherical storage vessels on the site, the 4 smallest all exploded and large fragments of them travelled at least 400 m. The two larger spheres did not explode but collapsed through their legs buckling. Virtually all housing within a 300 m radius of the plant was severely damaged. It should be noted that when the plant was originally constructed some 25 years before the accident the nearest housing was about 300 metres away. However poor quality, flimsily constructed housing had been allowed to encroach to within 100 m of the site boundary.

(iv) Dust Explosions

These explosions are a hazard whenever combustible solids of small particle size are handled. A significant number of these explosions have occurred in flour mills or in buildings used for storing or discharging grain. A particularly large explosion occurred at Westwago near New Orleans, Louisiana, USA, in 1977. Over forty silos containing corn, wheat and soya beans were involved and 35 on-site workers killed. Most of these were in an office block which collapsed when an 80 m tall concrete tower fell on it.

3.2.2.2 High levels of Thermal Radiation (Fires)

Following release of flammable materials there is the possibility (apart from the explosions described above) of the material igniting and burning in a manner which can give rise to high levels of thermal radiation. Depending on the physical properties (temperature, pressure, etc), the mode of release and the time of ignition the material can be involved in a pool, flash (vapour) or torch fire.

(i) Pool Fires

Liquid spilt onto a flat surface spreads out to form a pool. If the liquid is volatile, evaporation takes place and if the liquid is flammable then the atmosphere about the pool will be in the flammable range. If ignition takes place then a fire will burn over the pool. The heat from this fire will vapourise more liquid and air will be drawn in from the sides of the pool to support combustion. The system will then consist of a solid cylinder of flame burning above the pool. The principal hazard to people is from exposure to the high levels of thermal radiation generated. Whilst some of these fires can be spectacular, because the extent of injury depends on the proximity to the fire and the time of exposure, it is unusual for large numbers of people to be seriously affected and large accidents with multiple fatalities are rare. However plant damage and losses can be severe.

(ii) Flash Fires

A flash fire occurs when a cloud of a mixture of flammable gas and air is ignited. The shape of the fire closely resembles the shape of the flammable cloud prior to ignition but it also depends upon where within the cloud ignition occurred. In many cases the cloud extends back to the original point of release and can then give rise to a torch or pool fire dependent on the mode of release. When ignition occurs, the flame front races or 'flashes' through the cloud very quickly. People or property close to or within the cloud are at risk from thermal radiation effects. An example of a severe flash fire occurred at Meldrim, Georgia, USA in 1959 when LPG was released from a derailed train. The LPG spread over a wide area before ignition occurred. The resultant flash fire killed 23 people.

(iii) Jet or Torch Fires

A jet or torch fire usually occurs when a high pressure release from a relatively small opening (ruptured pipe, pressure relief valve, etc) ignites. This gives rise to a torch which can burn with flame lengths several metres long. The flame is a hazard to persons nearby but the main hazard is generally its effect on adjacent vessels which may contain flammable liquids. A number of BLEVEs have occurred as a result of flame impingement – a typical scenario being the torch fire from the pressure relief valve on an overturned rail tankcar impinging on an adjacent tankcar. Example includes the jet-fire torching from a safety valve on top of a 50 Te LPG tanker which was deflected onto its own unwetted surface and caused a BLEVE in Kingman, Arizona, USA in 1973. Thirteen firemen were engulfed in the ground level fireball and died.

3.2.2.3 Toxic Releases

Toxic chemicals can cause harm to both animal and plant life. Effects from explosions and fires are usually confined to a relatively small area but toxic materials can be carried by wind or water over greater distances and can cause lasting damage to man and environment. Harm from toxic material is a function of the concentration of the toxic material and the duration of the exposure time. The process of calculating harm is inexact and is complicated by the fact that, as far as man is concerned, individual susceptability varies considerably. The elderly, those in poor health, and the very young are those most at risk. Two of the most important toxic chemicals produced in bulk are chlorine and ammonia. Chlorine is produced at a rate of over 30 Mt/y. Therefore it is not surprising that there have been a number of accidental releases involving this material. Chlorine has also been used in warfare and some information concerning exposure to large releases has been obtained from World War I experience.

One of the worst industrial accidents involving chlorine occurred in December 1939 at Zarnesti in Romania. This disaster, probably caused by the rupture of a storage vessel, spilled 24 t of chlorine and killed 60 people. Many of those killed were close to the vessel but some were killed at a railway station about 250 m away. One person was killed about 800 m away – this is probably the greatest distance away from a peace-time chlorine release for a human fatality. It was fortunate that at the time the wind speed was low and therefore the rate at which the material dispersed enabled a number of people to escape to higher ground.

Ammonia is produced in similar quantities to that of chlorine but is much less toxic. Nevertheless, there have been a number of accidents which have resulted in fatalities. One of the worst occurred at Potchetstroom in South Africa in 1973. A pressurised storage vessel was being filled from a rail tank when the vessel failed, possibly from being overfilled. About 38 t of ammonia were released more or less instantaneously. Exposure to ammonia resulted in the deaths of 18 persons, 6 of them outside of the works boundary. Five persons who died were at a distance of between 150 and 200 m from the release point.

There are numerous reports of incidents involving chlorine and ammonia which have caused serious damage to the environment. At an incident in La Barre, Lousianna, USA in 1961, in which between 27 and 35 t of chlorine was released, there were reports of damage to animal life over an area of approximately 15 km^2. At an accident near Floral, Arkansas, USA in 1971, about 600 t of ammonia were released from a pipeline. This ammonia reached a watercourse and killed thousands of fish.

The most horrifying incident involving a toxic gas release occurred in December 1984 in Bhopal, India, in which an escape of methyl isocyanate killed at least 2500 people and may have injured 200,000 more. This disaster is possibly the worst industrial accident in the world's history. Due to reasons which have not been fully explained approximately two tonnes of water was added to 41 t of methyl isocyanate in a storage tank. Water amd methyl isocyanate can react together in an exothermic reaction. The use of a refrigeration system to deal with this eventuality had been discontinued some six months earlier. The increase in temperature resulted in an increase in pressure which burst a rupture disc fitted to the tank and gases passed along a long line to a scrubber system. This system was inadequate to pass a large volume of gas (it was designed to pass process ventilation products not the full flow from a runaway reaction) and so the gases passed untreated to a flare which, at the time of the accident, was shut down for repair. A further possible safety feature was a pressurised water spray curtain – this failed due to insufficient water pressure. A major contribution to the high death rate was that many of the nearby population were asleep at the time in very high density accommodation and poorly constructed dwellings which offered virtually no protection. A large number of animals were also killed.

An accident which caused considerable damage to the environment occurred at Seveso, Italy in 1976. Approximately 2 kg of the chemical dioxin was released which affected an area of about 17 km^2. Although no persons died directly as a result of the release a number of persons were found to be victims of chloracne. There were a large number of deaths among the animal population and many other animals were slaughtered as a protection against dioxin entering the food chain. The dioxin released proved capable of sterilising for agricultural use about 4 km^2 of land. The effects will last for several years. A large quantity of earth was removed from other areas in an attempt to return the land to agricultural use.

3.2.3 The Calculation of the Consequences from Accidental Releases of Hazardous Materials

The calculation of the consequences of an accidental release of a hazardous substance may be sub-divided into three main steps that relate to:

- physical models;
- effect models;
- consideration of mitigation effects.

The overall approach is illustrated in Tab. 3.3. Each of the steps involved are addressed by the following sections.

Table 3.3 Overall Approach To Consequence Estimations

Determine accident scenario's

pipe break, pressure vessel failure (partial or total), explosions, etc.

Establish mode of hazard realization

release of toxic material
release of flammable materials
release of energy

Determine mode of transmission to target

airborne or waterborne dispersion
high thermal radiation
overpressure
missiles

Calculate effects on target

thermal radiation effects
exposure to toxic materials
effects of blast overpressure

Take allowance of mitigating effects

shelter
evacuation
medical treatment

Assess/Consequences

assess probability of deaths, injury, structural damage, environmental harm, etc.

3.2.3.1 Physical Models

(a) Release or Discharge Rates

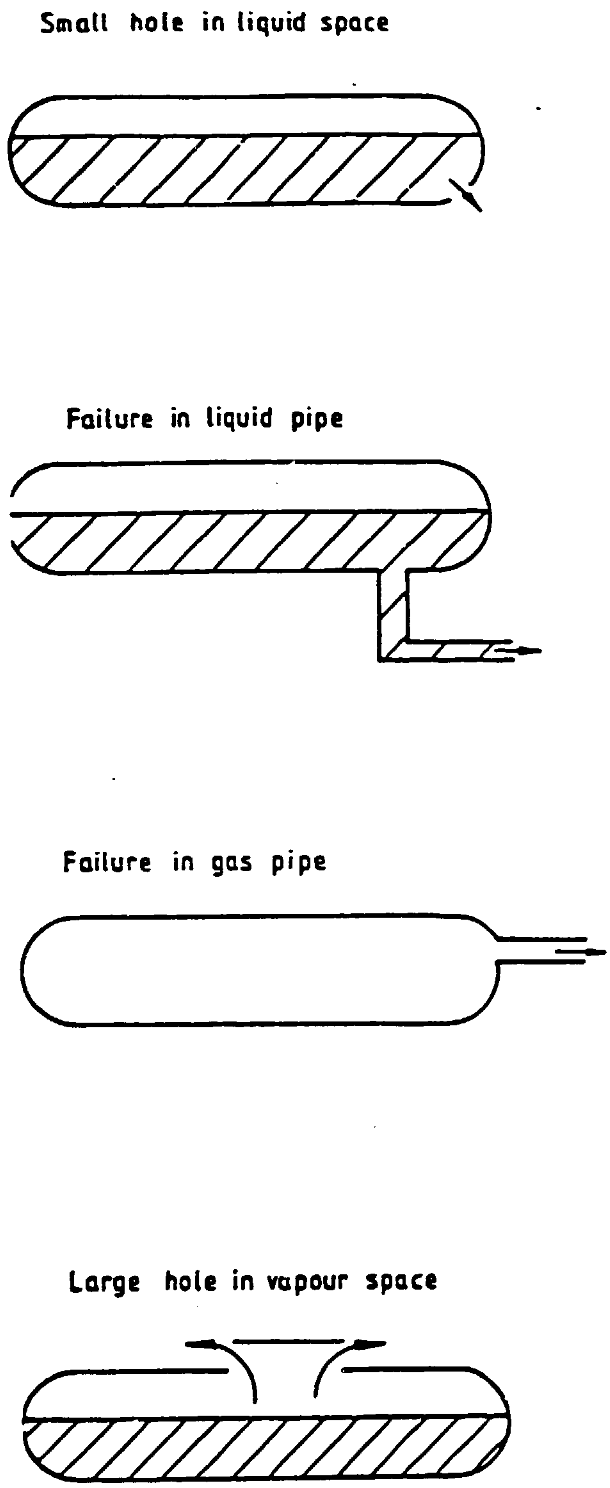
The objectives of this section is to review the release or discharge models currently used in consequence analysis. Most accidents are the result of a hazardous material escaping from its containment. This may be from a crack or hole in a vessel or pipework, it may be from catastrophic failure of a pipe or vessel, it may be from a wrongly opened valve or it may be from an emergency relief system. These leaks could be in the form of a gas, a liquid or a two-phase flashing liquid-gas mixture. It is essential at this stage to estimate the total amount of material involved. This may be greater or lower than the amount of material stored in any single vessel or pipework system due to interconnection with other vessels or pipework systems and also due to the relative position of the leak within the system.

Vessels may catastrophically fail or leak from a crack, a hole or at a connection to pipelines. The behaviour of the contents of the vessel depend on its initial conditions immediately before release – the main factors being the physical properties of the material and the temperature and pressure within the vessel. In the case of liquefied gases stored under pressure, the contents of the vessel which has catastrophally failed will rapidly flash off and form a vapour cloud, if unignited. If a source of ignition is found, then a large fireball will be formed. Other materials in liquid form, including many stored at reduced temperatures, will spill onto the ground below the vessel. The liquid will spread out to form a pool which will be confined in the event of the vessel being bunded (having a confining barrier around it). This pool will evaporate as a result of heat supplied from the air and the ground and form a vapour which will be dispersed in the atmosphere. Holes and cracks will have discharge rates similar to pipe breaks of similar sizes. Depending on the position of the leak relative to the liquid level within the system, the discharge can be a vapour (discharge always above the liquid level), or a liquid (discharge always below the liquid level). However, a leak located between these two extremes can experience a range of conditions going from liquid to two-phase to vapour with the flowrate varying under each of these conditions as the pressure and static level within the tank varies (Fig. 3.8).

These effects can be summarized as follows:

(i) <u>Gas/Vapour discharge results from:</u>

- a hole in equipment (pipe, vessel, etc) containing gas under pressure;
- a relief valve discharge of vapour only;
- evaporation or boil-off from a liquid pool;
- generation of toxic combustion products in fires.



LOCATION OF DISCHARGE POSITIONS

Figure 3.8

(ii) Two-phase discharge results from:

- a hole in a pressurised storage vessel containing a liquid above its normal boiling point;
- a relief valve discharge under certain conditions (possibly a foaming liquid, a runaway reaction or because the vessel it relieves has been moved and the valve is no longer at the top of the vessel).

(iii) Liquid discharge results from:

- holes under liquid head in atmospheric storage tanks or other atmospheric pressure vessels or pipes;
- holes in vessels or pipes containing pressurised liquids below their normal boiling point.

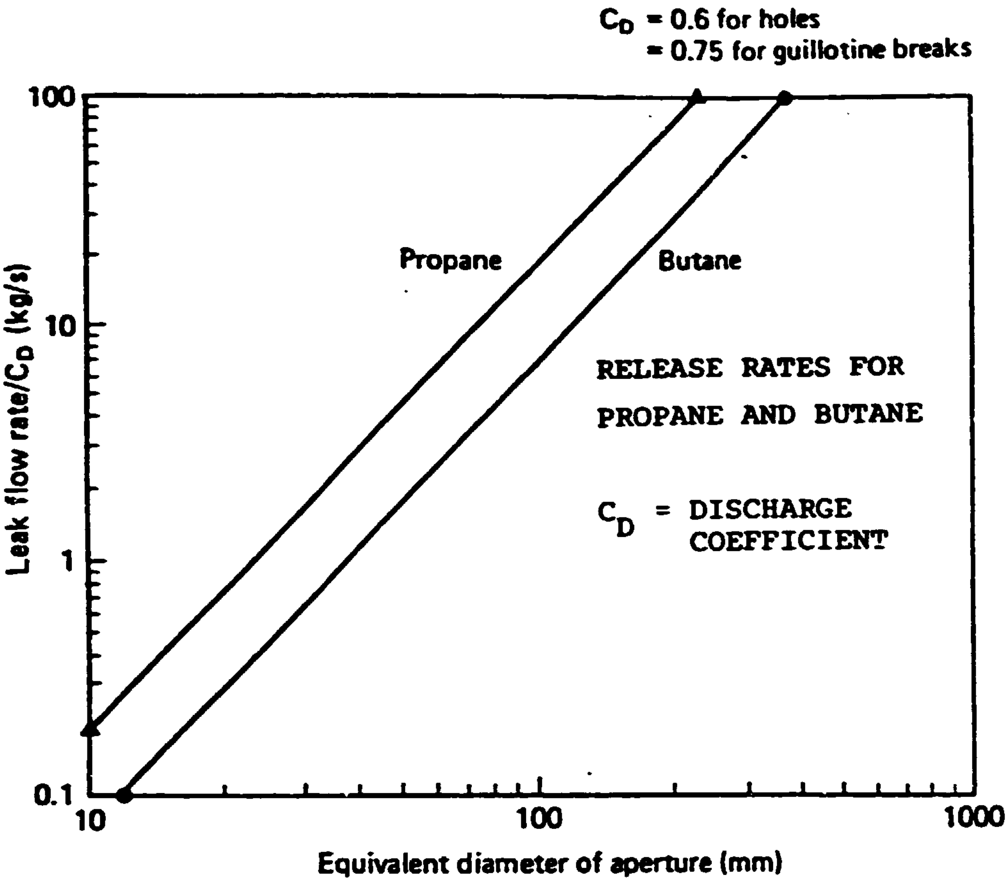
There are a number of equations and models which deal with the release of liquids, two phase mixtures and vapours from various leak regimes. The most important are detailed in **Lees and Ang**, 1989 [b], which lists example base cases for a range of hole sizes, **Ramskill**, 1987 [c], **AIChE/CCPS**, 1989 [d], **Perry and Green**, 1984 [e] and **CRANE Co**, 1981 [f]. Relief valve discharges can be determined by reference to the AIChE/DIERS work **Fauske et al.**, 1986 [g], and **Crozier**, 1985 [h].

Figure 3.9 shows some curves which may be used to make an approximate estimate of the release rates of propane and butane from apertures of different sizes. These curves are derived from work carried out by the UK Safety and Reliability Directorate during the preparation of the Second Canvey Report, **Health and Safety Executive**, 1981 [i].

There are a few computer codes which deal with discharge-rate calculations – these include the following:

DEERS (Two-phase flashing discharges (JAYCOR Inc) (see also **Klein**, 1986 [j]);
SAFIRE (AIChE, New York);
PIPEPHASE (Simulation Sciences Inc. Fullerton, California).

A few integrated computer packages for consequence analysis also include discharge calculation rate modules. In many cases the specific and detailed nature of the system under study may require manual calculations to be carried out. Apart from the specific references cited earlier, discharge rate calculation methods can also be found in the TNO so-called Yellow Book, 1979 [k] (currently being reprinted), the World Bank Manual – Technica, 1985 [l] and 1988 [ll], and SAFETI TECHNICA.


C_D = 0.6 for holes
= 0.75 for guillotine breaks
100
10
1
0.1
Leak flow rate/C_D (kg/s)
Propane
Butane
RELEASE RATES FOR
PROPANE AND BUTANE
C_D = DISCHARGE COEFFICIENT
10
100
1000
Equivalent diameter of aperture (mm)

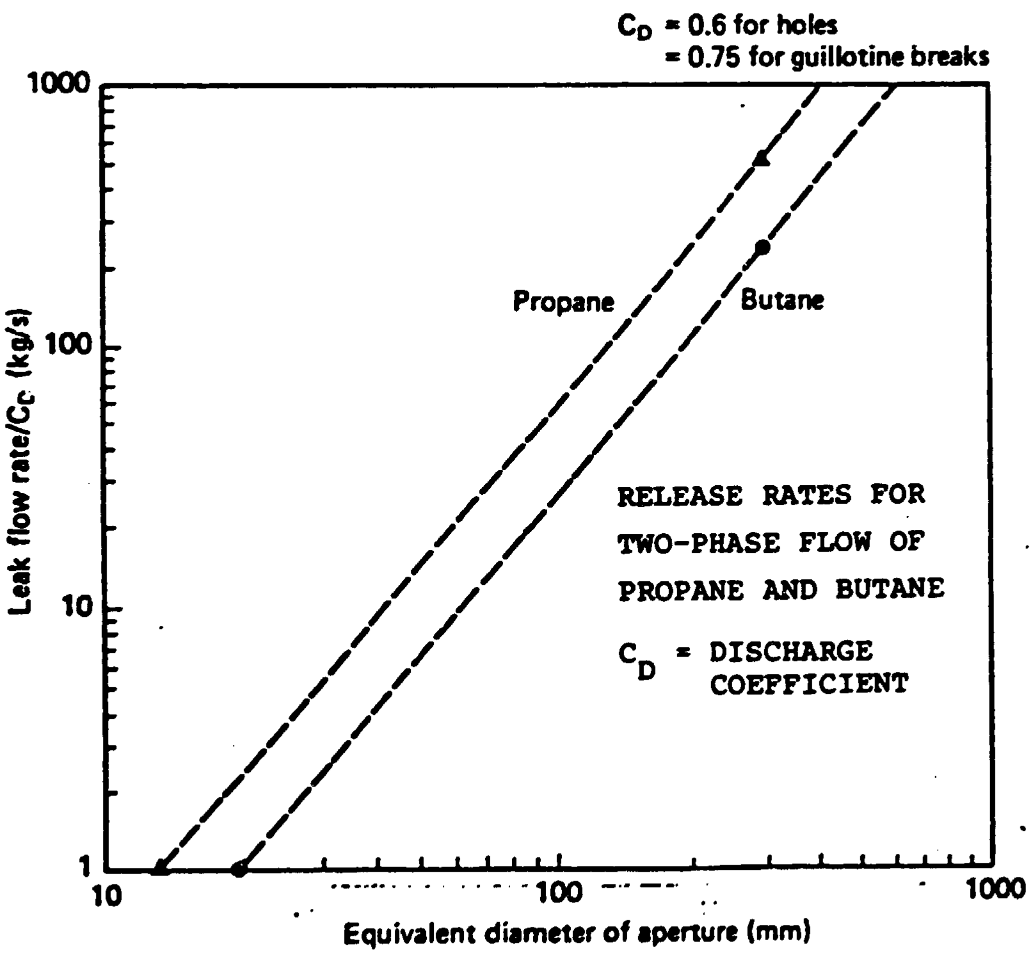

C_D = 0.6 for holes
= 0.75 for guillotine breaks
1000
100
10
1
Leak flow rate/C_D (kg/s)
Propane
Butane
RELEASE RATES FOR
TWO-PHASE FLOW OF
PROPANE AND BUTANE
C_D = DISCHARGE COEFFICIENT
10
100
1000
Equivalent diameter of aperture (mm)

Figure 3.9

In the following, simple models are illustrated which let the user to perform first hand calculations of the source term.

(i) Gas discharge

It is now described the calculation of the gas flowrate through openings in a pressurized reservoir (large vessel or large pipeline). The gas is assumed to behave as an ideal gas and the transformation is assumed to be a reversible adiabatic expansion. Two flow regimes are possible depending on the value of the critical pressure ratio:

$$r_{crit} = (p/p_a)_{crit} = [\,(\Gamma+1)/2\,]^{\Gamma/(\Gamma-1)}$$

where:

p = absolute upstream pressure (N/m^2);
p_a = absolute downstream pressure (N/m^2);
$\Gamma = C_p/C_v$ = gas specific heat ratio.

Depending on whether the ratio of the actual upstream and downstream pressures is lower or greater than r_{crit}, the flow regime is subsonic or sonic (chocked). The gas flow is given by:

$$G_v = C_d \frac{A\,p}{c}\,Y$$

where:

G_v = gas discharge rate (kg/s);
C_d = discharge coefficient;
A = hole area (m^2);
c = sonic velocity of gas at $T = (\Gamma RT/M)^{1/2}$;
T = absolute temperature in the reservoir (°K);
M = molecular weight of gas (kg-mol);
R = gas constant;
Y = flow factor.

The flow factor is dependent on the flow regime:

$$Y = \left\{ \frac{2\Gamma^2}{\Gamma - 1} \cdot (p_a/p)^{2/\Gamma} \cdot \left[1 - (p_a/p)^{(\Gamma-1)/\Gamma} \right] \right\}^{1/2}$$

subsonic flow for $(p/p_a) \leq r_{crit}$

$$Y = \Gamma \cdot \left\{ \frac{2}{\Gamma + 1} \right\}^{(\Gamma+1)/2(\Gamma-1)}$$

sonic flow for $(p/p_a) \geq r_{crit}$

(ii) Liquid discharge

Using Bernoulli's equation, the liquiq flowrate can be calculated with:

$$G_l = C_d \, A \, \delta \cdot \left[2(p - p_a)/\delta + 2gh \right]^{1/2}$$

where:

G_l = liquid discharge rate (kg/s);
C_d = discharge coefficient;
A = hole area (m^2);
δ = liquid density (kg/m^3);
p = storage pressure, absolute (N/m^2);
p_a = ambient pressure (N/m^2);
g = gravity constant (m/s^2);
h = liquid head above hole (m).

For fully turbulent flow at the discharge from small sharp edged orifices C_d assumes a value of 0.6-0.64.

If the liquid is superheated and if the diameter of the break is sufficiently small compared to the diameter of the pipeline or the dimensions of the tank (ratio of lengths lower than 12 [11]), the flow is assumed to remain liquid while it is escaping through the break. Immediately after, it flashes to vapour for the fraction:

$$f_v = \frac{C_{pl} \cdot (T_l - T_s)}{H_{lv}}$$

where:

C_{pl} = specific heat of liquid (kJ/kg/°K);
T_l = liquid temperature (°K);
T_s = saturation temperature at atmospheric pressure (°K);
H_{lv} = enthalpy of evaporation at atmospheric pressure (kJ/kg).

Non flashing liquid is entrained in the vapour phase as aerosol. As a first approximation, it can be assumed that all the liquid is entrained if $f_v \geq 0.2$; none, of course, if $f_v = 0$; for values included in this range, a linear relationship could be considered [ll].

(iii) Two-phase discharge

If a superheated liquid is discharged through a hole which has the equivalent diameter equal or greater than one tenth of the lenght of the pipe or the dimensions of the tank, or if the discharge is from the vapour space of a vessel containing a viscous or foamy volatile liquid, a two-phase critical flow develops. An empirical method by **Fauske**, 1965 [z2], adapted by **Cude**, 1975 [a3] and reported in the World Bank Manual – Technica, 1988 [ll], is explained in the following.

It is assumed that the two phases form a homogeneous mixture in equilibrium; it is assumed also that the ratio of the critical pressure p_c at the throath to the upstream pressure p for water systems (0.55) can be applied to other substances.

The fraction of liquid flashing at p_c is:

$$f_v = \frac{C_{pl} \cdot (T_l - T_{sc})}{H_{lv,c}}$$

where:

C_{pl} = specific heat of liquid (kJ/kg/°K);
T_l = liquid temperature (°K);
$T_{s,c}$ = saturation temperature at pressure p_c (°K);
$H_{lv,c}$ = enthalpy of evaporation at pressure p_c (kJ/kg).

The mean specific volume v_m of the two-phase mixture is:

$$v_m = v_g f_v + v_l (1 - f_v)$$

where:

v_g = specific volume of saturated vapour (m^3/kg);
v_l = specific volume of saturated liquid (m^3/kg);

The discharge rate of the mixture is:

$$G_m = C_d A_r \cdot [\, 2\,(p - p_c)/v_m \,]^{1/2}$$

where:

C_d = discharge coefficient (0.8 recommended);
A_r = effective hole area (m^2);
p = upstream pressure (N/m^2);
p_c = critical pressure (N/m^2).

The entrainment of liquid can be estimated as in the case of flashing immediately following the discharge (see above).

(iv) Evaporating pool

Liquid spilled from a containment forms a pool which would then evaporate and become dispersed to the atmosphere. Vapour generation rates from evaporating pools must be calculated before considering methods of estimating the dispersion of gases and vapours that is the subject of the next subsection. A liquefied gas can form a liquid pool if it escapes from refrigerated storage. Other liquids which boil above ambient temperatures can form slowly evaporating pools. The vaporisation rate of a pool is the product of the average local vaporisation rate and the pool area. However the local vaporisation rate is in itself largely dependant upon the pool area. The final shape and size of the pool will be a function of the quality of material involved, the nature of the surface upon which it was spilt and whether or not the pool size is confined by a physical barrier such as a bund.

Poo! vaporisation rates therefore depend on a number of variables, the principal ones being:

- the spread of liquid on land or water;
- heat and mass transfer from the atmosphere; and
- heat transfer to or from the surface upon which the material has been spilt.

The way pools spread is also a very complex problem. This is very much dependant on the nature and type of surface involved and is difficult to model in a generic manner.

The shear diversity and complexity of the physical phenomena which conspire to determine pool vaporisation rates have made numerical solutions to the problem absolutely necessary. Hand calculation methods can be used **AIChE/CCPS**, 1989 [d], but accurate estimates need sophisticated computer models. The most recent and thorough of these is **GASP - Webber et al.**, 1990 [n]. This code makes predictions for a wide range of continuous and instantaneous liquid spills on land and water. Because the physical properties of the substances involved are so important in determining the evaporation rate, the code has been coupled to a databank containing properties of a number of common hazardous substances. Other available computer codes include **Wu & Schroy**, 1979 [o], and **SPILLS - Fleischer**, 1980 [p].

(b) Dispersion Models

One of the most important factors governing dispersion of a hazardous gas or vapour closely following release is the density of that gas or vapour. It is convenient therefore to classify clouds according to whether they are lighter than air, they have the same density of air or are denser than air (positively, neutral or negatively buoyant, respectively). Positively, (lighter than air) buoyant clouds tend to naturally rise – in most circumstances this reduces the harm they can do, although hazardous situations can exist close to low-level releases. However, dense clouds can stay at a low level for a considerable distance downwind and can therefore pose a much greater hazard (indeed under relatively calm conditions large releases of dense gases can travel upwind whilst under the influence of gravitational forces such as slumping of large releases or due to topographical features. Unfortunately, many of the hazardous substances met in large quantities are either denser than air (e.g., LPG or chlorine) or behave as though they are denser than air due to their storage temperature (e.g., LNG or ammonia).

(i) Neutral and positively buoyant gases

Neutral and positively buoyant models are used to predict concentration and time profiles of flammable or toxic material downwind of a source. These models are almost always based on the concept of Gaussian dispersion. The models attempt to determine the concentration of a hazardous gaseous material downwind of a release. The basic work is best described by **Pasquill**, 1974 [q] and **Gifford**, 1976 [r]. Descriptions of neutral or positively buoyant gases and the way in which they disperse are given in **Hanna et al.**, 1982 [s], **Pasquill and Smith**, 1983 [t] and in the **TNO** Yellow Book, 1979 [k].

Hand calculations to estimate the dispersion of neutral or positively buoyant clouds are still common in chemical process plant risk assessment but in other models do use computerised techniques. A good review of these models is given in **AIChE/CCPS**, 1987 [u].

A brief description of gaussian dispersion models for continuous and puff emissions has been already reported in Section 2.4.2.

(i) Negatively buoyant gases (dense gas dispersion)

The importance of dense gas dispersion has been recognised for some time. Attempts have been made to develop comprehensive computer models and a number of field experiments have been carried out which confirm the fact that dense gases behave in a markedly different manner with respect to neutral or buoyant gases. Probably the largest and most comprehensive field experiments were those carried out under the supervision of the UK Health and Safety Executive (HSE) at Thorney Island in the early 1980's (**McQuaid**, 1985 [v] and **McQuaid and Roebuck**, 1985 [w]). These were co-ordinated by the HSE and funded by a wide range of contributors from a number of different countries.

There are a number of mechanisms by which a dense gas or vapour can disperse in the atmosphere and become progressively diluted as it mixes with air. These mechanisms depend mainly on the buoyancy and momentum of the material involved. Momentum forces are associated with the early stages of release from pressurised equipment although gravitational forces can provide momentum following the 'slumping' stages of large instantaneous releases. Whilst consideration of the momentum driven period of dispersion may satisfy relatively small releases of flammable gases which are diluted below the lower flammable limit during the momentum phase alone, in many other situations dispersion beyond the transition to the buoyant plume dispersion must be considered. The point at which this transition occurs depends on the momentum and buoyancy forces acting on the dispersing material, although in certain situations gravity effects and collision with solid surfaces (buildings, trees, very rough ground, etc) may become important before the momentum of the jet becomes negligible. It is here not possible to discuss in detail the mathematics which describe this dispersion process. The solutions of the equations describing the gravity-slumping of a heavier-than-air gas cloud, the simultaneous movement in the wind and the entrainment of air into the cloud, together with heat effects, is sufficiently complex to require computer modelling. Perhaps the most comprehensive review of vapour cloud dispersion models is that given by **HANNA and DRIVAS/CCPS**, 1987 [ss]. A number of codes are available, some of these deal only with instantaneous releases, others with only continuous releases, whilst there are others which are capable of dealing with both situations. At the moment, few codes can handle complex time-varying situations, although many codes are under development. These codes model the transition from a heavier-than-air cloud to a neutrally buoyant one, as the cloud dilutes and equilibrates with the temperature of the surrounding air. Therefore, they can also be used for neutrally buoyant releases, although the equations for this are generally simpler and, as stated earlier, can be, and often are, calculated by hand. Publications which describe methods of calculating the dispersion of dense gas in the atmosphere are numerous.

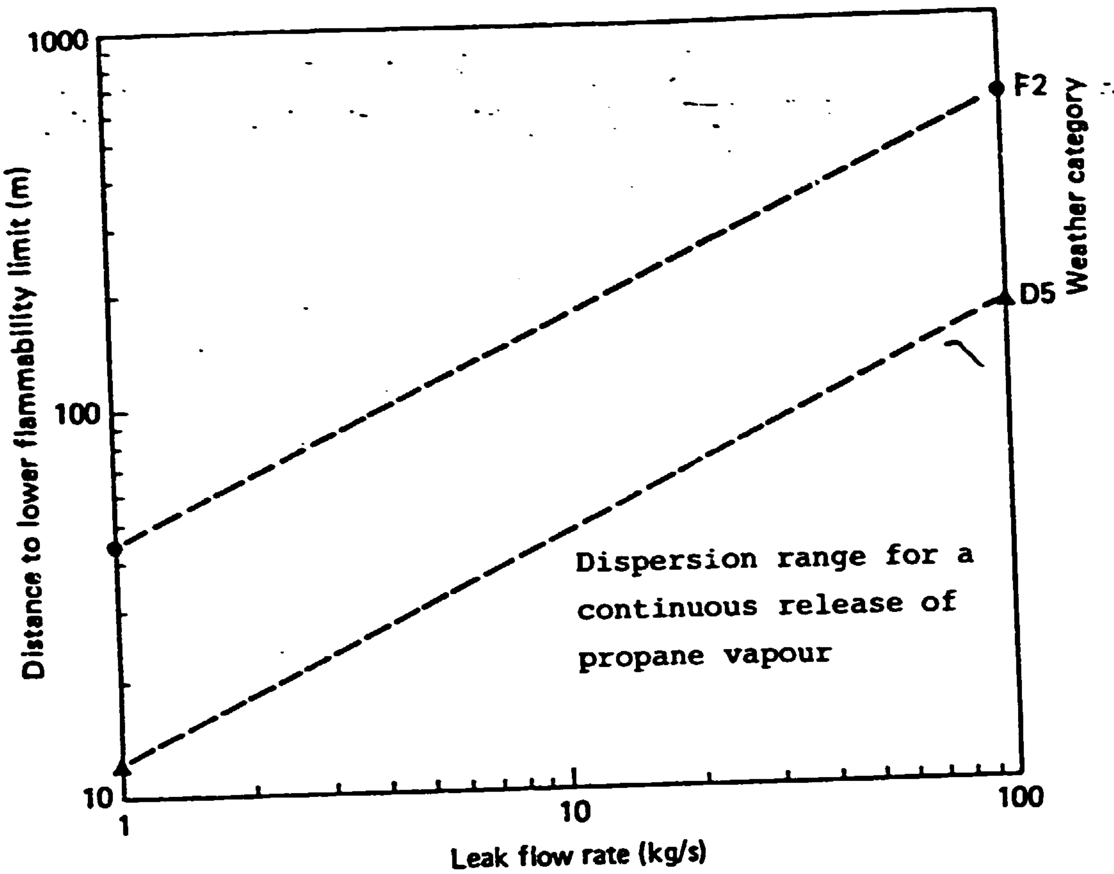
One of the most comprehensive is that by **BRITTER and McQUAID**, 1987 [y]. Other recent publications worth referring to are listed below:

Fryer and Kaiser, 1979 [z],
Blackmore et al., 1982 [a1],
Britter, 1982 [b1],
Havens, 1982 [c1],
Weber, 1982 [d1],
Bradley, 1983 [e1],
Jagger, 1983 [f1],
Hartwig, 1984 [g1],
Knox, 1984 [h1],
McQuaid, 1984 [i1],
Morgan, 1984 [j1],
Brighton, 1985 [k1],
Ermak, 1985 [l1],
Havens, 1985 [m1 and n1],
Spicer, 1986 [o1],
Journal Hazardous Materials, 1987 [p1],
Deaves, 1987 [q1],
Havens, 1987 [r1],
Webber, 1987 [s1],
Kukkonen, 1988 [t1],
Spicer, 1988 [u1],
Witlox, 1988 [v1],
Koopman, 1989 [w1].

Dense gas dispersion **computer codes** which have been made available in substantial numbers include the following:

CHARM (Radian Corporation, USA)
DEGADIS (US Coastguard)
HEGADAS (SHELL)
DENZ/CRUNCH (SRD, UK)
HASTE (ERT, USA)
SLAB (Lawrence-Livermore National Laboratory, USA)
SAFETI (Techica, UK)
TRACE (SAFER CORPORATION, USA)

It must be appreciated by now that the subject of dense gas dispersion is a very specialised, technical one, and because of this it is important that calculations of the hazard ranges, due to the dispersal of dense gases, are carried out by those who have more than just a passing acquaintance with the topic. Even with the modern tendency to make codes easier and more attractive to use, caution must always be taken to ensure that the situations presented to the


1000
100
10
1
10
100
Distance to lower flammability limit (m)
Leak flow rate (kg/s)
F2
D5
Weather category
Dispersion range for a continuous release of propane vapour

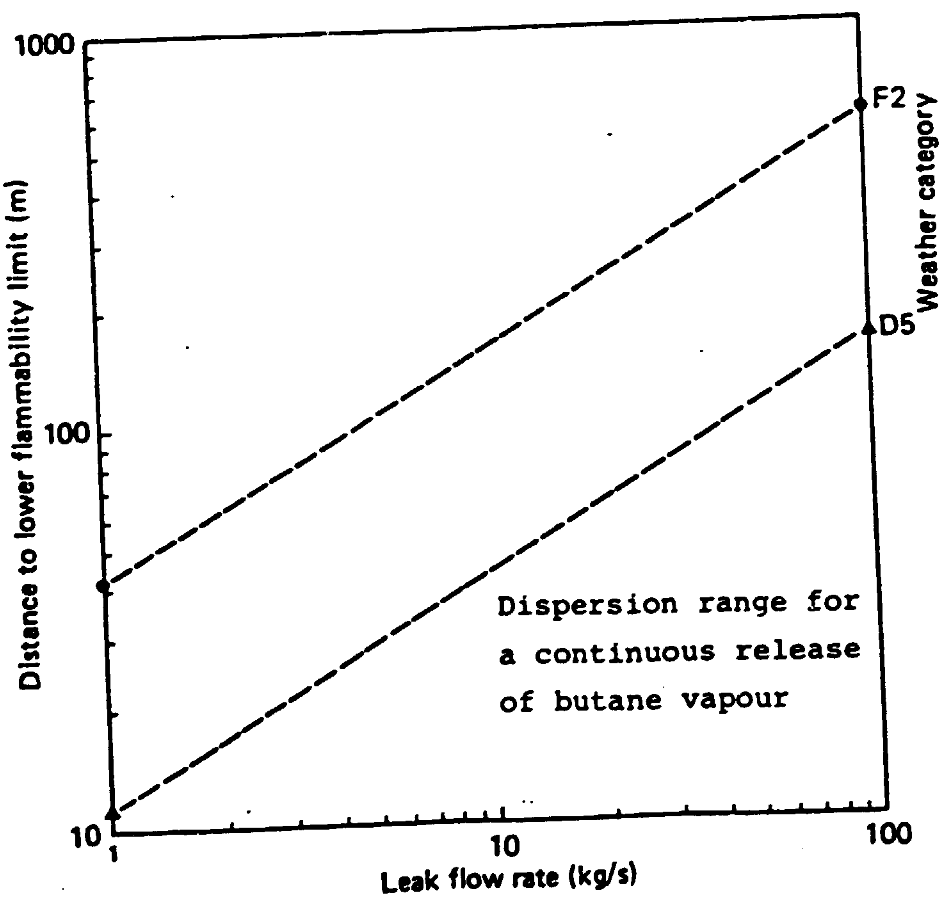

1000
100
10
1
10
100
Distance to lower flammability limit (m)
Leak flow rate (kg/s)
F2
D5
Weather category
Dispersion range for a continuous release of butane vapour

Figure 3.10

computer model is that which actually exists. There is no easy short-cut to carrying out dense-gas dispersion calculations but for a few of the more common hazardous materials encountered in everyday life there are curves, derived from the use of modern codes, which calculate gas concentration as a function of distance and time for a range of release scenarios. Examples of these for flammable gases and chlorine can be found in Chapters 8 and 14 of **Lees and Ang**, 1989 [b] and in **Chemical Industries Association**, 1987 [y1]. Figure 3.10 shows curves for the dispersion of a continuous release of propane or butane as a function of distance to lower flammability limit against the leak flow rate for two weather stability classes (D and F) and related typical wind velocities (5 m/s and 2 m/s, respectively). These curves were derived with the use of the SRD computer code CRUNCH.

(c) Fires

Four separate categories of fire can be considered: pool fires, jet fires, flash fires and the so-called fireballs.

- **Pool fire**: it occurs when an accumulation of flammable liquid as a pool on the ground or on a different liquid surface is ignited. A steadily burning fire is rapidly achieved as the fuel vapour to sustain the fire is provided by evaporation of the liquid by heat from the flames. For liquefied gases, significant heat transfer from the surface on which the pool is formed usually contributes to the vaporization of the fuel. The rate of consumption of fuel is a function of the properties of the fuel such as latent heat, heat of combustion etc, which results in typical rates of regression of the pool depth of 6-13 mm/min.

  There are three methods of calculating the thermal radiation fluxes from a pool fire. These are the point source method, the solid flame method and the volume emitter method.

  In the **point source method** it is assumed that the heat is radiated from the vertical axis at the centre of the pool. The radiation flux is given by the formula:

$$I = \frac{f H_c}{4 \pi R^2}$$

where:

I = incident radiation per unit area;

R = distance from the source;

f = the fraction of the heat of combustion assumed to radiate in all directions from the notional centrepoint source

H_c = the heat of combustion per unit time.

The **solid flame method** has the advantage over the simple point source method as it takes account of the actual shape and volume of the flame, although it is reduced to a simple geometrical shape for ease of manipulation.

It is however a simplification to assume that a flame emits thermal radiation solely from its surface. The **volume emitter method** takes account of the fact that the sources of radiation are hot molecules and particules distributed throughout the whole volume of the flame. The radiation is determined by factors like the path length, concentration and temperature of the molecules and particles. However, it is extremely difficult to do this; this is the reason why the normal procedure is to use the point source method.

The portion of the thermal radiation from a source which is incident upon a nearby target is given by the relationship:

$$Q_t = Q_s \cdot F_{ts} \cdot \tau$$

where:

τ = atmospheric transmissivity (a function of the path length and the physical characteristics of the atmosphere) (**Simpson**, 1984 [z1]);

Q_t = thermal radiation received at distance d (W/m^2);

Q_s = total heat radiated (W);

F_{ts} = geometrical view factor (or form factor or configuration factor).

The geometrical view factor is the fraction of the total radiation from one surface which is incident upon the other in its line of sight. The calculation can be difficult but fortunately tables are available which give the view factors for a large variety of shapes and orientations (**Considine**, 1984 [a2], **TNO**, 1979 [k], **Mudan**, 1984 [b2] and **Institute of Petroleum**, 1987 [c2]).

- **Jet fire**: it occurs when a flammable liquid or gas, under some degree of pressure, is ignited after release from a hole or crack in a pressure vessel, from the end of an open pipe or from the orifice of a pressure relief valve. The pressure behind the liquid or gas tends to generate a fairly long stable flame. This jet flame can be extremely intense and can impose high heat loads on nearby plant and equipment.

  Jet fire modelling is not as well developed as pool fire modelling. However, there are a number of publications which describe the various approaches (**Bagster**, 1986 [d2], **API 521**, 1982 [e2] and **Hustad and Sonju**, 1985 [f2]. The API method is relatively simple. An example of its application to an LPG jet flame is given in Fig. 3.11 which shows the flame length and the distance to a given level of thermal radiation against the flow rate.

- **Flash fire**: it occurs when a cloud of a mixture of flammable gas and air is ignited. The shape of the fire closely follows the shape of the cloud prior to ignition but also depends upon the position within the cloud where the ignition took place. The speed of burning depends on the concentration of the flammable material in the cloud and, to a lesser extent, on the wind speed. Ignition of the cloud may take place whilst the cloud still extends to the release point – under these circumstances this can give rise to a pool or a jet fire, depending on the nature of the release. It is also possible that the flame may accelerate to a sufficiently high velocity for an explosion to occur. Figure 3.12 shows the area of the plume to the lower flammability limit against leak flow rate for plumes of LPG for two weather stability classes (D and F) and related typical wind velocities (5 m/s and 2 m/s, respectively).

- **Fireball**: it occurs when there has been a release of considerable violence and vigorous mixing and rapid ignition takes place. The initial flammable cloud is often hemispherical before ignition but rapidly approximates to a rising sphere, due to thermal buoyancy. If the release of fuel is directed upwards, such as when a vessel suddenly ruptures, then a spherical shaped fireball forms immediately. An important source of a fireball is due to the phenomena known as a Boiling Liquid Expanding Vapour Explosion or **BLEVE**. These usually occur with flammable liquids stored under pressure at ambient temperature, liquids such as liquefied petroleum gas, propylene or ethylene oxide. The event starts with an external fire, possibly fuelled by a spillage or leak from the vessel itself, which has flames impinging on areas of the vessel which are in contact with the liquid contents. Boiling of the liquid increases the vapour pressure but keeps the wetted vessel surface relatively cool. However, where the flames impinge on areas of the vessel blanketed by vapour, heat transfer is poor and the metal surface temperature rapidly rises. At these high temperatures the metal weakens

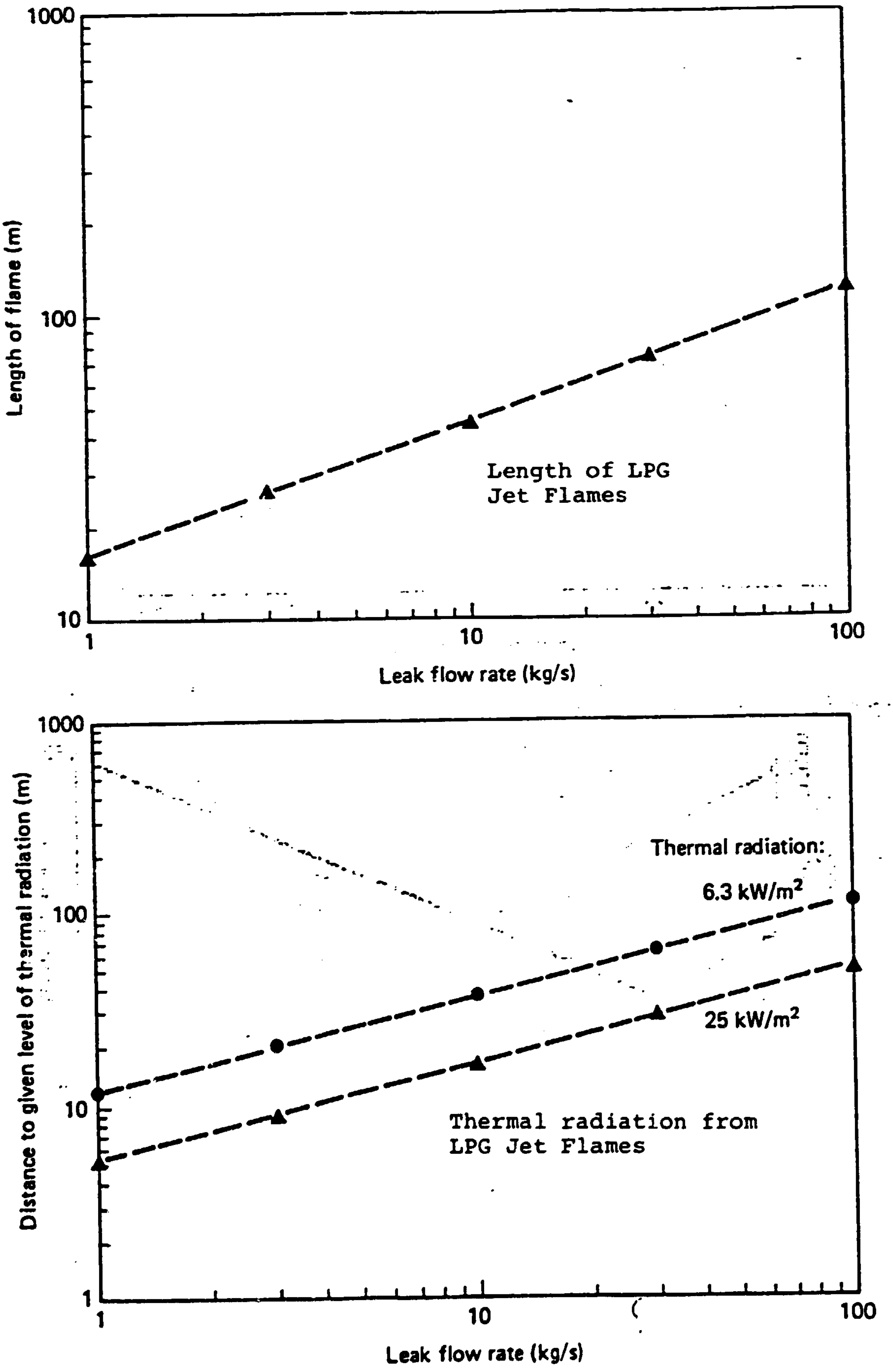

1000
100
10
Length of flame (m)
1
10
100
Leak flow rate (kg/s)
Length of LPG
Jet Flames
1000
100
10
1
Distance to given level of thermal radiation (m)
Thermal radiation:
6.3 kW/m²
25 kW/m²
Thermal radiation from
LPG Jet Flames
1
10
100
Leak flow rate (kg/s)

Figure 3.11

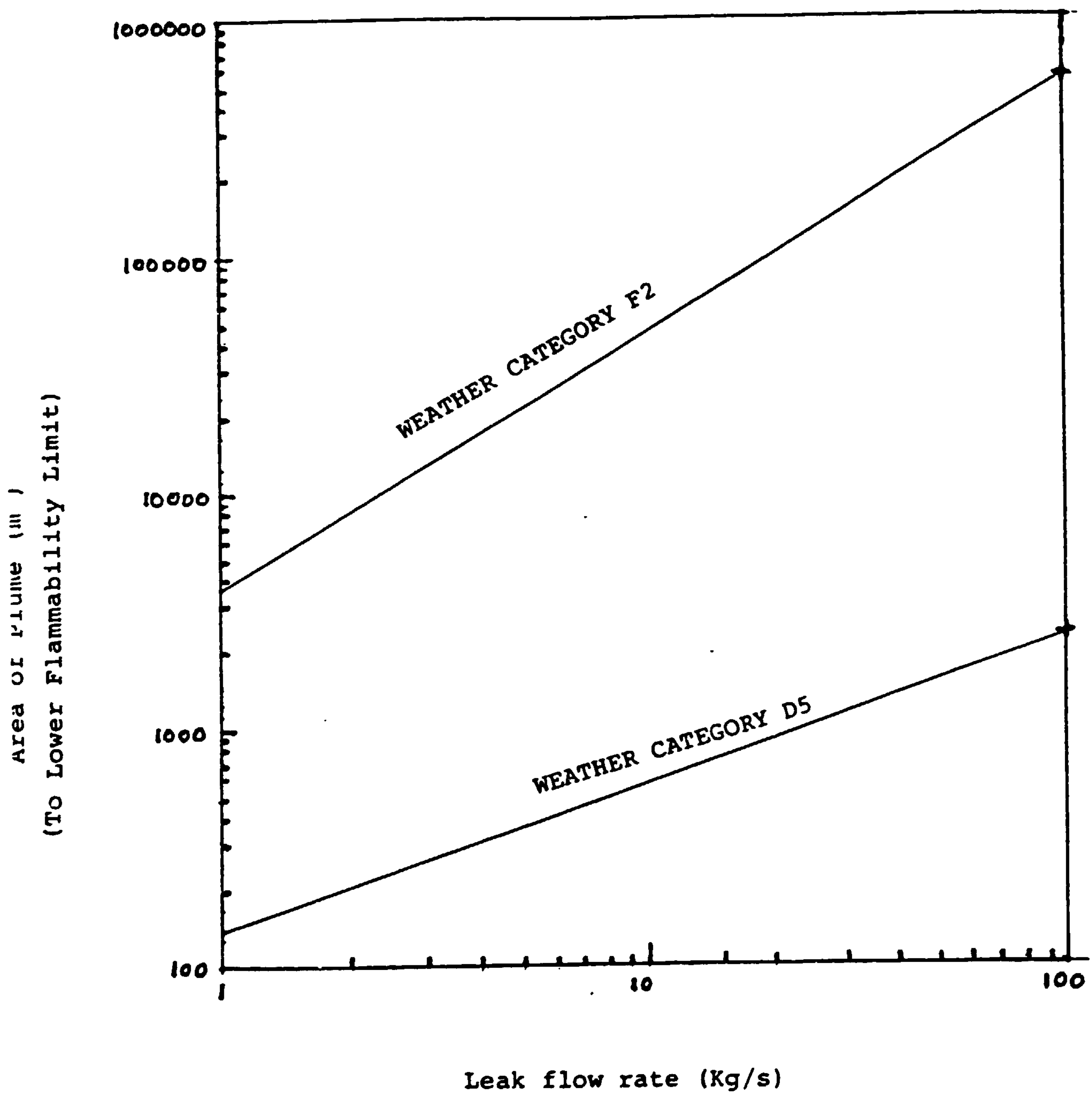

1000000
100000
10000
1000
100
1
10
100
WEATHER CATEGORY F2
WEATHER CATEGORY D5
(To Lower Flammability Limit)
Leak flow rate (Kg/s)

Figure 3.12

and, with increasing internal pressure, ruptures. As a result of the vessel failure the pressurised contents rapidly escape and expand forming a large cloud of vapour and entrained liquid. The cloud is ignited by the original flames and a huge fireball is formed. Casualties can be due to not only thermal radiation but also to the effects of the blast and to missiles.

Fireballs tend to produce large heat fluxes for a short period of time. Some useful formulas for fireballs produced by BLEVEs are given in **TNO**, 1979 [k].

Peak diameter D (m) of the fireball:

$$D = 29 \cdot M^{1/3}$$

fireball duration t (s):

$$t = 4.5 \cdot M^{1/3}$$

or

$$t = 8.2 \cdot M^{1/6} \quad \text{(for } M > 30 \text{ te)}$$

where M is the initial mass of flammable liquid (te).

The constants used in the above depend on the nature and amount of the material involved. Where some degree of precision is required, it is recommended the methods described in **TNO**, 1979 [k] (currently being revised), **Marshall**, 1987 [n2] and **Lees/Ang**, 1989 [b].

(d) Explosions

An explosion is a process involving the production of a pressure wave resulting from a very rapid release of energy. In the case of an explosion in air, the air will become heated locally due to its compressibility. This will increase the velocity of sound causing the front of the disturbance to steepen as it travels through the air, thereby increasing the pressure and density of the air until a peak pressure wave is developed at some nominal distance. The magnitude of this pressure wave will govern the loading and therefore the damage to structures, people, etc., nearby.

This section will consider the prediction of blast overpressure effects from vapour cloud explosions, condensed phase explosions and catastrophic failure of large vessels under pressure.

The idealized structure of a blast wave is shown in Fig. 3.13. Before the arrival of the front of the shock wave the pressure is at the ambient level. The time taken for the front to travel from the source of the explosion to the point at which the blast is measured is known as the arrival time t_a.

At the arrival time the pressure rapidly rises to a peak value which is known as the peak positive overpressure. This pressure then decays back to the ambient pressure in a time known as the positive phase duration. This is followed by a further decline to produce a pressure lower than ambient and eventually returns back to the ambient pressure. The period from the end of the positive phase to the final return to the ambient atmospheric pressure is known as the negative phase duration. The parameters of most interest are the peak positive overpressure and the area enclosed by the positive overpressure time curve. A vapour cloud explosion occurs when a release of gas mixes with air and is ignited. The mixture must be within a limited flammability range for an explosion to occur. The effects of a vapour cloud explosion depend to a large extent on the degree of confinement. Open-air, so called unconfined, vapour cloud explosions have been thought to be impossible and are very difficult to theoretically understand. However, the presence of relatively minor turbulence producing obstacles with the requirement for a certain critical mass may explain the fact that a large number of so-called unconfined vapour cloud explosions have occurred. The blast wave from an unconfined vapour cloud explosion is characterised by a relatively slow rise to peak pressure and a relatively long duration (typically a few tenths of a second). Vapour cloud explosions produce levels of overpressure of the order of 1 bar and do not produce craters.

Confined gas explosions may occur in equipment (such as storage tanks), amongst groups of plant items and/or buildings (partially confined explosions) or inside buildings. Under total confinement, most gases will, when mixed with air at atmospheric pressure, produce a maximum pressure of 8 bars when ignited (**Harris R.J.**, 1983 [o2] and **Marshall**, 1987 [n2]). The pressure profile for a totally confined explosion is shown in Fig. 3.14.

In most practical confined situations there will be a vent or a weak point (sometimes deliberately inserted) within the structure which will relieve some of the explosion gases and cause a reduction in peak overpressure.

Condensed phase explosions arise as a result of detonation of high explosives such as TNT or RDX or materials such as some organic peroxides which are used as propellants for military purposes. Condensed phase explosions are the type which most closely approximates that of the idealised blast wave

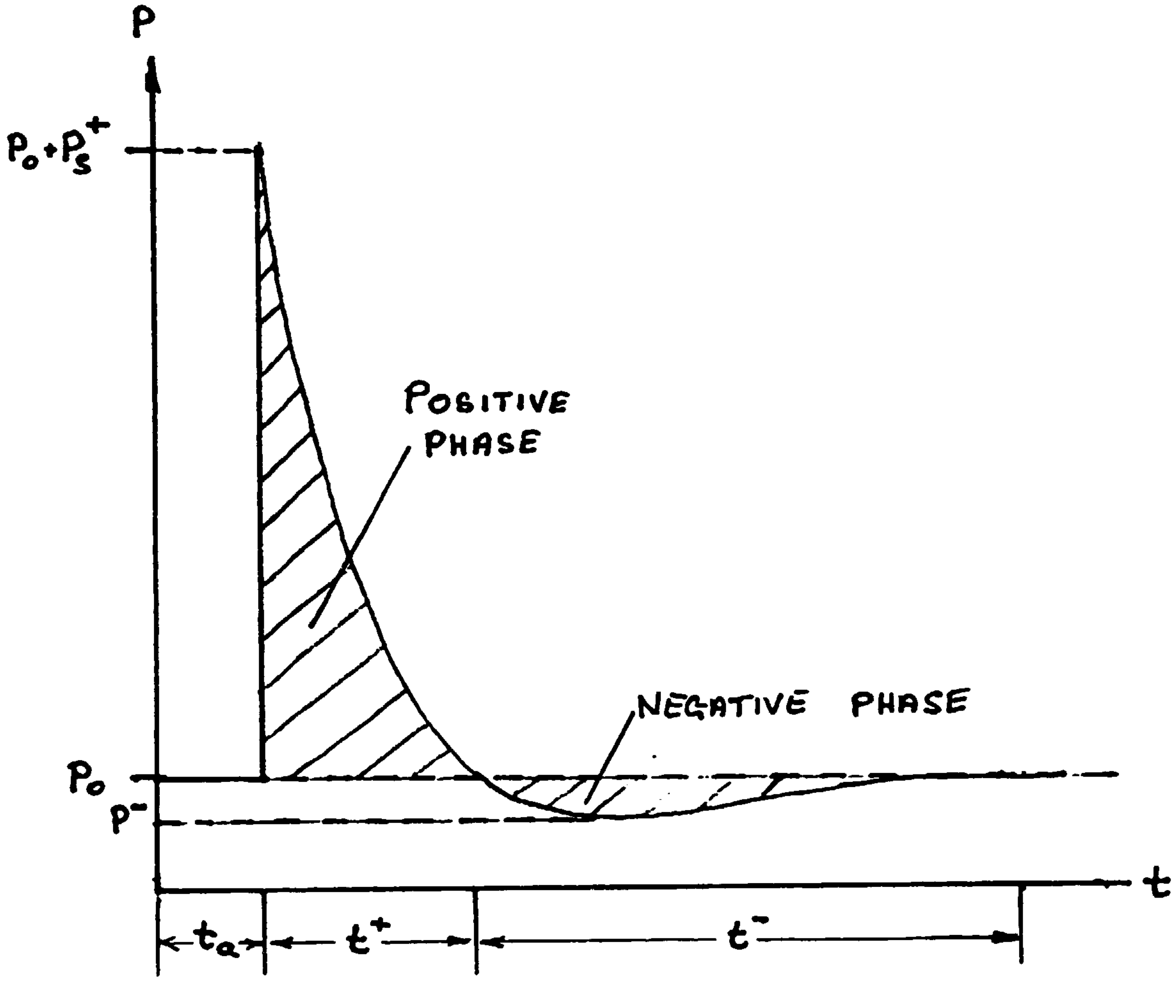
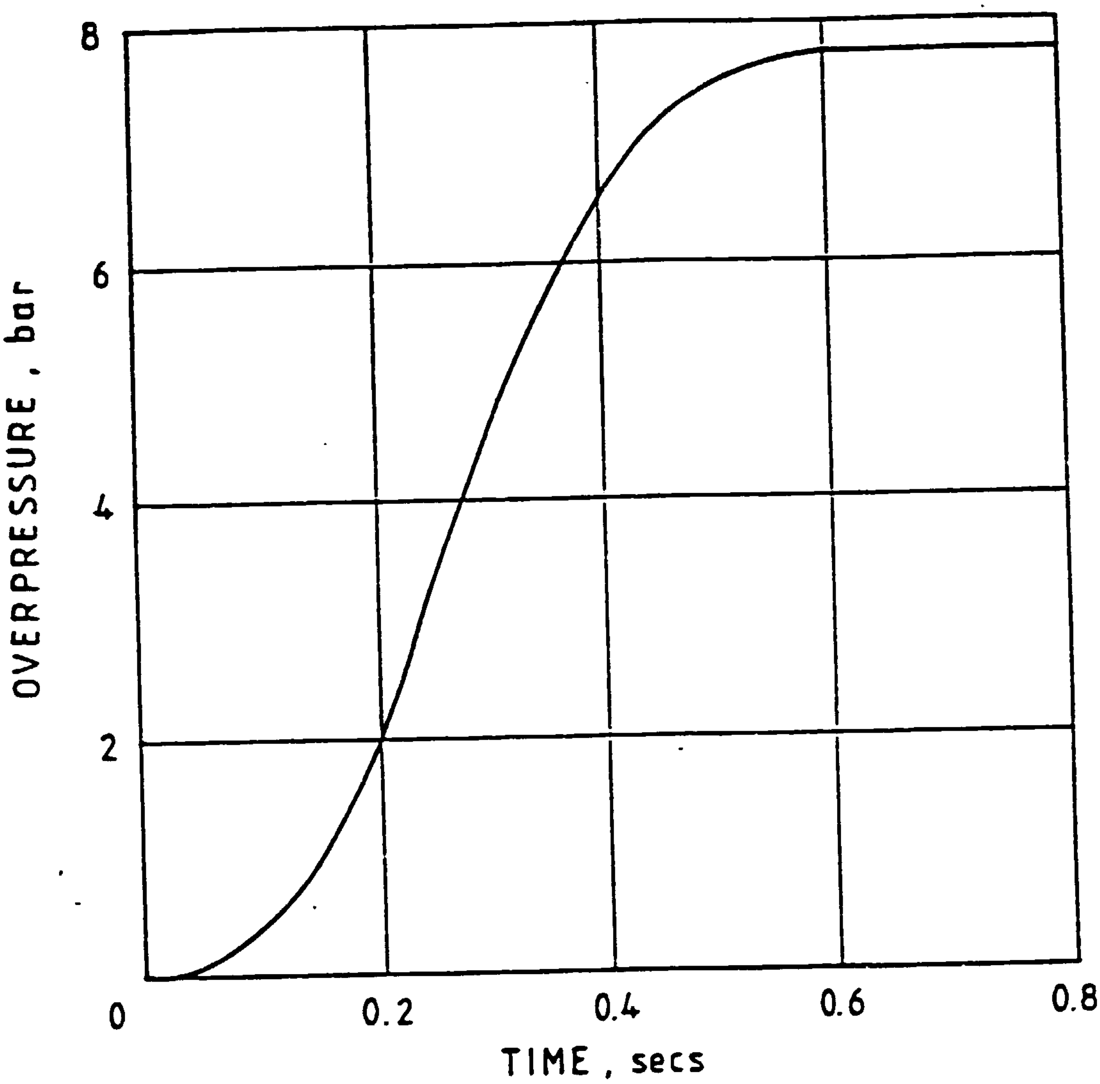


Figure 3.13



THE PRESSURE-TIME PROFILE FOR A TOTALLY CONFINED STOICHIOMETRIC PROPANE-AIR MIXTURE

Figure 3.14

structure described earlier in that it is characterised by an abrupt pressure rise, a short (1 to 10 ms) positive phase duration and a very high (10000 bar) peak positive overpressure. For confined or semi-confined explosions a further phase of the blast wave exists as a result of reflections from surrounding structures.

Failure of a large vessel under pressure results in a blast wave which is similar to the ideal blast wave structure during its positive phase but has a larger negative phase and is followed by multiple shocks. The stored energy released from the vessel is transferred to fracture energy, blast wave energy and kinetic energy of missiles. Generally something between 40 and 80% of the total energy is transferred to the blast wave. This depends on the amount of energy spent in fragmenting the vessel.

The most common method of estimating the effects of explosions is to determine the mass of TNT which would cause an equivalent amount of damage. This is based on the assumption that, in the far field at least, a blast wave from any source of explosion will tend towards that of a TNT explosion. This method is known as the TNT equivalence technique. This method has been outlined by the UK Advisory Committee on Major Hazards, **ACMH-2**, 1979 [p2]. This method is under review, to take account of improved understanding of the underlying mechanisms of flame acceleration in partially confining structures. A number of people also use a model developed by TNO **Wieckema**, 1979 [q2], which is based on actual unconfined vapour cloud explosions and employs one of two defined explosion yields. The model is limited to flammable materials of medium reactivity. Both methods are strictly empirical and are not based on solid theory.

For condensed phase explosions the TNT equivalent mass is evaluated by using a TNT efficiency factor which is an estimate of the proportion of the available energy of the explosion transferred to the blast wave. This efficiency factor is then multiplied by the total stored energy to determine the energy in the blast wave. The mass of TNT required to produce an equal energy blast can then be calculated using 4520 kJ/kg as the mass specific energy for TNT. The efficiency factor for high explosive varies from about 60% to 130%, however as a first approximation it can be assumed that 1 equivalent ton of high explosive will produce the same blast energy as 1 ton of TNT. Explosives used as propellants generally transfer only up to 25% of their available energy to the blast wave on explosion.

Having obtained the TNT equivalent mass for the scenario under consideration, it is then possible to estimate the blast parameters of an explosion at any distance from the source. A number of sources publish plots of blast parameters versus scaled distance Z for high explosives (**Baker W.E. et al.**, 1983 [r2]):

$$Z = \frac{R}{W^{1/3}}$$

where:

R = distance (m) from the source of the explosion;

W = charge weight (kg TNT).

Figure 3.15, which relates peak overpressure to scaled distance, is an example of the TNT blast relationship.

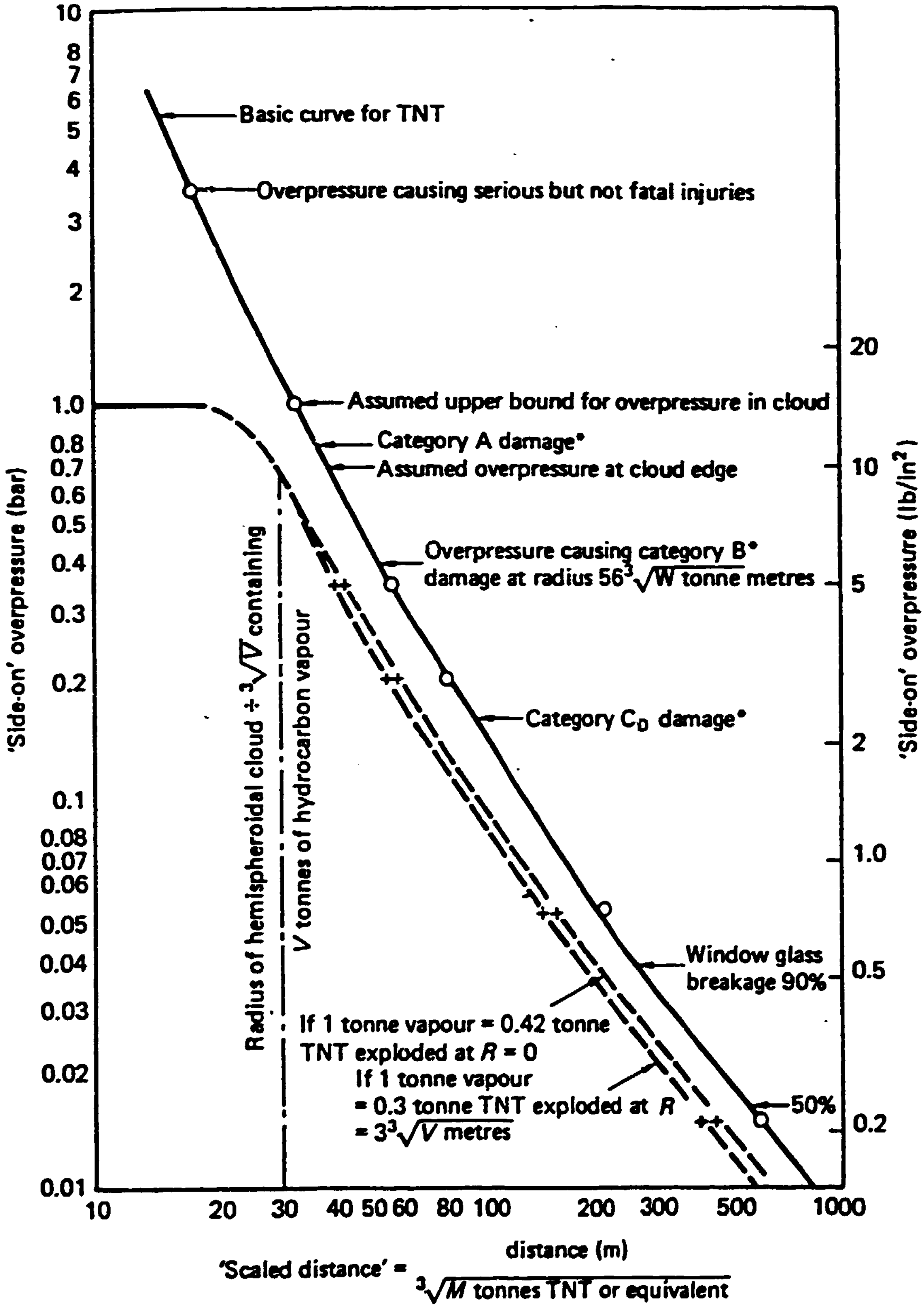
In the case of the rupture of a pressurised vessel, it can be assumed (as a first approximation) that the resulting pressure profile will be close to that of a TNT explosion and can be modelled accordingly using the TNT equivalence technique. It is generally accepted that this is more valid the further one is away from the source. The equivalence model tends to over-estimate the blast wave parameters close to the source and other methods need to be used (**Baker W.E. et al.**, 1983 [r2]). The total stored energy of a gas in a pressure vessel is given by:

$$E = \frac{p_1 V_1}{\Gamma - 1} \cdot [\ 1 - (p_a/p_1) \cdot (\Gamma - 1)/\Gamma\ ]$$

where p_1 and V_1 are the pressure and volume of the vessel; p_a is the atmospheric pressure and Γ the ratio of specific heats (C_p/C_v).

For a first approximation it should be assumed that 50% of the stored energy is transferred to the blast wave.

The TNT equivalent mass of a gas cloud explosion is difficult to estimate with any real accuracy. A large number of factors affect the magnitude of the blast wave energy. These include turbulence, the volume of gas, the composition of the cloud, the location of the ignition source relative to the cloud, the shape of the cloud and the proportion of the total energy transferred to the blast wave. The complexity of this problem led to the production of a number of models such as **ACMH 2**, 1979 [p2] and **Wiekema**, 1984 [s2]. The range of efficiency factors obtained from such models can be as low as a fraction of one per cent up to a few tens of percent. The UK Advisory Committee on Major Hazards recommends that an approximate value of 3% of the total available energy should be assumed to have been transferred to the blast wave. It should however be noted that the TNT method should not be used to predict blast wave parameters for gas explosions at a distance of less than 10 cloud diameters from the source



Basic curve for TNT
Overpressure causing serious but not fatal injuries
Assumed upper bound for overpressure in cloud
Category A damage*
Assumed overpressure at cloud edge
Overpressure causing category B* damage at radius 56 $\sqrt[3]{W}$ tonne metres
Category C_D damage*
Window glass breakage 90%
50%
Radius of hemispheroidal cloud ÷ $\sqrt[3]{V}$ containing V tonnes of hydrocarbon vapour
If 1 tonne vapour = 0.42 tonne TNT exploded at R = 0
If 1 tonne vapour = 0.3 tonne TNT exploded at R = 3 $\sqrt[3]{V}$ metres
'Side-on' overpressure (bar)
'Side-on' overpressure (lb/in^2)
10
8
7
6
5
4
3
2
1.0
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
20
10
5
2
1.0
0.5
0.2
10 20 30 40 50 60 80 100 200 300 500 1000
'Scaled distance' = distance (m) / $\sqrt[3]{M}$ tonnes TNT or equivalent

Figure 3.15

of the explosion. The TNO multi-energy method (**Wingerden**, 1989 [t2]) is now considered to give results which are much more representative of those observed in actual explosions.

Computer models do exist which attempt to model the basic physical principles of explosion behaviour. These models are generally neither simple nor easy to use. Probably the best known and most widely used is the code **FLAX** which was developed by the Christian-Michelson Institute at Bergen, Norway.

(e) Missiles

The consideration and prediction of the effects of fragments of pressure components which fail under incident conditions is important as there have been many deaths and cascade damage effects due to such fragments. Most of the events seem to be associated with the storage of flammable liquids such as liquefied petroleum, often resulting in the projection of missiles (sometimes still containing liquefied gas) to distances much greater than the thermal hazard range from the initial event. The effect of these missiles is to cause physical damage to property and people and to act as an initiating event for further incidents due to damage to plant and also as a result of starting secondary fires. A number of studies have been carried out into the cause, likelihood and effect of missiles. These include **Baker et al.**, 1983 [r2], **Association of American Railroads**, 1972 [u2] and 1973 [v2], and by **Holden**, 1989 [w2]. The comprehensive study by Holden confirmed the assumption of others that the probability of missile projection from cylindrical liquefied gas vessels which fail when affected by fire is almost 0.8. Major fire engulfment events usually produce up to about 4 fragments; non-fire events tend to produce slightly more – this is for cylindrical vessels. The generally larger spherical vessels tend to produce more fragments, a useful mean being around 10.

The distance travelled depends on the shape of the fragment produced. Cylindrical end tub fragments, which are closed at one end, tend to act like rockets and can travel anything up to 1 km. However, as a rough guideline, it can be assumed for cylindrical vessels that about 80% of the fragments will travel less than 200 m. For cylindrical vessels, the fragments are generally projected in directions roughly axial to the vessels orientation at the time of rupture. For spherical vessels there is a tendency of a non-random directional distribution.

When assessing the hazards from missiles, it should be particularly noted that nearby pipework and thin walled tanks are very vulnerable to impact from vessel fragments. Large thick-walled pressure components can also be susceptible.

3.2.3.2 Effect Models

The physical models discussed in the previous section considered the dispersion of airborne flammable or toxic materials, the creation of high levels of thermal radiation from various types of fires, the production of overpressures from explosions and the generation of missiles. This section will now consider the effects of these on people, property and the environment.

(i) Effects of Hazardous Material Dispersion (Toxicity Effect)

There are two main outputs from calculations of the way in which hazardous materials are dispersed in the atmosphere. The first is the determination of the concentration of flammable materials with a view to establishing the hazard ranges of these substances to some pre-determined concentration such as the Lower Flammable or Lower Explosive Limit. The results of these calculations are then used as inputs to the modelling and determination of the characteristics of fires and explosions. The effects of these will be considered under the heading of fires and explosions and so will not be discussed here. The main group of substances to be dealt with are therefore those which have toxic effects on plant and animal life.

The objective of using toxic effect models is to assess the consequences to man, animals and plants as a result of exposure to toxic materials. Considering first the effects on man it is difficult, for a variety of reasons, to evaluate precisely the toxic responses caused by acute exposures to toxic substances. Humans experience a very wide range of adverse effects which can include irritation, neurosis, asphyxiation, organ system damage and death. In addition the scale of these effects is a function of both the magnitude and duration of exposure. There is also a high degree of individual response among different persons in a given population, due to factors such as general health, age and susceptability. A further cause of difficulty is that there are known to be thousands of different toxic substances and there is by no means enough data (on even some of the more common ones!) on the toxic response of humans to permit a precise assessment of a substance's hazard potential. In most cases the only data available are from controlled experiments with animals under laboratory conditions. The extrapolation of the effects observed in animals to the effects likely to occur in humans or indeed in other animals is not easy and is subject to a number of judgements.

There are a large number of references which give useful information on the methods of predicting the likelihood that a release event will result in serious injury or death. A number of substances in common have been examined in depth. In the UK, Chlorine was considered by a sub-group of the UK I.Chem.E Major Hazards Assessment Panel and associated publications – **Withers**, 1985 [b3], **Major Hazards Assessment Panel**, 1987 [c3], **Withers & Lee**, 1985 [d3], have given an extensive review of the animal data for man. The same group has also reviewed ammonia - **Withers**, 1986 [e3] and a study is nearing completion of phosgene.

If an attempt is made to estimate the proportion of the population which may suffer a defined degree of injury it is necessary to have information on the statistical distributions relating the probability of injury to the dose (total intake). Typically this is a log-normal distribution but for these purposes can take the form of a probit equation which relates the effect of an exposure to a given concentration and duration.

The general form of a probit equation is:

$$P_T = a + b \log_e (C^n t)$$

where:

P_T is a measure of the percentage of people affected;
a, b, and n are constants;
C = concentration (ppm);
t = exposure time (min).

The quantity (C^n t) is known as the toxic load.
Table 3.4 [d] gives the constants for the lethal toxicity probit equation for a number of the more common chemicals.

Hence, for:

- Chlorine: $P_T = -8.29 + 0.92 \log_e (C^2 t)$
- Ammonia: $P_T = -35.9 + 1.85 \log_e (C^2 t)$

A probit (P) is a probability unit lying between 0 an 10, which is directly related to the % fatalities as shown in Tab. 3.5. To evaluate the probit, the toxic load (C^n t) must be calculated at positions of interest. At a given location the concentration will vary over time as the cloud passes and dilutes. The total toxic load for the location is obtained by considering different time steps and the average concentration during those time steps. Then for m time steps the total toxic load is given by:

$$\text{Total Toxic Load} = \sum_{i=1,m} (C_i^n t_i)$$

This total toxic load is then used in the probit equation.

The important factor is the determination of the effects of toxic material is to clearly study the known data about the material in question. These include the MHAP monographs for Chlorine, Ammonia and Phosgene, publications by

Substance	a (ppm)	b (ppm)	n (min)
Acrolein	−9.931	2.049	1
Acrylonitrile	−29.42	3.008	1.43
Ammonia	−35.9	1.85	2
Benzene	−109.78	5.3	2
Bromine	−9.04	0.92	2
Carbon monoxide	−37.98	3.7	1
Carbon tetrachloride	−6.29	0.408	2.50
Chlorine	−8.29	0.92	2
Formaldehyde	−12.24	1.3	2
Hydrogen chloride	−16.85	2.00	1.00
Hydrogen cyanide	−29.42	3.008	1.43
Hydrogen fluoride	−35.87	3.354	1.00
Hydrogen sulfide	−31.42	3.008	1.43
Methyl bromide	−56.81	5.27	1.00
Methyl isocyanate	−5.642	1.637	0.653
Nitrogen dioxide	−13.79	1.4	2
Phosgene	−19.27	3.686	1
Propylene oxide	−7.415	0.509	2.00
Sulfur dioxide	−15.67	2.10	1.00
Toluene	−6.794	0.408	2.50

Table 3.4 CONSTANTS FOR LETHAL TOXICITY PROBIT EQUATION

% Fatalities	0	1	2	3	4	5	6	7	8	9
0	-	2.67	2.95	3.12	3.25	3.36	3.45	3.52	3.59	3.66
10	3.72	3.77	3.82	3.87	3.92	3.96	4.01	4.05	4.08	4.12
20	4.16	4.19	4.23	4.26	4.29	4.33	4.26	4.39	4.42	4.45
30	4.48	4.50	4.53	4.56	4.59	4.61	4.64	4.67	4.69	4.72
40	4.75	4.77	4.80	4.82	4.85	4.87	4.90	4.92	4.95	4.97
50	5.00	5.03	5.05	5.08	5.10	5.13	5.15	5.18	5.20	5.23
60	5.25	5.28	5.31	5.33	5.36	5.39	5.41	5.44	5.47	5.50
70	5.52	5.55	5.58	5.61	5.64	5.67	5.71	5.74	5.77	5.81
80	5.84	5.88	5.92	5.95	5.99	6.04	6.08	6.13	6.18	6.23
90	6.28	6.34	6.41	6.48	6.55	6.64	6.75	6.88	7.05	7.33
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
99	7.33	7.37	7.41	7.46	7.51	7.58	7.58	7.65	7.88	8.09

Table 3.5 : *Transformation of Percentage Fatalities to Probits for Toxicity Calculations (Finney, 1971)*

NIOSH/OSHA, 1978 [f3], and **Haber**, 1986 [g3]. In any case, before interpretating the results of an assessment involving toxic materials, agreement should be reached with those concerned about the concentration of toxic material which should be considered as various action levels or hazard indicators. Major sources of toxicity information are **Bridges**, 1984 [h3], and **AIChE/CCPS**, 1988 [i3], there are also databases many of which are now computerised and some of which are on Compact Disc-Read Only Memory; these include RTECS-NIOSH, 1987 [j3], and TOXLINE, 1990 [k3].

(ii) Effects of Thermal Radiation

The modelling of high thermal radiation effects which are likely to cause injury or damage to people and property is much more straightforward than for toxic effects. A large amount of experimental data exists and a large number of simple tabulations, charts and theoretical models are available. Most of these charts, models etc. refer to bare skin. The effects can be considerably modified due to the presence of such factors as clothing (which most probably will protect but in a few cases may make the situation worse), instinctive responsive (to turn and run away) and the existence of solar radiation exposure in sunny climates.

Figure 3.16 (**Mudan**, 1984 [b2]) shows a simple relationship between incident thermal flux, time and damage (injury/fatalities).

Eisenberg et al., 1975 [m3] developed a probit model to estimate the injury levels for a given thermal radiation dose from pool and flash fires based on data from nuclear tests:

$$P_r = 14.9 + 2.56 \log_e (t\, I \cdot 10^{-4})^{4/3}$$

where:

P_r = probit;
t = exposure time (s);
I = thermal radiations intensity (W/m^2).

Table 3.6 [l1, q3] indicates the consequence effects of heat radiation on people and property.

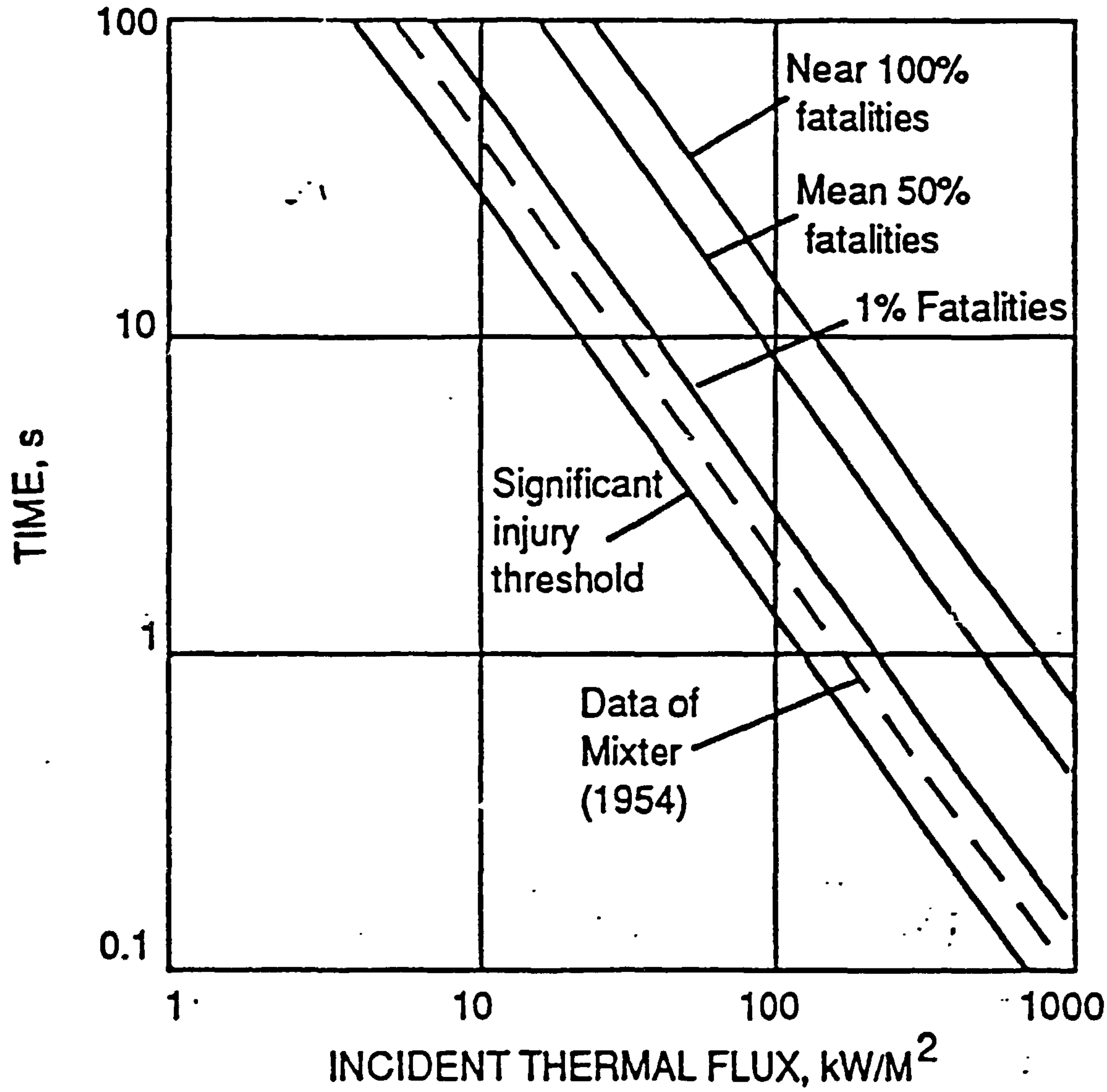


Figure 3.16

FATALITY AND INJURY LEVELS

FOR THERMAL RADIATION

Table 3.6 Consequence Effects of Heat Radiation on People and Equipment

Incident Flux (kW/m^2)	Damage to equipment	Damage to people
37.50	• Damage to process equipment. • Cellulosic equipment will pilot ignite within one minute exposure.	• 100% lethality in 1 min. • 1% lethality in 10 s.
25.0	• Spontaneous ignition of wood after long exposure. • Unprotected steel will reach thermal stress temperatures which can cause failure. • Pressure vessels need to be relieved or failure will occur.	• 100% lethality in 1 min. • Significant injury in 10 s.
12.5	• Minimum energy to ignite wood with a flame. • Melts plastic tubing. • Thin steel with insulation on the side away from the fire may reach a thermal stress level high enough to cause structural failure.	• 1% lethality in 1 min. • 1st degree burns in 10 s.
4.7		• Causes pain if duration is longer than 20 s but blistering is unlikely. • Possible injury after 30 s of exposure.
2.1		• Minimum to cause pain after 1 min.
1.6		• Causes no discomfort for long exposure.

(iii) Explosion Effects

The objective of explosion effect models is to predict the impact of blast overpressure on people and structures. It so happens that people are much more resilient to blast overpressures than structures. The major threat to people is produced by missiles, structural collapse or whole body translation. Death or injury to humans which arises directly from the blast overpressure alone varies with the position of the body and its relationship to possible pressure reflecting objects. Human organs which are particularly susceptible to direct blast effects are those where a large difference in density exists between adjacent organs such as the ears and lungs. Much of the data have been derived from nuclear experience and may slightly overestimate the fatalities from non-nuclear explosions. Table 3.7 indicates explosion effect on people.

Table 3.7 Effects of Explosion Overpressure on People and Buildings.

(A) Effects on Buildings	
Building almost completely destroyed	0.7 bar
Heavy building damage	0.35 bar
Repairable building damage	0.10 bar
Widespread glass damage	0.05 bar
10% broken glass	0.02 bar
(B) Effects on People	
100 % lethality	5 - 8 bars
50% lethality	3.5 - 5 bars
Threshold lethality	2 - 3 bars
Severe lung damage	1.33 - 2 bars
50 % eardrum rupture	2 - 2.33 bars (over 20 years of age)
50 % eardrum rupture	1 - 1.33 bars (under 20 years of age)

There have been a number of different approaches to determine the response of structures to a given blast load. A number of these draw a comparison between the magnitude of the predicted blast wave and existing data from explosions of a similar scale. Other approaches attempt to model the response of a structure to an applied load. Much of the data on explosions comes from military experience but a number of large industrial explosions have been investigated in depth. Table 3.7 outlines consensus correlation between residential building damage and blast overpressure.

It should be noted that this correlation is applicable to standard European or North American brick built dwellings and much more severe damage would be experienced by less strongly constructed buildings.

The damage to industrial buildings is less easy to correlate since these range from buildings with strong reinforced concrete walls to lightly constructed buildings with large wall and roof areas.

3.2.3.3 Mitigating Effects

The object of this section is to draw attention to some of the factors which may mitigate against the consequences of incident involving hazardous materials.

It has been observed in many accidents that the consequences to people and property were less severe than would have been predicted using the approaches described earlier. Obviously there are uncertainties in all the various stages of analysis and there are also modelling limitations which may lead to conservative assumptions and hence results. However, in addition to these factors, the results maybe less serious then predicted to topographical factors, physical obstructions and to evasive action taken by people. Such evasive action can include evacuation, sheltering and medical treatment. These are briefly described thereafter.

(a) Evacuation

This is a mitigating factor which can only be usefully employed if there is sufficient time for it to be effectively carried out. Evacuation is not without its own risks – useful references include **Prugh**, 1985 [n3], and **Aumonier and Morrey**, 1990 [o3].

(b) Sheltering

It has been observed that, following an incident, the effects on people who take shelter differ markedly from those for people in the open. This has been discussed by **Davies and Purdy**, 1986 [p3], in relation to building types and human behaviour. The effects of sheltering depend on:

* <u>The nature of the hazard</u> – shelters can have abeneficial effect for thermal and toxic effects but can be of limited benefit for flash fires due to the possibility of vapour ingress. In the case of explosion overpressure the hazards may be increased due to the increased risk of collapse of the structure providing shelter.

* <u>The time available</u> – escape to a shelter can be very beneficial in the case of pool and jet fires. There may well be insufficient time to shelter from a fireball and there may be no time to escape from explosion overpressure or missiles. There may be benefit in sheltering from releases of toxic materials, particular if time allows to reach shelter before there has been a significant exposure. However where the shelter has been exposed to a cloud of toxic material for some time it should be recognised that, once the outside concentrations decrease, an indoor concentration, albeit lower than the peak values experienced outdoors, may persist for

some time and the total exposure could be reduced by leaving the shelter once the cloud outside has passed.

(c) Medical Treatment

The effectiveness of training and the availability of equipment for 3emergency response and medical treatment can greatly improve the chance of survival for those seriously injured as a consequence of an incident involving hazardous materials. Of particular interest to those treating persons exposed to toxic materials will be the name, and the basic hazards of the material(s) involved. Modern methods of treating those who have experienced severe burn injuries have greatly increased the chances of survival. It should however be recognized that whereas facilities may exist for treating a few seriously burnt people at the same time there may be problems in treating tens or even hundreds of such people.

3.3 Estimation of the Probability of Accidents

3.3.1 Introduction

In the risk assessment process, it is essential to take into account the likelihood that hazardous incidents, while possible, may in fact never occur during the operating life of a plant or process. This is because of the design, standards of construction and other operational safety controls which can prevent their occurrence. Consequence analysis is therefore not in itself sufficient for the safety assessment of hazardous installations. The assessment process must also account for the likelihood or probability of hazardous incidents occurring, as well as for the likelihood of the effects of such incidents. Data is required to quantify both the probability of accidents (frequency analysis) and consequences (consequence analysis). Fig (xx) depicts data requirements for risk estimations.

Probability or frequency analysis involve the derivation of both the likelihood of incidents occurring **and** the likelihood of particular outcomes should those events occur. For example, in the case of a liquid petroleum storage, the probability of failure of various items such as pipes, pumps and storage vessels with the resultant releases should be established. The probability of source of ignition should also be established which in combination with the probability of failure could estimate the probability of a fire accident event occurring. Data is needed to determine the frequency of accident initiators, component failure data (for use in fault tree analysis) and human reliability data.

This section outlines techniques for the estimation of accident probabilities.

3.3.2 Estimation of Failure Frequency

3.3.2.1 Direct Estimation

If the hazard can be clearly defined, its causes understood, and data found on comparable historical failures under the same operating conditions, then these data should be sufficient to directly estimate the failure frequency of the item under consideration and the ensuing hazard. However, most significant hazards have sufficient unique features that frequency data of the hazard itself for the specific plant being evaluated, are not directly applicable. In addition, many other hazards are so unusual that direct knowledge of their frequency is impossible.

3.3.2.2 Synthesis of System Failure

In most cases of complex operations, some sort of modelling procedure is required in order to estimate the accident/incident probability. The nature and extent of the modelling vary with the applications' requirements of the study. The objective is to enable existing data to be used economically and efficiently to assess the safety performance of the plant. The modelling process consists of using basic generic data on the failure of components or subsystems, where possible to adjust such data to reflect any particular circumstances of the specific situation at hand, and then to synthesize the data through a logic sequence that gives an estimate of the frequency of the more complex event. The two modelling techniques most frequently used are those of **Fault Tree Analysis** and **Event Tree** Analysis. Both techniques have been outlined in section 3.1 of this chapter of the guide. Further examples are indicated in Figures (3.17) and (3.18). A number of computer based software exist which provide a ready tool in the preparation of fault or event trees.

3.3.3 Data Characteristics

Failure data are usually presented in two forms, depending on the nature of the equipment and the way it is used. The usual form for equipments in frequent or continuous use, is as a failure rate. This is expressed as failures per unit time, typically **failures/hour or failures/year**. Systems or components which are not normally in use, but which are calleJ upon to act infrequently, e.g. emergency equipment, alarms, etc. have their failure rate expressed as a probability of **failure per demand**.

Failure rate data is available for a wide range of equipment types. Equipments may be characterized as: components; systems or sub-systems; and processes. Most data are provided at the component level. Only limited information is available at the process level. A failure frequency analysis should start with as coarse a structure as the available data will permit. In this way, as little resources as possible need to be spent on those parts of the process which do not contribute significantly to the failure case under study. If the need arises, more detailed study can be undertaken at the component level in critical areas.

Table (xx) indicates the type of information required and potential data sources for the derivation of reliability data parameters.

Some examples of systems/sub-systems for which failure rate data are readily available are: pumps, vessels, pump-motors, gas detection systems, refrigeration systems.

3.3.4 Sources of Data

Failure rate data can be obtained from three principle sources of data: in-house records, open literature, data bank.

(i) **In-house records:** Data from own plant records, when applied to that same plant, are the most accurate data available. Such data reflect the design, construction, operation and maintenance practices of the particular organization and are very appropriate. Unfortunately, such data are rarely available. Several years of data collection would normally be necessary on items with a fairly high failure rate. More reliable equipment, or rarely used equipment, would require an even longer period to accumulate sufficient data.

PRA DATA ANALYSIS

DATA SOURCES: PLANT RECORDS

PARAMETER	REQUIREMENTS	POTENTIAL SOURCES
1. Probability of failure on demand	a. Number of failures	Periodic test reports, maintenance reports, control-room log
	b. Number of demands	Periodic test reports, periodic test procedures, operating procedures, control-room log.
2. Standby failure rate	a. Number of failures b. Time in standby	See 1a above Control-room log
3. Operating failure rate	a. Number of failures b. Time in operation	See 1a above Control-room log, periodic test reports, periodic test procedures
4. Repair-time distribution parameters	Repair times	Maintenance reports, control-room log
5. Unavailability due to maintenance and testing	Frequency and length of test and maintenance	Maintenance reports control-room log. periodic test procedures
6. Recovery	Length of time to recover	Maintenance reports, control-room log

(ii) **Open Literature:** Open literature is the most common source of generic failure data. It is accessible to all, and sources can be traced and checked if necessary. As might be expected from a 'free source', care must be taken in the use of data from the open literature as details are often lacking and it is often possible to find data which vary by a factor of more than 10. This may be caused by the fact that different sources may have different or inconsistent failure rate definitions and by the lack of information of component boundaries (i.e. what actuation failures and other support system failures are included). Appropriateness of data is also influenced by factors such as local practices for data gathering and record keeping, specific differences in component design and operating regime and effects of operating environment. In many cases, data published in the open literature originate from the nuclear and aerospace industries. Since their equipment and operating practices differ from the process industry, care is needed in data application. Lees (*) has numerous data tables, all references, on a wide range of process industry equipment and is a good start. The Institute of Electric and Electronic Engineers (*) has published a large volume of failure rate data, so did the U.K. Atomic Energy Authority. The IAEA has compiled generic reliability data from 21 sources and has made available this information in report and in a computerized data base formats (Ref...). The IAEA has also evaluated the factors which mostly influence the numerical data (Ref...).

A number of quantitative risk assessment studies have been published and provide a range of failure rate data with associated references. Notably amongst these, are the Rijnmond study (Netherlands), the Convey Island study (United Kingdom) and the Botany Bay Industrial Complex study (Australia). Failure rates data could also be found in special industry studies or impact assessment reports. In all cases, it is essential that when using failure data from the open literature, the source reference be consulted to ensure that the conditions applicable to the data are fully appreciated.

(iii) **Data Banks:** Information in data banks on failure rate data are generally regarded as the most comprehensive. Data banks are however, not (generally) freely available to all and in many cases restricted to members of a particular group. The National Centre for Systems Reliability of the UK Atomic Energy Authority maintains data on failure rates for both the nuclear and process industries. The data bank is open to the public at a fee.

Table X.Y **Failure Rates (Number of Failures per Hour) and Failures per Demand (identified by the symbols "/D" following the values)* [after a].**

COMPONENT	HIGH	AVERAGE	LOW	REF.
Accumulators	$1.93\cdot10^{-5}$	$7.2\cdot10^{-6}$	$4\cdot10^{-7}$	13
Air supply	$1.3\cdot10^{-5}$		$5.3\cdot10^{-6}$	3
Alternators		$7\cdot10^{-6}$		1
Batteries		$1\cdot10^{-6}$		1
Power supply	$1\cdot10^{-5}$	$3\cdot10^{-6}$	$1\cdot10^{-6}$	2
Rechargeable	$1.43\cdot10^{-5}$	$1.4\cdot10^{-6}$	$5\cdot10^{-7}$	13
Blowers	$3.57\cdot10^{-6}$	$2.4\cdot10^{-6}$	$8.9\cdot10^{-7}$	13
Boilers (all types)		$1.1\cdot10^{-6}$		7
Cranes		$7.8\cdot10^{-6}$		7
Cylinders				
Pneumatic-Hydraulic		$1\cdot10^{-7}$		1
		$1.7\cdot10^{-4}$		3
		$7.3\cdot10^{-5}$		3
Hydraulic	$1.2\cdot10^{-7}$	$8\cdot10^{-9}$	$5\cdot10^{-9}$	13
Pneumatic	$1.3\cdot10^{-8}$	$4\cdot10^{-9}$	$2\cdot10^{-9}$	13
Diaphragms	$9\cdot10^{-6}$	$6\cdot10^{-6}$	$1\cdot10^{-7}$	13
Metal		$5\cdot10^{-6}$		1
Rubber		$8\cdot10^{-6}$		1
Ducts	$1.3\cdot10^{-6}$	$5.12\cdot10^{-7}$	$2.1\cdot10^{-7}$	13
		$1\cdot10^{-6}$		1
Fans				
Exaust	$9\cdot10^{-6}$	$2.25\cdot10^{-7}$	$2.1\cdot10^{-7}$	13
		$9\cdot10^{-5}$		1
Filters	$8\cdot10^{-7}$	$3\cdot10^{-7}$	$4.5\cdot10^{-8}$	13
Blockage		$1\cdot10^{-6}$		1
Leakage		$1\cdot10^{-6}$		1
Flanges, Closures, Elbows	$1\cdot10^{-5}$	$3\cdot10^{-7}$	$1\cdot10^{-8}$	2
Flow Meters (fluids)		$1.2\cdot10^{-4}$		3
DP transducers (pneumatic & electronic)		$2.1\cdot10^{-4}$		3
DP transducers (electronic)		$3\cdot10^{-4}$		3
Indicating variable area		$3.9\cdot10^{-5}$		3
Magnetic		$2.5\cdot10^{-4}$		3

* Before the application of these data, the original references should be consulted.

Table X.Y (cont.)

COMPONENT	HIGH	AVERAGE	LOW	REF.
Gaskets	$1 \cdot 10^{-4}$	$3 \cdot 10^{-6}$	$1 \cdot 10^{-7}$	2
		$5 \cdot 10^{-7}$		1
D-ring	$3 \cdot 10^{-8}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-8}$	13
		$2 \cdot 10^{-7}$		1
Phenolic	$7 \cdot 10^{-8}$	$5 \cdot 10^{-8}$	$1 \cdot 10^{-8}$	13
Rubber	$3 \cdot 10^{-8}$	$2 \cdot 10^{-8}$	$1.1 \cdot 10^{-8}$	13
Gauges				
Pressure		$1 \cdot 10^{-5}$		1, 3
Bourdon tubes				
creep		$2 \cdot 10^{-7}$		1
leakage		$5 \cdot 10^{-8}$		1
Generators				
DC	$6.27 \cdot 10^{-6}$	$9 \cdot 10^{-7}$	$3 \cdot 10^{-7}$	13
		$9 \cdot 10^{-6}$		1
AC		$7 \cdot 10^{-6}$		1
Steam turbine		$3.6 \cdot 10^{-6}$		1
Gas turbine		$7.3 \cdot 10^{-5}$		6
Motor, diesel or gas engine		$7.6 \cdot 10^{-6}$		6
Heat exchangers	$1.86 \cdot 10^{-5}$	$1.5 \cdot 10^{-5}$	$2.21 \cdot 10^{-6}$	13
Heaters, electrical				
Elements	$4 \cdot 10^{-8}$	$2 \cdot 10^{-8}$	$1 \cdot 10^{-8}$	13
Hoses				
heavily stressed		$4 \cdot 10^{-5}$		1
lightly stressed		$4 \cdot 10^{-6}$		1
Level measurement (liquid)		$1.8 \cdot 10^{-4}$		3
		$2.6 \cdot 10^{-4}$		3
DP transmitter				
(pneumatic and electronic)		$2 \cdot 10^{-4}$		3
Float type level transmitter		$1.9 \cdot 10^{-4}$		3
Capacitance type level transmitter		$2.5 \cdot 10^{-5}$		3
Electrical cond. probe		$2.7 \cdot 10^{-4}$?		3
Meters (moving coil)		$3 \cdot 10^{-6}$		1, 3
		$1 \cdot 10^{-6}$		5

Table X.Y (cont.)

COMPONENT	HIGH	AVERAGE	LOW	REF.
Motors				
Syncronous		$7 \cdot 10^{-6}$		1
0-600 V		$8 \cdot 10^{-8}$		6
601-15000 V		$4.9 \cdot 10^{-6}$		6
Induction				
> 200 KW		$1 \cdot 10^{-5}$		1
		$5 \cdot 10^{-6}$		1
0-600 V		$5.9 \cdot 10^{-7}$		6
601-15000 V		$4.9 \cdot 10^{-6}$		6
Small, general		$4 \cdot 10^{-6}$		1
General		$1 \cdot 10^{-5}$		1
Stepper	$7.1 \cdot 10^{-7}$	$3.7 \cdot 10^{-7}$	$2.2 \cdot 10^{-7}$	13
		$5 \cdot 10^{-6}$		1, 3
Blower	$5.5 \cdot 10^{-6}$	$2 \cdot 10^{-7}$	$5 \cdot 10^{-8}$	13
Diesel				
(failure to start per demand)	$1 \cdot 10^{-1}$/D	$3 \cdot 10^{-2}$/D	$1 \cdot 10^{-2}$/D	2
(failure to run per demand)	$3 \cdot 10^{-3}$/D	$3 \cdot 10^{-4}$/D	$3 \cdot 10^{-5}$/D	2
Electric				
(failure to start per demand)	$1 \cdot 10^{-3}$/D	$3 \cdot 10^{-4}$/D	$1 \cdot 10^{-4}$/D	2
(failure to run per demand)	$3 \cdot 10^{-5}$/D	$1 \cdot 10^{-5}$/D	$3 \cdot 10^{-6}$/D	2
Servo	$3.5 \cdot 10^{-7}$	$2.3 \cdot 10^{-7}$	$1.1 \cdot 10^{-7}$	13
DC-All		$6.4 \cdot 10^{-6}$		6
Motor starters, contact type				
0-600 V		$1.6 \cdot 10^{-6}$		6
601-15000 V		$3 \cdot 10^{-7}$		6
Orifice				
Fixed	$2.1 \cdot 10^{-6}$	$1.5 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	13
		$1 \cdot 10^{-6}$		1
Variable	$3.7 \cdot 10^{-6}$	$5.5 \cdot 10^{-7}$	$4.5 \cdot 10^{-8}$	13
		$5 \cdot 10^{-6}$		1

Table X.Y (cont.)

COMPONENT	HIGH	AVERAGE	LOW	REF.
Power supply (electric utility)				
All		$3.5 \cdot 10^{-5}$		6
Single circuit		$6.1 \cdot 10^{-5}$		6
Double or triple circuit-all		$3.5 \cdot 10^{-5}$		6
Manual switchover		$5.2 \cdot 10^{-5}$		6
Automatic switchover		$3.8 \cdot 10^{-5}$		6
Loss of all circuits at once		$1.4 \cdot 10^{-5}$		6
Pressure measurement				
absolute pressure transducer (pneumatic)		$1.1 \cdot 10^{-4}$		3
differential pr. tr. (pneumatic, electronic)		$1.1 \cdot 10^{-4}$		3
absolute pressure transducer (electronic)		$2.4 \cdot 10^{-4}$		3
Process equipment				
Vaporizer		$6.9 \cdot 10^{-6}$		a
Superheater		$6.9 \cdot 10^{-6}$		a
Start-up heater		$2.9 \cdot 10^{-5}$		a
Reactor		$5 \cdot 10^{-4}$		a
Recycle compressor		$2.3 \cdot 10^{-5}$		a
Steam generator		$6.9 \cdot 10^{-6}$		a
Reactor cooler		$6.9 \cdot 10^{-6}$		a
Partial condenser		$6.9 \cdot 10^{-6}$		a
Waste gas compressor		$1.1 \cdot 10^{-4}$		a
Piping rupture		$2.3 \cdot 10^{-4}$		a
Pressure gauge	$7.8 \cdot 10^{-6}$	$4 \cdot 10^{-6}$	$1.35 \cdot 10^{-7}$	13
		$1 \cdot 10^{-5}$		1
Pressure switch		$1.5 \cdot 10^{-5}$		1
Pressure transmitter		$1.4 \cdot 10^{-5}$		a ?
Differential pressure transmitter		[illegible] $\cdot 10^{-5}$		a ?
Pumps				
Failure to start per demand	$3 \cdot 10^{-3}$/D	$1 \cdot 10^{-3}$/D	$3 \cdot 10^{-4}$/D	2
Failure to run	$3 \cdot 10^{-4}$	$3 \cdot 10^{-5}$	$3 \cdot 10^{-6}$	2
Electric drive	$2.74 \cdot 10^{-5}$	$1.35 \cdot 10^{-5}$	$2.9 \cdot 10^{-6}$	13
Boiler feed		$1 \cdot 10^{-3}$		7
Large gas circulators		$7.6 \cdot 10^{-5}$		7
Pump failure				
Centrifugal	$1.1 \cdot 10^{-4}$		$3.8 \cdot 10^{-5}$	a
Purge systems		$1.2 \cdot 10^{-4}$		3

Table X.Y (cont.)

COMPONENT	HIGH	AVERAGE	LOW	REF.
Regulators				
Flow and pressure	$5.54 \cdot 10^{-6}$	$2.14 \cdot 10^{-6}$	$7 \cdot 10^{-7}$	13
Pneumatic	$6.21 \cdot 10^{-6}$	$2.4 \cdot 10^{-6}$	$7.7 \cdot 10^{-7}$	13
Restrictors (flow)	$9.83 \cdot 10^{-7}$	$5.9 \cdot 10^{-7}$	$1.97 \cdot 10^{-7}$	13
		$5 \cdot 10^{-6}$		1
Rupture				
Vaporizer steam - Condenser line		$6 \cdot 10^{-6}$		a
Column condenser - Brine line		$6 \cdot 10^{-6}$		a
Column heat transfer fluid - Supply line		$6 \cdot 10^{-6}$		a
Rupture disk				
Fails to burst		$2.3 \cdot 10^{-6}$		a
Bursts prematurely		$5.7 \cdot 10^{-5}$		a
Seals				
Rotating	$1.12 \cdot 10^{-6}$	$7 \cdot 10^{-7}$	$2.5 \cdot 10^{-7}$	13
		$7 \cdot 10^{-6}$		1
Sliding	$9.2 \cdot 10^{-7}$	$3 \cdot 10^{-7}$	$1.1 \cdot 10^{-7}$	13
		$3 \cdot 10^{-6}$		1
O-ring		$2 \cdot 10^{-7}$		1
Sensors				
Thermistors	$2.8 \cdot 10^{-5}$	$1.5 \cdot 10^{-5}$	$1 \cdot 10^{-5}$	13
Vapour pressure - Bulb (temp. meas.)		$4.2 \cdot 10^{-5}$		3
Ion chambers - ? Leads		$5 \cdot 10^{-6}$		1
Thermocouples		$1 \cdot 10^{-5}$		1, 3
		$4.6 \cdot 10^{-5}$		3
		$1.5 \cdot 10^{-4}$		3
		$1.1 \cdot 10^{-4}$		3
Strain gauges	$2 \cdot 10^{-5}$	$1.2 \cdot 10^{-5}$	$7 \cdot 10^{-6}$	13
		$2.5 \cdot 10^{-5}$		1
Photoelectric cells		$1.5 \cdot 10^{-5}$		1
Resistance termometer		$3.7 \cdot 10^{-5}$		3
		$1.8 \cdot 10^{-4}$		3
Mercury in steel thermometer		$3.1 \cdot 10^{-6}$		3
Tanks				
Pressure, small	$3.24 \cdot 10^{-7}$	$1.8 \cdot 10^{-7}$	$1 \cdot 10^{-7}$	13
High pressure, small	$1.44 \cdot 10^{-7}$	$8 \cdot 10^{-8}$	$4.4 \cdot 10^{-8}$	13
Temperature measure		$3.3 \cdot 10^{-5}$		3
		$1.4 \cdot 10^{-4}$		3
Radiation pyrometer		$2.5 \cdot 10^{-4}$		3
Optical pyrometer		$1.1 \cdot 10^{-3}$		3

Table X.Y (cont.)

COMPONENT	HIGH	AVERAGE	LOW	REF.
Valves				
Butterfly	$5.33 \cdot 10^{-6}$	$3.4 \cdot 10^{-6}$	$1.33 \cdot 10^{-6}$	13
Check	$8.1 \cdot 10^{-6}$	$5 \cdot 10^{-6}$	$2.02 \cdot 10^{-6}$	13
? operated	$1.02 \cdot 10^{-5}$	$6.5 \cdot 10^{-6}$	$1.98 \cdot 10^{-6}$	13
		$1.5 \cdot 10^{-5}$		1
Solenoid	$1.97 \cdot 10^{-5}$	$1.1 \cdot 10^{-5}$	$2.27 \cdot 10^{-6}$	13
		$3 \cdot 10^{-5}$		1
(failure per demand)	$3 \cdot 10^{-3}$/D	$1 \cdot 10^{-3}$/D	$3 \cdot 10^{-4}$/D	2
Control, pneumatic	$1.98 \cdot 10^{-5}$	$8.5 \cdot 10^{-6}$	$1.68 \cdot 10^{-6}$	13
		$3 \cdot 10^{-5}$		1
		$6.5 \cdot 10^{-5}$		3
		$2.6 \cdot 10^{-4}$		3
globe		$1.5 \cdot 10^{-5}$		3
instrument air, control service (low flow)		$1.6 \cdot 10^{-5}$		4
instrument air, protective service (low flow)		$1.6 \cdot 10^{-5}$		4
Control				
clean fluid		$1.9 \cdot 10^{-5}$		3
dirty fluid		$1 \cdot 10^{-4}$		3
by-pass open		$5 \cdot 10^{-4}$		4
flow (fails open or sticks)		$6.2 \cdot 10^{-5}$		4
Block				
piston operated		$1.2 \cdot 10^{-5}$		4
Motor operated				
fails to operate per demand	$3 \cdot 10^{-3}$/D	$1 \cdot 10^{-3}$/D	$3 \cdot 10^{-4}$/D	2
fails closed per demand	$3 \cdot 10^{-4}$/D	$1 \cdot 10^{-4}$/D	$3 \cdot 10^{-5}$/D	2
rupture	$1 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$1 \cdot 10^{-9}$	2
Positioner (pneumatic)		$4.7 \cdot 10^{-5}$		3
?		$1.4 \cdot 10^{-4}$		3
Vacuum				
failure to operate per demand	$1 \cdot 10^{-4}$/D	$3 \cdot 10^{-5}$/D	$1 \cdot 10^{-5}$	2
rupture	$1 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$1 \cdot 10^{-9}$	2
Orifices, flow meters (test) - rupture	$1 \cdot 10^{-7}$	$1 \cdot 10^{-8}$	$1 \cdot 10^{-9}$	2
Manual				
failure to remain open (plug)	$3 \cdot 10^{-4}$/D	$1 \cdot 10^{-4}$/D	$3 \cdot 10^{-5}$/D	2
Relief				
fail to open per demand	$3 \cdot 10^{-5}$/D	$1 \cdot 10^{-5}$/D	$3 \cdot 10^{-6}$/D	2
premature open	$3 \cdot 10^{-5}$	$1 \cdot 10^{-5}$	$3 \cdot 10^{-6}$	2
leakage	$1.41 \cdot 10^{-5}$	$5.7 \cdot 10^{-6}$	$3.27 \cdot 10^{-6}$	1
		$2 \cdot 10^{-6}$		1
blockage		$5 \cdot 10^{-7}$		1
Vessels, pressure				
General		$3 \cdot 10^{-6}$		1
High standard		$3 \cdot 10^{-7}$		1
Water, cooling towers (closed-circuit)		$1 \cdot 10^{-4}$		a
Welds (leak)	$1 \cdot 10^{-7}$	$3 \cdot 10^{-9}$	$1 \cdot 10^{-10}$	2

Table X.Y (cont.)

References

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[1] GREEN and BOURNE, Reliability Technology, Wiley (1972) 563-570.

[2] RASMUSSEN, N.C., et al., Reactor Safety Study: an Assessment of Accident Risks in US Commercial Nuclear Power Plants, Appendix III - Failure Data, Rep. WASH-1400, United States Nuclear Regulatory Commission, Washington, DC (Oct. 1975).

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[5] DEUSCHLE, R.S., GOLDBERG, J., A reliability primer, Parts 1 and 2, Instruments and Control Systems 47, 51 and 67 (Feb. and Mar. 1974).

[6] INSTITUTE OF ELECTRICAL AND ELECTRONICAL ENGINEERS, Reliability of Electrical Equipment, IEEE Transaction on Industry Applications, Vol. 1A-10, No. 2 (Mar./Apr. 1974).

[7] FARMER, F.R., Experience in the reduction of risk, Institute of Chemical Engineers Symposium Series No. 34 (1971).

[13] GANICK, B.J., et al., HN-190, United States Atomic Energy Commission Research and Development Report (May 1967).

Table Z.V Selected equipment failure rates published by the UKAEA* [after 1, 2]

Equipment	Failure rates (failures/h)
Bellows	$5 \cdot 10^{-6}$
Boilers (all types)	$1.1 \cdot 10^{-6}$
Boiler feed pumps	$1.0 \cdot 10^{-3}$
Bolts	$2 \cdot 10^{-8}$
Cranes	$7.8 \cdot 10^{-6}$
Diaphragms (metal)	$5 \cdot 10^{-6}$
(rubber)	$8 \cdot 10^{-6}$
Ducts	$1 \cdot 10^{-6}$
Electric motors (general)	$1 \cdot 10^{-5}$
Filters (blockage)	$1 \cdot 10^{-6}$
(leakage)	$1 \cdot 10^{-6}$
Gaskets	$5 \cdot 10^{-7}$
Hoses (heavily stressed)	$4 \cdot 10^{-5}$
(lightly stressed)	$4 \cdot 10^{-6}$
Nozzle and flapper assemblies (blockage)	$6 \cdot 10^{-6}$
(breakage)	$2 \cdot 10^{-7}$
Nuts	$2 \cdot 10^{-8}$
Orifices (fixed)	$1 \cdot 10^{-6}$
(variable)	$5 \cdot 10^{-6}$
Pins	$1.5 \cdot 10^{-5}$
Pipe joints	$5 \cdot 10^{-7}$
Pipes	$2 \cdot 10^{-7}$
Pressure vessels (general)	$3 \cdot 10^{-6}$
(high standard)	$3 \cdot 10^{-7}$
Seals (O-ring)	$2 \cdot 10^{-7}$
(rotating)	$7 \cdot 10^{-6}$
(sliding)	$3 \cdot 10^{-6}$
Unions and junctions	$4 \cdot 10^{-7}$
Valves (Ball)	$5 \cdot 10^{-7}$
(Control)	$3 \cdot 10^{-5}$
(Hand-operated)	$1.5 \cdot 10^{-5}$
(Relief: blockage)	$5 \cdot 10^{-7}$
(Relief: leakage)	$2 \cdot 10^{-6}$
(Solenoid)	$3 \cdot 10^{-5}$

* Before the application of these data, the original report should be consulted.

References

[1] LEES, F.P., Loss Prevention in the Process Industry, Butterworths, London (1980).

[2] GREEN, A.E., BOURNE, A.J., Reliability Technology, Wiley, New York (1972).

Table Z.T Selected failure rates and event data used in the Canvey Study [after 1, 2].

Installation or activity*	Failure rates and event probabilies
Pressure vessels (LPG, ammonia, HF): frequency of spontaneous failure	10^{-5}/y-10^{-4}/y
Pressure circuit (HF): frequency of spontaneous failure	10^{-4}/y
frequency of release due to operational fault	10^{-4}/y
frequency of penetration by missile	10^{-4}/y
High speed rotating machine: frequency of disintegration of rotor	10^{-4}/y-10^{-3}/y
Pipework (LPG): frequency of failure (whole refinery installation)	$5 \cdot 10^{-3}$/y
Pump (LPG): frequency of catastrophic failure	10^{-4}/y
LPG filling point: frequency of large vapour release	$5 \cdot 10^{-3}$/y
LNG tank (above ground): frequency of serious fatigue failure	$2 \cdot 10^{-4}$/y
frequency of overpressurization by overfilling	10^{-5}/y-10^{-4}/y
frequency of rollover involving structural damage	10^{-5}/y-10^{-4}/y
Fire: frequency of major fire in a refinery	0.1/y
Explosion: probability of refinery explosion, given major refinery fire	0.5
Missiles: probability of missile generation, given refinery explosion	0.1
frequency of missile-generating explosion in a refinery	$5 \cdot 10^{-3}$/y
average number of missiles generated per explosion	~6
probability of missile hitting large storage sphere at 300 m	10^{-3}
Unconfined vapour cloud explosion: frequency in a refinery	10^{-3}/y
Pipeline (butane): frequency of failure of a 0.15-0.2 m diameter pipeline	$3 \cdot 10^{-4}$/km/y

* Before the application of these data, the original report should be consulted.

References

[1] LEES, F.P., Loss Prevention in the Process Industry, Butterworths, London (1980).

[2] HEALTH AND SAFETY EXECUTIVE, Canvey: An Investigation of Potential Hazards from Operations in the Canvey Island/Thurrock Area, HM Stationery Office, London (1978).

3.3.5 Guiding Examples

Tables (3.8), (3.9), and (3.10) contain a selection of component failure rates, equipment failure rates and event failure data from a number of reference sources, as indicated. In all cases, it is essential that the original source references be consulted before the application of these data.

3.4 Risk Estimations and Risk Assessment

3.4.1 Individual and Societal Risk

The consequence and probability of each of the postulated incident events are cumulatively combined for the various hazardous incident scenarios to yield quantified risk levels at various distances from the plant or process. Risk results are commonly expressed in terms of human fatality. The analysis and results can, however, also be expressed in other terms such as levels of injury, property damage and environmental damage. Human fatality risk results are expressed in two forms, individual risk and societal risk.

Individual Risk: Defined as the chance (likelihood or probability) per year that anyone will suffer a detrimental effects as the result of exposure to an activity. The exposure can be **acute**, caused by an incident (fire, exposure or toxic emission), or **chronic**, resulting from the presence of toxic chemicals in the environment. The same apply for the effect, which can be acute (sudden death) or long term. Individual risk is often represented in terms of risk contours (iso risk).

Societal Risk: Defined as the relationship between the number of people killed in a single accident (N) and the chance or likelihood (F) that this number will be exceeded. The use of this criterion, which has until now only been suggested for the assessment of the safety of hazardous installations, makes it possible to take into account the density of the population that could be affected by an incident from the operation of hazardous installations. Events as those that occurred in Bhopal and Mexico City illustrate the importance of accounting for the number of people and type of land uses in establishing risk assessment criteria for hazardous activities.

Figure (3.19) is an example of individual risk contour. Figure (3.20) is an example of a societal risk curve.

3.4.2 Estimation of Individual Fatality Risk

Following the definition of individual risk of fatality given in the previous section, the individual risk for a single event and consequence type, can be determined from the following basic expression:

Individual Risk, $I = P_{haz} \times P_c \times P_{occ}$

where: P_{haz} is probability of a hazardous event, such as a pool fire, torch, flash fire, fire ball or explosion

P_c is chance that an individual at a defined location will be subject to a specified level of injury from such a hazardous event

P_{occ} is the chance that the individual will be at such a location when the hazardous event occur.

When evaluating individual risks if the 'person at most risk' approach is adopted for a given location, then it is usually assumed that $P_{occ} = 1$. Expanding P_{haz} in terms of the chance of a release P_{rel} and the probability that it will give rise to the hazardous events, P_{esc}, leads to the expression

Individual Risk, $I = P_{rel} \times P_{esc} \times P_c$, for the individual most at risk

where: P_{rel} = Probability of the release
P_{esc} = Probability of the hazardous event occurring as the result of the release

For a number of releases and hazardous events,individual risks are summed, over all possible accident scenarios and types of accidents, i.e.

$$I = \Sigma P_{rel} (\Sigma P_{esc} \times P_c)$$

The following steps may be give guidance in the computation of individual risk of fatality:

1) Define the location of the individual relative to the point of release

2) Define the type of injury for which the risk is to be evaluated

3) Select a release scenario, with a probability P_{rel}

4) Establish the probability of the hazardous event occurring, given the release:

   This is P_{haz}. ($P_{haz} = P_{rel}$ * probability of escape becoming a hazardous event).

5) Use an appropriate consequence model to determine P_c for the location selected - P_c being the probability of the consequence at this location. For hazardous events with immediate ignition at or near the source, P_c is directly related to P_{haz}. For dispersing toxic clouds, the probability of wind direction and other meteorological conditions (e.g. stability class) would have to be taken into account.

6) Postulate the probability that an individual will be present at that location- P_{occ} (assume P_{occ} = 1 for the person most at risk approach).

7) Individual risk $I = P_{haz} \times P_c \times P_{occ}$.

3.4.3 Estimation of Societal Fatality Risk Levels

For societal risk from a single event, one must evaluate the probability, s, of a given number of people, n, being subjected to a specified level of injury in a specified time interval.

Societal Risk $s = P_{haz}$
tor $n = \Sigma P_c P_{occ}$

where the sum is over all people within the area affected by the hazardous event.

When evaluating the number of people affected by a given hazardous event, the following expressions are often used:

$$s = P_{rel} \times P_{esc}$$

$$n = \Sigma n (k) P_c (k)$$

where n(k) is the ^{K} time - averaged number of people subject to an average casualty probability P_c (k).

Societal risk from a number of events is normally expressed in a cumulative form, i.e. as a probability of arriving at N or more casualties. This is usually expressed for a number of values of N and is obtained by summing all values of s for events where $n \geq N$.

The following procedural steps may be of relevance in the estimation of societal risk levels.

1) Define the type of injury for which risk is to be evaluated.

2) Define the casualty numbers, N, which are to be used in expressing societal risks.

3) Select a release, j, with associated probability P_{rel}.

4) Define the hazardous event from that release with a probability $P_{haz} = s$.

5) Use damage model to evaluate the number of casualties n. This can be done by allocating ranges of exposure to discrete values of P_c and evaluating the number of people n who fall within each exposure range.

6) Repeat steps 3-5 for all releases.

7) Select a value for N.

8) Sum all values of s for which $n > N$.

9) Repeat all steps 7 and 8 for all values of N.

3.4.4 Assessment of Resultant Risk Levels

The qualitative and quantitative results of the analysis can be applied in the assessment process as follows:

a) Risk impacts at various distances from the plant may be compared against safety targets or criteria: an overview of such criteria is presented in section 3.5. A judgement can be made about the hazard impact. A general principle of assessment is that the risk impacts from the development should be well below the levels of risk which people and the environment are regularly exposed to from the development and other sources.

b) The analysis should particularly highlight the major contributors to risk and their nature and extent and, secondly, areas where risk can be eliminated or cost-effectively reduced. These results can be used to develop prevention and protection measures including priority allocation of resources for hazard control.

3.5 RISK CRITERIA

3.5.1 Overview

All activities have an associated risk. Risk can be assessed and managed, but never eliminated. Indeed, zero risk cannot be achieved even if the activity itself is eliminated. In many cases this simply leads to risk transfer which is an important concept in risk assessment and management.

In going about their daily-life individuals continuously assess situations and make decisions on whether the risk associated to a particular action is justified. Such decisions are mostly made under conditions of uncertainty and involve value judgements which normally cannot be explicitly expressed in terms of quantitative criteria. This is often the case when the risk is of a voluntary nature, i.e. it is taken as a free choice (e.g. smoking, down hill skiing). On the other hand when the individual cannot fully chose to avoid exposure to risk, it is termed as involuntary (e.g. natural disasters, large industrial accidents) and the decision making process needs to be more explicit using quantitative data. Moreover, people are generally willing to expose themselves to quite different levels of risk depending on whether it is of a voluntary or non-voluntary nature. Table 3.11 indicates a range of various voluntary and non-voluntary risks to which people are generally exposed as the result of various activities.

Table 3.11 - Examples of some Annual Individual Mortality Rate

* Voluntary Risks (average to those who take the risk)

Smoking (all effects)	5×10^{-3}	5000 in one million
Riding a motorcycle	1×10^{-3}	1000 in one million
Drinking alcohol	4×10^{-4}	400 in one million
Driving a car	1.5×10^{-4}	150 in one million
Travelling by train	3×10^{-5}	30 in one million
Travelling by plane	1×10^{-5}	10 in one million

* Risks Averaged over the whole population

Cancers (from all causes)	2×10^{-3}	2000 in one million
Accidents at home	1×10^{-4}	100 in one million
Walking	3×10^{-5}	30 in one million
Storms and floods	2×10^{-7}	0.2 in one million
Ligthning	1×10^{-7}	0.1 in one million

The increased societal awareness on the need to protect the environment, the complexity of modern industries and their potential to cause accidents of large consequences are related to involuntary risks. Decisions involving these issues are often dominated by emotional arguments. Therefore, a rational decision making process requires the establishment of a consistent framework with standards to express the desired level of safety. Probabilistic Safety Criteria (PSC), which are quantitative expressions for the probability of occurrence of an undesirable event within a given period of time, can play the role of such standards. The purpose of this section is to provide a general guidance concerning the setting and applications of such criteria.

3.5.2 Risk Categories

In addition to the voluntary versus involuntary nature of risks, a broader categorization is needed to put risks in proper perspective and to develop risk management strategies.

Firstly, public health risk should be assessed separately from environmental risk.

Figure 3.2.1 outlines the broad categories of risks usually adopted to assess and compare the health and environmental impacts of different hazardous activities. In all cases, risks to the environment should be assessed and compared separately from risks to human health.

Health Risk

Source	People at risk	Exposure	Effects
Routine or accidents	Workers and public	Short or medium and long term	Fatal and non-fatal Immediate/ delayed-immediate/ delayed

Environmental risk

Source	Effects	Effects
	Duration	Extent
Routine or accidents	Short or medium and long term	Local, regional and global

Fig. 3.12 Categories of risk

In terms of health impacts, occupational and public risks should be treated separately. Two categories of risk apply as a result of direct or indirect impacts:

- **Fatal effects**, either immediate (resulting from direct exposure or accidental situation) or delayed (resulting from chronicle exposure to hazardous substances);

- **Non-fatal effects**, (injuries, diseases) of either an immediate or delayed nature.

In relation to environmental risk, categorization of risks can be made on the basis of extent: local, regional and global; and on the duration of the effect: short or medium term and long term.

Some environmental effects are of such a long term nature that they are virtually, or actually irreversible. The complete destruction of vegetation and soil cover in certain mining operations is one such example; widespread loss of species in an area is another. Planning is the only way in which such irreversible environmental effects can be avoided.

Risks from routine operations should also be differentiated from those resulting from major accidents. The criteria proposed in this chapter refer to this latter type.

To date, emphasis has been place on the development of risk criteria in terms of acute (immediate) health effects, mostly fatalities and in some cases immediate injuries to people. Few examples exist (The Netherlands being an exception) where an encompassing overall quantified risk criteria have been established for long-term chronic exposure to chemicals from one-off or repeated accidental exposures. For the long-term effects of chemicals, the assessments have until now relied mostly on translating animal tests results to people. Recommendations established by National Health Councils are relied upon in that regard.

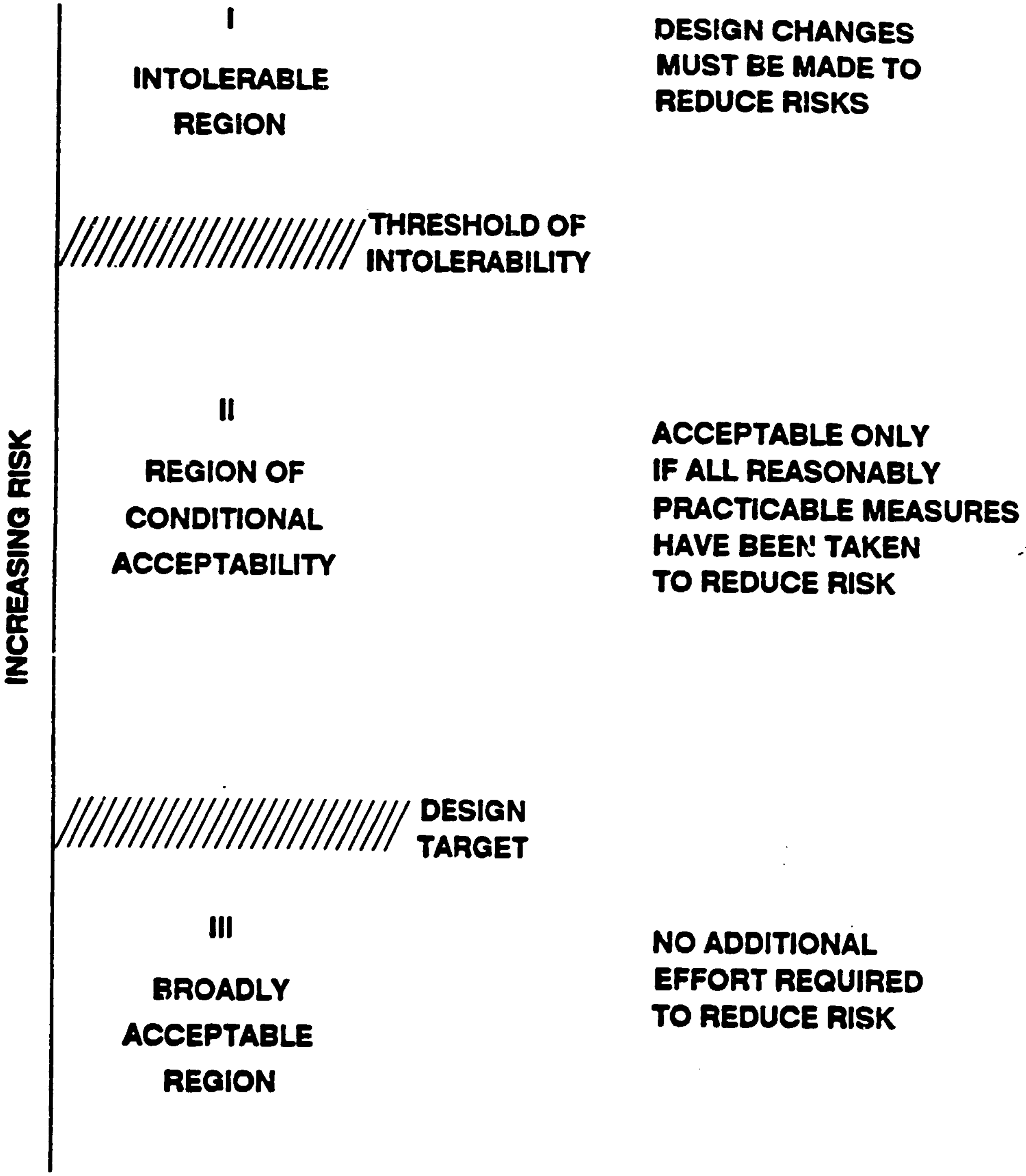
There are also very few cases of probabilistic safety criteria that apply to accidental releases of chemicals into the natural environment. The diversity of response mechanisms (in type and nature) to the multitude of species within the different exosystems, including the issue of irreversibility and/or recoverability of damage make it difficult to establish a uniform criteria in this area. Such criteria will largely depend on local circumstances and may need to be developed on a case by case basis.

3.5.3 Probabilistic Safety Criteria (PSC) Framework

The basis adopted in many cases in setting a PSC is that the criteria ought to be set below (and in many cases well below) known voluntary and non-voluntary risks associated with the different daily activities to which any one person or the society as a whole is exposed. Although it has been argued that by setting assessment criteria in such a way, such criteria should provide an 'acceptable' level of risk, the notion of risk 'acceptability' has been and still is the subject of significant debate. Attention is now being given to the setting of a 'tolerable' level of risk. The tolerability of such risks may be suggested by both reference to other levels of risks experienced by the society and that may be tolerated in relation to both the costs and benefits associated with the activities under consideration. Social and economic considerations become therefore integral aspects of the setting of such tolerable risk levels.

Within the context of the above a framework suggested in setting PSC is one that embraces three "regions of risk": an upper region (I) inwhich the risk is judged to be so high as to make the practice or activity intolerable whatever its benefits, an intermediate region (II) where the risk is acceptable subject to the overriding requirement that all reasonable practical measures have been taken to reduce the risk, and a lower region (III) in which the risk is judged sufficiently low as to be broadly acceptable with no additional effort required to further reduce it. Figure 3.22 depicts the three regions described. This is based on the approach promulgated in a United Kingdom Policy Paper on the Tolerability of Risks from Nuclear Power Stations.

It is recognized that it is difficult to define the boundaries between Regions I, II, and III as single precise values. In addition, the practical application of QRA inevitable involves uncertainty and imprecision in the estimation of risks. These factors need to be taken into account in assessing QRA results within this framework and the criteria must not be used as absolute go/non-go rules, hence


INCREASING RISK
I
INTOLERABLE REGION
DESIGN CHANGES MUST BE MADE TO REDUCE RISKS
THRESHOLD OF INTOLERABILITY
II
REGION OF CONDITIONAL ACCEPTABILITY
ACCEPTABLE ONLY IF ALL REASONABLY PRACTICABLE MEASURES HAVE BEEN TAKEN TO REDUCE RISK
DESIGN TARGET
III
BROADLY ACCEPTABLE REGION
NO ADDITIONAL EFFORT REQUIRED TO REDUCE RISK

they are shown as hatched zones, rather than single values in Fig. 2. Within such a framework it is unnecessary to define separate levels for old and new plants. However, it is recognized that it will generally not be reasonably practicable to reduce the risks from plants in operation to the levels achievable on new plants.

The establishment of specific upper and lower risk criteria may be influenced by many considerations which will vary with the type of risk addressed. These considerations include public health, social and economic factors. The basic choice of the appropriate levels of the public health and societal impact related criteria is essentially a socio-political decision and can only be made in a national context. The translation of this decision into a technical definition is, however, a process in which judgement will inevitably be involved.

Principles and procedures used in establishing compliance with existing PSC in the presence of the quantified uncertainties are still evolving. It is recommended that where distribution of frequencies has been calculated in QRA, the mean value rather than an upper or lower bound should be used. Where only point values have been used they should be representative of a central value.

4. Individual Risk Criteria

Individual risk is usually defined as the probability per year that anyone person will suffer a detrimental effect as the result of exposure to an activity.

PSC for individual risk are proposed under the consideration that risks arising from accidents in hazardous installations should present only a small increment to the risk to which individuals are already exposed.

The criteria is intended for application to an individual risk calculated using the following assumptions:

- the individual should be considered to be resident at the location off-site, yielding the largest risk, for a representative period of time or until such time as realistic off-site emergency plans can be affected,
- the individual should be considered to be an average individual with respect to dose susceptibility,
- atmospheric dispersion calculations should be realistic, i.e. making allowance for the variability in weather and wind direction.

Whilst individual fatality risk levels include all components of risk - i.e. fires, explosions and toxicity - there may be uncertainties in correlating toxic concentrations to fatality risk levels. The interpretation of 'fatal' should not rely on any one dose-effect relationship, but involve a review of available data.

Table 3.12 provides an overview summary of risk criteria suggested or adopted by different national authorities. Selected examples are presented hereafter.

3.5.4.1 Practices in some countries

Australia

Criteria for individual fatality

An individual fatality risk criteria of one in a million per person per year ($1x10^{-6}$ per year) has been adopted as the limit for risk acceptability for residential area exposure. A higher level of risk is still generally considered acceptable in industrial areas. Criteria for various categories of land use are indicated in Table 3.13.

Criteria for injury

Subsidiary to criteria for fatalities, risk criteria have also been set in terms of injury to people which will not necessarily cause death. The following are injury risk criteria from.

- Incident heat flux radiation at residential areas should not exceed 4.7 kW/m^2 at frequencies of more than 50 in a million per year.

- Incident explosion overpressure at residential areas should not exceed 7 kPa at frequencies of more than 50 in a million per year.

- Toxic concentrations in residential areas should not exceed a level which would be seriously injurious to sensitive members of the community following a relatively short period of exposure at a maximum frequency of 10 in a million per year.

- Toxic concentrations in residential areas should not cause irritation to eyes or throat, coughing or other acute physiological response in sensitive members of the community over a maximum frequency of 50 in a million per year.

Table (3.12) **Overview Summary of Risk Criteria**

Year	Advisory Body/ Government	Risk Level per year	Comment
1976	Advisory Committee on Major Hazards	10^{-4}	Serious accident frequency (at the plant level)
1976	Royal Commission on Environmental Pollution	10^{-5} $< 10^{-6}$	Warnings on individual risk Individual Risk considered acceptable
1981	HSE Canvey Study	20×10^{-6} to 400×10^{-6} (individual fatality risk)	Cessation of operations considered not required
1983	Royal Society Study Group	$< 1 \times 10^{-6}$ $> 1 \times 10^{-3}$ 1×10^{-6} to 1×10^{-3}	Risk acceptable Not acceptable Compare risks, detriments,costs and benefits
1984	Netherlands Government	$< 10^{-6}$ Graphs for societal risk	Risk acceptable Extrapolation from individual risk
1989	HSE, UK	$< 1 \times 10^{-6}$ $< 0.3 \times 10^{-6}$ $> 10 \times 10^{-6}$ No numerical criteria justified for group risk	Risk acceptable Sensitive land uses may not be acceptable
1989	Dutch National Environmental Policy Pan	1×10^{-6} 1×10^{-8} 1×10^{-6} - 1×10^{-8} 10^{-5} for 10 fatalities - 10^{-7} for 100 fatalities 10^{-7} for 10 fatalities - 10^{-9} for 100 fatalities	Max permissible Negligible Risk reduction Max permissible societal risk Negligible societal risk
1990	Department of Planning, NSW, Australia	$< 1 \times 10^{-6}$ $< 0.5 \times 10^{-6}$ Societal risk on a case by case	Risk acceptable Sensitive land uses Additional criteria for injury

Table 3.13: Suggested Individual Fatality Risk Criteria for Various Land Uses

Land Use	Suggested Criteria (risk in a million per year)
Hospitals, schools, children facilities, old age housing	0.5
Residential, hotels, motels, tourist resorts	1
Commercial developments including retail centres, offices and entertainment centres	5
Sporting complexes and active open space	10
Industrial	50

Netherlands

The limits set for individual mortality risk take account of the fact that lethal accidents will also result in a number of less seriously injured casualties. Stochastics effects (i.e. late effects) are taken into account. The limits set for individual risk are:

- the maximum permissible level is defined as 10^{-6}/year;
- the negligible level is defined as 10^{-8}/year.

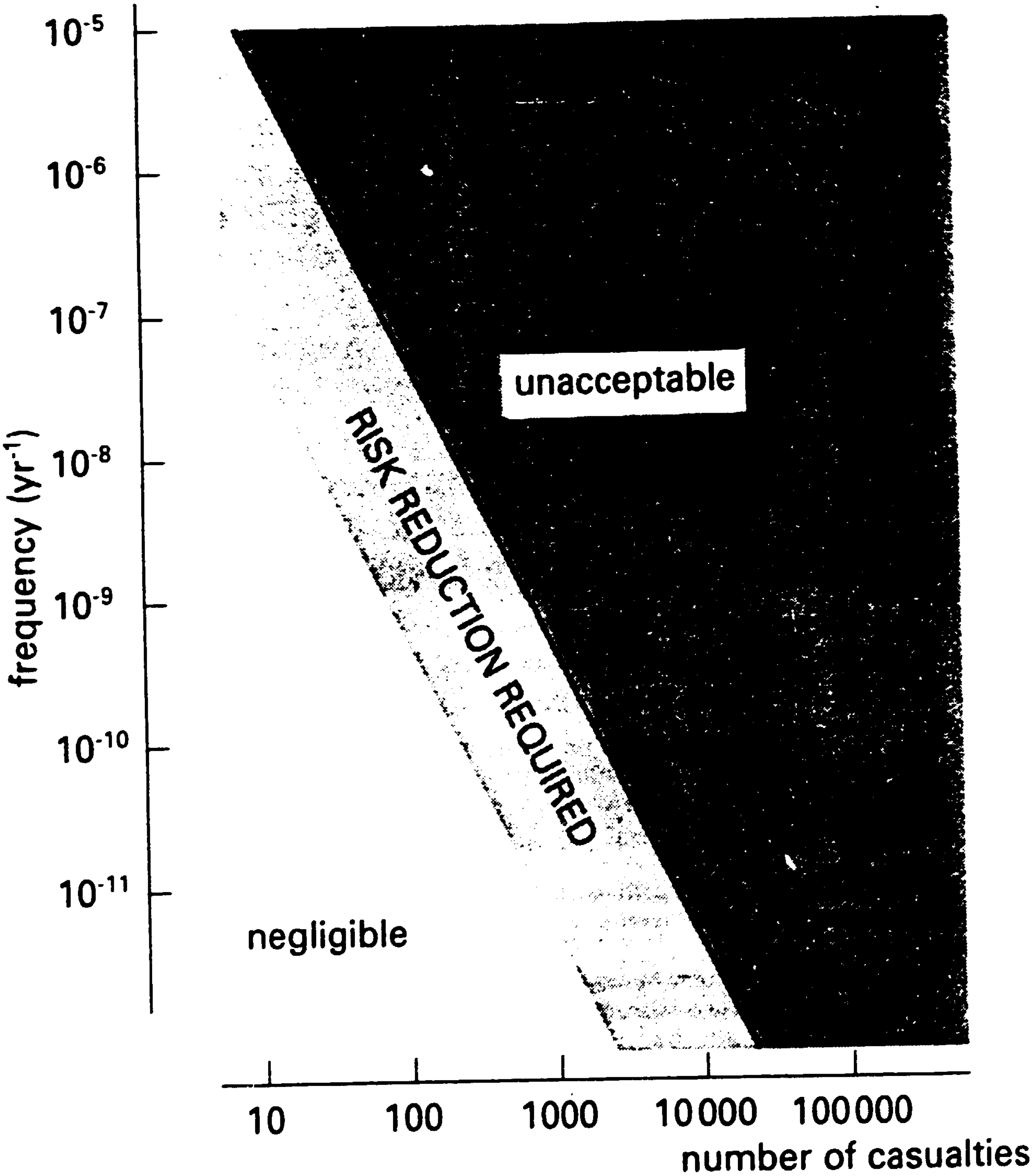
As people may be exposed to hazards from many different activities, limits have also been established for cumulative risks. Individual risks criteria for combined activities are:

- the maximum permissible level is defined as 10^{-5}/year;
- the negligible level is defined as 10^{-7}/year.

3.5.5 Societal risk criteria

There is a general agreement that societal or group risks should be considered when assessing the acceptability of any hazardous industrial facility.

Societal risk is usually defined as the relationship between the number of people killed in a single accident and the chance or likelihood that this number will be exceeded. It is usually presented in the form of an 'F-N curve', which is



10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
frequency (yr^-1)
unacceptable
RISK REDUCTION REQUIRED
negligible
10
100
1000
10000
100000
number of casualties

a graphic indicating the cumulative frequency (F) of killing N or more people.

Group risk does not involve the calculation of the individual risk of death but rather the risk of a number of deaths.

There are many ways of expressing the societal impact of serious accidents, such as the number of predicted, prompt, or latent fatalities, agricultural restrictions, large scale evacuation and economic loss. There is no international consensus on which of these or other measures should be chosen to develop societal risk criteria. Individual countries will need to choose the impacts of greatest concern to them.

A number of factors should be borne in mind when developing PSC based on societal risk, including public aversion to accidents with high consequences. The risk level chosen should decrease as the consequence increases. The criteria should be relatively simple to understand, and should recognize the imprecision of QRA estimates that predict societal effects (either health or otherwise).

3.5.5.1 Practices in some countries

Australia

Judgements on societal risk are made on the basis of a qualitative approval on the merit of each case rather than on specifically set numerical values. It is suggested that individual fatality and injury risk contours at the individual risk criteria levels applicable to the various land use categories should be established (see Table 3.13). Wherever practicable, the frequency of each potential accident and the number of people that may be affected by each accident should be estimated (FN curves).

Netherlands

In estimating group as well as individual risk acute deleterious effects are determined on the basis of death up to two or three weeks after exposure.

The limits set for group risks are:

An increase in the number of deaths by a factor 'n' in a given situation is only acceptable if the probability of this event occurring is a factor n-squared lower for both types of level.

The maximum permissible risk levels for disasters are defined as 10^{-5}/year for n=10 or more deaths and 10^{-7}/year for n=100 or more deaths. The corresponding negligible levels are defined as 10^{-7}/year for n=10 or more deaths and 10^{-9}/year for n=100 or more deaths etc.

Figure 3.23 depicts group risk limits for major accidents as applied in the Netherlands.

3.5.6 Safety Assurance

Further to proposing criteria to express the desired level of safety, it should be discussed to which extent risk estimates and their compliance with risk criteria can assure safety.

First, it should be kept in mind that severe accidents are rare events and as such their estimated probability of occurrence is the result of an engineering model representation of the reality and not the result of observable repetitive events. Therefore, when we refer to the probability of a certain undesirable outcome, we are expressing, according to the subjective concept of probability, our degree of belief that such events may happen.

Second, any model includes assumptions which have to be respected for the results to be credible. They also form the basis for the "safety assurance" which is both a fundamental safety concept and a requirement for QRA results to be a realistic qualitative and quantitative measure of plant safety.

In this context the concept of a "living" QRA, one which is kept constantly updated, should any changes in the conditions used in the base case calculation be introduced, has emerged and is increasingly being used as a tool for operational safety management and risk monitoring.

It goes without saying that low risk estimates are not surrogates to sound plant design and sound operational practices and to constant operators' safety awareness required for safe plant operation.

3.5.7 Qualitative Risk Assessment Criteria

Irrespective of the numerical value of any risk criteria level for risk assessment purposes, it is essential that certain qualitative principles be adopted as yardstick for safety assessment and management. The following qualitative criteria are appropriate when assessing the risk implications of a development project of a potentially hazardous nature or the locational safety suitability of a development in the vicinity of a potentially hazardous installation:

a) All 'avoidable' risks should be avoided. This necessitates the investigation of alternative locations and alternative technologies, wherever applicable, to ensure that risks are not introduced in an area where feasible alternatives are possible and justified.

b) The risk from a major hazard should be reduced wherever practicable. irrespective of the numerical value of the cumulative risk level from the whole installation. In all cases, if the consequences (effects) of an identified hazardous incident are significant to people and the environment, then all feasible measures (including alternative locations) should be adopted so that the likelihood of such an incident occurring is made very low. This necessitates the identification of all contributors to the resultant risk and the consequences of each potentially hazardous incident. The assessment process should addresses the adequacy and relevancy of safeguards (both technical and locational) as they relate to each risk contributor.

c) The consequences (effects) of more likely hazardous events (i.e. those of high probability of occurrence) should, where ever possible, be contained within the boundaries of the installation.

e) Where there is an existing high risk from a hazardous installation, additional hazardous developments should not be allowed if they add significantly to that existing risk.

Guidance Notes on Implementation

The following notes are provided to assist in the formulation and implementation of appropriate risk assessment criteria.

a) The individual fatality and societal risk criteria should include all components of risk,: fire, explosion and toxicity.

b) The implementation of the criteria must acknowledge the limitations and in some cases the theoretical uncertainties associated with risk quantification. Two approaches are usually adopted to account for such uncertainties: a 'pessimistic' approach, i.e. assumptions err on the conservative side with overestimation of the actual risk; or 'best estimates' using realistic assumptions with an estimated risk that could either be an overestimate or an underestimate of the actual risk. The criteria suggested in this section are set at a realistic level.

c) In the context of b), a degree of flexibility in the implementation and interpretation of the absolute values of the risk criteria may be justified in some cases. There may also be variations in local conditions. Consideration of vulnerability of people and situations is necessary. The criteria are best implemented when used as targets rather than absolute levels. Nevertheless, any substantial deviations from such targets should be fully justified. It is advisable that in all cases the assessment process emphasize the hazard identification and risk quantification process and procedures rather than entirely relying on absolute risk levels.

d) Given the probabilistic nature of the assessment process, care must be exercised in interpreting/assessing compliance with a risk criteria in terming plants which exceed the suggesting criteria as 'unsafe'. Nevertheless, a higher resultant risk level relative to the suggested criteria indicates land use safety incompatibility and locational safety constraints.

e) The implementation of the risk criteria should differentiate between existing land use situations and new situations in terms of applicability to reflect a tighter locational and technological standard applying now than at earlier times. In the case of ex existing industry, compliance with a risk criteria is part of an overall strategy to mitigate existing risk levels by reducing both the risks and the number of people exposed to those risks. As such, risk criteria designed for new plants can only be used in targets for existing plants as part of an overall safety strategy.

f) The risk to an individual and/or to the public in the vicinity of an industrial site, arise from all industrial activities in the area. The basic risk criteria (to various land uses) need to be related to the site. It may also be appropriate to plan for sub-criteria for each individual site to account for cumulative impact of developments.

g) In a large industrial complex, risk criteria should also provide for the potential for accident propagation. The risk of an accident ar one plant triggering another accident at another neighbouring plant should be kept low. Adequate safety separation distances should be maintained.

h) The application of the risk criteria should also apply to development/re-development of residential and other sensitive land uses in the vicinity of hazardous installations.

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PROCEDURAL GUIDE FOR INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

VOLUME II

METHODS AND PROCEDURES FOR HEALTH AND ENVIRONMENTAL RISK ASSESSMENT

CHAPTER 4

ASSESSMENT OF HAZARDOUS WASTES

Chapter 4: ASSESSMENT OF HAZARDOUS WASTES

Industrial area risk assessment and management is incomplete without comprehensive and integrated consideration of wastes. Whilst some wastes are inherently hazardous, others become hazardous when they are not properly stored, transported or treated. The identification and analysis of hazards and risk from wastes must be based broadly rather than on narrow definitions of classes of waste as hazardous. The assessment methodologies which are used for hazardous materials generally can be applied to hazardous wastes. There are, however, special features of waste which distinguish it from other hazardous materials, particularly negative economic value. Careful, case specific analysis is particularly appropriate in respect of wastes. Generalisations are likely to result in hazards missed and to under or over estimation of risks. Generalisation is also likely to result in inappropriate risk management decisions.

This chapter outlines general principles of assessing hazardous wastes. The management aspects are dealt with separately in Chapter 3, volume 3 of the guide. The following publications by WHO and UNEP should also be considered:

4.1 Introduction

It is essential that potentially hazardous wastes be treated in a comprehensive and integrated way in industrial area risk assessment and management. As well as the risk impacts of the waste and waste management operations themselves, risk management decisions may have consequences for waste management and waste management decisions impact on broader risk management.

Other chapters in this guide deal with waste streams emitted to air (as gases or particulates) and liquid wastes discharged directly to water bodies or to sewerage systems.

The purpose of this chapter is to address hazardous solid, liquid and gaseous wastes produced during normal operations which are not routinely discharged to air or water. This is an important category of waste which has long been a source of problems. Wastes in this category include many of the most hazardous. As restrictions on emissions to air and water are tightened, wastes in this class must grow unless the generation of wastes is also reduced. Wastes arising from accidents and incidents are also covered in this chapter.

The chapter deals first with defining hazardous waste (an important issue as many wastes, even domestic garbage, can be hazardous if not properly managed) and the broad identification of types of hazardous wastes. A generalised approach to the identification and assessment of wastes generated, of existing management practices and facilities and of likely impacts on people and on the biophysical environment is described. The range of waste management strategies and options, economic considerations and regulatory approaches are discussed in volume 3, chapter 3.1 of this Guide. Aspects of the technologies which can be applied within these options are briefly discussed in section 3.2. Problems associated with the siting of facilities for waste treatment and community perception are discussed in section 3.3, volume 3. Waste transport, which can be a particular area of concern and source of risk to people and the environment, is discussed in section 3.4, volume 3.

4.2 Hazardous Wastes

4.2.1 Why are Wastes Different?

Why should wastes be dealt with separately in this guide? What is it that sets wastes apart from other hazardous materials? Why should waste handling, treatment or disposal facilities be regarded as different from other potentially hazardous facilities? An understanding of these issues is fundamental to the successful integration of wastes into area risk assessment and the adoption of appropriate management practices.

The perception of wastes, as much as their physical and chemical characteristics, necessitates the separate treatment of the subject. The characteristic that typifies wastes is that they have a negative value - they are unwanted and a cost is involved in their disposal. This characteristic can lead to wastes being handled differently to hazardous materials which are regarded as valuable. As a generalisation wastes are more likely to be handled without due care and more likely to be inadequately dealt with in the design and assessment of industrial facilities than raw materials or products.

Note: Because it is the negative value of a material that causes it to be classed as a waste, and not the characteristics of the material, what may be considered a waste in some circumstances will be a useful material in others. This situation can change as local, domestic and international demand and supply change. It is also dependent on the knowledge of demand.

Further, wastes are often mixtures of materials or impure or contaminated materials and this increases the likelihood of accidental inappropriate handling, treatment or disposal. It also complicates the assessment of impacts of releases.

The historical record of problems arising from past disposal practices and the negative connotation of "waste" has resulted in a perception in the public mind of risk from waste storage, treatment and disposal facilities that is often disproportionately high.

While the characteristics outlined above do require some special treatment in assessment and management, the basic methodologies of hazard identification, consequence and frequency analysis and risk assessment are applicable to the potentially hazardous waste materials and waste handling operations. As with other specific aspects of potentially hazardous industrial activities, the nature of management measures and strategies and the recommendations for remedial action which may result from the analysis are, however, particular to the waste management aspects.

4.2.2 What are Hazardous Wastes?

In their original state or through decomposition, reaction or other change, wastes can present a wide range of hazards to people, property and the biophysical environment through fire, explosion, toxicity (including acute effects, carcinogenicity, teratogenicity, mutagenicity etc), corrosivity, eutrophication/pollution, spread of disease (human and animal), radiation, physical impact contribution to climate change and perceived health problems.

Whilst the focus of this guide is on industrial activities it is important to consider waste streams not only from industrial and other operations which are hazardous in themselves, but also hazardous wastes from other sources, including waste management facilities which may themselves be significant sources of problem wastes.

Wastes of many types can be hazardous if they are not appropriately managed. Domestic garbage, for example, can play a role in spreading disease if it is not treated or disposed of by land filling. In landfills it can present an explosion hazard if methane produced is confined in and under buildings. Methane produced also contributes to greenhouse problems. It can also contribute to pollution of waterways and ground water through leaching of nutrients, heavy metals, organics etc. If burnt or incinerated then dioxins, furans, heavy metals and other emissions to the air can be a problem. A further example is mine wastes which may be hazardous because of heavy metal contaminated leachate, dust or runoff, radioactivity, asbestos contamination, or physical bulk and stability. The latter case is illustrated by the 1966 Aberfan (Wales) coal slag heap landslide which killed 144 people including 116 children in an elementary school.

There are a number of different definitions and waste classification systems which have been developed around the world by governments and international organisations such as the OECD and UNEP. A number of these systems are covered in the references at the end of the chapter. For the purposes of these guidelines it is more important to direct attention broadly to the range of wastes and to allow for the specific analysis to follow through on detailed questions such as classification. (Legislative and regulatory approaches including classification are discussed briefly in section 3.1, volume 3).

Principal types of hazardous waste include: radioactive materials; pesticide residues and byproducts; sludges contaminated with heavy metals; halogenated and halogen free organic solvents; PCB contaminated materials; asbestos contaminated materials; hospital and quarantine wastes; pickling liquors; phenol containing sludges; arsenic contaminated sludges; cyanide containing sludges, liquors and spoil heaps; radioactive materials; slags containing metal salts; mineral oils and tars.

Table 4.1 sets out typical activities which could be considered as possible sources of hazardous wastes. The table shows typical waste materials involved, nature of hazards, and potential health and environmental impacts.

TABLE 4.1 HAZARDOUS WASTE GENERATING OR HANDLING FACILITIES

ACTIVITY	TYPICAL HAZARDOUS WASTES	NATURE OF HAZARDS	POTENTIAL ENVIRONMENTAL IMPACTS	POTENTIAL HEALTH IMPACTS
A. MINING				
Coal mining/ washeries.	Spoil heaps/tailings waters/dams.	Physical impact/ pollution.	Pollution of water courses.	Fatality/injury from landslides/dam failures.
Non-ferrous metal mining (particularly gold).	Spoil heaps/tailings dams containing heavy metals/salts, cyanide arsenic etc.	Toxicity/pollution/ physical impact.	Contamination of ground and surface wastes (runoff and leachate). Aquatic environment damage.	Fatality/injury - chronic and acute. Through food chain and water supply.
Asbestos mining.	Tailings heaps high in asbestos.	Asbestos fibres/dust.	Land sterilisation.	Fatality/injury - chronic - asbestosis and mesothelioma.
Gas and oil extraction.	Oily muds/sludges.	Pollution/fire.	Land/groundwater/ surface waste contamination.	Chronic through water, food and air.
Uranium mining.	Radioactive tailings and waters. Other minerals and metals in tailings waters.	Radiation/pollution.	Pollution of water bodies and impact on aquatic and other species.	Health impact through water supply or food chain - acute or chronic.
B. MANUFACTURING				
Gas works.	Phenol/mercaptan/ cyanide containing sludges.	Toxicity.	Adverse impact on plants and animals. Soil and water contamination.	Illness/fatality through food and water - acute or chronic.

ACTIVITY	TYPICAL HAZARDOUS WASTES	NATURE OF HAZARDS	POTENTIAL ENVIRONMENTAL IMPACTS	POTENTIAL HEALTH IMPACTS
Oil refineries.	Sludges/tars/aqueous wastes.	Fire, explosion, toxicity.	Water pollution, land contamination. Fouling of shorelines etc.	Chiefly chronic through food/water and vapours combustion products in air.
Leather production/ tanneries.	Sludges containing chromium and other heavy metals/salt/ sulphide.	Toxicity.	Soil/water/silt contamination.	Fatality/injury - chronic/acute through food/water/direct exposure. Cancers.
Coke works.	Sludges and tars. Solvents.	Toxicity.	Soil/water/silt contamination.	Chiefly chronic through food or water.
Aluminium smelters.	Fluoride and cyanide containing residues.	Toxicity/pollution.	Surface and groundwater contamination. Impacts on plant and animal life.	Chronic through water/ food.
Electro-plating works.	Sludges containing chrome, cyanide, cadmium.	Toxicity.	Contamination of soil and groundwater. Pollution of surface waters and silts etc. Acute and/or long-term depending mode of release.	Fatality/injury from food and water. Short or long-term.
Pharmaceutical works	Halogenous and halogen free solvents.	Toxicity.	Contamination of soil and water. Impacts on plants and animals.	Acute/chronic through food/water/vapours.
Asbestos works.	Asbestos dusts/ residues.	Health.	Land sterlisation.	Chronic - asbestosis and mesothelioma.
Metal pickling works.	Acid mixtures/sludges containing metal residues.	Corrosivity, toxicity.	Changes in pH of water bodies. Soil or groundwater contamination. Aquatic toxicity.	Fatality/injury - through food and water.

ACTIVITY	TYPICAL HAZARDOUS WASTES	NATURE OF HAZARDS	POTENTIAL ENVIRONMENTAL IMPACTS	POTENTIAL HEALTH IMPACTS
Plastic manufacturing.	Sludges/halogenated residues/solvents.	Fire/toxicity/pollution	Soil/water/silt contamination. Impacts on plants and animals.	Combustion products from fires and vapours. Cancer, mutations, birth defects etc.
Rubber production/ processing.	Solvents.	Toxicity.	Soil/water contamination.	Chronic through food and water.
Paint/resin manufacturing.	Sludges/heavy metals/ solvents.	Toxicity/pollution/ fire.	Soil/water/silt contamination. Adverse impact on plant and animal life.	Toxic combustion products/vapours. Acute/ chronic through air, food and water.
Coating works.	Spent acids/solvents/ metals/salts.	Fire/toxicity/ pollution.	Soil and water contamination. Adverse impact on plant and animal life.	Toxic combustion products and vapours. Acute/ chronic. Air food and water.
Pesticide production.	Out of specification pesticides and byproducts. Contaminated filters etc.	Toxicity.	Extensive plant and animal kills. Bioaccumulation and persistence in environment.	Fatality/injury, acute/ chronic through food and water. Mutations, cancer, birth defects etc.
Non-ferrous metal refining.	Slags and sludges containing lead, cadmium, arsenic, mercury, cyanide.	Toxicity.	Soil and water contamination. Plant and animal kills acute and long term.	Fatality/injury, acute/ chronic through food and water.
Uranium refining and fuel rod production.	Radioactive/heavy metal containing sludges and waters.	Radiation/toxicity.	Adverse impact on plants and animals. Soil and water contamination.	Mainly chronic impacts from radiation and chronic from heavy metals etc.

ACTIVITY	TYPICAL HAZARDOUS WASTES	NATURE OF HAZARDS	POTENTIAL ENVIRONMENTAL IMPACTS	POTENTIAL HEALTH IMPACTS
C. AGRICULTURE				
Cropping and animal husbandry including feed lots, piggeries, chicken batteries etc.	Unused/expired/spent pesticides. Manure, antibiotics - contaminated manure etc.	Toxicity/pollution/ infection.	Soil and water contamination. Eutrophication. Animal/disease. Methane from manure - greenhouse gas.	Injury/fatality. Acute/ chronic through food and water.
D. MEDICAL AND VETERINARY FACILITIES				
Hospitals and medical clinics.	Infectious wastes, radioactive material.	Human disease, radiation.		Human fatality/illness.
Quarantine stations, abattoirs etc.	Waste infectious to animals and humans.	Infection.	Spread of animal diseases. Contamination of water/soil.	Disease/fatality through water/food/direct contact.
E. WASTE MANAGEMENT OPERATIONS				
Sewage treatment.	Bacterial sludges, sludges with heavy metals organics etc.	Infection/toxicity/ pollution.	Spead of disease/ pollution/eutrophication.	Spread of disease/heavy metal etc exposure through food and water. Chronic/acute.
Domestic/commercial landfill.	Methane and other gases/vapours, leachate.	Fire/explosion/ pollution/toxicity.	Greenhouse gases. Water contamination. Eutrophication/ pollution.	Illness/fatality through water contamination and fires/explosions.
Incinerators.	Metals, organics, nutrients, salts and ash with heavy metals, dioxins furans etc.	Toxicity/pollution.	Contamination of ground and surface water. Adverse impacts on plants and animals.	Illness/fatality through food/water.

ACTIVITY	TYPICAL HAZARDOUS WASTES	NATURE OF HAZARDS	POTENTIAL ENVIRONMENTAL IMPACTS	POTENTIAL HEALTH IMPACTS
F. ENERGY PRODUCTION/ DISTRIBUTION				
Power stations/ switching/trans- former stations.	PCB contaminated oil, fly ash (leachate).	Toxicity.	Persistent and bioacumulative.	Illness through food chain and direct.
Nuclear power plants/fuel production.	Spent fuel/reprocessing residues. Contaminated materials.	Radiation.	Contamination of soil and water. Impacts on plants and animals.	Acute/chronic. Illness/ birth defects, cancers etc.
G. TRANSPORTATION				
Vehicle washings, slops from change- overs of products in pipelines.	Full range of wastes possible.	All types	All types.	All types.
H. MILITARY				
Munitions production/military.	Surplus or expired conventional, chemical and biological weaponry.	Explosion, fire, toxicity, infection.	Contamination of land, water. Direct impact on biota.	Injury/fatality.
I. RESEARCH FACILITIES				
Scientific laboratories etc.	Wide range of hazardous materials usually in relatively small quantities.	Infectious/toxic/radio- active etc.	Disease/pollution/ contamination.	Disease/injury/fatalities from infectious and toxic substances.

ACTIVITY	TYPICAL HAZARDOUS WASTES	NATURE OF HAZARDS	POTENTIAL ENVIRONMENTAL IMPACTS	POTENTIAL HEALTH IMPACTS
J. CONSTRUCTION INDUSTRY				
Demolition and excavation.	Contaminated equipment/residues/contaminated soil.	Potentially all types.	All types.	Chronic/acute through dust, food/water. All types.
K. ACCIDENTS AND SPILLS				
Deliberate and accidental fires/explosions/spills etc during production, storage and transportation.	Contaminated fire fighting water/soil/"cocktails" of hazardous materials.	All types.	All types.	All types.

The listing of potential impacts should not be taken to mean that they will eventuate.

The table is necessarily generalised and indicative and should not be regarded as definitive. As is stressed in earlier chapters, the strength of the approach to risk assessment and management set out in this document lies in case specific systematic analysis.

Waste streams will vary greatly from case to case. Different raw materials, different technologies and different waste management practices will all greatly effect the type, form and hazardousness of the waste stream. The general activity descriptors of the first column of the table encompass a number of different specific operations and activities. Within each specific activity the waste profile will differ with the technology, waste management etc. Further, many waste streams, as shown in the table, will involve a variety of hazardous components. As the environmental and health impacts will be specific to the materials and processes they cannot be covered in detail in a generalised table such as this. The manner of release also critically effects impacts (for example the slow leakage from sludge settling ponds with long term low level contamination of a water body as against the sudden failure of containment and sudden gross contamination). Similarly high short term levels of exposure to a toxic material may, for example, product acute or chronic effects while low level exposures may produce chronic effects or acute effects once a threshold level is reached. It is essential therefore that the complexities and the diverse range of possible impacts are dealt with by the use of the careful case specific approach.

Whilst this chapter is focused on materials with potential for local or regional impact, the inclusion in the assessment of materials with wider impacts, such as greenhouse gases and ozone depleting substances (both as wastes and as emissions of waste disposal facilities) should not be overlooked.

4.3 Identification and Assessment of Waste Generation Systems

As stated, both the hazardous waste generation of industrial and other activities and waste management operations which handle hazardous waste (and may themselves be a source of hazardous emissions) should be covered in the analysis. Coverage of both the waste generators and management operations also helps ensure that the fate of all hazardous waste is known. An appreciation of hazardous waste type and volume being received by management operations may also be a useful check to ensure all potentially hazardous industry operations have been identified in the study. The transfers of wastes from sources to waste facilities by all modes of transport also needs to be included in the analysis to ensure hazards and risks are fully addressed.

Figure 4.1 shows a schematic overview of the various elements of waste generation and management systems. The specifics will vary industry to industry but the various elements should all be considered.

It must be again emphasized that hazardous wastes are simply hazardous materials which because of the lack of perceived usefulness are dubbed wastes and that waste management facilities are facilities which process or store those hazardous materials called wastes. As such the methodologies outlined in earlier chapters for the identification of hazards and analysis of frequencies and consequences are applicable to hazardous wastes and waste facilities. As discussed already in this guide (see 4.2) there are, however, some aspects of wastes and waste operation which make them a special case. The discussion in this section focuses on these aspects. Figure 4.2 shows schematically how the analysis of hazardous waste, hazardous waste transport and waste management facilities relates to the overall industrial area analysis.

4.3.1 Identification

Potentially Hazardous Industrial Facilities: the general hazard identification carried out for the area as described in chapter 1 of this volume will have identified a number of facilities for closer analysis. A routine element of the initial hazard identification should be to consider emissions (to air, water and ground) and solid, liquid or gaseous waste generated (including materials collected in air filtration and scrubbing, and sludges etc from water treatment) which is stored or disposed of by means other than release to the environment. The hazard potential to the biophysical environment is likely to be particularly important in this regard. Through consideration of hazards resulting from wastes, facilities can be expected to be included on the list which would not pose any significant off-site risk from any other cause than unsound waste disposal practices. As can be seen from the list in Table 4.1, a number of metal processing works for example generate hazardous wastes but many of these operations would not otherwise pose significant fire, explosion or toxic release hazards.

The analysis of selected sites, should involve following through of processes and ctivities from inputs to outputs. Particular attention should be paid in this analysis to waste outputs. Opportunities for waste streams to be wrongly directed or handled should be carefully identified.

A notional "mass balance" can usefully be considered to check for any discrepancies between expected and observed or stated outputs.

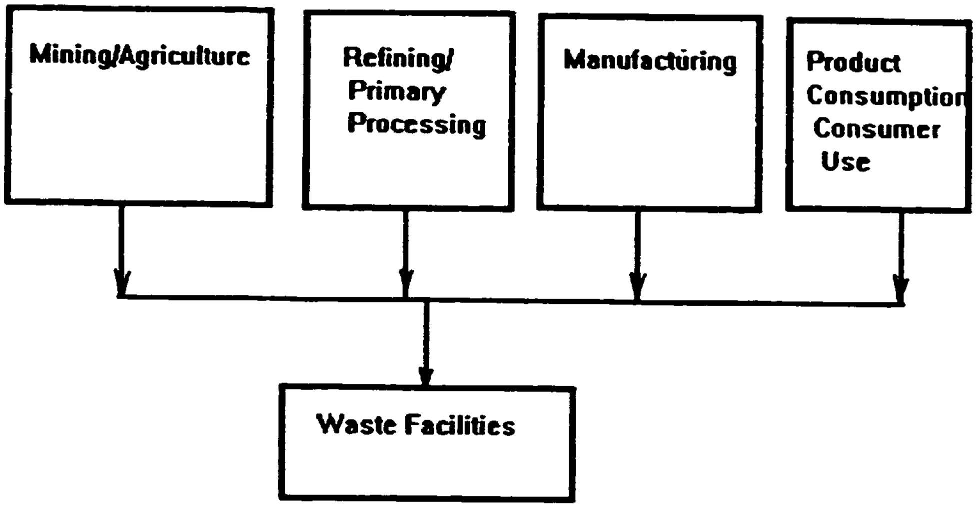


Fig. 4.1.a

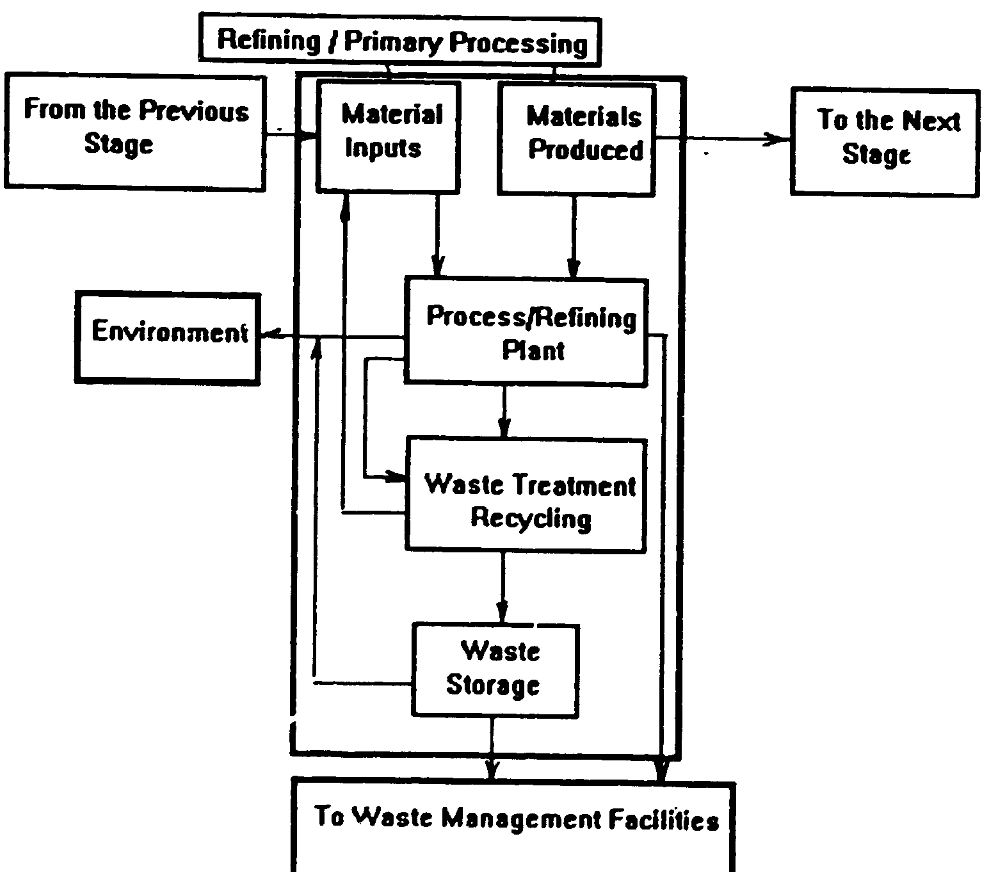


Fig. 4.1.b

FIGURE 4.2

HAZARDOUS WASTE RISK ASSESSMENT PROCESS

Identify potentially hazardous waste sources within area

Identify waste management measures

On-Site

Off-Site

Include in site analyses

Identify external waste sources

Identify transport routes, modes etc and destinations

Include in overall transport analysis

Waste management facility analysis

Inputs from site analyses

Development of Recommendations re waste management risk reduction measures

Inputs from transport analysis

This methodology should be regarded as a means of identifying problems for inclusion in the analysis rather than a basis for eliminating matters from the analysis. One reason for this is that large scale problems are more likely to be identified by this means while relatively small but potentially significant waste streams, particularly very toxic substances, may be missed.

Consideration should be given not only to the operations as currently carried out but to conditions and practices which may have applied earlier (for example, discontinued process or operation or changes in inputs used) and possible future changes which may generate hazardous wastes (for example, new processes or operations or diversion of waste from air or water emissions or unsound disposal practices). Risk management recommendations of the area risk analysis may result in the diversion of wastes into a recognisable hazardous waste stream.

The possibility of stored wastes, including storage of unwanted materials which may not normally be regarded as wastes (such as materials acquired for operations now discontinued or products no longer saleable e.g. banned pesticides), should also be considered.

Any history of on-site or nearby landfill operations should be thoroughly investigated.

Other Facilities: facilities which may generate hazardous wastes but may be outside the "industrial" facility category should also be considered. As indicated in Table 4.1, facilities such as hospitals and other large medical treatment operations, quarantine facilities, research laboratories, energy production and distribution facilities, mines and agricultural activities should also be considered to help build up a comprehensive picture of hazardous waste sources and management practices.

Waste Storage, Treatment and Disposal Facilities: currently operating and former storage, treatment and disposal sites and facilities should be carefully identified. The identification process should consider national, regional and local government waste management operations of all types as well as operations conducted by privately owned entities or by industrial organisations (both private and public). Landfill operations should receive particular attention due to their potential to create problems which may only show up many years later.

The waste hierarchy and technologies discussed in sections 3.1 and 3.2 of volume 3, respectively provide a framework which may be useful in ensuring all relevant waste management facilities have been identified.

The classification in that section can be a useful guide to ensure comprehensive identification. Particular attention should however be given to storage, landfill/marine dumping and incineration operations as these are the most likely to be hazardous. The contamination of land and groundwater by waste disposal practices, such as absorption of metal processing wastes in on-site pits, should be factored in to the overall analysis.

Transportation: the analysis of hazards from wastes would not be complete if only sources and management facilities are considered. Careful identification of the volumes, mode of transport (truck, rail, pipeline or ship etc), type of containment/packaging, routes used, control systems in place and safeguards including regulatory systems, is an essential step in ensuring appropriate management. Vessel/vehicle and pipeline washings etc should be considered as a waste source. This aspect is dealt with more fully in section 3.4, volume 3.

Wastes from Incidents/Accidents: in addition to wastes generated from normal production and from waste management operations, a further source of waste is contaminated material from production failures (e.g. out of specification pesticides) and incidents and accidents involving unintended releases. This waste stream can be particularly problematic as it may be outside the parameters of the wastes normally managed, may be in large volume and may require prompt action, at least on a holding basis.

The hazard analysis for the area should specifically consider the adequacy of the provisions for incident waste management in area and industry emergency plans for all identified significant potential incidents.

Classification and Registration Systems: the identification of waste streams and fates is much easier where there is a regulatory framework which records them and their movements, (see further section 3.1, volume 3). The adequacy of any such system should be reviewed in the risk assessment study. The information gathered from these sources should not be relied on in isolation as, even at their best, such systems are likely to be reliable only for those wastes which are being handled responsibly.

If recommendations are made as a result of the study, then care should be exercised to ensure that they are implementable in the relevant cultural and social context.

Incident Records: as with other hazardous materials and facilities, the incident history in the area and more widely should be examined. In the case of wastes in particular, this examination should extend to cover land and surface water and groundwater contamination. Transport incidents should receive particular attention. Records of any known illegal dumping and prosecutions or other regulatory intervention can also be usefully examined. The absence of any record of incidents should not be taken to mean that none have occurred.

It may be appropriate to address incident and near-incident reporting in the recommendations if current systems are inadequate.

4.3.2 Assessment of Waste Practices and Controls

The components of waste management strategies are discussed in chapter 3, volume 3. This section deals with the elements of assessment of practices and controls in the area study process without pre-empting discussion of the appropriateness of such practices.

Assessment of waste operations needs to be holistic, following wastes from source to ultimate fate. As well as the technical controls, the organisational and institutional measures to prevent, control and contain/clean-up accidental releases and deliberate acts of unsound disposal, need to be comprehensively assessed.

As for other hazardous materials, consequence and frequency analysis and risk assessment should be carried out in respect of hazardous wastes for identified industrial, waste management and other facilities. Incident scenarios and exposure pathways and the impacts on people, property and the biophysical environment should be carefully assessed in accordance with methodologies outlined in chapters 2 and 3 of the present volume. This analysis may be complicated by the fact that the composition of wastes may be variable and uncertain or unknown. The analysis must also take account of delayed release, particularly for stored or landfilled wastes. This aspect complicates frequency analysis as the period of delay may in some cases be many years and standards of management and the controls exercised may well deteriorate with time, particularly with wastes which are no longer generated from current operations.

Analytical approaches must be suitably conservative to cope with the high degree of uncertainty often associated with waste composition and other factors.

Records of waste generated and transferred for storage or disposal should be checked and any significant discrepancies noted and investigated. As stated previously, record systems are likely to be not entirely accurate and should not be relied upon alone. Such recording and regulatory systems are an important element of the safeguards and their adequacy should be assessed.

Waste storage, treatment and disposal facilities should be subjected to the same type of analysis. Particular attention should be paid however, to waste input information and systems for verifying waste composition. The adequacy of waste management should then be assessed in the context of social and economic factors as well as technological.

The assessment of hazardous waste safety should encompass natural hazards such as floods and earthquakes as initiators of releases. The likelihood of failure of engineered containment structures, such as dams and secure landfill in these events, as well as structural failure without such additional stress, should be carefully assessed. A notable example of significant failures of this type is the sodium cyanide sludge dam failure on the Kanogawa River in Japan in 1978.

4.4 Conclusions

This chapter has attempted to provide some broad, general guidance on identification and assessment of hazards and risk arising from wastes in the context of area risk assessment and management. There is a substantial general and specialised literature on hazardous waste issues, management, technologies etc, a selection of which is included in the further reading list. It is not appropriate nor possible to cover this large, diverse and complex subject in any detailed or comprehensive way in a guidance document such as this. Instead the intention has been to advocate the inclusion of wastes into the area risk analysis. As is the thrust of these guidelines generally, the emphasis is on careful, case-specific analysis without prejudgement. The holistic, systematic approach proposed should provide a sound basis for hazardous waste management strategies to minimise risk to people, property and the biophysical environment.

PROCEDURAL GUIDE FOR INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

VOLUME II

METHODS AND PROCEDURES FOR HEALTH AND ENVIRONMENTAL RISK ASSESSMENT

CHAPTER 5

ASSESSMENT OF TRANSPORTATION RISKS

Chapter 5: ASSESSMENT OF TRANSPORTATION RISK

This chapter focuses on the methods of assessment of transportation risks of hazardous materials by road. The formulation of appropriate routes for such transportation necessitates integrated considerations of three inter-related elements: Transportation risk and environmental and land use safety factors; capability of the existing road network and cumulative traffic implications; and, economic distribution considerations and operator's requirements for practical transport economics. Assessment method and procedures for each are highlighted in the chapter. The management of transportation risk is dealt with separately in volume 3, chapter 3 of this guide.

5.1. Overview and Scope of Applications

The transport and distribution of hazardous substances, such as petroleum products, liquified petroleum gases, chlorine gas, pesticides, chemicals/petrochemicals and radioactive materials, inevitably involve the potential for incidents and accidents which may result in death or injury to people, property damage or damage to the bio-physical environment through the effects of fire, explosion or toxicity. An increasing number of transportation accidents involving hazardous substances have occurred worldwide. Such accidents with their resultant effects on people and the environment have increased awareness in government, industry and the community at large and resulted in a re-think in the risk assessment process for hazardous substances transportation. In that context, it is now recognized that the safety planning of transportation routes, accounting for the type and nature of surrounding land uses, is an integral component of the safety management of hazardous substances transportation. Delineating hazardous substances transportation routes is, as such, a significant and essential complementary measure to technical and operational safety and environmental controls on the hazardous substances containers and associated regulatory processes. It is relevant to note that fixed installations are more amenable to locational, organizational and operational hazard controls. Transportation systems are dynamic systems with additional external variables (e.g. drivers, traffic conditions, etc.) difficult to bring into one overall control system.

This chapter of the guideline will focus on the analysis and assessment of **transportation routes** (truck route systems) for the carriage of hazardous materials. The integrated risk assessment approach to the safety of hazardous substance transportation necessitates consideration of three main elements in an integrated manner:

(a) **Transportation risk and environmental and land use safety factors;** including the identification and quantification of risks to people, property and the environment from the transport of hazardous material, particularly as they relate to effects on land uses and environmental ecosystems along the transportation routes. These are environmental and risk factors;

(b) **Capability of the existing road network and cumulative traffic implications;** including overall traffic movement, congestion and level of service on used or potential routes, accident rates, road conditions. These are traffic related factors;

(c) **Economic distribution considerations and operator's requirements for practical transportation economics;** including considerations of travel distance and time and the transportation costs of alternative route systems.

An integrated assessment of the safety adequacy of an existing hazardous substances transportation route or the formulation of alternative routes for the safety management of such transportation necessitate the quantification and weighing of all three elements indicated above. Although a brief description of elements (b) and (c) will be provided, the focus of the chapter is on the risk and environmental considerations of hazardous material transportation in line with the main focus of this guideline document.

There are **three main applications** for the information, tools and techniques outlined in this chapter:

(i) identification, analysis and assessment of the environmental and safety land use implications (as well as traffic and economic implications) of existing routes and transportation of hazardous materials on a regional scale. The output being a quantification of existing risk from the transportation of hazardous material and assessment of the adequacy and appropriateness of existing routes for the transportation of such material;

(ii) the formulation and designation of hazardous material transportation routes as an integral component of the environmental and safety management of such transportation, including the exclusion of routes with the highest risk to people and the environment (chapter 3 of volume 3 deals with the management aspects of dangerous goods transportation);

(iii) providing the basis for the assessment of both the individual and cumulative environmental and safety implications of a development proposal which generates or receives hazardous material.

The assessment of the safety suitability of an existing road network for the transport of hazardous material and the formulation of routes for the safe transport of such material are therefore major objectives.

5.2 Analysis and Assessment of Transportation Risk and Environmental and Land Use Safety Factors

5.2.1 Overview

This section describes the procedures for analyzing and comparing alternative routes for the transportation of hazardous materials on the basis of land use and environmental safety. It is not intended to provide in-depth documentation of the assumptions and processes implicit in the methodology. Rather, the purpose is to highlight the most relevant procedural information and a concise description of the criteria that may be applied for hazardous materials routing.

Factors that influence routing decisions, from an environmental safety viewpoint, may be grouped into three inter-related categories (see Figure 5.1):

- Mandatory factors, including legal and physical constraints;

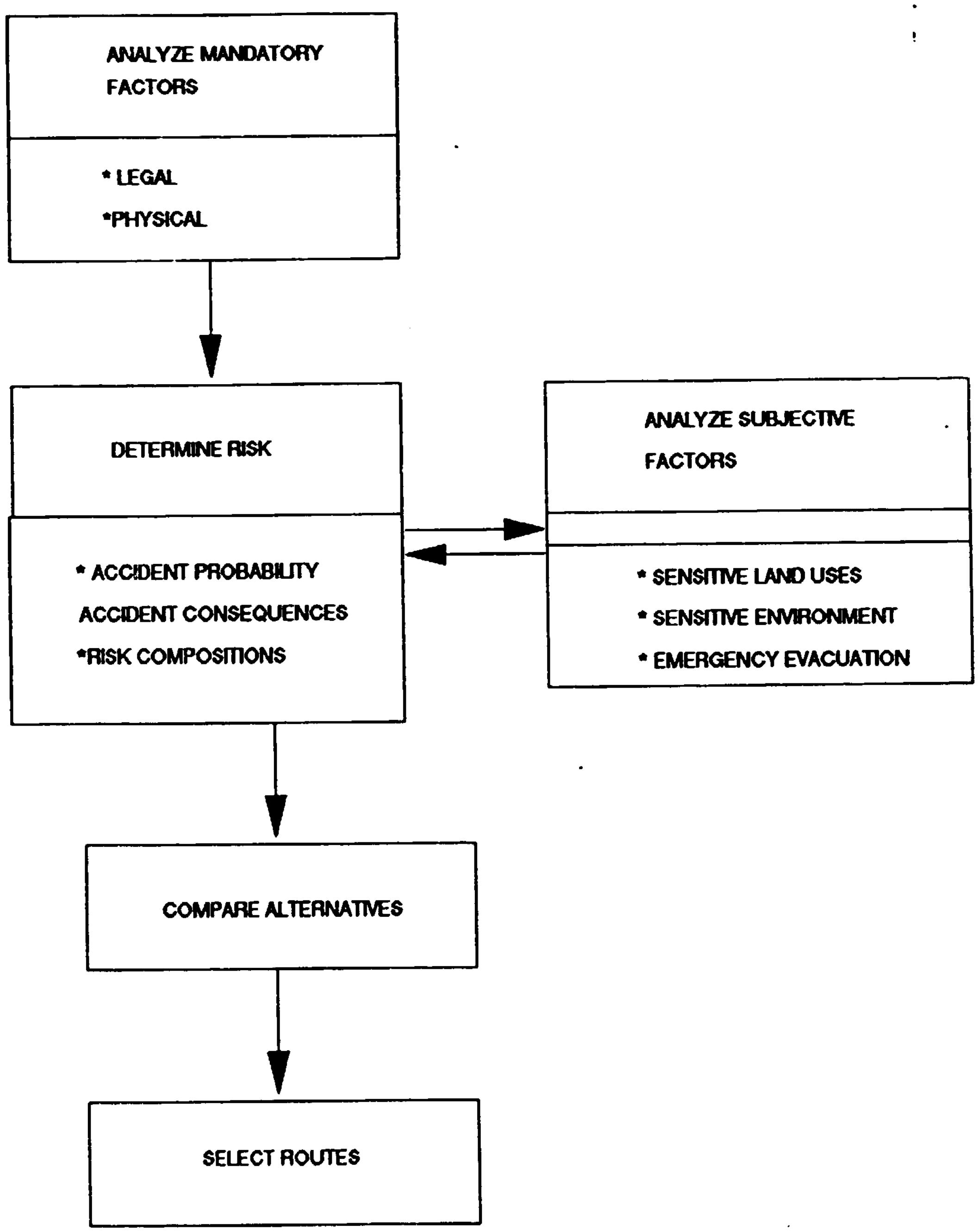


Fig. 5.1 Overall Appro ch to Risk Comprisons and Assesssment for Hazardous Materials Transportation Routes

- Environmental and land use risk, including the identification of hazards and the quantification of risk;
- Subjective factors that reflect community priorities and values which may not be easily quantified. Such factors include special populations, special land uses, emergency response.

Consideration of each of the above factor may on its own or in combination preclude the use of any particular route for the transportation of hazardous material or favour an alternative route.

5.2.2 Mandatory Routing Factors

(a) **Physical mandatory factors** that may preclude a routing alternative include: weight limitations on bridges, height restrictions on overpasses, inadequate shoulders for breakdowns, extensive construction activities or inadequate parking and turning spaces.

(b) **Laws and regulations** may apply to any routing alternative in prohibiting the transport of hazardous materials through certain roads or structures (e.g. tunnels, bridges). Local, state and national transport authorities should be consulted in all cases. Such prohibited roadways are obvious first cut alternatives to be eliminated.

5.2.3 Environmental and Land Use Safety Factors

The overall environmental and land use safety criteria for route selection is that the route which has the lowest risk value to surrounding people, property and the natural environment should be selected. In this context, risk is determined in terms of the cumulative combination of the probability of accidents and the consequences of such accidents. These two elements of risk are dependent on the extent of population exposed and number of properties or extent of natural environment ecosystems and the accident rates. **In general, roadways with the smallest adjacent population as well as accident rates, will have the lowest risk values.**

In designating routes for the transportation of hazardous materials, the risk values in absolute terms are of limited practical use. It is the relative difference in the risk values that should mainly be considered when differentiating between the different route alternatives. If sufficient differences exist between the risks of alternative routes (e.g. 25% or more), it may be possible to designate the preferred hazardous materials route on the basis of the mandatory factors and the risk calculations.

5.2.3.1 Estimations of the Consequences of Hazardous Materials Transportation

The estimation of the consequences of accidents from the transportation of hazardous materials necessitate data on:

- The nature of materials being transported;
- The storage/transportations conditions (e.g. temperature, pressure);
- The quantity of the load;
- The nature of the transportation tanker(s) including configuration of major characteristics;
- Prevailing meteorological conditions applicable to the road network under consideration (including wind speed, direction and where possible atmospheric stability).
- Topographical characteristics of the general area-both natural and man-made;
- Land use survey of the surrounding areas along the transportation routes, including the type and nature of land use (residential, commercial, schools, hospitals,...) and the residential/population density associated with each type of land use.

Based on accident scenarios, including: leakage of the tanker's contents, pool fires, tanker fire, explosions or the release of toxic substances into the environment. The consequences of each accident scenarios are computed, usually in terms of heat flux. explosion overpressure and toxic exposure using consequence modelling tools (see Chapter 3 of this guide). Based on such estimates and the population densities for land use adjoining each route, the number of people affected by the postulated incidents, in terms of injuries or fatalities can be determined.

Table 5.1 outlines potential areas of impact based upon the mazimum recommended evacuation distance. The values indicated are conservative: greater rather than smaller potential impact distances are used. The analyst may therefore use either the locally derived impact distances (more accurate) or the values in Table 5.1 as a general guide. Whatever distance is chosen must be consistently applied in each alternative analysis for an objective evaluation.

Table 5.1
Potential Impact Area for Different Classes of Hazardous Materials

Class of Hazardous Material	Impact Area
• Combustible Liquid	0.8 km all Directions
• Flammable Liquid	0.8 km all Directions
• Flammable Solids	0.8 km all Directions
• Oxidizers	0.8 km all Directions
• Non-Flammable Compressed Gas	Downwind 2.1 km wide x 3.2 km long
• Flammable Compressed Gas	0.8 km all Directions
• Poison/Toxic	Downwind 0.3 km x 0.5 km long
• Explosives	0.8 km all Directions
• Corrosive	Downwind 0.8 km long x 1.1 km wide

5.2.3.2 Estimations of the Probability of Transportation Accidents

The probability of a hazardous materials accident is the likelihood or chance that a vehicle carrying hazardous materials will be involved in a roadway accident. To calculate this probability, the analyst derives the accident rate applicable to the load and the route segment and then must adjust this accident rate to reflect the amount of exposure or vehicle experience.

The sequence of steps involved are summarized as follows:

(i) **Determine the accident rates on a particular roadway:** ideally, the most reliable data concerning accident rates would be those associated specifically with hazardous materials transportation tankers in terms of No of hazardous materials accidents per tankers. If such information is available then it should be used directly into probability estimations. In many cases, however, such information is not readily available. It is usually necessary therefore to rely on accident rates statistics for all vehicles and then to adjust these to reflect the smaller share of hazardous materials in the traffic stream.

The first step is usually to obtain statistics from historical records of the total rates of accidents from all vehicles, usually in terms of Accidents/vehicles-km, (say symbolized by A_T).

(ii) **Calculate the probability of an accident for any vehicle based on vehicle exposure:** the probability of any vehicle being involved in an accident of a specific segment is calculated by multiplying the segment accident rate (A_T from (i) above, with the road segment length (or amount of exposure). this probability is in terms of Accidents/vehicles.

(iii) **Factor the probability statement for any vehicle to reflect the incidence of hazardous materials vehicles in the traffic stream:** this is done by multiplying the probability figure from step ii by the hazardous materials accident factor (being the ratio of hazardous materials transport accidents/all vehicles transport accidents). This probability is in terms of Hazardous Materials Accidents/vehicles.

The above three steps may be summarized as follows:

$$\text{Probability (Hazardous Material Accident)} = \frac{\text{All vehicles Accidents}}{\text{Vehicle - km}} * \text{Length of road segment (km)} * \frac{\text{Hazardous material Accidents}}{\text{All vehicles accidents}}$$

Note: Vehicle-km above refers to the totalnumber of kms travelled by all vehicles for which accident statistics are available.

Where the Hazardous material accidents could be obtained from available statistics, then the following steps could be directly applied:

- Obtain the accidents statistics applicable to hazardous material tankers and convert to Hazardous Materials Accidents/vehicle - km (i.e. per total number of km travelled by all hazardous material tankers to which statistics apply);

- Obtain probability of hazardous material accident:

$$\text{Probability (Hazardous Material Accident)} = \frac{\text{Hazardous Materials Accidents}}{\text{vehicle-km}} * \text{Length of road segment}$$

Note: It is necessary in some justifiable circumstances to further introduce a correction factor that reflect physical characteristics of the particular roadway segment which may increase the probability of an accident on that particular roadway. The above equation should incorporate an allowance for this factor (F).

5.2.3.3 Risk Computations

The potential consequences (population and/or property) and accident probabilities for each roadway segment are multiplied together to calculate the segment risk. The cumulative summation across all route segments produces the total risk for the route. It is noted that the accident probabilities derived per impact. The probability of a release and a hazardous event occurring is computed using tools such as event and fault tree analysis to incorporate factors such as: whether the load will be dislodged as the result of an accident, the extent of such load loss and ensuing spillage, the effectiveness of any containment/emergency procedures and the likelihood of the spill or release reaching environmentally sensitive areas or having an effect on people, buildings, etc.

Rapid Risk Comparison of Alternative Transportation Routes

If one considers the movement of a road tanker, carrying hazardous materials along a route, for each sub-segment (i) of the route, there is a probability of the tanker being involved in an accident Pai.

For each accident there are a number of possible accident scenarios (Sj), each of which may be considered to be fatal to individuals present within a radius rj of the accident, with a probability Psj.

The number of people present and affected at the scene of an accident depends on the population density Pi:

$$= \pi r^2 jPi$$

Thus if one considers the passage of the tanker through a route segment i, the probability of someone being killed for scenario j is:

$$= Pai * Psj * \pi r^2 jPi$$

The probability of someone being killed from the passage of the tanker along the sub-segment i is the sum of the probabilities for all possible accident scenarios:

$$= \sum_j Pai * Psj * \pi r^2 jPi$$

Fatality Probability = $PaiPi \Sigma \pi r^{2j} Psj$

For anyone type of load, the term $\pi r^2 Psj$ is a constante, independent of the route. This term can be termed the Severity Index for the load SI.

Thus the probable number of fatalities from the passage of a truck carrying load L along sub-segment i is

$$Pai\ Pi\ (SI)_L$$

and for the entire length of the route = $(SI)_L \Sigma$ Pai Pi. For anyone given load, it is possible to compare the relative safety of two alternate routes by comparing the term Σ Pai Pi i.e. the population density along the route x the probability of an accident.

A method for the computation of transportation risks along different route segments, based on the cumulative combination of the consequences and probabilities of accidents is suggested in the plate. **The following procedural steps are appropriate:**

(a) For each substance (load category) transported, establish the range of hazardous events scenarios, the probability of each event and the radius of fatality (or injury) effect from each event. Figures 5.2, 5.3 and 5.4 are examples of event trees that may be followed. The depth, extend and number of hazardous scenarios will depend on the coprehensiveness of the analysis study. It may be possible for simplified case analysis to postulate two or three hazardous accident scenarios and assign probabilties and estimate the radius of fatality (or injury) effects from each event.

(b) From the above, estimate the severity index for each category of hazardous load:

- Calculate $p\pi r^2$ for each hazardous scenario, where p = probability of scenario occurring (should a tanker accident take place); r = radius of impact, π = 3.1416

- Calculate the severity index (S.I.) (by summing-up $\Sigma\, p\pi\, r^2$ for all postulated scenarios.

(c) Multiply the severity index for each load category ($\Sigma p\pi r^2$) by the probability of a hazardous material accident as determined in section 5.2.3.2 of this chapter of this guide.

(d) Multiply the result of step (c) above by the population density along each of the transportation route under consideration. This is the population risk for the route(s) under consideration for the hazardous load.

<u>Note:</u> the population density (Number of people/km^2) may be obtained by calculations or from population statistics for different categories of land uses.

(e) Compare the population risks for the different route alternatives.

5.2.4 Subjective Routing Factors

Subjective routing factors in the selection (or elimination) of routes for the transport of hazardous materials usually include:

- The location along the roadway or in its vicinity of sensitive land uses such as hospitals, schools, old age person housing, churches or items of heritage or cultural significance; or the location of sensitive eco-systems and natural landscape such as park reservations, wetlands.

Fig. 5.2 EVENT TREE FOR PETROL TANKER ACCIDENT

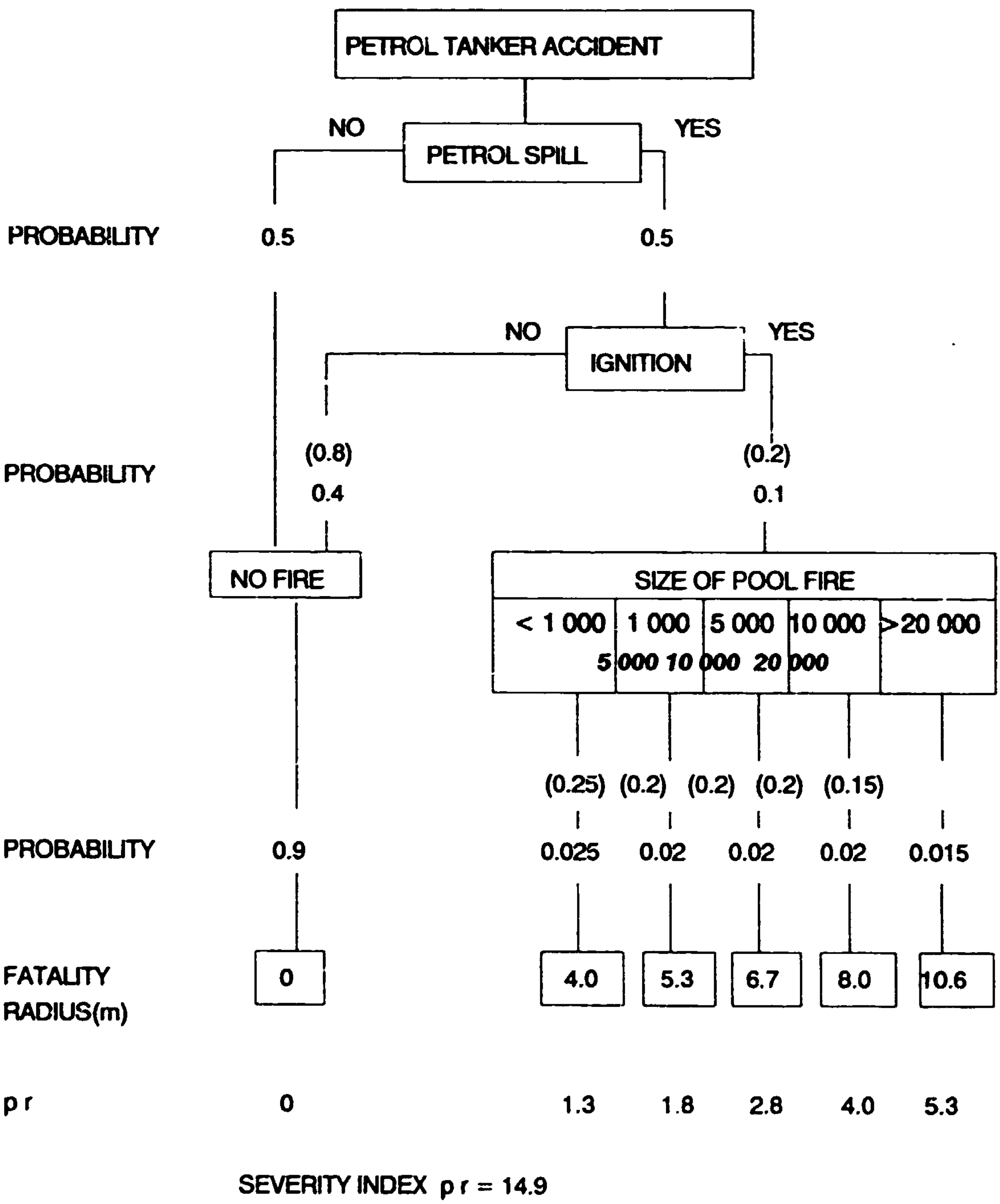
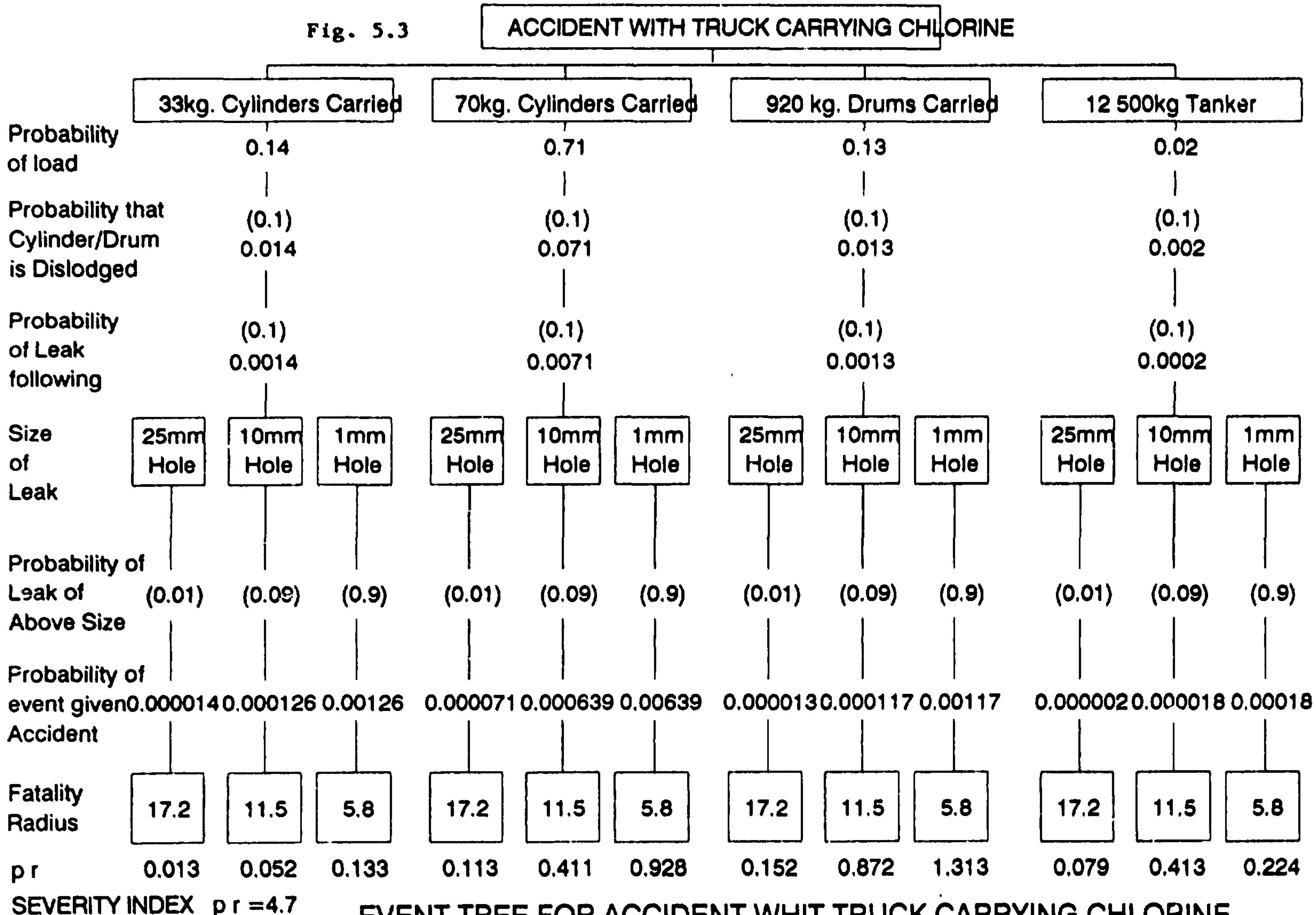
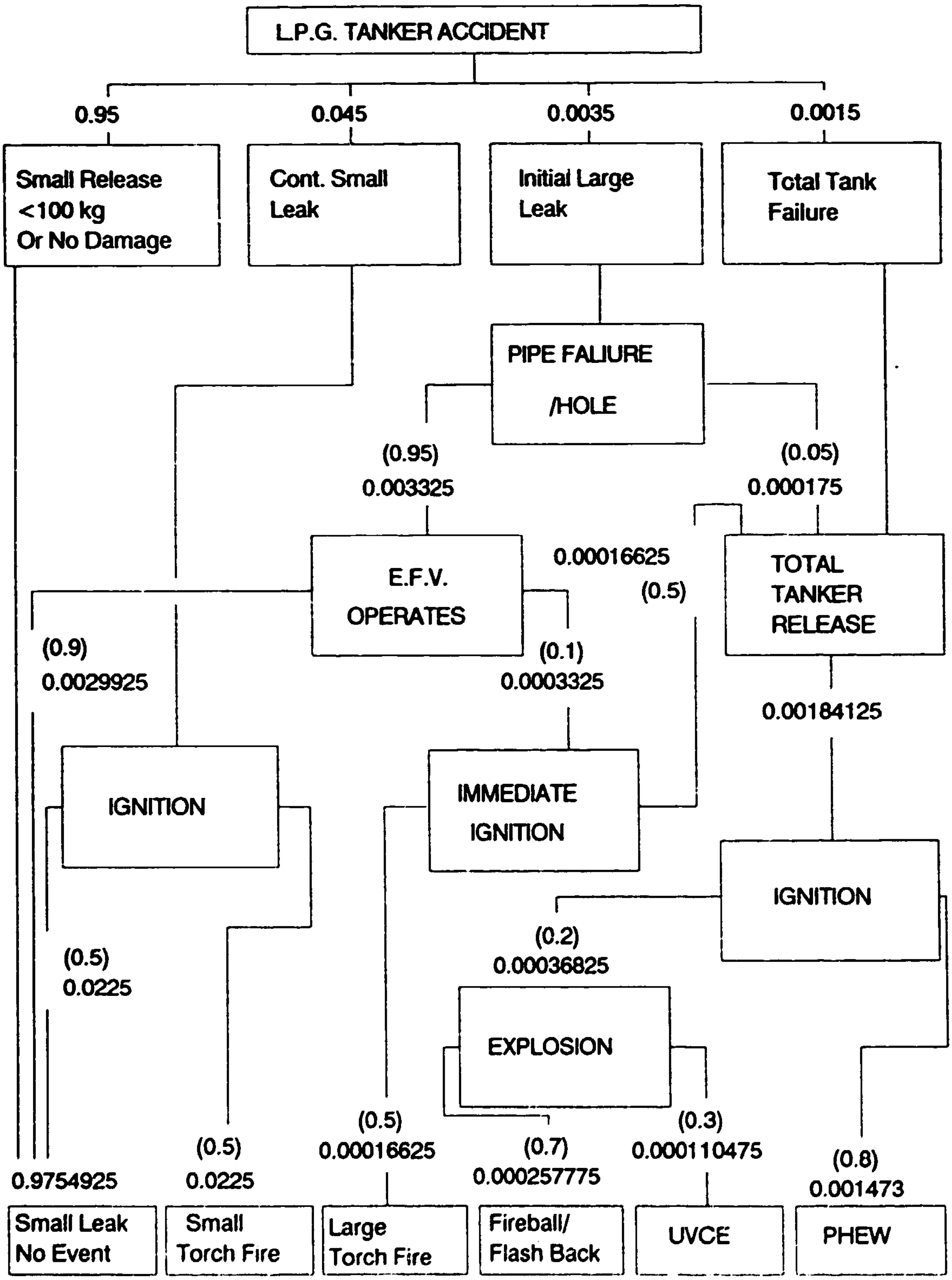


Fig. 5.3



EVENT TREE FOR ACCIDENT WHIT TRUCK CARRYING CHLORINE

Fig. 5.4. EVENT TREE FOR LPG TANKER ACCIDENT



- Emergency and evacuation planning and infrastructure, including: the availability of formalized emergency and evacuation procedures and plans, the location of emergency response teams and their ability to respond to hazardous material release, access and ease of emergency evacuation.

Subjective factors should reflect community priorities and values and should preferably arrived at through community discussion and consensus. These factors are particularly relevant in the assessment process when not one alternative is clearly superior to the others. As such, whether or not the analyst chooses to select and apply subjective factors which will depend upon the outcome of the risk calculations and how conclusive the findings are.

5.2.5 Guidance implementation

The attached guidance working sheet may be used as a guide in the computation of the land use safety factors for assessment purposes.

Guidance Working Sheet for Hazardous Materials Routing
Based on Land Use Safety Factors

1. GENERAL ROUTE CHARACTERISTICS

Alternative No:........................ Length:......................kms

Origin:...................................... Destination:.....................

General
Description:..

Type of Hazardous Materials
Transported:..
....

---

2. MANDATORY FACTORS

Are there any physical constraints
(explain):..
....

Are there any legal constraints
(explain):..
....

---

3. SUBJECTIVE FACTORS (optional)

Explain any of the following subjective factors, as applicable:

Special Population:..

Special Properties:...

Emergency response capabilities:...

Other factors:...

4. RISK ESTIMATION

Segment No.	Probability of a Hazardous Material Accidents		Population Density		Hazard Index		Population Risk
....	....	x	....	x	....	=	....
....	....	x	....	x	....	=	....
....	....	x	....	x	....	=	....
....	....	x	....	x	....	=	....
....	....	x	....	x	....	=	....
....	....	x	....	x	....	=	....
....	....	x	....	x	....	=	....
....	....	x	....	x	....	=	....

TOTAL:

5.3 Analysis and Assessment of the Transport Operational and Traffic Factors

The following traffic factors reflect the ability of a route to effectively and safely move the traffic flows using it:

- Traffice volume and composition
- Carriageway level of service
- Structural and geometric adequacy of roads
- Number of traffic signals
- Travel time
- Availability of alternative emergency routes

An overview outline of each of these factors is provided thereafter.

5.3.1 Traffic volume and composition

The composition of vehicles by size and type is required to assess the road's structural adequacy as well as its operating level of service.

Traffic volume and composition along various sections and segments of the road network may be obtained from published statistical information but preferably through field screening surveys. Traffic volume may be expressed in terms of: Annual Average Daily Traffic (AADT); hourly traffic volume (average and peak). The directional distribution of traffic should also be obtained. This information together with hourly intersection counts cn be used to estimate the peak directional hourly volumes along all road sections within the study area.

Classification counts to establish the type of vehicles would differentiate as a guide between: Light vehicles and heavy vehicles (both rigid tankers and articulated tankers).

5.3.2 Carriageway Level of Service

'Level of service' for a road section indicates the capability of roads for moving the type and volume of traffic using it. One definition of 'Level of service' is 'qualitative measure describing operational conditions within a traffic stream, and their perception by motorists and/or passengers'. It describes these conditions in term of several factors such as speed and travel time, traffic interruptions, safety, driving comfort. A possible designation of the level of service is from A to F with level of service A representing the best operating conditions (i.e. free flow) and F level of service the worst (i.e. forced or break down flow).

Table 5.2

Example of One-Way Traffic Volumes (PCU)* for Urban Roads at Different Level of Service

(Interrupted Flow Conditions)

Type of Road Carriageway	Level of Service A	B	C	D	E	F
2 Lane Undivided	540	630	720	810	900	F
4 Lane Undivided	900	1050	1200	1350	1500	O
4 Lane Undivided with clearway	1080	1260	1440	1620	1800	R
4 Lane Divided with clearways	1140	1330	1520	1710	1900	CED
6 Lane Undivided	1440	1680	1920	2160	2400	FL
6 Lane Divided with clearway	1740	2030	2320	2610	2900	OW

PCU = Passenger car unit, i.e. heavy vehicle volumes are converted into passenger car equivalent.

A 'service volume' is defined as 'the maximum hourly rate at which vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under the prevailing roadway, traffic and control conditions while maintaining a designated level of service. Table 5.2 indicates suggested one-way hourly volumes for interrupted traffic flow at different level of service.

It is suggested that for arterial/sub-arterial roads used for hazardous material transportation a level of service C not be ideally exceeded with an utmost level of service D in urban situations. Traffic volume estimated as per 5.3.1 may therefore be used to estimate the appropriate level of service of each road under consideration.

5.3.3 Structural and Geometric Adequacy of Roads

The structural and geometric adequacy of the routes under consideration to cater for heavy vehicles carrying hazardous material should be assessed.

Routes with good geometry (e.g. wider carriageway with minimum horizontal and vertical curves) and good line of sight should be selected in preference to routes of lesser quality. In situation, where for other reasons, a route in the latter category was selected then it should be upgraded to provide better geometry and reconstruct, if necessary, the pavement to cater for increased volumes of heavy vehicles.

5.3.4 Number of Traffic Signals

The number of traffic signals is often used as a measure of delays along a route section. A route with a smaller number of signals would most likely be chosen as it would have the potential for less delays.

5.3.5 Travel Time and Travel Speed

Travel time for vehicles using a route indicate the congestion points as well as reflect the level of congestion. Travel time information are usually available from transport authorities or may have to be undertaken by way of field surveys. NAASRA ( ) has suggested the average vehicle travel speed for different level of service included in Table 5.3. According to this table, travel speeds in the range 25 km/hr - 30 km/hr corresponds to levels of service C-D bordering the range of suitability for route selection. Routes with higher travel speeds are selected in preference to those with lower speeds.

5.3.6 Availability of Alternative Emergency Route

In case of an emergency which would require the closure of a route designated for the transport of hazardous material, an alternative route should be available.

Table 5.3
Example of Travel Speed and Flows for different Categories of Level of Service

Level of Service	Type of Flows	Average Overall Travel Speed (km/hr)
A	Free flow (almost no delay)	≥50
B	Stable flow (slight delay)	≥40
C	Stable flow (acceptable delay)	≥30
D	Approaching unsuitable flow	≥25
E	Unsuitable flow (congestion)	25 (app.)
F	-----	≤25

5.4 Transport operational Costs and Operator's Requirements

An important criterion in the assessment and selection of a route network for the transportation of hazardous material is the relative cost of delays and travel time. The analysis of this information would enable the determination of the economic implications of particular routes for the transport of hazardous material and the transport operator's requirements for practical transport economies.

Transport costs fall into two basis categories: fixed costs and variable costs (usually referred to as operating costs). Generally, the former costs do not vary significantly with the vehicle-kilometers travelled. If the tanker carrying hazardous materials need to change to a route of a longer or shorter distance, (only) the operating costs will be higher or lower respectively. In many cases, both operators' cost requirements and operators' 'convenience' result in the use of the shorter route irrespective of safety implications.

Operating costs are based on two main components-a variable cost for operating the road tanker and the cost of the driver's time.

<u>Total vehicle operating cost = Unit cost component by distance travelled</u>
<u>+ Unit cost component by time taken to travel the distance</u>

These factors could be reflected by the distance travelled and the travel time along the route.

For the above, it is indicated that the main cost criteria when assessing or comparing alternative routes for the transportation of hazardous materials is the expected increase or decreases in travel time (the main component that influence operating costs).

An increase or decrease in operating costs of over 10% is considered to have a significant effect on the cost of transporting hazardous materials. It is also considered that the distance cost could increase further as long as the traveltime was within the 10% For example, a longer distance route could have, or be developed with less congestion thereby resulting in a travel time about the same as the shorter route.

PROCEDURAL GUIDE FOR INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

VOLUME II

METHODS AND PROCEDURES FOR HEALTH AND ENVIRONMENTAL RISK ASSESSMENT

CHAPTER 6

SOCIO-ECONOMIC ANLYSIS

PROCEDURAL GUIDE FOR INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

VOLUME II

METHODS AND PROCEDURES FOR HEALTH AND ENVIRONMENTAL RISK ASSESSMENT

CHAPTER 7

INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT

UNEP
United Nations Environment Programme

World Health Organization

International Atomic Energy Agency

UNIDO
United Nations Industrial Development Organization

Inter-Agency Programme on the Assessment and Management of Health and Environmental Risks from Energy and Other Complex Industrial Systems

PROCEDURAL GUIDE FOR INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

Volume III

Elements of Integrated Risk Management for Large Industrial Areas

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PROCEDURAL GUIDE

FOR

INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

VOLUME III

ELEMENTS OF INTEGRATED RISK MANAGEMENT FOR LARGE INDUSTRIAL AREAS

United Nations Environment Programme
World Health Organization
International Atomic Energy Agency
United Nations Industrial Development Organization

<u>Information and Clarification concerning this document may be obtained from the following organizations</u>

- United Nations Environment Programme
  Industry and Environment Office
  Tour Mirabeau, 39-43 quai André Citroën
  75739 Paris, Cedex 15
  France

- World Health Organization
  Division of Environmental Health
  CH-1211, Geneva 27
  Switzerland

- International Atomic Energy Agency
  Division of Nuclear Safety
  Department of Nuclear Energy and Safety
  P.O.Box 200
  A-1400 Vienna
  Austria

- United Nations Industrial Development Organization
  P.O.Box 300
  A-1400 Vienna
  Austria

PREFACE

There is a growing need to ensure that health, environmental and safety issues are addressed as an integral part of social and economic development. This can be achieved through an integrated approach to environmental risk assessment and safety management where all elements of risk are identified and assessed and where priority management actions are formulated in an integrated way. Recognizing the emergence of such needs, the United Nations Environment Programme (UNEP) within the framework of its programme on Awareness and Preparedness for Emergencies at Local Level (APELL), the World Health Organization (WHO), the International Atomic Energy Agency (IAEA) and the United Nations Industrial Development Organization (UNIDO) have joined efforts to promote and facilitate the implementation of integrated risk assessment and management for large regional industrial areas. Such an initiative includes: the compilation of procedures and methods for environmental and public health risk assessment and the transfer of knowledge and experience amongst countries in the application of these procedures. The preparation of a procedural guide on integrated environmental risk assessment and management is part of the initiative.

This Procedural Guide provides a reference framework for the undertaking of integrated environmental risk assessment for large industrial areas and for the formulation of appropriate safety and risk management strategies for such areas.

This guide is presented in four inter-related volumes:
Volume I outlines the organization and management issues associated with the process of integrated risk assessment studies; **Volume II** presents the methods and procedures for health and environmental risk assessment; **Volume III** (this document) highlights the different elements of integrated risk management; and, **Volume IV** specifies the documentation requirements.

PROCEDURAL GUIDE FOR INTEGRATED ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

VOLUME I: ORGANIZATION AND MANAGEMENT OF THE INTEGRATED RISK ASSESSMENT STUDY PROCESS

VOLUME II: METHODS AND PROCEDURES FOR HEALTH AND ENVIRONMENTAL RISK ASSESSMENT

VOLUME III: ELEMENTS OF INTEGRATED RISK MANAGEMENT FOR LARGE INDUSTRIAL AREAS

VOLUME IV: DOCUMENTATION REQUIREMENTS FOR INTEGRATED RISK ASSESSMENT STUDIES FOR LARGE INDUSTRIAL AREAS

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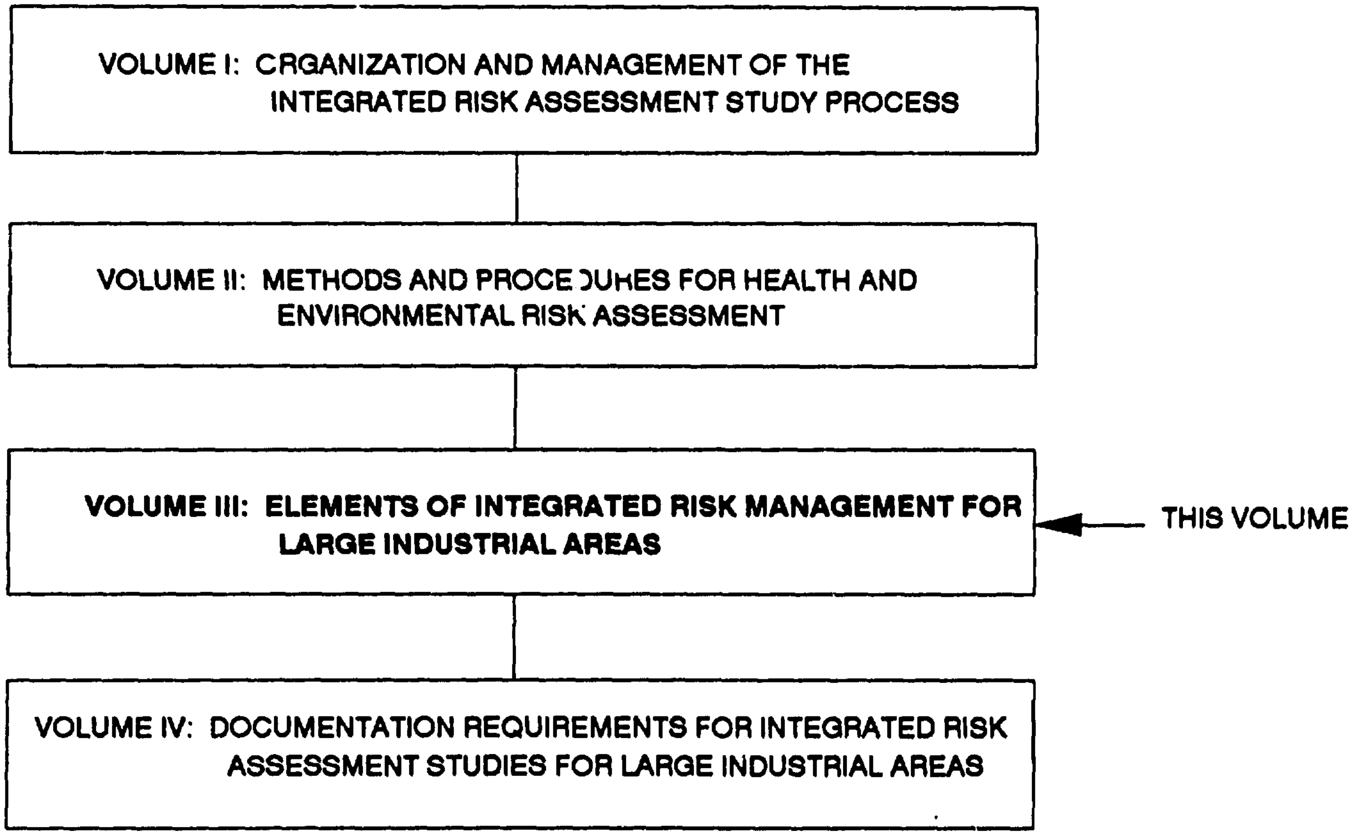

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CHAPTER 1

OPERATIONAL SAFETY MANAGEMENT AND CONTROLS

Chapter 1: OPERATIONAL SAFETY MANAGEMENT AND CONTROLS

This chapter addressess the design and operational technical aspects of safety management and control. Consideration is given to both 'hardware' as well as 'software' aspects of safety management.

The contents of the chapters are based on information and a report prepared by Dr. Ian Lake, ICI Engineering Pty. Ltd., Sydney N.S.W., Australia.

Chapter 1: OPERATIONAL SAFETY MANAGEMENT AND CONTROLS

1.1 Introduction

The inherent safety approach has evolved over the last two decades in the process industry as the standard and well accepted philosophy for current plant design. The clear intent is to reduce plant hazardous inventories to a bare minimum and in so doing reduce the potential release size due to the loss of containment of these inventories.

An equivalent approach applies when plant design utilises the substitution of potentially hazardous processes with relatively benign processing techniques. The capability for example of bypassing undesirable intermediate stages of the process (which may involve high risk of chemical toxicity or the propensity for chemical instability) pays dividends in reducing the overall hazard potential of the process.

The inherent safety approach is also reflected in the process control and protection systems in terms of designing for fail-safe fault conditions. More complex protective voting systems can substantially reduce the number of spurious plant trips without conceding too much in terms of plant protective system reliability.

In the past the emphasis has been directed towards developing high standards for design and operation concentrating on the equipment or "hardware" aspects. More recently there has been a growing awareness of the importance of the less tangible procedures and human factors or "software" aspects.

The major essential elements in software management systems comprise :

- Organisation
- Procedures and methods
- Knowledge, skills and training
- Documented standards and records
- Attitudes

All the above elements are interrelated. In a soundly operated process industry all the above key features are in place and are being actively monitored to protect against complacency and potential deterioration of attitudes and commitment.

1.2 Safety Management

1.2.1 General Review of Safety Software Management Systems

The key features in any well operated process industry which reflect its level of safety software management are itemised below:

- Health, safety and environmental policy
- Safety organisation
- Formal safety studies
- Incident and accident reporting
- Formal (written) operating procedures
- Maintenance work permit systems
- Plant modification procedures
- Safety training programs
- Allowance for other human factor aspects (e.g. communication, emergency response, appropriate manning levels)

Each of these items is briefly elaborated in Table 1.1. It is not the intention of this guideline to further detail the aspects of each of the key features tabulated. It is noteworthy however that these safety software attributes are established in all process operating industries as a condition of the minimal acceptable level of safe operation. These requirements often form part of an operations "**Minimum Requirements for Safe Operations**" statement which essentially give practical detail to the more general philosophy embodied in a "**Health, Safety and Environmental Policy**".

A key additional feature is the need to have proper safety audit programs in place in order to check whether the safety software management systems are functioning to the level which was intended. Such audits need to be rigorous and penetrate to the core of the management systems in order to reveal potential weaknesses and oversights.

Table 1.1

SOFTWARE MANAGEMENT SYSTEM	FEATURES / CONSIDERATIONS
Safety and Environmental Policy	Safety culture; safety information; safety personnel
Safety Organisation	Safety management structure; line management responsibilities; independent auditing systems; key job descriptions
Formal Safety Studies	Hazard studies systems; hazard identification techniques; personnel involved; implementation of recommendations
Incident and Accident Reporting	Target criteria; supporting documentation; monitoring of incident details and statistics; investigation requirements
Formal Operating Procedures	Quality and updating of documentation; suitably for operating personnel; ease of access and distribution
Maintenance Work Permit Systems	Work permit for routine maintenance versus hot work and confined space clearances; records and documentation followup; quality assurance in procurement; maintenance policy and critical duty pipework and equipment
Plant Modification Procedures	Documentation for approval of change; HAZOP requirements and policy; authorisation and review procedures
Safety Training Programs	Safety (and related) training resources; documented systems for achievement; personnel trained (operators, engineers, management, maintenance); retraining requirements
Other Human Factors Aspects	Communications systems; management reporting; manning levels; emergency response responsibilities

In addition to the above safety management systems there is the need to consider the interface between the software and hardware safety systems such as critical duty piping, fire protection systems; control room alarms and plant protective systems and control room ergonomics.

1.2.2 Practical Guidance on Improving Process Safety

If an organisation wishes to improve its process safety and loss prevention, it may be able to do so in a number of ways. It can start by trying to reduce the inherent hazard, then considering in turn its existing safety measures: containment, control, protection and damage limitation. It is not uncommon to find that there are certain changes in plant design or layout where improvement will be most cost effective. However, on existing plant, as distinct from a new project in the planning phase, there may be limited opportunity to reduce the inherent hazard, or to improve the separation. The options often narrow down to improved hardware and software for containment, control and protection.

It is common for the hardware option to be preferred : it is tangible and it can be implemented at a definable cost using the normal production and project management procedures, but often there is insufficient attention given to the associated human factors. Protective hardware may be dramatically improved (on paper) by expenditure on high integrity protective system, but for that improvement to be realised and maintained, the following would also need close and continual attention :

- Instrument system design standards
- Calibration and testing standards, methods, supervision
- Instrument maintenance facilities, standards, methods, supervision

Therefore it is likely that all, or nearly all, major improvement in process safety and loss prevention on existing plant will require human factors improvement either in partnership with hardware improvement or on its own.

A Systematic Approach for Improving Plant "Software"

The following is suggested as a systematic approach to improving software for safety and loss control, and for identifying areas where hardware may also warrant improvement. Assuming that there is a real need, recognised by the senior managers in the organisation, the steps are as follows :

STEP 1 Explain the situation throughout the plant organisation; why technical safety and loss prevention are important and need improvement. (Recognising that many people are more committed to their own welfare than that of the organisation, personal benefits should also be discussed.)

STEP 2 With a suitable group, representing people at all levels of the plant organisation, identify the major potential hazards and potential sources of loss. It is important that this be done in a participative manner including representation from plant operators, so as to get as close to the facts as possible, and to increase the extent of shared understanding.

This step could start by considering the potential hazards and losses inherent in the process materials and process operations. It essentially short-lists the areas for detailed study.

STEP 3 Identify the possible causes of the potential hazardous incidents, and how they can be either avoided or recognised early and stopped.

This step should be undertaken participatively using the same group as earlier, considering each of the short-listed areas in detail, using an organised approach similar to a HAZOP (Section 1.4.2) study, but with the guide words changed or edited to reflect the short-listed areas and types of incident.

STEP 4 Define procedures or equipment to facilitate avoidance or early recognition and control of the potential incidents. Again, this should be done participatively at least to the point of defining a need for a procedure or equipment to be designed by someone outside the meeting.

This step will result in a list of changes in operating and maintenance methods and inspections, changes to equipment, investigations, etc.

It is common to find that operating instructions concentrate on what is necessary for good safe operation, but have insufficient clarity, or specific guidance, for early recognition of faults.

STEP 5 Define responsibilities for carrying our the procedures, and for periodic checks.

Where a procedure is defined in the meeting, the organisational position responsible could be discussed and agreed on the basis of what the situation requires, but where procedures need further definition outside the meeting this may not be practicable.

It is notable that an unchecked procedure cannot be relied upon any more than an untested trip system.

STEP 6 Define any further training requirements for those responsible to carry out the new procedures properly, or to operate and maintain any changed or additional equipment.

STEP 7 Determine a practical implementation program which takes into account the priority of the findings. It is important to implement some of the easier findings at once. Discouragement will set in if implementation is deferred until the whole study is completed.

STEP 8 Monitor and maintain software awareness by ongoing technical safety auditing.

1.3 Process Plant Safety Design Considerations

1.3.1 Types of Potential Incidents

The main types of incidents which could, in theory, occur in the process industry cover the range from fires (including toxic combustion products), explosions and toxic gas releases. A more detailed summary of the types of incidents are :

- Fire
- Flash fire
- Vapour cloud explosion
- BLEVE (or fire ball)
- Dust explosion
- Other kinds of explosion (including confined space explosions and detonation)
- Toxic gas escapes
- Toxic fumes from fires

The types of installations or operations which could give rise to such incidents are set out in the following Table 1.2.

In a process plant operation where plant layout and early warning systems are inadequate it is conceivable that relatively minor initial incidents could escalate to the major incidents outlined above. Major incidents in turn could lead to "knock-on" events : the so-called domino incidents.

In order to mitigate against such escalation, the following sections give practical guidance on how to avoid or contain initiating incidents that stem from loss of containment type scenarios.

TABLE 1.2

TYPE OF MATERIAL AND INSTALLATION / OPERATION	TYPE OF INCIDENT							
	FIRE	BLEVE	FLASH FIRE	EXPLOSIONS : VCE	DUST	OTHER	TOXIC GAS	TOXIC FUMES
Liquefied Flammable Gas								
• Pressurised storage	✔	✔	✔	✔				
• Atmosphere pressure storage	✔		✔	✔				
• Processing plant	✔	✔	✔	✔				
• Road/rail tanker loading bay	✔	✔	✔	✔				
• Road/rail transport	✔	✔	✔	✔				
• Shipping & wharf operations	✔	✔	✔	✔				
• Cross country pipelines	✔		✔	✔				
Flammable Liquid								
• Tank storage	✔							
• Drum storage	✔	✔						
• Processing plant	✔	✔	✔	✔				
• Road/rail tanker loading bay	✔							
• Road/rail transport	✔							
• Shipping & wharf operations	✔							
• Cross country pipelines	✔							
Storage or Processing								
• Flammable gas	✔		✔	✔				
• Flammable powder (or dust producing solids)	✔				✔			
• Highly reactive materials	✔			✔	✔	✔		✔
• Toxic gas							✔	
• Materials with toxic combustion products								✔

1.3.2 Design to Avoid Major Fires

In plants handling flammable materials, specific action is required to prevent a fire starting and to control any fire which is initiated.

Actions likely to **prevent** a fire are :

- Reduction if the risk of a release of flammable material
- Limitation of the quantity of material that can leak
- Provision of early warning of a release
- Separation if ignition sources from likely release points

Actions likely to **control** the size and effect of a fire are:

- Reduction of flammable inventories
- Separation of flammable inventories from each other and from critical areas (people and plant)
- Provision for access for fire-fighting and movement of personnel
- Provision of reliable, adequate and appropriate fire-fighting facilities
- Protection of vital structures and equipment from fire damage

Plant experience indicates that minor fires will occur from time to time, and if they are detected and dealt with promptly they pose little risk to people and plant in most cases. Design emphasis should therefore be placed on the control of minor fires to prevent them from developing into major fires or other serious incidents.

1.3.3 Design to Avoid Vapour Cloud Explosion

Current understanding of vapour cloud explosion indicates that there needs to be some degree of confinement or congestion before an explosion or deflagration is possible. Alternatively a flash fire which is associated with the rapid combustion of a vapour cloud (with a rate of combustion too low to generate a percussive pressure wave) could still kill or injure people if they are enveloped within the flame.

The general principles for the reduction of risks from vapour cloud explosions and flash fires are :

- Improve intrinsic safety by such means as reduction or elimination of potentially hazardous inventories

- Reduce the likelihood of leaks by the use of good design codes, standards and practice, plus good quality assurance during construction and maintenance

- Provide for rapid detection and isolation of any leaks which do occur, by such means as flammable gas detectors and remotely operated isolation valves

- Design plant layout to allow rapid dispersion of any vapour cloud which forms, and avoid partial confinement of flammable vapours

- Control ignition sources to reduce the likelihood of ignition

- Protect people and adjacent plant by either provision of adequate separation distances, or by selectively strengthening buildings or structures.

The general principles for layout are as detailed in the previous Table 1.3.

1.3.4 Design to Avoid Toxic Gas Releases

Leakage of toxic material, the formation of a toxic vapour cloud and dispersion of the cloud constitutes a major concern in hazard analysis because the toxic cloud has the potential for affecting both the plant operating site, adjacent plants and neighbouring populated areas. The longer people are exposed to a toxic gas at a particular concentration, the more severe the effect.

Graphs 'concentration versus exposure time' are designed for a range of toxic gases which are broadly indicative of the effects on people. Clearly such graphs must be only broadly indicative and the effects will vary between people and the circumstances. For example, a person under stress at the time of a gas escape would probably be breathing harder than normal and may therefore be affected more rapidly.

In order to manage a plant's performance in preventing escapes, target criteria are necessary. Appropriate targets will vary from site to site, but typically could be in terms of the frequency of each effect at the site boundary with public areas. The targets need to be developed and agreed by discussion among the local managers in the light of the local situation, but for the example of chlorine gas the following broad hazard categories (Table 1.4) could be used as a starting point for that discussion.

TABLE 1.3

PLANT LAYOUT CONSIDERATIONS	CONTROL OF FLAMMABLE LEAKS	DETECTION AND ALARMS	FIRE PROTECTION AND FIRE FIGHTING FACILITIES
• Configure equipment and pipework so that flammable gaseous leaks can disperse freely • Separate flammable inventories from ignition sources • Locate pumps handling flammable liquids for ease of access for surveillance, maintenance, fire fighting, etc • Separate critical pumps from offices and other critical plant items • Allow for remote isolation of key pumps and compressors • Avoid level glasses and bellows in flammable duties, wherever possible • Design for remote depressuring facilities for critical duties • Equipment which could leak should not be located under or immediately adjacent to piperacks	• Steam or water curtains should be used where adequate distances between flammable inventories and ignition sources cannot otherwise be obtained • Flammable sealed liquid storage tanks should be bunded (and sealed to prevent leaks escaping into groundwater; reduce flash evaporation in the event of a spill of flashing liquid) • Provide a valved drain at the low point of a bunded area, of adequate size to cope with water from fire hoses • Grade the bunded area so that leaks drain *away* from the storage tank • Drainage of the plant area should be such that spills drain away from vessels and plant to a sump in an open area • Drainage separators are required to allow fire water or rain water to drain away while retaining any flammable materials	• Flammable gas detectors can be installed to warn of leaks from such points as pumps, compressors, etc • Combustion detectors may be installed in places where non-gaseous flammables could ignite • Flame detectors are preferable out-of-doors, e.g. UV or IR, suitably shielded from flare stacks, etc • Such detectors should raise alarms in the control room, indicating which alarm is activated • The speed of response to alarms from detectors is a very important factor and needs to be emphasised in the procedures and training	• Water deluge systems on main potential sources or targets of fire e.g. pumps, operable manually or automatically via thermal detectors, etc • Fire proofing of structural steelwork; critical duty pipelines, large vessels, electricals, instrument cables (especially alarm, trip and vital protection circuits) • Fixed or portable monitors located such that all flammable inventories can be covered by at least two monitors • Fixed foam facilities of the correct type in atmospheric pressure tanks containing flammable liquid

Table 1.4 Possible Targets for Controlling Toxic (Chlorine) Releases	
HAZARD CLASS	**FREQUENCY OF EXCEEDING SPECIFIED CONCENTRATION - EXPOSURE TIME HAZARD LIMITS**
1. Smell	Two per year
2. Nuisance	One per 10 years
3. Serious	One per 100 years
Note "Serious" means that the release concentration and duration has the potential to cause injury and, more remotely, death	

Clearly the acceptability of the targets will relate to the nature of the toxic chemical being considered. The above example applies for the specific case of chlorine releases. Differences between the toxic gases can be more readily interpreted by comparing their 'concentration versus exposure time' graphs.

A summary of the control measures that can be taken to above the likelihood of severe toxic gas release scenarios is presented in Table 1.5.

1.3.5 Safety Design for Plant Layout

A systematic approach to the layout of a large new plant handling flammable materials is as follows:

1. Set out the plant in distinct process blocks.

   The blocks may each comprise capital cost of around $10-20 million, but this is only a rough guide.

2. Separate those blocks with the greatest chance of flammable leaks (e.g. handling and pumping liquid flammable gases) as far as possible from blocks with unavoidable sources of ignition (e.g. furnaces).

3. Check that the necessary pipebridge routes will not impede crane access to all necessary parts of the plant.

4. Aim for plant blocks to be separated from each other by 15m (between process equipment) where there is a significant fire risk, and possibly by more if the equipment is very tall. In some cases, where the fire risk is low, less separation may be acceptable.

5. With the equipment provisionally located on the plan, study the drainage.

TABLE 1.5

POTENTIAL CAUSES	CONTROL MEASURES (ALL CASES)
Leaks ❒ Mechanical failure (sudden or gradual) due to any of the following : • Impact • Overpressure • Overheating • Fragility, e.g. glass, plastic lines • Corrosion e.g. lines, vessels • Explosion damage • Overstressing e.g. temp cycling • Mechanical seals • Compressor glands • Vibration	❒ Minimise inventories ("What you don't have, can't leak") ❒ Concentrate on mechanical and process integrity in areas with direct access to liquid inventories or high pressure gas ❒ Protective equipment should be seen as a *second* line of defence
Process Releases (vents, safety valves) ❒ Control system and protection failure (process upset conditions) ❒ Maloperation of plant (beyond design limits) ❒ Maloperation of filling or unloading operations ❒ Improper purging before maintenance	❒ Plan for prompt recognition of the existence of leaks, accurate diagnosis of the location, easy decision about corrective action, remote isolation facilities, emergency procedures ❒ Implement management controls over modifications ❒ Implement special inspection procedures for the most vulnerable areas
Unforeseen Reactions ❒ Drains (e.g. hydrochloric acid and sodium hypochlorite) ❒ Side reactions within the process ❒ Reactions between chemicals and inappropriate fire fighting reagents ❒ Reactions within effluent plants (combinations of materials under upset conditions)	

Any area where a flammable liquid or liquefied flammable gas may spill should be hard paved. The paving should be graded to form catchment pans each averaging about 10m square. The gradient in the catchment pans should be around 1 in 50.

6. Locate vessels with significant inventories on the ridges or high areas of the grade so that any leaks will flow away from them.

   Locate pumps and other potential leak sources as close as possible to the drain opening.

   If this is done, leak paths will be short, pool areas minimal, flame heights minimal, flames remote from vessels, so that the need for fireproofing is reduced.

7. Locate pumps handling flammables 6m from pipebridges where possible.

   Similarly, where possible, vessel end connections and complex pipe fittings (e.g. heat exchange flanges) should be 6m from pipebridges.

8. Pay close attention to valving. Potential leak sources, especially pumps, connected to large flammable inventories, should be capable of being isolated from the inventories by either :

   2 manual valves physically separated such that a leak and a fire will not prevent access to both valves, or

   Remotely operated emergency isolation valve, with 10-15 minutes fire protection on the actuating mechanism.

9. Fireproof steel structures within 6m of pumps or connections to significant flammable inventories. Fireproof for a height of 9m.

   Fireproof cable trays within 12m of such fire courses. (Radiation can damage cables, but flame impingement or near impingement is mostly needed for damage to steel.)

10. Install fixed sprinkler systems where fireproofing is needed but passive protection (e.g. concrete) is not possible,

    Install fixed sprinklers over pumps handling flammable liquids, and where the liquid is a hydrocarbon. Include inductor equipment to allow use of a film-forming foam additive, which floats on the hydrocarbon spills.

    Avoid sprinklers over pumps handling liquefied flammable gases. Water increases vaporisation and intensity of the fire.

11. Locate flammable gas detectors or combustion detectors (or both) at strategic points. Carefully select the type of combustion detector to suit the

location. (Smoke detectors are rarely useful out of doors; UV or IR are better for external use).

12. Locate hydrants and monitors such that every vessel is capable of being cooled by at least two monitors (from different directions).

Hydrant isolation valves should be underground with an extended spindle, rather than an integral part of the hydrant. (Hydrants are sometimes damaged in a fire and it must be possible to access and isolate them individually).

In summary, the above steps involve addressing the requirements of :

- Spacing
- Drainage
- Detection of leaks
- Isolation of leaks
- Passive fire protection
- Fixed sprinklers
- Cooling
- Firefighting

1.3.6 Firefighting

The firefighting approach for each plant needs to be designed and considered separately. However there are a few general principles which apply. Every plant handling flammables will have small fires occasionally. Fast, appropriate response at the plant level is needed to prevent the fire escalating.

Typical requirements include :

- Fire alarms (well signposted) located such that no-one needs to go more than 50m.
- Two portable fire extinguishers located at each fire alarm button. Extinguishers to be of the appropriate kind. "Monnex" dry powder is good for a wide range of chemical fires including hydrocarbons. Water is often not helpful for hydrocarbon fires, so fire hoses are *not* a first-aid (wrong medium, too slow to deploy).
- Dry powder extinguishers have only limited cooling effect, and therefore it is often necessary to apply water to hot surfaces to prevent re-ignition.

- Larger supplies of appropriate media e.g. wheeled trolleys of dry powder with larger inventory and application rate than portable units, or foam units of the correct type such as AFFF or AFFF/ATC or high expansion synthetic foam.

- Fire training of employees on a range of types of fire and using a range of media. This can be done in conjunction with local external fire authorities as local brigades often lack, and welcome, experience with chemical fires and special extinguishing media.

- Formal documented fire plan for each plant, developed in discussion with the external brigades.

1.4 Process Safety Hazard Identification and Evaluation Techniques

This section gives an overview of some examples of process safety hazard identification and evaluation techniques that are currently well utilised by the process industries. It is not intended to be an all embracing survey of the techniques available, but a highlight of well established techniques giving an indication of both their strengths and weaknesses.

The main techniques which are focused on in this section are :

- FAR (Fatal Accident Rate analysis)
- HAZOP Study (Hazard and Operability Study techniques)

1.4.1 Existing Plants - The "FAR" Approach

Historical Safety of Employees: consider the following situation. In a 30 years period a large industrial company (e.g. chemical) had 9 fatal accidents to its own employees. This is approximately 4 fatalities per 100,000,000 worked payroll hours. Of these fatalities, almost half were due to causes related to the process itself, whilst the others were not related to the processes or technology but were due to a wide variety of miscellaneous causes.

Because employees are not exposed to the risks from a fatality for 24 hours a day a specific measure of risk called the FAR or Fatal Accident Rate is used. The FAR is defined below :

- Number of fatalities per 100 million worked hours by payroll employees.

Therefore the fatal accident rate in the chemical process industry under consideration is approximately 4 with an FAR of 2 being associated with the process technology itself.

The achieved FAR of 2 for process risks is the result of a variety of risks, some high and some low; this is illustrated in Figure 1.1. The operators on some plants are shown as having FAR's well above 2 for process reasons, while those on other plants are appreciably below.

Principles Adopted for Employees' Safety on New Plant

When designing a new plant there is the opportunity to incorporate safety features from the outset. This is best done by initially looking at intrinsic safety (small inventories, low temperatures, pressures, etc) and then by adding control and protective systems as necessary to match any remaining intrinsic hazard.

Perfect safety in unattainable. Whatever we do imposes some risks to our health or life. As the target cannot be perfect safety, some point must be defined beyond which further safety improvement will not be sought.

If safety targets are set too tight, an industry or a company could price itself out of existence because of the cost of hazard reduction activities. If the business has a real value to the community and if the risk levels are not markedly above those elsewhere in the community then those hazard reduction activities could probably be regarded as contrary to the community interest.

An industry could be charged with complacency if it were content to operate to standards which it achieved over previous decades before new technology and new methods were available. A much more defensible position is to aim for a continuing improvement consistent with what is economically feasible and with community requirements.

Some companies adopted for the operator most at risk on any new plant to have an FAR not exceeding 2.0 from process causes. The effect of this is shown in Figure 1.2 below.

If the operator most at risk on a new plant has a FAR not exceeding 2, then the average for all the operators on such a plant will normally be less than 2.

As new plants are commissioned, and as in due course older plants are decommissioned, the company average FAR will fall progressively.

The experience to-date indicates that this target for new plants appears to have been achievable without adoption of methods which are uneconomic or technically unattractive.

Applying the Principles to Existing Plant

In a community in which there are constantly rising expectations for environment protection, safety, and corporate responsibility, it is inevitable that work done years ago will sometimes fail to meet current standards.

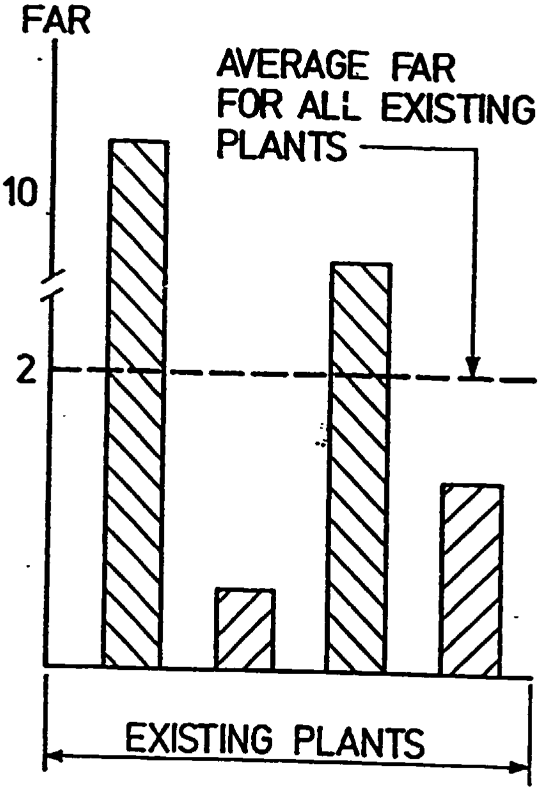

FAR
AVERAGE FAR FOR ALL EXISTING PLANTS
10
2
EXISTING PLANTS

Fig. 1.1

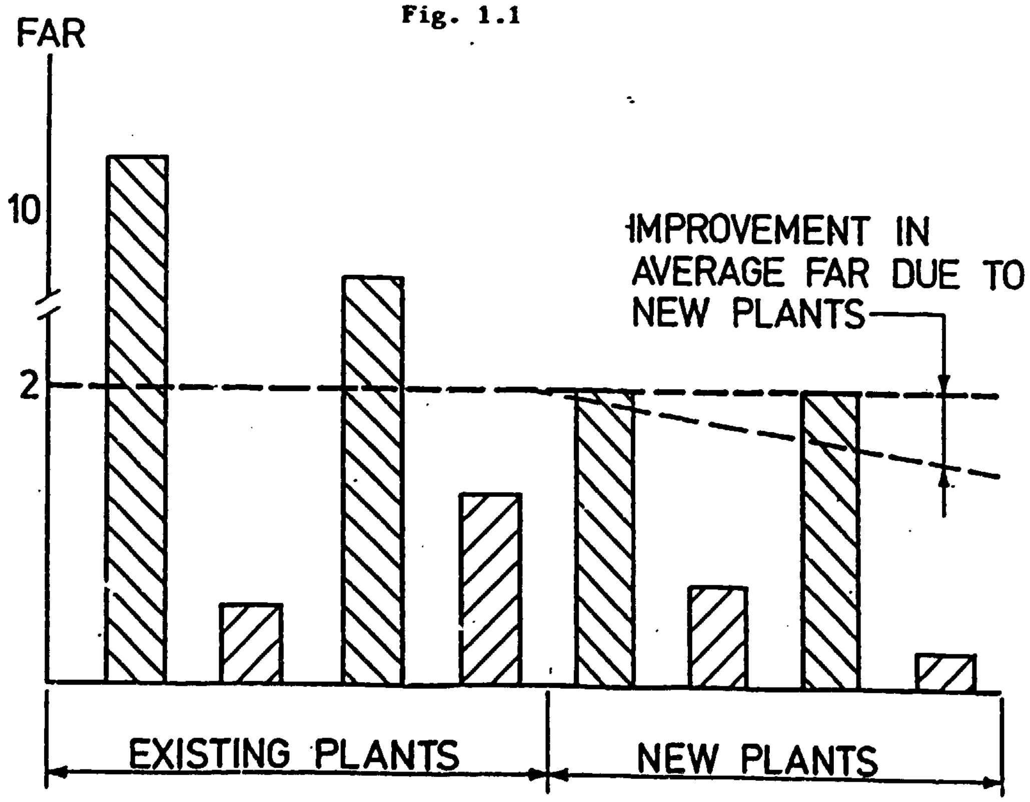

FAR
10
2
IMPROVEMENT IN AVERAGE FAR DUE TO NEW PLANTS
EXISTING PLANTS
NEW PLANTS

Fig. 1.2

In the case of plants built before the current understanding of the techniques and management methods available for building technical safety into an evolving design, it may be found that the targets set for new plants cannot be achieved in existing plants without extensive and uneconomic rebuilding.

Even if no improvements are made to the safety of existing plants, the average FAR will continue to improve as new plants are commissioned and older plants progressively decommissioned.

However, rather than accepting risks on existing plants for (in most cases) the considerable remaining life of those plants, the program of selective risk reduction, which has been a feature of operations for many years, will continue. However, it is not appropriate to use the same risk targets as for new plants. Nor is it necessary.

As shown in Figure 1.2 the average FAR will continue to fall with the passage of time.

But by selectively reducing the risk to the "tall poppies" within existing plants, further reduction will be achieved as shown in Figure 1.3. In Figure 1.4 the FAR for an industrial, chemical company is presented, expressed as a 5 year moving average, for a reference period 1960-1982.

Priority

In the real world, with limited resources, it is not possible to do everything at once, or even to do everything one would ideally wish. Priorities are needed.

Allocation of priority to risk reduction capital expenditure is governed by a number of factors, including :

- The current level or risk
- The number of people exposed at that level
- The cost of achieving reduction of risk
- The extent of reduction achievable
- The remaining productive life of the plant

There is no simple basis for allocating priority which can sensibly be applied without exception.

In principle, priority should be given to risk reduction projects where :

- The current level of operator risk is high
- Substantial reduction can be achieved

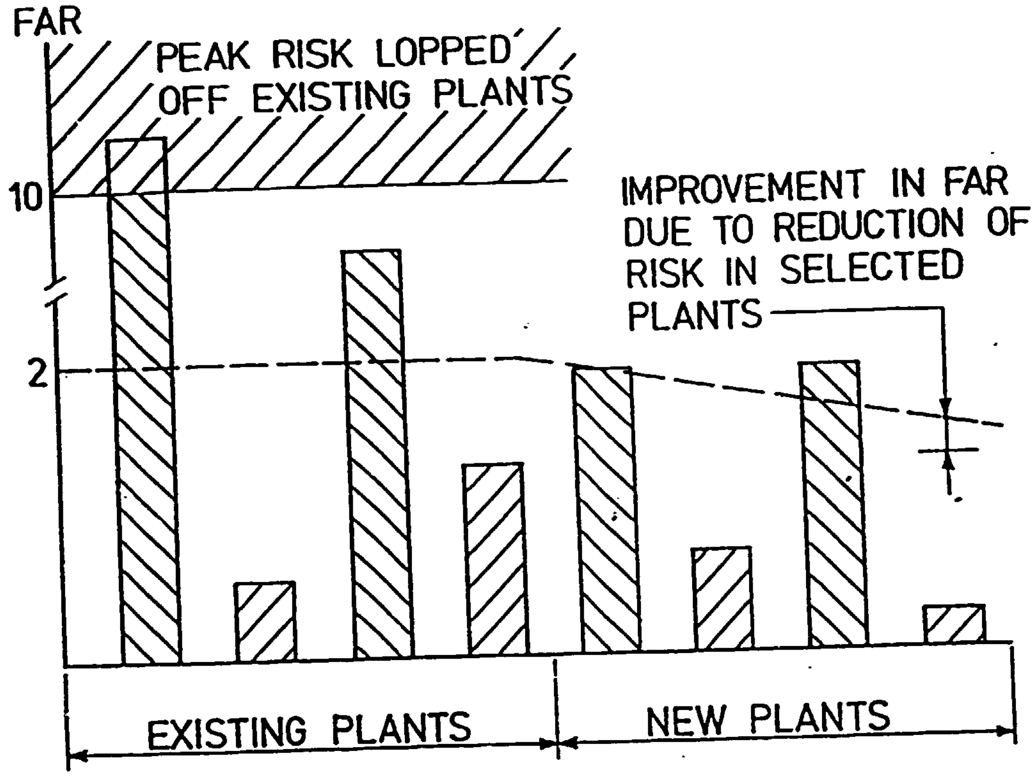
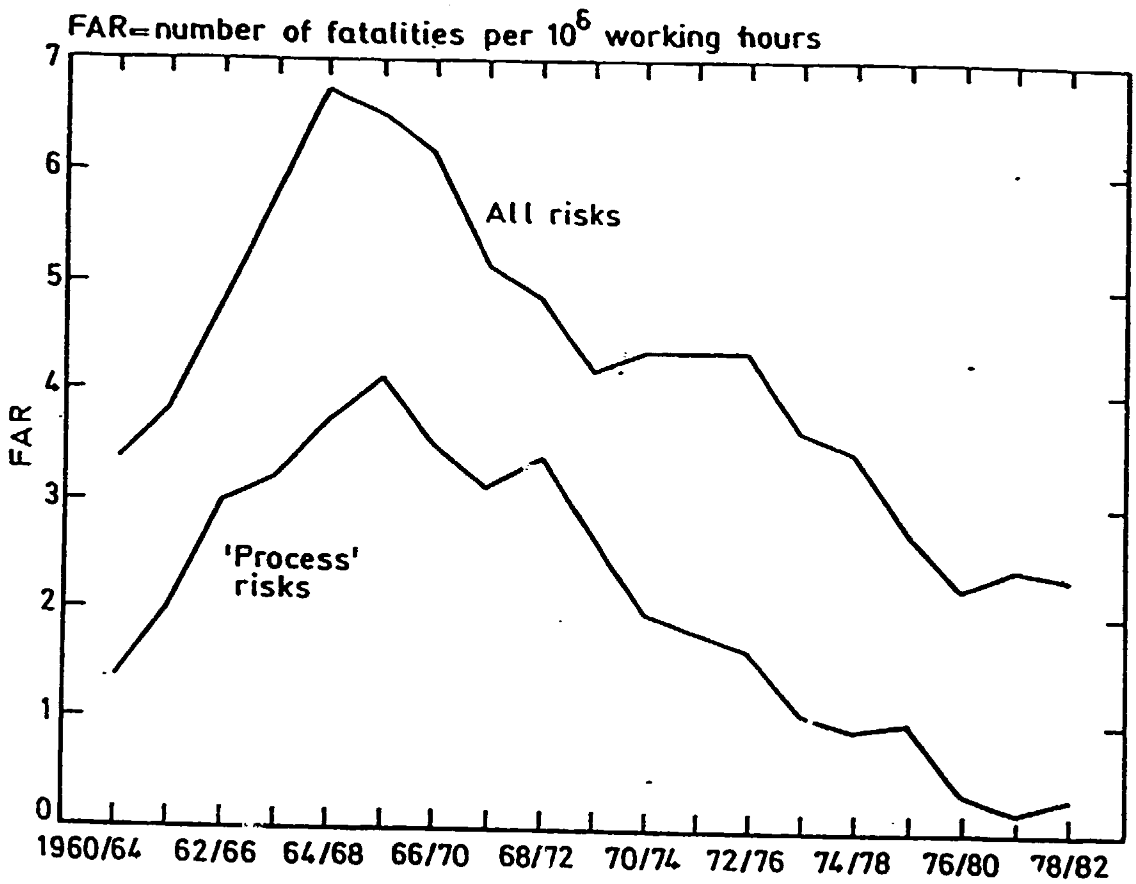

FAR
PEAK RISK LOPPED OFF EXISTING PLANTS
10
IMPROVEMENT IN FAR DUE TO REDUCTION OF RISK IN SELECTED PLANTS
2
EXISTING PLANTS
NEW PLANTS

Fig. 1.3



FAR=number of fatalities per 10^6 working hours
FAR
7
6
5
4
3
2
1
0
All risks
'Process' risks
1960/64
62/66
64/68
66/70
68/72
70/74
72/76
74/78
76/80
78/82

Fig. 1.4

- A large number of operators are exposed
- Capital and staff requirements are low
- There are no plans to decommission the plant

It is unlikely at present that existing plant risks resulting in a FAR of 10 or less will attract any significant priority.

In comparing one safety project with another on the basis of cost effectiveness, the following value factor could be used.

$$\text{Cost Effectiveness Factor} = \frac{\text{Reduction in FAR x Av No of People Exposed}}{\text{Annual Cost (Capital Charges, Operating Costs etc)}}$$

This cost effectiveness factor can be used as a method for ranking the relative importance of safety enhancement projects under consideration. As decisions about priorities for safety improvement require consideration of moral and legal issues as well as cost effectiveness, judgement will need to be applied.

1.4.2 Hazard and Operability Study Techniques

A HAZOP study is a systematic technique for identifying potential hazards and operability problems. It involves essentially a multi-disciplinary team which methodically "brainstorms" the plant design focusing on deviations from the design intention. The effectiveness of the hazard identification process relates strongly to the interaction of the team and the individual diverse backgrounds of the personnel involved. The method aims to stimulate reactivity and generate ideas. The ultimate objectives are to facilitate smooth, safe and prompt plant startup; to minimise extensive last minute modifications, and ultimately to ensure trouble-free long term operation.

HAZOP studies are systematic techniques were developed using a multi-disciplined team for the evaluation of hazards and plant operability. The HAZOP technique is based on the assumptions that the plant:

- Will perform as designed in the absence of unintended events which will affect the plant behaviour
- Will be managed in a competent manner
- Will be operated and maintained in accordance with good practice and in line with the design intent

- Protective systems will be tested regularly and kept in good working order.

The HAZOP procedure is more completely described in the Chemical Industry Safety and Health Council's *A Guide to Hazard and Operability Studies* (1977). In simple terms, the HAZOP procedure takes a full description of the process and systematically questions every part of it to discover how deviations from the design intent can occur. The consequences of such deviations are then determined and if significant are reviewed and remedial action either recommended or flagged for further study.

All modes of plant operation must be considered :

- Normal operation
- Reduced throughput operation
- Routine start-up
- Routine shutdown
- Emergency shutdown
- Commissioning

The standard and level of penetration of a HAZOP study is very difficult to demonstrate conclusively to a non-participant because the results depend more on the experience and attitudes of the participants and on the leadership style adopted than on the procedure itself.

For an effective HAZOP study, the participants should be selected to provide the necessary experience, knowledge, skills and authority in the following areas:

- Process design
- Instrument and control design
- National and corporate engineering standards
- Plant operation
- Plant maintenance
- Design and construction management
- Project management

A comparison of the benefits and potential pitfalls of HAZOP studies are indicated in the following Table 1.6.

Table 1.6
Review of HAZOP Study Requirements, Benefits and Upsets

REQUIREMENTS	BENEFITS	POTENTIAL PITFALLS
HAZOP Team • A properly experienced and balanced study team with an experienced leader • A positive, open and questioning attitude during the meetings and when deciding upon action to take on the points arising • Adoption of a systematic, detailed approach which concentrates on abnormalities • The conscientious undertaking of pre HAZOP study preparation, including the suitability of guide words and methodology *Information* • A full description of the process under study with access to the design basis and intent • A set of mechanical, piping and instrumentation drawings to allow an item by item review • Safety and environmental hazards data sheets and specifications	• Ensure that the majority of design flaws are identified early in the project when design changes are still capable of being implemented • Reduce the possibility of undesirable capital expenditure on major modifications at the startup phase • Reduces significantly the time taken at commissioning/startup to achieve process flowsheet production notes • Intangible benefits in terms of the reduction of potential hazards due to the adverse interaction of various plant parameters • Allows detailed understanding of the design and operational principles across a broad range of personnel • Establishes the basis of safe work practices for novel or difficult processes where the hazards are not immediately apparent	• Potential excessive use of resource time if the HAZOP team is led by an inexperienced leader or if the participants do not have the necessary knowledge and experience levels • The validity of the HAZOP is directly determined by the accuracy of the information used as input and from which problems can be inferred • Management shortcomings often prohibit the availability of the most knowledgable and experienced personnel • The application of a cursory HAZOP of insufficient depth and understanding can lead to complacency and problems being overlooked • Shortage of technical information or key design personnel can create frustration and expediency and reduce HAZOP effectiveness

1.4.3 HAZOP Study of Continuous Chemical Processes

Studies of continuous chemical processes are carried out in a series of meetings where mechanical and piping diagrams are examined line by line, vessel by vessel, using a list of guidewords to stimulate the hazard study teams' considerations of all conceivable deviations from design intent.

The list of guidewords depicted in Figure 1.5 is worked through systematically by the team of mixed disciplines, led by a trained hazard study leader. Should potential problems be identified, then a review of the preventative or corrective measures designed to minimise the likelihood and consequences should be specified. Any further action should be noted and progressed outside the meeting.

The main information recorded on the proforma sheet for the HAZOP minutes is as follows :

HAZOP Minutes Record Sheet Information

- Deviation Guide Word
- Possible Causes
- Consequences
- Existing Safeguards
- Action Required
- Responsible Person

Additional information is presented showing the persons present at the meeting and all relevant details concerning the line diagram under review.

1.4.4 HAZOP Study of Batch Processes

The general characteristics of batch plants as compared with continuous plants are as follows :

- The status of the various parts of the plants are changing cyclically with respect to time and therefore an engineering line diagram gives a very incomplete picture of the process operation
- The processes are usually multi-stage and the individual units are often multi-purpose

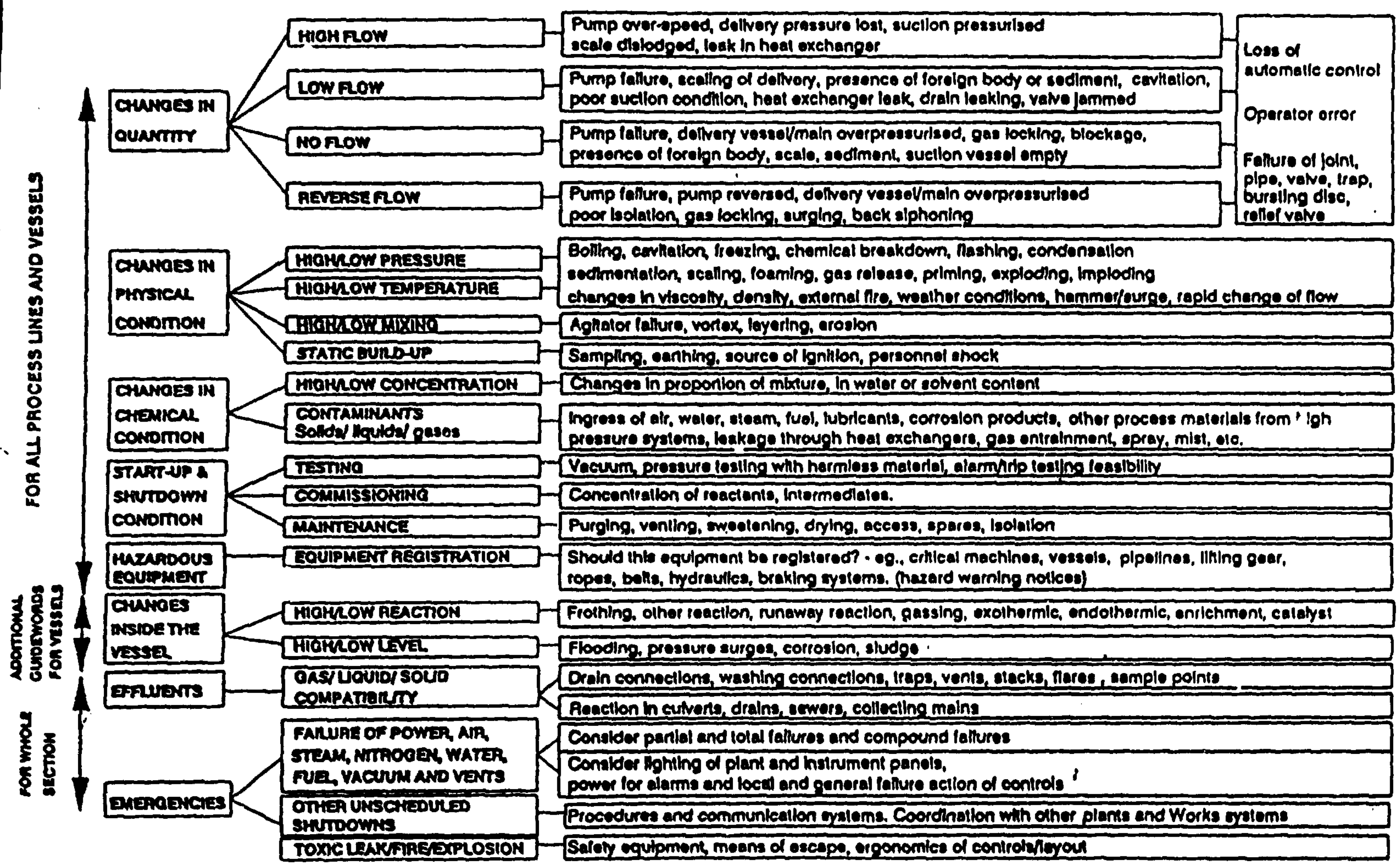


Figure 1.5 - Hazard Study 3 Guide Diagram for Continuous Processes

- Batch plants are often multi-product and reaction units usually have to be cleared out and modified when changing from one product to another.

From the above aspects it is clear that these can be several modes of operation for batch plants. At the very least, two fundamental states should be considered. These are :

- An "active" state when the item is in use, and

- An "inactive" state when the items is not in use.

This is in contrast to a continuous plant where, in steady state operations, a fixed mode in terms of flow, pressure, temperature etc can be defined for each part of the plant.

The approach therefore adopted in a hazard and operability study (HAZOP) of a batch process is to apply the guide words initially to each step (see Table 1.7) of the process. The additional guide words of "sooner than" and "later than" must be considered at each step. In addition the interactions between each of the steps need to be considered.

This means that the HAZOP process for a full batch study is significantly more complex than for a steady-state continuous process. Considerably more detailed information is required in terms of batch operating procedures and valve status indications at each step of the process in order to meaningfully judge the potential process deviations.

Table 1.7
HAZOP Guide Diagram for Batch Processes

GUIDE WORD	MEANING	EXAMPLE OF DEVIATION
NO (NOT OR NONE)	THE ACTIVITY IS NOT CARRIED OUT OR CEASES	NO FLOW IN PIPE NO REACTANT CHARGED TO PROCESS BATCH NOT COOLED CHECK OMITTED
MORE OF	A QUANTITATIVE INCREASE IN AN ACTIVITY	MORE (HIGHER, LONGER) QUANTITY, FLOW, TEMP, PRESSURE, BATCH, CONCENTRATION, TIME
LESS OF	A QUANTITATIVE DECREASE IN AN ACTIVITY	LESS (LOWER, SHORTER) OF ABOVE
MORE THAN OR AS WELL AS	A FURTHER ACTIVITY OCCURS IN ADDITION TO THE ORIGINAL ACTIVITY	IMPURITIES PRESENT, EXTRA PHASE (SOLID OR GAS IN LIQUID PHASE) EXTRA (UNPLANNED) PROCESS OPERATION
PART OF	THE INCOMPLETE PERFORMANCE OF AN ACTIVITY	REDUCED STRENGTH, MISSING COMPONENT, OPERATION ONLY PART-COMPLETED
REVERSE	INVERSION OF THE ACTIVITY	BACK-FLOW OR BACK-PRESSURE HEAT RATHER THAN COOL
SOONER/LATER THAN	AN ACTIVITY OCCURRING AT THE WRONG TIME RELATIVE TO OTHER ACTIVITIES	THE ACTIVITY OCCURS AT THE WRONG TIME
OTHER (THAN)		WRONG MATERIAL CHARGED NON-ROUTINE CONDITIONS, START-UP, SHUTDOWN, MAINTENANCE; CLEANING, ETC FAILURE OF SERVICES

The first aspect will be the assessment of the **initial state** of the system. This implies some form of inspection by the operator/technician, presumably against a checklist. That is, the required state is defined and the procedure should ensure that it is met before proceeding. In applying the HAZOP study method, the question needs to be asked as to what the actions will be to remedy anything that is not in the required state and what the consequences would be if the state was other than as required.

Suitable guide words to explore this **initial state** may be :

Missing	Equipment, information or material missing
Insufficient	Insufficient supply/condition of materials, equipment or information
Wrong	Incorrect material, person, information, etc
Time	Insufficient time allowed or available
Other	Deviation of some other variable

Having been satisfied that the initial state of the system is appropriately set up, the **procedural** aspects must be studied. HAZOP Guide Words for procedures should be used effectively for preparing and examining **operating procedures** for plants (see Table 1.8).

Once the **final state** has been reached, the same basic approach used in assessing the starting state can be applied.

Responding to Deviations: as with all HAZOP studies, once a deviation has been discovered, the significance must be assessed.

The questions to ask at this stage are:

- If the deviation does occur, will it matter?;
- If it does, how often is it likely to occur?

Based on the answers to these questions, the need to introduce some form of check or balance is assessed. Exactly what can be done to either avoid the deviation, lessen its consequences or reduce its frequency is up to the study team to decide. Likewise, the appropriateness of any such action is up to the team.

1.5 Further Developments in Process Safety Techniques

The HAZOP methodology has been applied successfully to a diverse range of process operations including computer applications as well as plant procedures. Some examples of these techniques are outlined in Section 1.5.1.

The HAZOP technique identifies potential hazards and the possible mechanisms by which these hazards can occur. A further technique which is used to enhance hazard assessments and which focuses on key concerns in a process operation is **fault tree analysis**. This technique allows both a qualitative appreciation of the potential ways in which an incident may develop (as a logic tree) as well as a quantitative assessment where suitable failure rate and demand frequency data are available. A further development of this technique has been to modify and interpret the fault tree in a positive sense as a "hazard warning tree". A general outline of this technique is given in Section 1.5.2.

1.5.1 Advances in Hazop Techniques

1.5.1.1 HAZOP Study of Procedures

In applying the HAZOP Study methodology to procedures the same basic approach used in continuous process plant HAZOP studies is used. The aim is still to systematically and critically examine the intentions of the procedure and assess the hazard potential of possible deviations from these intentions.

However, the HAZOP study of procedures is s. fficiently different to warrant special attention. In examining a continuous process, there is a steady state of conditions (e.g., temperature, pressure, flow, composition) and the HAZOP study seeks to identify deviations in these. A procedure is distinctly different and can be considered as having the following basic attributes :

- Starts from a defined state
- Follows a defined series of operations or activities
- Ends with another defined state

In any general procedure the defined starting point or state will include : the condition, provision, location and state of equipment, plant and materials; the training and skill of the operator/technician; the available support staff; lines of communication; etc.

The procedure will define the activities necessary to move from this defined starting state to the end state (which will include most of the factors considered previously).

Thus the totality of the procedure must cover the flow of materials and information and the detailed activities. The HAZOP principle is then to thoroughly investigate all aspects of the procedure to discover possible deviations and to assess the consequences and likelihood of them.

Useful questions to probe any suggested corrective action are:

- Is it practical?;
- Is it sensible?;
- Is it cost effective?

Table 1.8
HAZOP Guide Words for Procedures

PARAMETER	PURPOSE	DEVIATION
WHAT has to be done?	WHY; for what purpose?	WHAT IF OMITTED? WHAT ELSE? AS WELL / INSTEAD?
WHEN?	WHY THEN?	EARLIER / LATER?
WHERE?	WHY THERE?	ELSEWHERE?
HOW?	WHY THAT WAY?	SOME OTHER WAY?
HOW MUCH?	WHY THAT MUCH?	MORE / LESS?
HOW FAST?	WHY THAT FAST?	FASTER / SLOWER?
HOW OFTEN?	WHY THAT OFTEN?	MORE / LESS OFTEN?
WHO?	WHY THEM?	SOMEONE ELSE?
		WHAT ELSE CAN GO WRONG?
IF DEVIATION : DOES IT MATTER? HOW OFTEN? WHAT THEN NEEDS TO BE DONE?		
Note The statement on the initial state of the plant implies an inspection - against a check list - by the operator. It seems prudent to inquire what may happen if the operator finds any part of the plant in other than the required state and takes steps to correct the state, for example, opens a closed valve which should have been open before starting the procedure detailed.		

Human Error: at all stages of the HAZOP study, the possibilities of human error must be considered. This does not imply that the people performing the task are either incompetent or inadequately trained. In fact, psychological studies have indicated that simple errors in well known routines can become more likely as our skill in the routine increases.

1.5.1.2 Study of Selected Construction Activities

On some projects, construction work is necessary on existing working plant or in close proximity to hazardous pipe routes or processes. It may then be necessary to examine selected construction activities systematically at appropriate stages in the construction program. Prior to bringing equipment and personnel on site (i.e. contract teams), each contractor should submit written proposals of how the activities are to be achieved and supervised. A series of meetings can then be held at appropriate stages in the construction program, to examine systematically the adequacy of the proposed detailed construction activities. Each activity should ensure that :

- All reasonable provisions are being made to ensure the job is carried out safely.

- The contractor understands the implications of deviating from his defined method of working.

- The contractor and supervisors understand that safety and safe working practices have a higher priority than achieving target completion dates. The basic guidance is: "If in doubt or concerned, stop the job and seek operations management advice".

- Sufficient thought is given to access/egress to the construction site, which on occasions involves checking the suitability/standards of the vehicles, linking with the plant control room, providing escorts for abnormally large vehicles and providing permits to work, etc.

- Appropriate Site and Plant induction training is given in advance to all contract personnel employed on site.

A guide to the HAZOP style examination of the proposed construction activities and a list of factors to consider is given in Figure 1.6.

1.5.1.3 HAZOP Study of Computer Based or PLC Systems

Studies of computer systems can be conducted in several ways depending on the nature of the system. The procedure can be assisted by the use of block diagram representations of the equipment within defined cut points. The interfaces between each item of equipment can be systematically examined using an approach similar to that for batch processes where the basic guide words (less of, more of, etc) trigger detailed consideration of the transfer of information/data, and the performance of critical items of equipment (e.g. power supplies, alarm annunciators printers etc).

The HAZOP Study guide words can be modified and used to prompt detailed consideration of the failure modes of modern computer based or PLC type control systems and this approach encourages a structured examination of each key unit in the control loop (e.g. DP cell, P/I, controller/ computer, I/P, control valve). Many new instruments contain PLCs (DP cells, density meters, controllers etc) and their failure modes can be very different from conventional instruments (e.g. loss of input can default, such that automatic control reverts to manual without any audible alarm). Such novel failure mechanisms can only be revealed by lateral consideration of cause/effect deviations in input/output

METHOD STATEMENT

DEFINE

- WHAT HAS TO BE DONE ?
- HOW IS IT TO BE DONE ?
- WHEN HAS IT TO BE DONE ?
- WHERE WILL IT BE DONE ?

CONSIDER

- What effect on live plant equipment? What precautions?
- How will it be co-ordinated/supervised?
- Any checks or tests needed?
- Is it a recognised safe practice or one-off?
- Is timing critical?
- Is access/egress and boundary security satisfactory?

QUESTION DEVIATIONS

WHAT IF ?
(ie., What can go wrong ?)

HAZARDS AT CONSTRUCTION/DEMOLITION STAGE

WHO CHECKS :-

1. EFFECT ON ROAD TRAFFIC (need for good quality road signs eg. diversion,barriers etc.)
2. GUIDANCE TO CONSTRUCTION TRAFFIC (route plan,signs etc.)
3. OBSTRUCTION TO NORMAL TRAFFIC/EMERGENCY VEHICLES (cranes,HGV's,contractors vehicles)
4. INCREASE IN SITE TRAFFIC -Implications? SIZE OF VEHICLES (pipebridge clearances?)
5. QUALITY OF SAFETY EQUIPMENT & SIGNS ON NEW PLANTS (support and fixings durable?)
6. PERSONAL SAFETY EQUIPMENT (attitudes/quality)
7. STANDARDS OF WORK,SAFETY,CLEANLINESS (contractors vehicles,tools,methods of working)
   NB. First impressions & state on completion

WHO CO-ORDINATES :-

1. THE ACTIVITIES (eg. to ensure job A is done before job B)
2. PERMITS TO WORK etc. (linking with plants & service groups - encourages co-operation)
3. COMMUNICATIONS (who needs to know,why,when)
4. TRAINING (planning,advance notice,supervisor involvement-gains committment)

WHO AUDITS :-

1. SAFE WORKING PRACTICES (eg. scaff-tags,permits,safety equipment etc)
2. THE WORKPLACE (housekeeping,on completion of the job)
3. KNOWLEDGE OF THE CONTRACTOR (does he understand ? does he know ?)
4. EMERGENCY TRAINING/RESPONSE (exercises ?)

What is the role of the safety representative?

Figure 1.6 Framework for Assessing Selected Construction / Demolition Activities circuitry and software programs. In particular the wider implications of common mode failure should be addressed. In Figures 1.7 and 1.8 guide diagram for computer interfaces and a computer control HAZOP setup are presented.

For micro-processor based systems, the effect of a hardware component or software failure on the output of the device is generally the most important consideration. Where a multi-input/multi-output device is being considered then each output (analogue and digital) should be considered separately.

Overall system safety integrity relies on :

a) Configuration (ergonomics, loop design)

b) Reliability and capability (performance, confidence)

c) Quality (information displayed, log)

Two key aspects of HAZOP studies of computer systems are to:

1. Focus on any novel features of the device and examine the effects of their performance;

2. Systematically examine potential causes and effects of foreseeable fault modes which could result in potentially adverse output

A "novel feature" is an operation of the device which a user would not consider part of the standard functionality. It has normally been added by a manufacturer to give them an edge on their competitors. In many instances such features can add to the integrity of the device rather than detract from it. Examples of "novel features" are: set-point tracking, forced default to manual, memory sum-check failure, and specific action on initiation of 'watchdog'(a software checking routine).

Procedure: the following guide words can be considered in reviewing the safety and operability of a computer based system :

PARAMETER	DEVIATION
1. MORE OF	Blocks of data / transfer frequency
2. LESS OF	Incomplete transfer / system crashes during transfer
3. NONE OF	No transfer of data
4. OTHER THAN	Mismatch due to re-format / software change / process variable change
5. SOONER / LATER THAN	Questions how measurements are processed / time out / out of sequence / averaging assumptions
6. CORRUPTION OF	Noise, magnetic fields, radio interference, welding ,lightning
7. WHAT ELSE	Maintenance, simulation, earthing, high voltage due to fault condition
8. REVERSE OF	Repeat steps 1 to 7 looking at data transfers in the opposite direction
REPEAT 1 TO 8 FOR ALL LINKS ACROSS COMPUTER CONTROL INTERFACES	

These deviations can be applied in either (or both) of two general approaches :

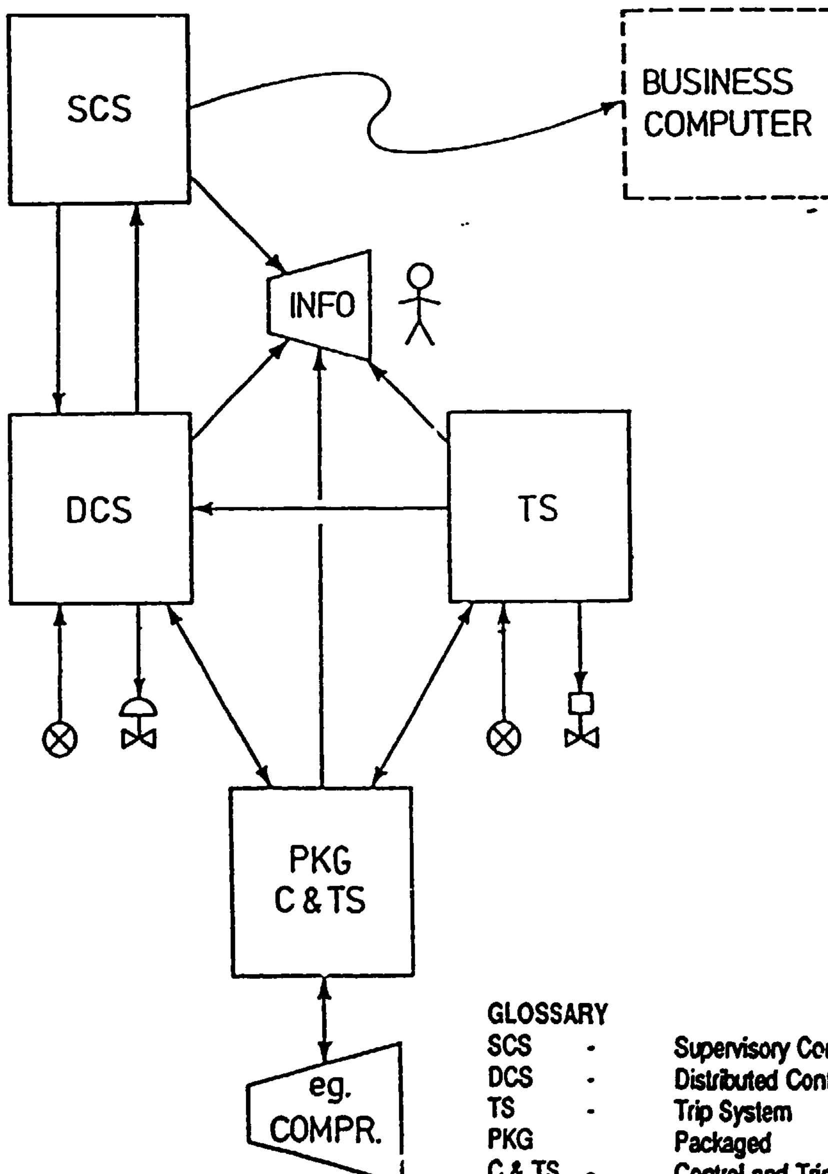
1. A "loop-by-loop" analysis using the electrical/instrument loop diagrams as the major review item

2. A "block-by-block" analysis focusing on the potential for adverse interactions between sub-systems.

In either approach, allowance for human error (involving control room VDU layout and ergonomic factors) should always be considered.

Team Composition: the team composition will be biased towards participants with a strong computer/instrument/electrical background. A senior process/operations adviser must be present. It is advisable to have an independent HAZOP Leader for significant computer based projects. Such a person should be conversant with computer based systems and ideally should have had previous experience and participation in similar reviews.

Figure 1.7
Hazard Study 3 Guide Diagram for Computer Interfaces



GLOSSARY

SCS -	Supervisory Control System
DCS -	Distributed Control System
TS -	Trip System
PKG	Packaged
C & TS -	Control and Trip System

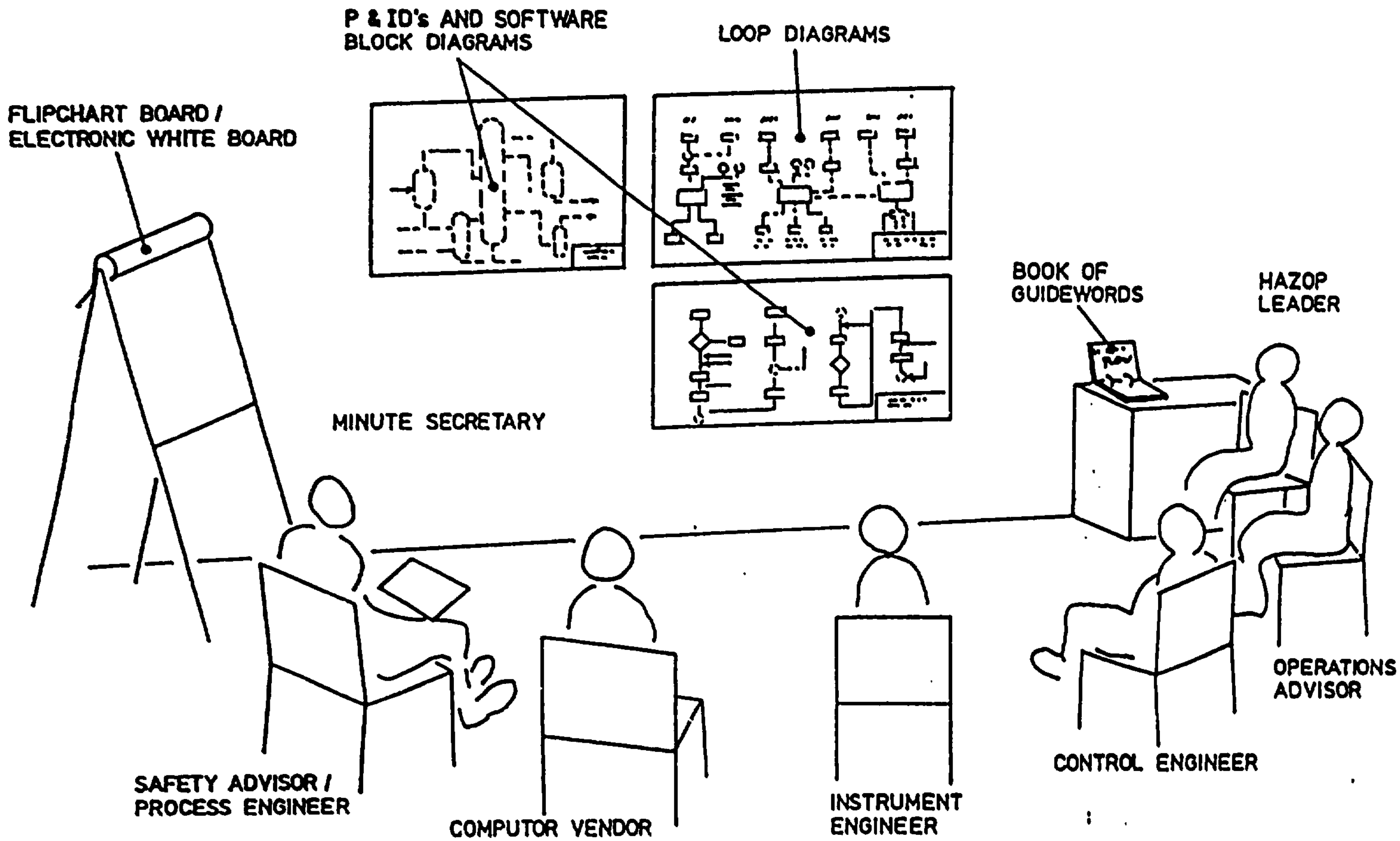


Figure 1.8 Computer Control HAZOP Setup

1.5.2 Hazard Warning Approach

1.5.2.1 Hazard Warning Concept

The fact that there are a likely to be a lot of lower level incidents prior to a major accident is a well known statistical axiom. The statistical basis of the hazard structure has been explored by Heinrich (1951) and many others in the occupational health and safety fields. The interpretation of the so called "pyramid of accidents" type structure reveals that a major hazard is in all probability going to be preceded by a series of preliminary warnings. These "warnings" are events that may occur more frequently than the top event (the major hazard) and usually terminate at various degrees of "near miss" or "minor damage" type levels (below the top event). This, of course, assumes that there are various levels of containment that need to be breached before the major hazardous event can occur.

The possibility that a series of "intermediate level" or precursor incidents are likely to occur before any of the initiating events escalates to the major event is an essential concept in quantitative measurement of process safety known as Hazard Warning. The basic principle of the Hazard Warning Structure is that if the lesser events are not occurring then there is good assurance that the major incident will not occur either.

It is recommended in the literature that a practical technique for monitoring operational and maintenance incidents be developed to provide warning as to potentially more serious hazardous events (UK Health and Safety Commission, 1984). Methods based on the fault-tree approach, appeared at that stage to be the most promising. The goal is that industry develop the concept of hazard warning as an auditing tool in such a way that is convenient to use and operable by a wide selection of personnel.

1.5.2.2 Fault Tree Methodology

The fault tree methodology has a number of attractive features with regard to hazard identification and these include :

- A mechanistic understanding of the fault sequence leading up to a major incident or equipment failure is identified
- An estimate of the likely frequency of occurrence of the major incident and of subsidiary incidents leading to the incident is obtained
- The true redundancy of backup safety systems is obtained (provided that common mode failures are identified)
- A written record of the analysis is produced, understandable by those who were not involved in the original study.

The fault-tree method employs successive sequences and AND or OR gates to discover the combination of faults necessary for a particular event to occur. Normally, the top event or major incident is identified first (e.g. explosion, loss of key equipment item, etc) and the immediate faults leading to this are then identified. The procedure continues down one level at a time with itemised faults listed explicitly, extending the detail of the previous level until base faults or initiating events are identified. These are events for which no further breakdown is warranted and for which estimates of frequency or probability can be made. Boolean algebra is used to compute all frequencies higher up the tree, eventually predicting the overall failure rate of the top event and of all preceding faults.

1.5.2.3 Hazard Warning Structure

In hazard warning a quantitative safety monitoring system based on the combination of the fault tree method with the Poisson probability distribution of predict the number of occurrences of minor events before some undesirable higher event would occur is proposed. This method, was in need of further development of its quantitative aspects to allow convenient or practical application.

The hazard warning system is based on the observation that most incident sequences in a fault-tree terminate well before reaching the top event. These subsidiary events which do not propagate should be treated as hazard warnings the top event could have occurred, but that time it did not. By applying statistical analysis to the fault tree frequencies, the likelihood of the top event occurring, given the occurrence of some subsidiary event, can be computed. This is by definition a **failure of hazard warning** - as the top event is now assumed to have occurred. The likelihood of failure of hazard warning should be kept as low as possible.

The General Hazard Attenuation Factor

Lees' later published case studies (1984, 1985) which concentrated to a large extent on the most conspicuous quantitative feature of hazard warning. This is the clear attenuation that is apparent in a fault tree between the major outcome (top event) and any preceding events right down to the initiating events at the base of the fault tree. He argued the case that this type of information can be used quite effectively in the analysis of post accident outcomes and cited several examples from the Canvey Island study and other public reports to show its application.

Simply stated, the 'attenuation factor' approach is to compare the frequencies of occurrence of two events at different levels in the fault tree; the ratio of the more frequent lower event to the mitigated higher event is the "warning factor".

How likely or unlikely a hazard will occur must depend on the structure of the hazard i.e. on the incident pathway (or pathways) to the undesirable occurrence of the major event. This implies that some hazards which are mitigated against by a range of hardware or software measures may require many successive "levels" of mitigation failure for the major hazard to occur. It would therefore be regarded as having a "high warning structure". Other potential hazards may have little in the way of controls or protective systems and therefore constitute a "low warning structure".

Lees therefore attributed to each accident scenario either a "high" or a "low warning structure" depending upon the number of incident escalation levels, each with mitigation features, and the overall incident attenuation factor.

The Statistical or Probabilistic Approach

While there are a number of possible statistical distributions to describe failures, the Poisson time related distribution applies to the random occurrence of isolated events in a continuum of time and is, by its similarity to the exponential distribution, also suitable for the examination of low probability events such as failures of protection systems (i.e. probabilities less than 0.1). (Strictly, this distribution is not the Poisson but is known as the Erlangian distribution and is simply the time-dependent form of the Poisson discrete distribution).

Using the Poisson-related statistical theory, it is possible to calculate the probability that the upper level (top event or 1st level) will occur given that the preceding event (at the 2nd level) occurs no more than n times :

$$P_T(t,k<n) = \exp(-f_2 t) \sum_{k=1}^{n} p(k) \frac{(f_2 t)^k}{k!}$$

$$\textit{Where} \quad p(k) = \sum_{j=1}^{k} \frac{k!}{(k-j)!j!} p^j (1-p)^{k-j}$$

Note f_2 represents the failure frequency of 2nd level event

t - time duration of interest (for example, the plant life time)

k - number of "2nd level" event occurrences (k = 1 to n)

The probability mathematics appear rather awesome at first sight but can be easily handled by modern personal computer systems. Further explanation and examples may be found in the literature (Pitblado & Lake, 1987).

1.5.2.4 Benefits of the Hazard Warning Approach

The use of fault trees in the chemical industry is likely to expand greatly given the need to reduce major hazards and the prompting of governmental authorities and the international chemical engineering institutions and standards associations. Extensions to the fault tree method via the 'hazard warning' approach appear to be eminently suitable for auditing of process plant safety performance.

The major practical uses of developing hazard warning systems are the following :

- It can assist in the communication of risk information with external authorities or public interest groups as a way of explaining the causes and likelihood of potential incidents. This technique is suitable for appeasing the public's perception based on the fear that a "chemical disaster could happen tomorrow, without warning".

- It can be used as an additional analytical tool for the risk assessment or evaluation of post-release scenarios or in the evaluation of documented case studies

- It can be used as an aid in chemical factory operations where it can be used to identify and assess the priority pre-release incidents (warning events) and in the setting of targets for the precursor events for specific incident scenarios. In a similar way it would be used in conjunction with conventional hazard auditing techniques

- It can be used as an aid to the factory development sections in determining quantified risk reduction benefits that can be used to assess the cost-effectiveness of additional safety related expenditure.

In conjunction with the fault tree analysis, the hazard warning approach offers a convenient means for examining the ongoing technical safety level of an operating plant.

PROCEDURAL GUIDE FOR INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

VOLUME III

ELEMENTS OF INTEGRATED RISK MANAGEMENT FOR LARGE INDUSTRIAL AREAS

CHAPTER 2

EMERGENCY PLANNING AND RESPONSE

Chapter 2: EMERGENCY PLANNING AND RESPONSE

Emergency Planning, Preparedness and Response are essential elements of integrated risk management.

The United Nations Environment Programme Awareness and Preparedness for Emergencies at Local Level (APELL) provides a comprehensive process of emergency planning involving all relevant parties.

This chapter is based on the APELL process and further includes guidance on the preparation of emergency plans at the local as well as area-wide levels. Emergency plans and procedures should closely relate to the specific hazards in the area. Hazards identification and evaluation are therefore an integral part of the emergency planning process. The chapter also provides guidance on fire protection and prevention as an important aspect of emergency response.

EMERGENCY PLANNING AND RESPONSE

2.1 Overview

Emergency planning and fire prevention and protection measures are essential elements of the integrated risk management process at both levels of the plant and the overall area. Both mechanisms in the integrated management of risk, primarily aim at the protection of people, property and the environment from the effects of hazardous incidents and accidents, should they occur.

Emergency planning and preparedness achieve both the containment of the effects of accidents on the site as well as the orderly evacuation of people. Formalized procedures and pre-tested plans will prevent incidents from developing into major disasters. Further, the early development of such plans enables the orderly and systematic implementation of necessary mitigating actions and isolation of impacts. Without such formalized procedures, appropriate response actions to hazardous occurrences can only be haphazard and of limited value. The process of formulating emergency plans and procedures which involve in many instances the postulation of incident scenarios also provide the opportunity to examine safety systems and as such, emergency planning can also be considered as hazard prevention tool.

Fire protection and prevention measures include fire safety hardware, equipment and fire fighting media (water, foam, powder) that aim at containing hazardous fire incidents and mitigating their impacts at the source. This include mechanisms for isolation/shutting-off the source of the hazard, isolation of the affected area, extinguishing the fire and cooling neighbouring facilities to prevent spreading.

In the context of integrated risk management, both emergency planning and fire prevention and protection mechanisms are essentially post-accident management tools although growing emphasis is being placed on their use as hazard prevention tools. It is necessary in this regard to relate emergency procedures and fire prevention/protection mechanisms to the specific hazards associated with an industrial operation and to the whole industrial region. The process of hazard identification and quantified risk assessment must be considered therefore as an integral component of the formulation and implementation of emergency procedures and fire protection and prevention strategies. This chapter outlines the framework of guidelines for the preparation of emergency plans and procedures at both the local plant level as well as the regional level; and factors to be considered in the management of fire risks through fire protection and prevention.

A. Emergency Planning

2.2 Awareness and Preparedness for Emergencies at Local Level (APELL)

2.2.1 Framework of APELL Process

The Industry and Environmental Office of the United Nations Environment Programme (UNEP) has developed in co-operation with industry, a process for Awareness and Preparedness for Emergencies at Local Level (APELL). The process, detailed in a handbook is designed to assist decision-makers and technical personnel in improving awareness of hazardous installations at the level of a community local and to prepare adequate plans should unexpected events at the installations endanger life, property or the environment. The process heavily relies on ensuring strong and effective co-ordination between the three main parties: local authorities, industry and local community and interested groups. Provisions are made for the local community in particular to participate in the process with the right to be informed about the nature and extend of hazards applicable in their area and to participate in response planning for hazardous events. A co-ordinating group with community participation and with responsibilities to gather facts, assess risks, establish priorities, organize human and other resources to implement emergency response actions, is promoted through the APELL process.

The main goals of APELL are:

- prevent loss of life or damage to health and social well being;
- avoid property damage;

Objectives of APELL

- Provide information on the hazards involved in industrial operations on the site, and the measures taken to reduce these risks.
- Establish emergency response plans in the local area.
- Integrate industry emergency plans with local emergency response plans in a single plan.
- Involve members of the local community in the process of the overall emergency response plan.

2.2.2 Responsibilities of the Different Parties under APELL

Specific responsibilities and roles of APELL partners are the following:

- **Industrial Facilities:** the plant manager is normally responsible for safety and accident prevention precautions and specific emergency preparedness measures within the plant boundaries. Members of the public may also seek from the local plant manager information on hazards and risks. The plant manager must be prepared to respond to these inquiries. Within the framework of the APELL process, all industrial facilities have a responsibility to establish and implement a "facility emergency response plan"; safety review of facility operations plays a fundamental role.

- **Local Authorities:** have the basic duty to develop awareness of and preparation for emergencies at local level.

- **Community Leaders:** they serve to bring the attention of industry and government; the concerns of the community on hazardous activities. Figure 2.1 presents the APELL information and organization flow chart.

- **Co-ordinating Group:** provides the bridge between industry and local government with the co-operation of community leaders and develop a unified and co-ordinated approach to emergency response planning and communication with the community (see Figure 2.2).

- **National Governments:** have the responsibility of organizing, maintaining and reviewing all the conditions for an adequate level of preparedness in emergency conditions. They are encouraged to establish a climate conducive to the implementation of the APELL process.

2.2.3 Scope and Content of APELL

Specific issues have to be addressed in emergency preparedness planning according to the APPEL framework:

- identify local agencies (e.g. fire department, police, public health agency, environmental agency, NGO etc.); making up the community's potential local awareness and response preparedness network;

- identify the hazards (e.g. industrial, transportation) that may produce an emergency situation;

- establish the current status of community planning and co-ordination for hazardous materials emergency preparedness and assuring that potential overlaps in planning are avoided;

- identify the specific community points of contact and their responsibilities in an emergency situation;

APELL INFORMATION AND ORGANIZATION FLOW CHART

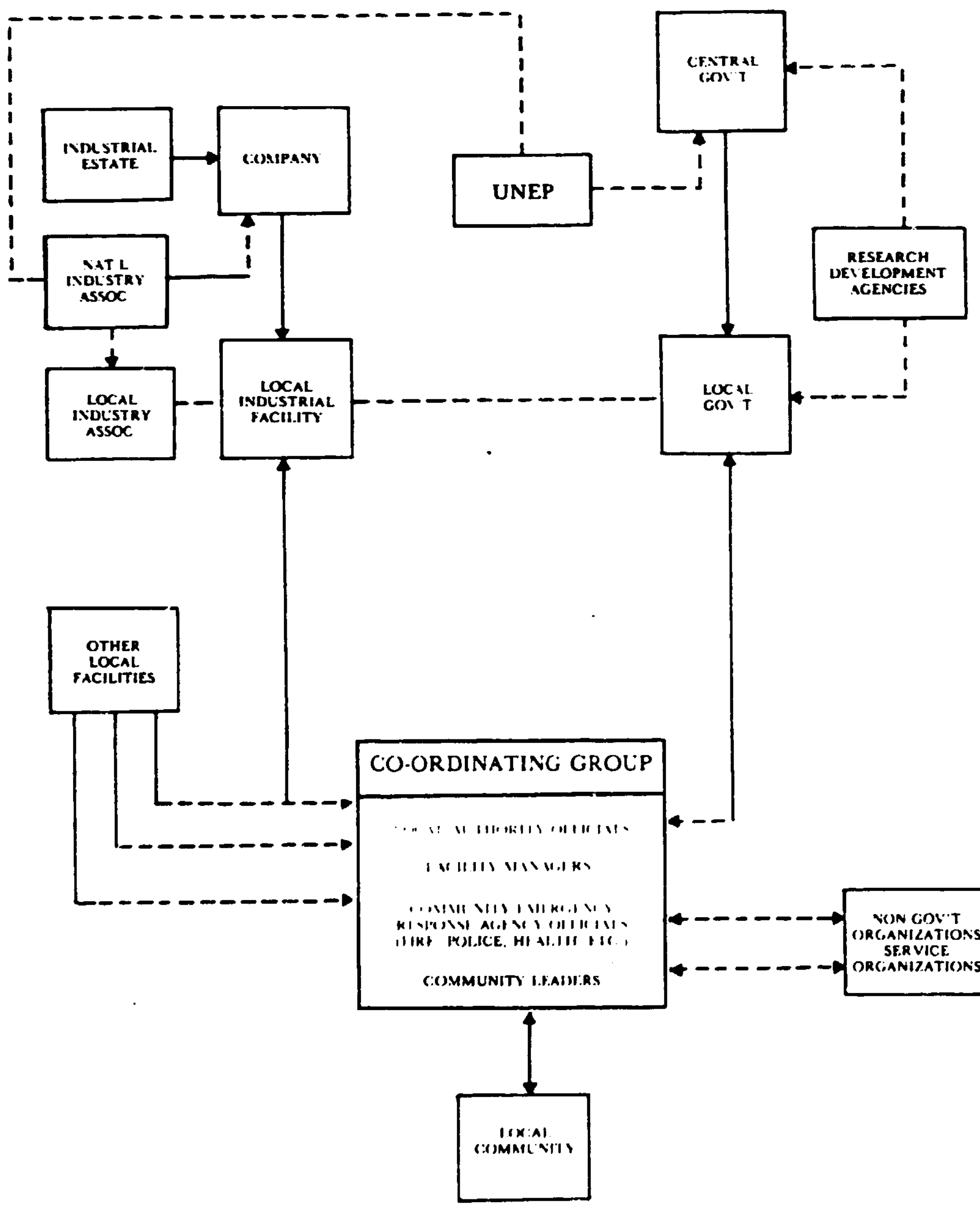


Figure 2.1

RESPONSIBILITY BRIDGE

INDUSTRY RESPONSIBILITIES

1. Assure safe work practices.
2. Assure personal safety of employees and visitors.
3. Establish safety programmes.
4. Protect lives and property on-site.
5. Co-ordinate all plant personnel during an emergency.
6. Develop plans and procedures to respond to emergencies.
7. Provide security, safety equipment, training, and information on chemical hazards.

CO-ORDINATING GROUP BRIDGING ACTIONS

- Open lines of communications
- Information sharing
- Co-ordinate emergency plans and procedures
- Interact with other emergency response agencies
- Joint education and training
- Common problem solving group
- Mutual aid assistance

LOCAL GOVERNMENT RESPONSIBILITY

1. Provide a safe community.
2. Assure the safety and well-being of all residents and transients within community.
3. Establish public safety programmes.
4. Protect lives, as well as private and public property.
5. Co-ordinate community emergency response forces during an emergency.
6. Develop plans and procedures to respond to emergencies.
7. Conduct training, drills, and exercises with other response agencies within the community, area, or state.
8. Maintain communication channels with national governments

Figure 2.2

- identify the equipment and materials available at the local level to respond tr emergencies;

- identify organizational structure for handiing emergencies (e.g. the Co-ordinating Group, chain-of-command);

- verify if the community has specialized emergency response teams to respond to hazardous materials releases;

- define and verify the operability of the community emergency transportation network;

- set up the community procedures for protecting citizens during emergencies;

- set up a mechanism that enables responders to exchange information or ideas during an emergency with other entities.

The practical experience of dealing with emergency situations lead to a ten step approach for the APELL process for planning for emergency preparedness. The corresponding flow chart for implementation is given in Figure 2.3.

A time-table for APELL implementation is community independent; the practice of establishing practical target dates will facilitate achievement of the goal. It is relevant to mention that the Co-ordinating Group will develop the plan for other groups and individuals through the community to resolve a hazardous situation.

Criteria for assessing local preparedness reflect the basic elements judged to be important for a successful emergency preparedness programme. The criteria are separated into six categories (hazards analysis, authority, organizational structure, communications, resources and emergency planning) all of which are closely interrelated.

Emergency response planning elements considered within the APELL process are; organizational responsibilities, risk evaluation, notification procedures and communication systems emergency equipment and facilities assessment capabilities, protective action procedures, post-emergency procedures, training of programme maintenance. The status of each item has to be evaluated in accordance with a specified structure which outlines the issues for each planning element. A checklist for evaluation of emergency response plan is meant to determine if the plan that does exist adequately addresses the needs of the community or entity for which the plan was developed. A matrix approach for emergency response plan evaluation is presented in Figure 2.4. The APELL process recommends status report for industry as well as for local authorities.

COMMUNITY EMERGENCY PLAN IMPLEMENTATION FLOW CHART

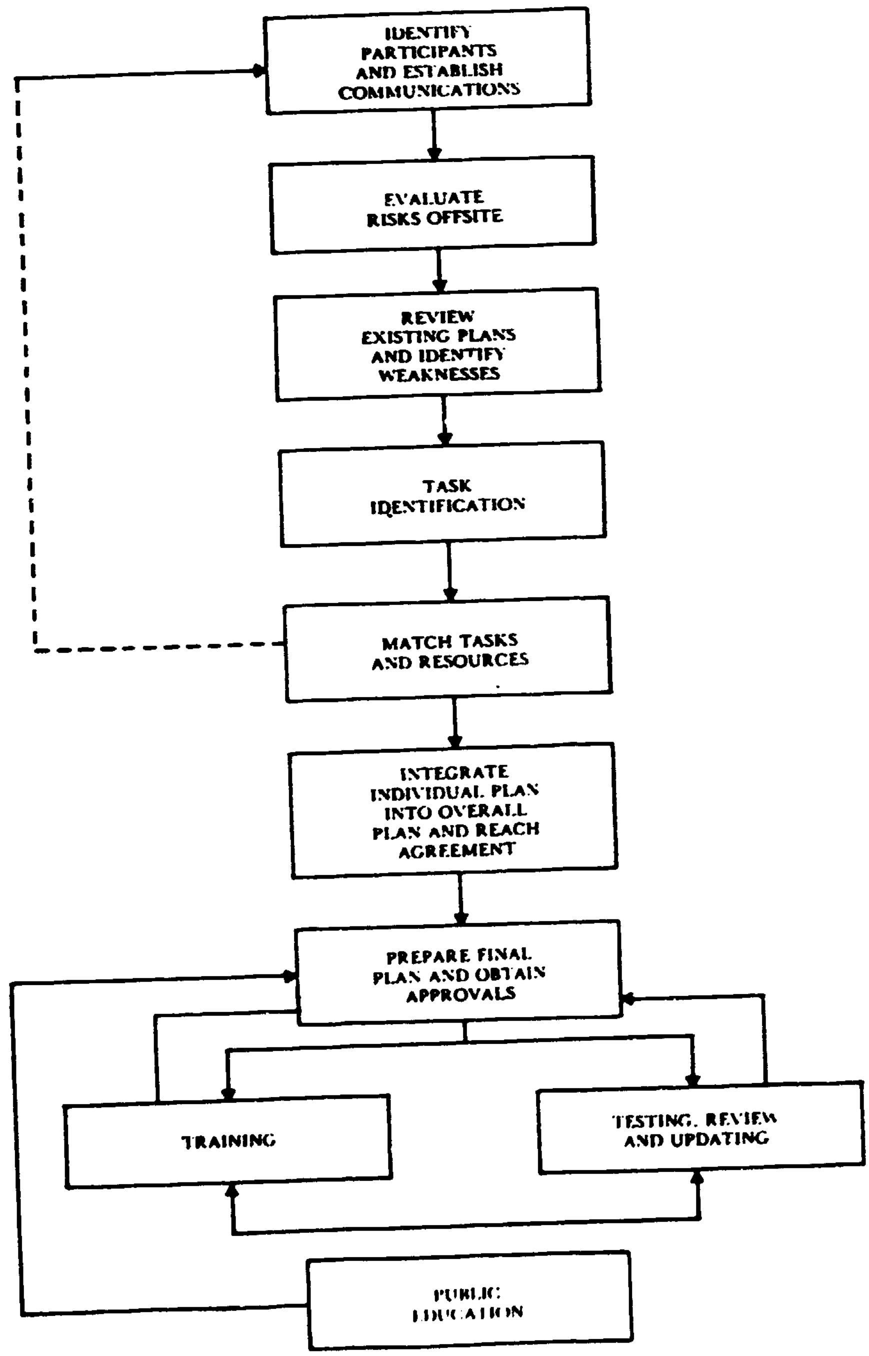


Figure 2.3

EMERGENCY RESPONSE PLAN EVALUATION MATRIX

	Regional				Local Governments (Country/City/Town)							Other (Industrial/ Intitutional)				
Plans Evaluated																
Planning Elements																
Organizational Responsibilities																
Risk Evaluation																
Notification Procedures and Communications Systems																
Core Elements in Place and Emergency Equipment and Facilities Readiness																
Assessment Capabilities																
Protective Action Procedures																
Public Education and Information																
Post-Emergency Procedures																
Training and Drills																
Programme Maintenance																

KEY:
A - Acceptable
B - Minimal work needed
C - Substantial work needed
N - Not applicable

Figure 2.4

2.3 Emergency Planning and Procedures at the Plant Level

2.3.1 Overall Framework

This section outlines specific guidelines for the preparation of emergency plans and procedures for premises which process, store or transport hazardous materials. These plans and procedures should be developed and tailored to the specific needs and hazards at each premises. A clear understanding of potential hazards will aid the development of preventive measures.

Emergency plans should be simple but complete. The emergency plans will deal in detail with on-site emergencies but consideration must also be given to the extent of possible off-site effects. Actions to control and minimize off-site effects must be listed. Access to adjacent properties may be required to implement the emergency plans under some circumstances. Response actions in the plan must be clear and easy to implement promptly. The emergency plans should be in a simple format to allow revision.

<u>Essential Elements of Emergency Plans</u>

The critical elements of an emergency plan are:

- The clear identification of the site and its location;
- Clear identification of hazardous materials and their quantities;
- Clear site specific identification of the nature and extent of potential hazardous incidents and emergency situations;
- Clear definition of authority in the plan's command structure and authority for its preparation and revision;
- Demonstrable company commitment to the plan;
- Clear exercise, review and revision arrangements to test the plan and keep it operational.

<u>Principles Applying to Emergency Plans</u>

The following principles apply to the development of an emergency plan and must be incorporated in the plan.

Control: every effort must be made to control, reduce or stop the cause of any emergency provided it is safe to do so. For example, if there is a fire, isolate the fuel supply and limit the propagation of the fire by cooling the adjacent areas. Then confine and extinguish the fire (where appropriate) making sure that re-ignition cannot occur. If it is a gas fire it is usually appropriate to isolate the fuel and let it burn itself out but keep everything around the fire cool.

Damage Control: every effort must be made to minimize any secondary damage and to prevent the propagation of damage after the initial emergency.

Rescue and First-Aid: the basis of good first-aid in an emergency, is to reconnoitre the area and commence rescue with the aim of doing the greatest good for the greatest number of people. All the people who were on-site must be accounted for. If someone cannot be accounted for after an exhaustive check a rescue search must be commenced immediately.

Rescue operations must never endanger the safety of the rescuers.

The rescue team must have adequate personal protection to carry out the search safety.

Any injured people who can be moved safely or are likely to sustain further injury must be taken to safety for treatment. Those people who are trapped or unable to be moved immediately must be given first-aid on the spot.

Care must be taken in selecting the treatment area to ensure that the area is safe and that there is adequate vehicle access.

Communications: effective communications are usually the most difficult and demanding aspect of any emergency. The need for simple standard procedures, frequent training, testing and retraining cannot be over stressed.

Time: the plan must be based on the likely event of an emergency occurring at any time not only during normal business hours.

Stages in a Planned Emergency Response: Figure 2.5 shows in a generalized form the stages in a planned emergency response. The elements in Figure 2.5 should be taken into account in drafting the company plan.

STAGES IN EMERGENCY RESPONSE

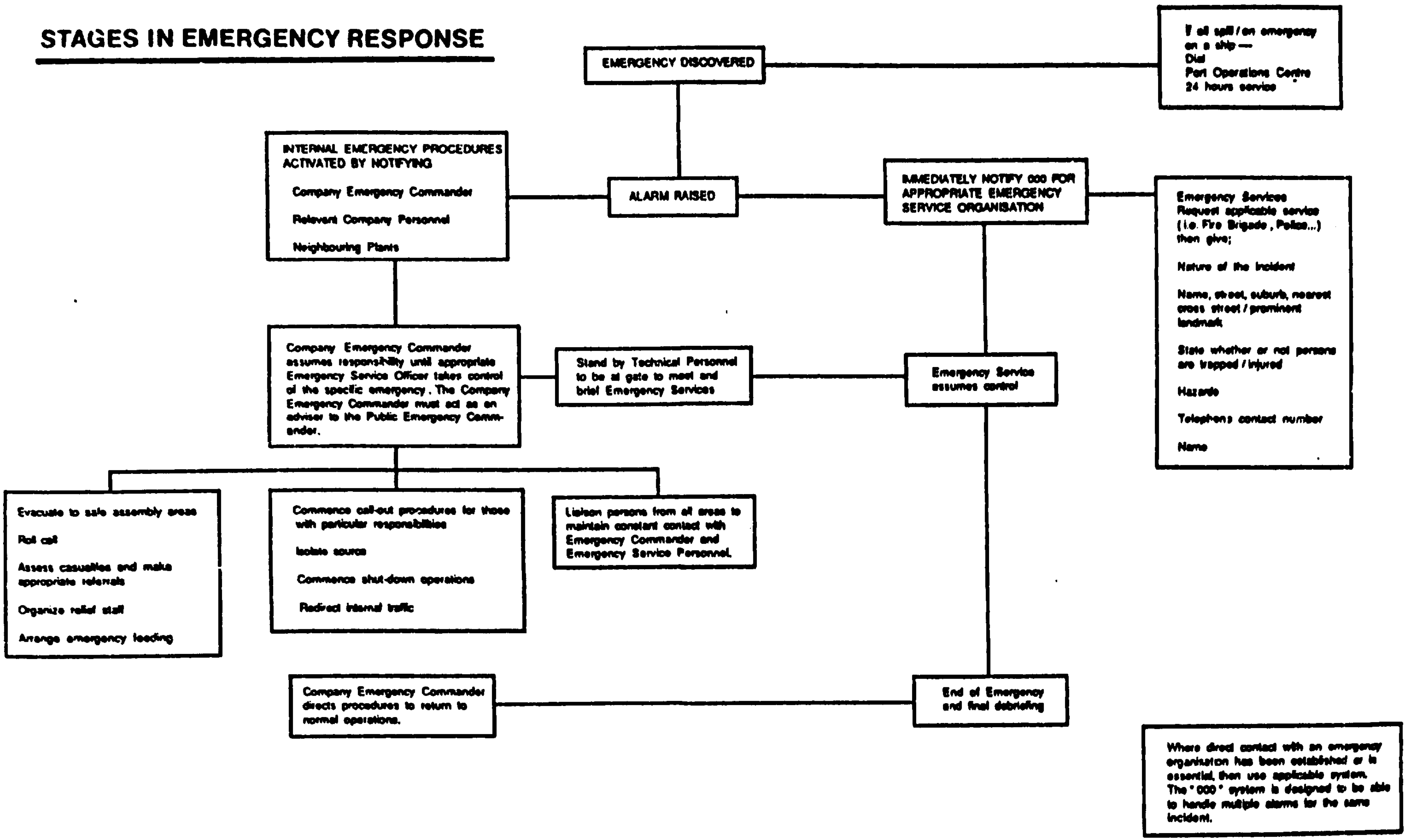


Figure 2.5

2.3.2 Scope and Content of Emergency Plan

The following information should ideally be included in the formalized emergency plans (see box).

	Scope and Content of Emergency Plan at the Plant Level
■	Plant size and layout of the facility
■	Definition of situations Covered under Emergency
■	The Aims of Plan Preparation
■	Purpose of the plan
■	Inventory of Hazardous Materials on the site
■	Details of the types of Emergency

i) The Plan Site

A brief description of the facility covered by the plan should be included together with appropriate site layout.

ii) Definition of Situations Covered

A clear, simple definition of what constitutes an emergency on the site and the various levels of emergency which are possible must be adopted.

An emergency can be described as an abnormal and dangerous situation needing prompt action to control, correct and return to a safe condition.

An emergency is a situation which may not be contained immediately by the people on duty using the available resources; where injuries have or could be incurred; where damage has occurred or property is placed in jeopardy or where the impact has the potential to result in serious environmental consequences.

The suggested levels of emergency are:

- local **Alert** for any situation which **Threatens Life**, property or the environment;
- site **Alert** where effects may spread to other areas on the site;
- external **Alert** where effects may spread and impact on the people, property or the environment outside the site or cannot be contained by site resources.

The plan should make it clear that if there is any doubt an event should be treated as an emergency. For example, all fires must be treated as emergencies.

(iii) **The Aims of the Preparation of the Plan**

A simple statement of aims would usually include the following elements:

- to decrease the level of risk to life, property and the environment;

- to control any incident and minimize its effects;
  to provide the basis for training and preparedness for all people who could be involved in any emergency at the site.

(iv) **Purpose of Plan**

The intent of the plan should be set out along the following lines:

- to control or limit any effect that an emergency or potential emergency may have on site or an neighboring areas;

- to facilitate emergency response and to provide such assistance on the site as is appropriate to the occasion;

- to ensure communication of all vital information as soon as possible;

- to facilitate the reorganization and reconstruction activities so that normal operations can be resumed;

- to provide for training so that a high level of preparedness can be continually maintained; and

- to provide a basis for updating and reviewing emergency procedures.

(v) **Hazardous Materials, Manufactured, Stored or Used On-Site**

A list of hazardous materials and harmful substances should be included with the associated information on: international code; safety data sheet; average/maximum inventory in storage; average/maximum inventory in process; the location of each of these materials clearly indicated and cross referenced to the site layout diagram.

The place where the Material Safety Data Sheets are stored must be nominated. It is prudent to have at least two sets of Safety Data Sheets to provide for a situation when the initial set cannot be accessed safely.

Each company of the industrial complex (plant) must prepare their own lists of dangerous goods.

All people who could be involved in any emergency must be familiar with the information contained in the Material Safety Data Sheets. Training and retraining will be required.

Note: Accurate and Up-to-Date Information on Hazardous Materials is Vital to the Plan.

(vi) Types of Emergencies

This is the crux of the plan. If the types of emergencies are not properly identified then the rest of the plan cannot be soundly based.

This section of the emergency plan must include consideration of the following emergencies and their potential impact on the site:

Fire (Including toxic combustion products)

Explosion

Spills (Liquids, solids, radioactive or other dangerous materials)

Gas Leak - toxic

Natural Events:

flood, grass fire, bush fire
earthquake
cyclones, wind and electrical storms
tsunamis (seismic sea-waves)
exotic stock/plant disease
human epidemic/plague
land slip/subsidence

Impact Events

road vehicles
railways
aircraft

Civil Disturbances

riots
bomb threats.

For all these cases initiating and secondary events must be considered, e.g. an LPG explosion or fire which causes a nearby vessel to fail and release flammable or toxic materials; a windstorm causing structural damage which results in a liquid spill.

This emergency identification requires a systematic approach such as formal hazard identification and consequence analysis. Frequency/probability analysis and quantified risk assessment may also be useful in determining appropriate levels of preparedness.

All plants must have intrinsically safe operating conditions if any of their services are interrupted, i.e. electric power, town water, etc. The intrinsic safety of plant when services fail must be tested on a regular basis and the results of these tests recorded.

Risks may be higher at specific times or during particular operations, e.g. loading or unloading.

(vii) Alarm Initiation

This section of the emergency plan must include a description of the alarm systems which are installed, how they are operated, when they are tested and details of the test records.

An alarm is a communication act to which there must always be an appropriate response.

The plan must provide that any person discovering an emergency situation or a situation which is likely to give rise to an emergency must activate the alarm procedure and then immediately contact a supervisor or senior person.

If in doubt always activate the alarm first and then clarify the doubt.

If the site supervisor is on site he/she or a specifically nominated person will become the on-site emergency commander, who will **Authorize or Confirm:**

- local **Alert** for any situation which **Threatens Life**, property or the environment;
- site **Alert** where effects may spread to other areas on the site; and
- external **Alert** where effects may spread and impact on the people, property or the environment outside the site or cannot be contained by site resources.

This section must cover:

- who can raise alarm (alarm points must be clearly identified);
- what does alarm activate;
- identification of signal;

visual	(e.g. flashing red light);
audio	(e.g. siren);
hard copy	(e.g. printed message)

- who receives alarm (e.g. Fire Brigade);
- what are actions on receipt of alarm; this should be a pre-planned response;
- how is alarm raised;
- how is raising of alarm confirmed;
- duplication of alarm system (will system work in power failure?);
- how and when is the alarm system tested;
- how test results are recorded and by whom;
- arrangements for independent verification by person within organization of alarm testing and recording.

The ability of the alarm system to reach all relevant people under all operating conditions, must be tested regularly.

(viii) Emergency Response and Control

The plan must identify clearly who will be the Company emergency commander and how that person can be recognized at all times. The functions of a Company emergency commander are presented in Figure 2.6.

The Company emergency commander must have:

- site knowledge;
- current knowledge of materials on site;
- knowledge of processes used on site;
- adequate personal protection for all possible emergencies.

The plan must also nominate the location of the site command centre.

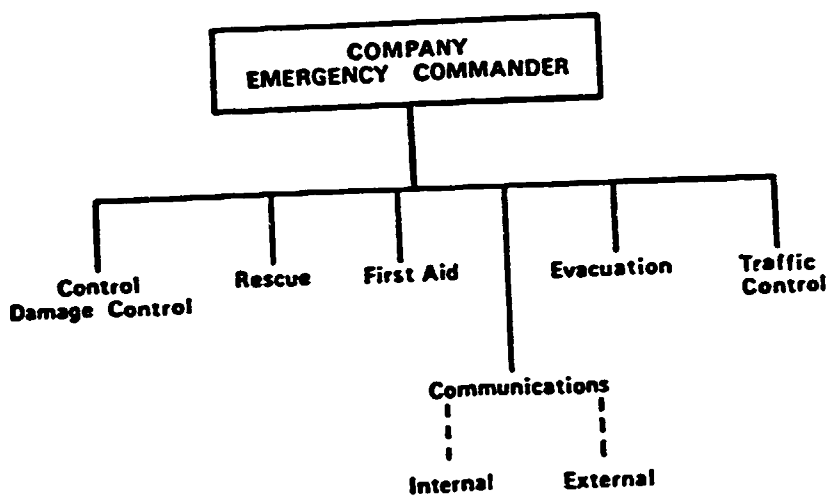

COMPANY
EMERGENCY COMMANDER
Control
Damage Control
Rescue
First Aid
Evacuation
Traffic
Control
Communications
Internal
External

Figure 2.6

An emergency can occur at any time not only during normal business hours.

The plan must nominate alternate emergency commanders for the times when the first nominated commander is not on site and arrangements for times when the site is not staffed.

If the site is unmanned, a list of emergency contact numbers (key holders) must be available for the public emergency services at the appropriate public emergency service headquarters. This list must be kept up to date.

If the emergency situation develops into an **'External Alert'** then hand over of emergency co-ordination to the **Public Emergency Service Commander** will occur. However, the Company Emergency Commander must act as an adviser to the **Public Emergency Service Commander** especially with regard to plant hazards and how best to minimize these during the emergency.

The organizational structure during the initial period of any emergency and for the particular local or site **Alert** shall be considered as in Figure 2.7.

The plan must nominate the persons who will perform each of the above functions. The person who has any of these functions delegated to him must accept full responsibility and have the necessary authority to implement the actions needed. The Company Emergency Commander must be free to command and therefore it is not appropriate for him to be involved in detailed actions. Depending on the size of the site and the emergency some of these functions may be combined.

(ix) Interaction with Emergency Services and Relationships to Existing Plans and Procedures

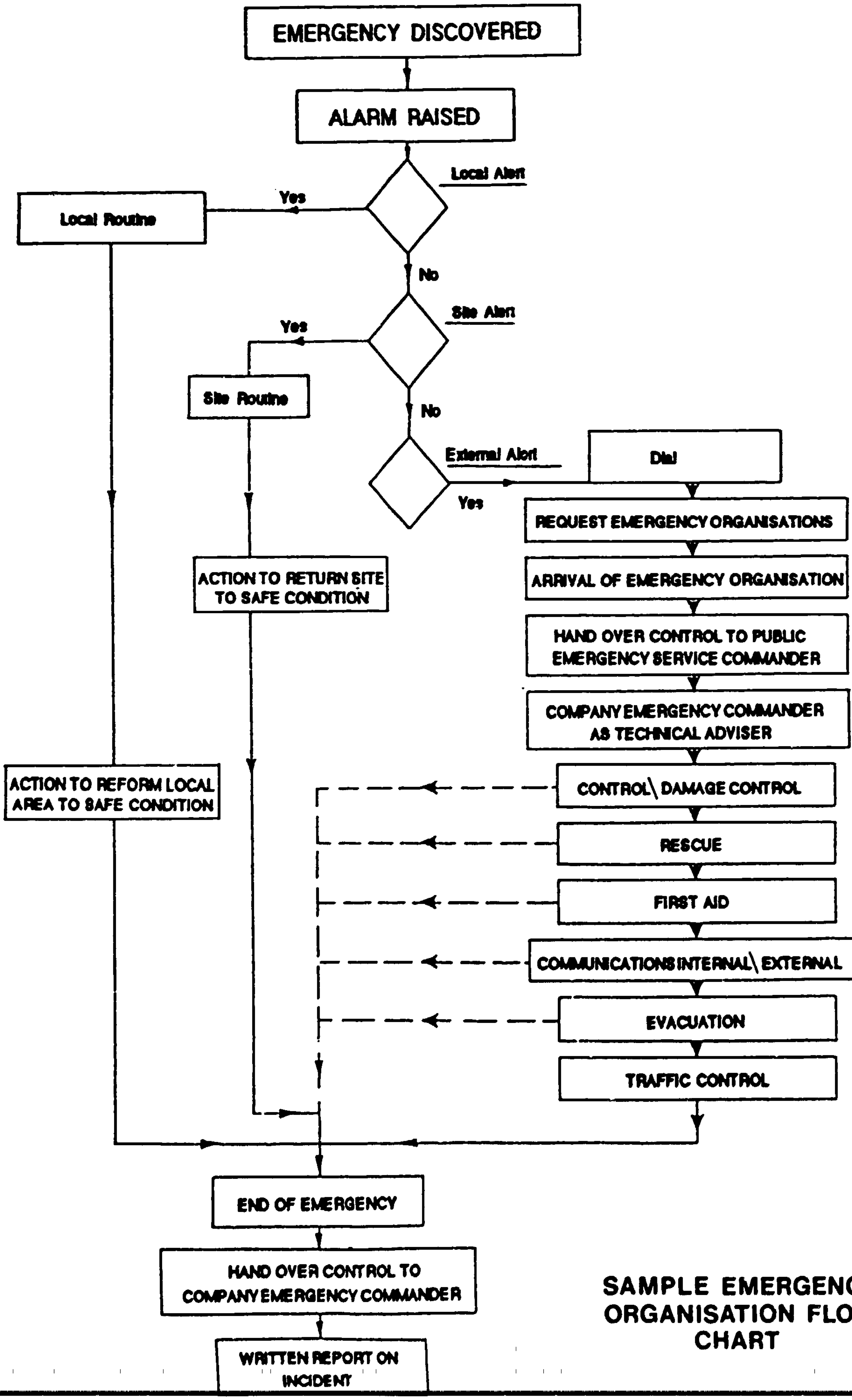
The plan should specify how the company's emergency response operates in relation to the various emergency services.

Some important general elements of interaction are described below.

In any emergency, internal roads must be free of vehicles not involved in handling the emergency. Access must be clear for large service vehicles at all times. Remember that there should always be two access paths to the site of an emergency.

Vehicles which are not directly involved in the emergency must not be allowed on site. The control of external roadways, pedestrian and vehicle control is the responsibility of the police department.

If the emergency operations control is activated, the public emergency service commanders would attend there and control the operation from that centre. All external communications, directions or requests would then be relayed



SAMPLE EMERGENCY ORGANISATION FLOW CHART to and from emergency co-ordination centre.

The company emergency commander will remain at the site.

Where it is apparent that a serious incident has taken place which has or may result in serious injury or death to a significant number of people, immediate steps are to be taken to initiate a disaster medical plan.

(x) Notification of Authorities

The plan must set out the procedures for contacting the public emergency services and adjacent companies and other neighbors.

Emergency services: Direct telephone contacts or alarm systems should be made available to the emergency services. The communication system must be designed such as to handle multiple alarms for the same incident.

Neighbouring companies: notification procedures for adjacent companies, other neighbors and the public in the area need to be developed specifically for each site. Contact people, phone numbers or alternative communication systems should be mutually agreed and documented. Notification procedures should cater for emergencies outside normal operating hours of the company and its neighbors.

(xi) Internal Emergency Resources

An internal emergency resources that are available should be listed and their locations shown.

e.g. - Emergency vehicle(s)
Fire teams
Self-contained breathing apparatus etc.
Fire fighting equipment
Fire control media i.e. foams, etc.

First-Aid Room
Trained First-Aiders
Medical Staff etc.

Rescue teams
Specialist equipment (e.g. ladders, cutting equipment, gas detectors, etc.)

The adequacy of these resources should be tested against the emergencies identified. It is essential that the emergency resources are well maintained and regularly tested.

(xii) **Emergency Communications**

Effective communications are usually the most difficult and demanding aspect of any emergency. The need for simple standard procedures, frequent training, testing and retraining cannot be over stressed.

The Company emergency commander 'must' set up a pre-planned command centre from where he will be able to manage and control the emergency. He 'must' have available means for internal and external communications.

The type, quantities location and limitations of internal and external emergency communications equipment must be listed.

A back-up communications system must be available and able to be operated in a power failure. It is essential that equipment is robust and reliable.

Note: some communications equipment may be a source of ignition and therefore may not be intrinsically safe for all uses particularly when flammable vapor/gas mixtures may be present.

(xiii) **Evacuation**

Procedures for evacuation of people on-site and off-site should be detailed.

Personnel on Site: the company procedures must provide for the evacuation of its employees. People should be moved in an orderly fashion and the numbers accounted for before and after each move. Visitors and contractors must not be overlooked. The procedures should specify who is responsible for making the decision to evacuate any section of the site.

Nearby People Who May be Affected: if the emergency is an external Alert then a procedure must be set out to make the people potentially affected safe.

Any evacuation of people outside the site is the responsibility of the relevant emergency authorities in the country (police, fire brigade...); control of external roadways, pedestrian and vehicle control is the responsibility of those authorities. The plan must make adequate provisions for co-ordinating actions between the company concerned and external emergency authorities in this regard.

(xiv) **Procedure for Terminating an Emergency**

When the **Public Emergency Service Commander's** role is complete he will hand back control to the Company emergency commander.

The Company emergency commander will carefully consider the overall situation. He may require additional actions to be completed before he declares the emergency complete. His task will then be to facilitate the reorganization and reconstruction activities so that normal operation can be resumed.

This section of the plan must include provision for clean up, safe storage and disposal of all contaminated material.

(xv) Public Relations and Debriefing

It is important that communications to the news media during an emergency are well planned. The news media can be very helpful during an emergency. In planning the public information system, consideration must be given to the proper drafting of news releases, provision for clearances of all releases by a responsible company executive and the expeditious distribution of releases to all media. Consideration must be given to providing a Company spokes person for radio and television. This spokes person may require training to adequately discharge this important function. A careless answer on the news media can destroy public confidence and exacerbate the emergency.

The ideal media release should include:

a) cause of the emergency;
b) action taken;
c) effectiveness of corrective action;
d) expected time when emergency will be terminated; and
e) co-operation needed from the media.

Note: Only State Facts.

(xvi) Statutory Investigation

There may be a statutory investigation into any emergency.

A coronal enquiry may be held in the case of fire and will be held in the case of fatalities.

Relevant government authorities may also require investigations.

The plan must provide for co-operation in these investigations and in particular should ensure that evidence is preserved.

The Company Emergency Commander must ensure that there is no interference with evidence and that any cleaning up, movement of bodies, repairs etc., apart from that necessary to bring the emergency under control does not occur without approval of investigating officers.

(xvii) **Written Report on Emergency and Review of Plan**

The plan must provide that immediately the emergency is complete, steps must be taken to ensure that a written report os the incident is produced.

It is prudent after any real emergency to review and revise the existing emergency plan. The plan should specify how and when this should be done.

(xviii) **Training and Evaluation**

As the plan is being written a training syllabus and schedule must be prepared for all of the people who could be involved in an emergency at the site. Some specialist training may be required e.g. fire control, the use of self-contained breathing apparatus, first-aid etc. Training for new people who join the organization must also be provided and records of training kept. Retraining is also an ongoing need.

The best method to evaluate an emergency plan is to simulate an emergency and have several observers watch and record what actually happens. Simulated emergencies are excellent training aids. The plan, and where applicable specific emergency procedures and sub-routines, should be regularly exercised by way of simulated emergency. Exercising should be carried out as frequently as is necessary to maintain the effectiveness of the plan.

(xix) **Review and Revision of the Emergency Plan**

In addition to review and revision arising from real emergency situations and training exercises, the plan will require on-going amendment to take account of all significant changes affecting the plan and periodic review and revision to ensure that it is still up-to-date, effective and in line with changing community standards. The plan should set out the procedures for such review and amendment and the frequency of periodic review. It should say how amendments will be made and who will authorize them.

It is essential for there to be periodic arrangements for independent auditing of the plan. This can be carried out by an appropriately independent person within the company or by an appropriate person from outside.

The format should be suitable for any amendment. Individual pages should show date of issue and person issuing.

(xx) **Distribution List**

An up-to-date list of all persons supplied with a copy of the plan should be included. The preparation and updating of the distribution list should ensure that all people who should receive a copy do. This list is also necessary to ensure that revisions and updates are provided to everyone holding the plan.

2.4 Emergency Planning and Procedures on an Industrial Area Basis

2.4.1 Overview

Emergency procedures and plans at the plant level are limited to the locality in the immediate vicinity of the plant. At the larger industrial area level, it is essential to formulate emergency procedures and plans that account for the overall cumulative emergency requirements, specific to the hazards in the area, and with specific provisions (organizational and operational) for the co-ordination of the individual emergency plans at the plant level. Emergency response strategies with associated resources and infrastructure needs will have to be formulated and tested on a regional basis.

This section outlines the most important elements and contents of the regional area wide emergency plan. It is essential, however, to ensure that each individual facility within the study has its own emergency plan (which may be considered as sub-plan of the overall area plan).

2.4.2 Scope and Content

The following items are suggested sections to form the basis of the emergency plan (see also the next box).

Outline scope and content of Area Wide Emergency Plan

- Purpose/scope of Plan
- Definition of Emergency
- Authority
- Emergency Plan Committee
- Characteristics of the Area
- Hazardous Materials Identification
- Types of Emergencies
- Related Plans and Procedures
- The Operational Plan
  - Alerting Procedures
  - Command
  - Control Centres
  - Access to Technical Information
  - Response
  - Evaucation
  - Incident Public Relations
  - Terminating an Emergency
- Resources
- Training and Testing
- Review and Revision

(i) **Purpose:** The main purpose(s) and objectives of the plan should be specified. Such purposes include: to help ensuring that emergency preparedness, response and recovery for incidents involving hazardous materials are adequate and appropriate for the whole area under consideration. The objectives of the plan should be clearly specified. Such objectives may include:

- To identify and test the adequance of response resources and response capacity in the region for major emergencies;
- To encourage/facilitate the development of measures to reduce impacts of hazardous incidents;
- To ensure that information on hazards, emergency planning, and incidents is effectively communicated to people living and working in the area;
- To provide for inter-actions with other plans;
- To develop and communicate a clear understanding of roles and responsibilities for emergency response and control.

(ii) **Scope of The Plan:** this should specify:

- The area to which the plan applies, including the range of activities and maps/plans for the area and its boundaries.
- The definition of emergency, in the context of the plant.

(iii) **Authority:** The government authority(ies) or committee who is responsible for the preparation and administration of the plan should be identified. Any statutory reference in the administration of the plan should be indicated.

(iv) **Emergency Plan Committee:** The formulation, administration, implementation, update and review should be undertaken by a committee comprising representatives of all relevant organizations, ideally: emergency service organizations (police, fire brigade, ambulance), industry (operating plants in the area), health authorities, local councils, community groups where applicable. In addition to the preparation of the overall plan, the committee should be responsible for its continuous update, the committee also has the responsibility for vetitng and reviewing the individual industry plans and other sub-plans and for ensuring consistency with other related plans.

(v) **Plan Area Characteristics:** The subject region and its characteristics should be comprehensively described in the emergency plan document, with associated support maps. Information to be included shall consider a description of the location, type, nature and characteristics of industrial developments, residential, commercial and other land uses, open space areas, roadways, demographic characteristics associated with population, environmental characteristics of the area including ecosystem, natural elements, etc.

(vi) **Hazardous Materials:** The central element of the hazards identification for the area emergency plan is the identification of the hazardous materials stored, in-process, or transported through the area. The location and quantities of such materials should be identified by categories and transport routes.

(vii) **Types of Emergencies:** For emergency planning, it is important as far as possible to comprehensively identity and quantify the type, scale, nature of possible events requiring emergency response, the nature and scale of impacts and the required response. It is important therefore for the plan to comprehensively and systematically postulate hazardous incident scenarios and to compute their consequences and magnitude and nature of harm to both people and the environment.

Emergency situations can be broadly divided into three categories: (i) hazardous materials incidents; (ii) natural events; (iii) other man-made technological event failures. From the inventory and location of hazardous materials and processes in the area, it is possible to estimate the area of fatality of injury impacts and the number of people affected from incident scenarios, under various postulated conditions of: fire, BLEVE/fireball, flash fires, vapour cloud explosions, releases with fire or explosion potential, dust explosion, toxic gas release, release of toxic vapours, toxic reaction of combustion products production, release with potential contamination of the environment and release of other health/environmentally hazardous materials.

The estimation of the area and number of people that may be affected provide a sound basis for estimating emergency response needs. It is important as well to have an appreciation of the likelihood (or probability) of such events occurring in practice, so that the allocation of resources to emergency response reflect realistic assumptions. An evaluation of the impact and likelihood of natural events which may need emergency preparedness should be included to enable emergency preparedness and planning. Other technological events that may have to be considered include: aircraft crashes, shipping accidents, building/bridge/tunnel collapse, crane or other equipment collapse/failure.

(viii) **Related Plans and Procedures:** The overall area plan should related to and refer wherever possible to other emergency plans or procedures applicable to the ares. Most importantly, the overall plan should ensure the integration of all individual emergency plans at the plant level.

(ix) **The Operational Plan:** This section of the plan should formulate and documen. the specific measures to be followed in the case of an emergency, including co-ordination between the various emergency organizations and industry, the roles and functions of the various parties and specific evacuation and associated measures. The following outlines the most essential elements to be covered:

- **Alerting Procedures:** specifying the prompt mechanisms for alerting and the people/organization to be alerted. Alarm mechanisms, telephone contact numbers and other alerting mechanisms should be clearly stipulated.

- **Command:** specifying the structure, functions and co-ordinating mechanisms of a specific chain of command during the emergency. The responsibility of each command level should be clearly specified at each level.

- **Control Centres:** to be established and specified in the plan. The function of these centre(s) is to act as the centre for communication and co-ordination during emergencies.

- **Access to Technical:** information access to acurate data on the chemicals at the time of an incident is essential. The operating plan shouldmake provisions for the location and access to update data sheets and relevant information.

- **Response:** the operatina plan should sepcify response action needed for the different postulated incident scenarios. The type of emergencies, impacts and responses required should be outlined. It should be noted that evacuation is not always the best reponse to a situation. The functions and duties of all personnel involved in the emergency response action should be specified. Such personnel include site personnel, transport personnel, general public, emergency service personnel.

- **Evacuation:** procedures should be specified. This should include on-site and off-site evacuation procedures, traffic control points, evacuation routes and assembly points. The conditions for which evacuation may be essential should be stipulated.

- **Incident Public Relations:** the operating plan should specify procedures for public notification and information during and after an emergency.

- **Terminating and Emergency:** the re-establishment of safe stable conditions will be the main factor in determining the timing of the termination of an emergency. The operating plan should specify the conditions and procedures for terminating the emergency.

(x) **Resources:** The plan committee should maintain an up-to-date resource list to be maintaned in the site plans and in related plans and procedures. The adquancy of resources against the range of emergencies should be carefully considered.

(xi) **Training and Testing:** The hazard, emergency identification and response requirements identified in the plan should be integrated into the training of company and emergency service personnel. At least once a year a major field exercise of the Plan based on a realistic scenario to test the effectiveness of the plan should be undertaken. Other 'table top' should be held as frequently as necessary to test and maintain the viability of the plan. Site plans should be tested at least once a year.

(xii) **Review and Revision:** The plan should be reviewed as periodically as possible to identify changes in hazards, resources, personnel, etc. Deficiencies should be identified and rectified. The plan should be reviewed:

- after every major incident;
- after every significant change in hazards, resources and other factors;
- after each annual exercise.

Table top exercises involving review against particular scenarios should be conducted from time to time.

B. Fire Prevention and Protection

2.5 Overview

The provisions of adequate facilities and infrastructure for the prevention of major fires and the protection of people, property and the environment from the effect of such fires should they occur, are essential elements of safety management. This applies at both levels of the individual plant as well as at the overall industrial region level where cumulative infrastructure requirements should be considered. The basic principle is that each industrial facility handling hazardous materials should accommodate adequate design, equipments, operational and organizational measures commensurate with the level of risk on-site. Every attempt should be made for each facility to be self-sufficient in this regard, ensuring the relevancy and appropriateness of fire prevention and protection measures.

An adequate level of fire protection at the plant level however, can not be achieved in most cases without appropriate support infrastructure external to the plant. This becomes particularly important and relevant when considering the safety management of an entire industrial region with a concentration of hazardous plants, where cumulative requirements need to be considered. The adequate provisions of fire prevention and protection infrastructure at a regional level should complement on-site plant level provisions and be an integral part of the overall safety management process.

This chapter provides an overall guidance as to the safety management aspects of fire protection and prevention at both the plant and the regional levels.

2.5.1 The Objectives and Principles of Fire Prevention and Protection

There are two components to a fire 'system': the physical or hardware components (e.g. smoke detectors, alarms, fire sprinklers) and the operational arrangements or software (e.g. maintenance and testing, training, emergency planning).

The principle of fire prevention and protection is that the fire safety 'system' should be based on specific analysis of hazards and consequences and that the elements of the proposed or existing system should be tested against that analysis. This should always produce a better outcome than the application of generalized codes and standards along.

Defining the hazard potential of a region, plant and/or operations involves the process of hazard identification and estimation of the potential consequences of credible incidents.

In addition to the hazard potential a number of other factors must be taken into account in the selection of the system. These include:

(i) **Land use safety considerations:** the impact of incidents on the surrounding land uses, and the sensitivity of these land uses (both at the individual process level and from postulated major incidents on a regional level).

(ii) **Infrastructure available:** e.g. water mains supply, area emergency planning, fire brigade response times and access;

(iii) **External factors:** effects from surrounding land use (e.g. other hazardous industries, bush fires), weather, etc;

(iv) **Regulations:** requirements of statutory bodies.

Too often, fire safety systems are seen merely as an adjunct to a facility and are not integrated into design and management. The importance of prevention in the overall system cannot be emphasized enough. The hazard potential and the risk of death or injury, property loss, or damage to the biophysical environment are at least as dependent on the design and layout and the management of a facility as on the nature of the activities involved and the nature and quantity of hazardous materials.

The fire protection and prevention system should be concerned with all the effects of fire. It therefore should not only address the direct effects of flame, radiant heat and explosion but also the potential for the release of toxic materials and toxic combustion products in the event of fire and the potential for the release of contaminated fire fighting water.

The fire protection requirement should be based on the worst case scenario(s); the step approach for a fire safety study is given in Figure 2.8.

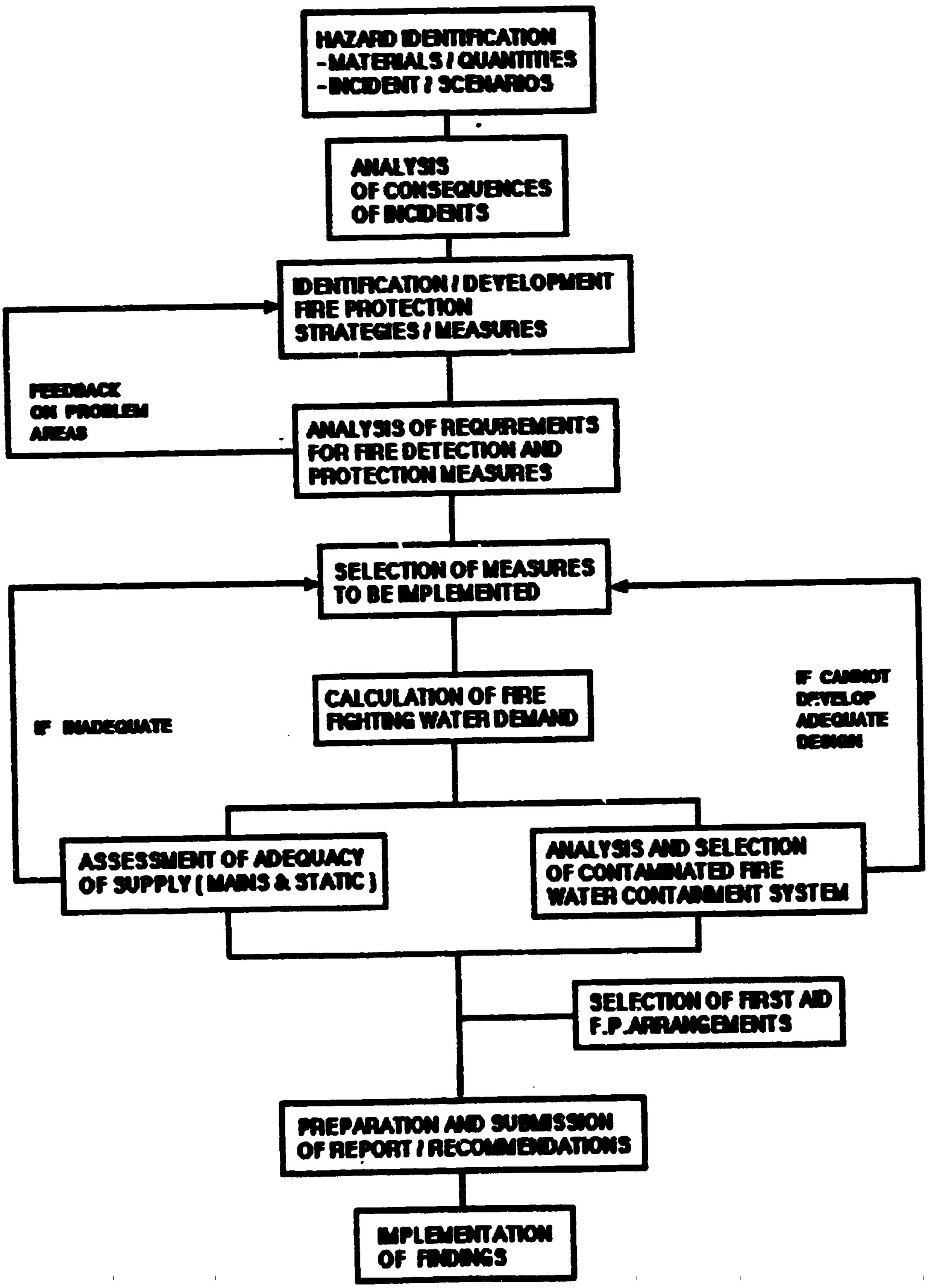
While the basis of these studies is specific analysis, codes and standards are an important resource in carrying them. These codes are generally minimum or basic requirement. Only after a specific hazard analysis is carried out, can the adequacy of the codes or standards to meet the need of the particular situation be determined.

2.5.2 Identification of Fire Hazards

This is the first step in the study, involving the identification of all possibly hazardous materials, processes and incidents. The possible internal and external causes of incidents should also be identified.

For example, if a storage terminal has tanks containing flammable liquids, such as petrol, then the possibility of tank fires, bund fires, fires due to pipe and pump failure and fire in loading or drum filling operations, etc. must be considered. Similarly, if a plant processes and stores large quantities of liquified flammable gases then the possibility of jet fires, vapor cloud explosions, flash fires and BLEVEs must be addressed. In the case of storage of materials with potential for generating toxic combustion products and/or contaminated water run

Flow Diagram for a Fire Safety Study



off, these hazards must be addressed.

On an area basis, it may be appropriate to postulate worst case accident scenarios for the major inventory of hazardous materials stored or in process in the area. The possibility of a domino effect that is an incident at one installation in the area triggering a hazardous event at an adjacent installation should also be considered.

The analysis should cover the nature of the materials and quantities involved, the nature of hazardous events (e.g. loss of containment), potential initiating events, ignition sources, etc.

It is important that the possibility of the site and the area being exposed to hazards external to the site is dealt with.

Word diagrams may be useful in the hazard identification. Table 2.1 is a sample word diagram.

2.5.3 Analysis of Consequences of Incidents

Once the hazards have been identified, the consequences of incidents can be estimated. The consequence analysis should address both the direct impacts of incidents and the potential for propagation and secondary incidents, particularly on an area basis.

The analysis should relate selected targets (people, equipment, buildings, etc.) to specific time related exposures (heat flux, explosion overpressure, toxic concentrations, etc.).

Justification must be given for the selection of targets, exposures and models used in the consequence calculation.

There are various models available for estimating the consequences of events. Generally, each model has a range of applicability outside of which its use is inappropriate.

All models and assumptions used to estimate consequences should be justified.

Note: If a quantified risk assessment study has been carried out for the site, the hazard identification and consequence analysis components of the fire safety study should be able to be largely drawn from that study.

2.5.4 Fire Prevention Strategies/Measures

The most basic element of fire safety is prevention. Appropriate design and layout of the facility and operating procedures and arrangements are essential to fire prevention. The study should move from the hazard identification and consequence analysis to identifying measures which minimize the likelihood of fires and/or reduce their severity or extent.

TABLE 2.1 SAMPLE HAZARD IDENTIFICATION WORD DIAGRAM

FACILITY/ EVENT	CAUSE/COMMENTS	POSSIBLE RESULTS CONSEQUENCES	PREVENTION/ DETECTION/ PROTECTION REQUIRED
Tank Farm			
Petroleum tank fire	. Static electricity build up and spark due to fast filling. . Pressure vent valve fails, tank roof fails and ignition.	. Tank roof may fail, fire of entire roof area. if not controlled or extinguished may involve other tanks in same compound.	. Pressure vent valves checked prior to fill/ discharge. . Foam injection system in all class 3(a) tanks. . Water cooling system on each tank.
Petroleum bund fire	. Corrosion tank base/floor . Pipeline/pump leakage/rupture. . Tank overfilled.	. Leakage of tank contents into bund. If ignited may result in pool or bund fire.	. Tanks cleaned, inspected, integrity tested annually. . Adequate foam stocks on site. . High high level alarms to be provided on all storage tanks. . Foam/ monitors to be provided in and around bund compound.
Petro-chemical tanks(s) (cool fire)	. Adjacent tank fire or bund fire heating tank contents to decomposition.	. Emission of Toxic products or vapours. Down-wind effects depend on toxicant released and wind/ stability conditions.	. Tanks placed in seperate bund. . Cooling system on all tanks.
LPG Road Tanker Facility			
. Flexible hose failure	. Road tanker drives away whilst still connected. . Third party damage or excessive wear.	. Gas disperses. If ignited may result in flash fire. Impact local.	. Fixed deluge system at road tanker bay. . Scully system on tanker loading.
. Pipe failure	. Mechanical impact. . Corrosion.		. Area drained. . Gas detectors around perimeter of LPG area.
. Pump seal failure	. Pump not maintained. . Pump run dry.		. Pump shut off at two locations, local and remote. . Isolation systems on main liquid lines.

Table 2.1 cont'd.

Warehouse Dangerous Goods Store			
Warehouse fire	. Wiring not flameproof. . Handling equipment not intrinsically safe. . Shrink wrapping fired by LPG, undertaken on site. . Arson . Lighting not intrinsically safe. . Unsafe storage of drums.	. Fire involving warehouse contents Exploding drums/packets depending on material stored.. . Toxic combustion products evolved.	. All products segregated by Class. Thermal/smoke detectors provided, linked to alarm and local brigade. . Warehouse sprinkler system provided. . Area bunded. . Flameproof wiring used in dangerous goods store. . Diesel fork lifts only. . Security firm employed after hours. . All lighting intrinsically safe . Drum storage racked or drum height restricted.
LPG Storage			
Catastrophic vessel failure	. Direct flame impingement on tank, from pipes, tank fittings or pump failure and ignition.	. Pressure inside tank rises, if fire not extinguished, vessel may weaken and fail resulting in a BLEVE/fireball. Damage widespread.	. Vessel fitted with pressure relief valves, discharge vertical to atmosphere. . Deluge system. . Isolation valves fitted to all main liquid lines. . Pump shut off at two locations.
Large leak	. Mechanical impact . Corrosion . Failure of tank or associated fittings, pump or pipework and ignition.	. On dispersion vapour may form a gas cloud. If ignited may result in UVCE or flash fire.	. Isolation valves on all main liquid lines. . Pump shut offs at two locations, local and remote. . Gas detection on perimeter of LPG area. . Fog nozzles provided. . Crash barriers provided around tank.

Examples of matters which should be considered as part of fire prevention include:

- building design and compliance with building regulations;
- elimination/minimization of hazardous materials in storage or in process;
- elimination of ignition sources;
- bund design, construction and capacity;
- type of medium suitable for the hazard (e.g. minimizing use of fire fighting water);
- separation of incompatible materials;
- housekeeping, etc.

Site security has implications for fire safety, as fire preconditions and fires themselves are often caused by intruders. The provision of physical barriers such as fencing and intruder detection systems (alarms) should be considered together with the staffing and operational arrangements.

The location of gatehouses, patrolling of the site, who responds to alarms, etc. should be considered. Arrangements to restrict access to critical areas or plant components should also be considered in order to reduce the possibility of employee or visitor actions which could lead to fire or fire pre-conditions (e.g. locking of valves, etc.).

Site upkeep (housekeeping) can be particularly important. Issues include removal of trade wastes; regular maintenance of installed facilities and equipment; clearance and checking of drains and collection pits.

Safe work practices, including observance of standards, codes and regulations, provision of material data including safety data sheets and company policies and procedures, all have important bearing on fire safety and should be explicitly addressed.

Procedures and practices covering contract work should be carefully considered, especially hot work controls and permits and gas/vapor checks.

Appropriate emergency plans and procedures are an important part of fire prevention. Appropriate and early action can prevent small incidents developing into serious situations and can limit the scale and extent of the impact of incidents. The development or analysis of fire prevention strategies and measures should therefore be integrated with emergency planning.

2.5.5 Analysis of Requirements for Fire Detection and Protection

From the consideration of prevention measures, the analysis should move to the requirements for fire detection and protection. This should include detection of pre-conditions for fire, such as flammable atmosphere detection, and physical protection measures such as purging with inert gases of vapor spaces.

Issues to consider include:

- Prevention of fire pre-conditions, e.g. inert vapor spaces;
- Detection of fire pre-conditions, e.g. leaks and spills of flammables, flammable or explosive atmospheres, overheating in process vessels, etc;
- Explosion suppression;
- Detection of combustion, smoke, flame - early warning systems, thermal alarm systems;
- Fire suppression, e.g. automatic sprinkler systems, foam systems (type of foam), gas flooding, (Halon 1301, CO_2, hydrant systems, hose reel systems; monitors (water and foam);
- Prevention of propagation, e.g. cooling, deluge systems, drencher systems;
- Isolation of fuel supply especially means of control of gas or liquid flows from storage vessels, including pump controls etc., valves, switch or control actuators (local or remote).

Road and rail vehicle and ship loading and discharge facilities should be fully covered in the protection systems.

In some cases it may be better to contain rather than extinguish a fire, e.g. it is generally best to let LPG jet fires burn rather than extinguish the fire and allow the possibility of a vapor cloud explosion.

The type of extinguishing or control medium needs to be carefully considered as not all fires can be extinguished or controlled with water. Some require foam, dry powder, CO_2, even water in various forms, e.g. fog, jet or spray.

Another consideration is that water may be used for cooling of exposures but a different medium used for extinguishing or control. Where this is the case, compatibility between the two mediums is essential. If, for example, water breaks down the foam applied, the design foam application rates need to allow for foam breakdown, or alternatives to cooling water used (for example, insulation of vessels to be protected).

The use of halons for proposed, was well as existing, developments should be re-examined. Because of their contribution to ozone depletion and the greenhouse effect the future use of these materials will be restricted. However, while alternatives should be sought, in some cases halons may be the only feasible solution.

The need to control spillage and drainage from the area in the event of fire, should be built into the analysis, including the need to contain or limit run-off of contaminated fire-fighting water.

Ventilation can be a factor in confined places. Control of smoke or toxic releases also needs to be addressed.

Design features identified through the fire prevention measures analysis (such as mounding of pressure vessels, increased separation distances, in-built safety features etc.) can reduce the need for fire protection. For example, reducing the number of tanks in any one bunded area may reduce the requirement for foam and/or water.

2.5.6 Fire Fighting Water Demand and Supply

A crucial part of the fire protection system is ensuring that the hydraulic design is sufficiently satisfactory to cope with the hazards and consequences. There are three elements: fire fighting water demand, fire fighting water supply and contaminated water containment and disposal. The demand calculation is based on the protection system selected. If the supply cannot be made sufficient to meet the demand, or the contaminated water systems cannot cope with water applied, the choices of protection systems will need to be reviewed.

Once the protection systems have been selected, the fire fighting water demand can be calculated. This calculation should be based on the worst case fire scenario(s) and its/their foam/cooling water requirements. The demand will depend on the duration and intensity of potential fire(s), the prevention measures including facility design and the protection systems selected. Demand will be particularly influenced by choice of fire fighting media and facility layout (especially in relation to cooling water). Other features of particular significance include fire rated construction, vapor barriers, and compartmentalizing of storage (including separate bunding).

Analysis of supply should cover details of the fire water pumps. This would include the number of pumps and their configuration, power supply; pump details including capacity, type etc.; pump curves, backup, etc.

The calculations justifying the fire protection should show pressure and flows on operation of any and all of fire fighting facilities in the area under review.

Where appropriate the facility should be divided into fire areas and the water requirements calculated for each area.

The design of the water supply system must be assessed against the calculated water demand.

The adequacy of the water supply available from towns mains should be assessed based on written advice from the local water authority.

Where the mains water supply is not adequate in terms of quantity or reliability the need for static water supplies should be considered and the size and type of storage identified with drawings showing location of mains, size and street hydrants.

On-site water storage should be calculated to meet worst case demand. The minimum requirement is generally 90 minutes supply.

The analysis needs to include careful consideration of the effect of potentially competing demands for reticulated and static water supply.

In most cases the supply of fire water to the site is achieved by a combination of static water storage (on the site) supplemented by town mains water supply.

2.5.7 Containment of Contaminated Fire Fighting Water

The importance of the containment of contaminated water will depend on the nature of the materials held on site and where the site drains to. For example, if substantial quantities of biocides are involved and/or the site drains to a sensitive environmental area then special attention would be warranted.

Factors that need to be taken into account in the design of the retention system include control, drainage, storage and disposal.

The design of the contaminated water containment and disposal system should be based, where appropriate, on a probabilistic analysis. The analysis should account for not only the total containment of the calculated run-off of potentially significantly contaminated water from the worst case scenario fire but also the availability of the retention capacity as affected by rain events, testing, treatment and disposal arrangements. The possibility of soil and groundwater contamination should be considered in the analysis.

2.5.8 First Aid Fire Protection Arrangements and Equipment

In addition to fixed fire protection systems, provision for first aid fire protection equipment and operational arrangements must be considered.

Relevant matters to be covered would include:

- Provision of portable fire extinguishers - size, type, medium, number, location, testing and maintenance.

- Provision of hose reels - number, location, type, testing and maintenance. Installed hose reels can remove the need for water type extinguishers.

- Provision of warning signs (including exit signs and first aid fire fighting equipment use instruction signs) - location, type, size.

- Site fire crews - formation, training, responsibilities and drills.

- Training of operators/staff - knowledge of plant, materials, emergency action/shut down procedures.

- Road vehicles measures - extinguishers, driver/operator instruction, placarding, vehicle maintenance, etc.

The interaction of these matters with emergency planning should be carefully considered.

2.5.9 Additional Consideration for Fire Prevention and Protection on an Area Basis

In addition to the above, it is essential to ensure that adequate fire prevention and protection infrastructure is available on a regional basis, accounting for the cumulative requirements of the various plants. The following safety management principles apply in this regard:

- An adequate fire water reticulation and water supply/piping system should be available to cover the entire area. Two critical factors are important: the flow and pressure of water supply should be such as to adequately meet the requirement of each installation based on the installed static water storage. Hydraulic computations should also account for con-current demand by at least two installations simultaneously under worst accident scenarios. The second factor relates to the reliability and security of the main fire water supply system. In addition to regular testing and maintenance of that system, it is important to ensure that an alternative system is available should failure occur to the main fire water supply system.

- Adequate access provisions should be made throughout the region, including the provision of roadways, to ensure fire brigade attendance under emergency conditions.

- It is useful in many cases to provide for a centralized shared facility for appropriate fore fighting media such as foam, dry powder, emergency equipment, etc. The facility's location should be optimized in terms of accessibility to the different joint users.

- The formation of a mutual aid group to coordinate joint fire prevention and protection amongst the different industrial organizations, including the sharing of information should be encouraged.

- Adequate documentation on hazardous substances, location of fire fighting media and equipment should be available on a centralized basis for all facilities in the industrial region under consideration.

PROCEDURAL GUIDE FOR INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

VOLUME III

ELEMENTS OF INTEGRATED RISK MANAGEMENT FOR LARGE INDUSTRIAL AREAS

CHAPTER 3

WASTE AND TRANSPORTATION INFRASTRUCTURE RISK MANAGEMENT

Chapter 3: WASTE AND TRANSPORTATION INFRASTRUCTURE RISK MANAGEMENT

This chapter outlines the risk management principles for both waste and hazardous material transportation.

The development of waste management strategies must consider wastes from "cradle to grave" and must consider all sources, plus transportation and waste management operations, including storage. Waste management is often economically beneficial in direct terms, even at the production unit levels. At the broader regional, national and global level the direct and indirect economic benefits can be very substantial. Integrated waste management offers many economic and technical benefits and encourages holistic solutions. This does not however necessarily mean integrated facilities. The assessment and development of waste management strategies must have regard to the particular social, economic, political and environmental context and any recommendations must be capable of implementation in that context. Borrowing uncritically from the experience of other countries is unlikely to produce good results.

The formulation of safer alternatives for the transportation of hazardous materials by road having due regard for land use, social and economic constraings, is an essential element of the overall integrated management approach. A systematic evaluation of these factors provides the basis for the formulation of appropriate transportation strategies on an integrated basis.

(A) Waste Management

3.1 Overview

Historically waste "management" was waste disposal. Wastes were materials to be got rid of as quickly as possible with the least disposal cost and little regard to impacts. As problem impacts became clear, remedial measures were introduced - often however, these involved a higher chimney, a bigger hole or a longer pipe! Whilst in some cases waste management did develop a degree of sophistication quite early, for example activated sludge sewage treatment, for many hazardous wastes, particularly those where impacts were not immediately felt, relatively crude methods such as basic landfill or simple incineration have continued to be used. The multitude of sites identified for clean up in industrialised countries bears testament to this - the most dramatic example perhaps is the 1800 sites identified as national priority sites under the Superfund by 1990 in the United States.

Typically there has been a lack of co-ordination and integration of waste management policies and practices. Individual industries have been left to solve their own problems or commercial operations became involved in dealing with parts of the problem. This approach has generally proved to be unsatisfactory and increasingly in recent years more holistic solutions have been sought. Whilst progress has been made in this regard, at all levels in both the developed and developing countries, much remains to be done.

The fundamental starting point for the development of integrated waste management strategies is to understand that waste management must be socially, institutionally and economically appropriate as well as technologically and environmentally appropriate. Waste management policies and strategies which are imported from other cultures and political systems without modification are unlikely to succeed Policies which rely for implementation on an institutional framework which does not exist will fail and strategies which impose costs to the local, regional or national economies which cannot be sustained will also fail. Once this perspective is adopted the development of viable waste management strategies can usefully be attempted.

3.1.1 Waste Management Hierarchy

A common framework for the development of waste management strategies and the assessment (see chapter 4, volume 2) of existing practices and policies is a hierarchy of management practices moving from most to least desirable in terms of environmental impact. There are many variations on the expression of this hierarchy but the ranking is usually along the following lines:

- Prevention
- Minimisation
- Recycling/reuse
- Treatment (physical, chemical, biological)
- Incineration

Prevention, sometimes referred to as avoidance, involves changes in product mix, use of alternative methods of production or management of wastes such that they are rendered non-hazardous. If no hazardous waste is generated the hazard is eliminated.

As not all hazardous wastes can be eliminated entirely, minimisation may be appropriate whereby the volumes or hazardousness of the waste stream are reduced.

Recycling or reuse can be within a production operation or after product use. There are many unrealised opportunities for this form of waste management in most industrial areas. Care needs to be exercised, particularly with off-site recycling operations, that the recycled material is fit for the end use rather than being an unsound practice in itself (e.g. burning PCB contaminated oils or solvents in ordinary furnaces).

Treatment covers a whole array of different processes and may result in a useable product or a non-hazardous or less hazardous waste. Simple neutralisation, distillation, separation etc may be relatively cheap and straightforward. For some wastes, however, treatment can be complex and expensive e.g. synroc or vitrification for radioactive wastes. Biological treatment with bacteria or fungi is a developing form of waste treatment particularly for low level contamination in soils etc.

Incineration is one form of physical/chemical treatment and is separately mentioned because of its prominence and often controversial nature. Under appropriate conditions incineration can, however, be a low hazard and environmentally benign means of waste disposal.

Landfill has been a traditional means of waste disposal which has left a legacy of contaminated sites and contaminated ground and surface water in many countries. Landfill and secure landfill operations, however, are likely to continue to remain a necessary waste management option for some time. It is important therefore that such operations are carefully managed and located to minimise impacts. Marine dumping is increasingly constrained by international treaties and has only a limited future. Nonetheless it is likely to continue for some years and may be an appropriate option for some classes of waste. Such operations need extreme care and supervision.

Long term storage is also likely to remain necessary and appropriate for some wastes and its proper management and security need to be carefully addressed.

Whilst this hierarchy is presented in broadly descending order of priority,

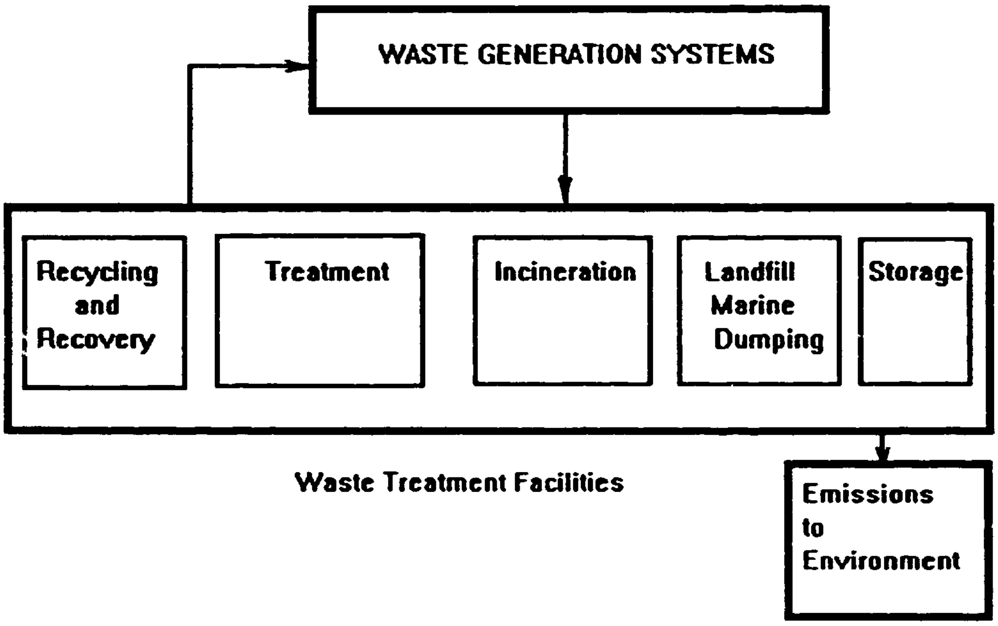

WASTE GENERATION SYSTEMS
Recycling and Recovery
Treatment
Incineration
Landfill Marine Dumping
Storage
Waste Treatment Facilities
Emissions to Environment

Fig. 3.1

it must be stressed that detailed consideration is required to ensure the right mix of measures (see Figure 3.1).

Waste prevention, for example, is clearly the highest objective as it eliminates any hazard by eliminating the particular waste. However, the full set of implications of a waste prevention measure must be considered. In some cases the economic or social cost of prevention policies may be too high, whilst in others risks or other environmental impacts may be being transformed or shifted geographically or temporally. In such cases, equity considerations or negative net benefits may militate against proposals.

An example of this is the transfer of hazardous waste generating activities to other regions or nations - the products can still be enjoyed but the waste is someone else's problem.

At the other end of the hierarchy, long term storage, which is generally considered undesirable, may in fact be the best option when other technologies do not exist. Storage, for example, may be preferable to secure landfill as the integrity of containment may be more readily able to be checked.

The divisions of the hierarchy are necessarily somewhat arbitrary and in practice individual initiatives may have components of several elements e.g. minimisation, treatment and recycling in on-line solvent recovery.

3.1.2 Economic Considerations

Economic considerations are of great significance in assessing and developing waste strategies. The cost side of the equation is more often considered than the benefits. However, the benefits can be substantial in direct terms from the production unit level upwards. If less direct benefits are considered then, by definition, the benefits of sound waste management measures will outweigh the costs.

At the production unit/industry level in many cases efficient production methods will generate less waste. In such cases there are likely to be savings in energy and in raw material inputs. Recycling and reuse of materials offers much scope in this regard. Some waste treatment operations also generate energy which can be used. There may also be savings through reduced payments for waste disposal.

For the wider regional, national and global economy there are benefits in internalising costs to the waste generating activities. There are also the benefits of avoiding the adverse impacts on the environment and on people with attendant direct and remediation costs. Internalising costs aids resource allocation decision making and sound waste management minimises the transfer of waste costs/impacts to people not benefiting from the activity and to future generations.

In making waste management decisions long term as well as short term costs and benefits must be considered.

3.1.3 Integrated Waste Management

It is widely acknowledged that waste management for urban and industrial areas should be comprehensive and integrated. Integration enables an optimum mix of management strategies so that environmental impact, including risk impact, and costs can be minimised. It must be stressed, however, that it is the waste management policies and strategies which need to be integrated, not necessarily treatment or the treatment/disposal facilities.

The best solution to a waste problem in some cases will be on-site, including on-line, treatment. This could particularly apply to large petrochemical plant, for example, where capital, technology and expertise, together with the elimination of any need for transportation, may combine to make this the option with the least environmental safety impact. In other cases collection and transfer to a centralised facility may be preferable. Where, for example, waste generators are of a small scale and numerous and the appropriate treatment technology is expensive and requires a certain scale and expertise, the centralised approach is likely to be preferable. The critical aspect of the analysis is that, as with other aspects of area risk assessment and management, the specific analysis should be relied upon to develop recommendations and solutions. Decision making in this regard should not be based on generalised rules or preconceptions.

A further aspect is that where treatment/disposal processes are integrated it is not necessarily optimal to have the facilities all in the same location. Transport economics and transport risk considerations for example may favour the location of an incineration operation close to waste sources. For the lower volume and less hazardous ash and salt residues on the other hand, transportation to a more distant suitable landfill sites may be appropriate. As waste management is often at its best and easiest if waste streams are kept separate, integrated waste treatment should not involve bringing together mixed wastes for subsequent separation.

In integrated waste management, particular attention must be paid to ensuring comprehensive coverage of wastes generated and full "cradle to grave" control. Procedures must be in place to ensure that wastes are known and controlled to ensure that treatment processes etc are not compromised and that no inappropriate (accidental or deliberate), disposal of the waste occurs. Control of transportation operations clearly forms a critical part of this overall management. Monitoring of the performance of facilities in procedural terms and physical monitoring of emissions, and of the potentially affected environment is also an essential component. Before decisions are made on particular waste management options, careful consideration needs to be given to the technical and economic limitations of monitoring and the consequences of inadequate monitoring. In all cases, monitoring costs should be factored in to the waste management cost calculations. Responses to deviations detected by monitoring should be pre-planned.

Consideration of the transportation issue raises the possibility of movement of waste into or out of the area under study. An important international principle, is that international transfers of hazardous wastes are to be discouraged. The basis of this approach is that countries should accept responsibility for the disposal of the wastes they generate. This is likely to maximise waste avoidance and minimisation and sound management generally.

This principle can also be applied to an industrial operation, local area or region and whilst it may lead to better waste management in some cases it should be applied judiciously. For reasons of scale, technology, expertise and sensitivity/suitability of the area (for particular forms of landfill for example) inter-regional and international transfer of wastes may in some cases be justifiable. The area analysis should have regard to this in the identification of waste streams and the development of management recommendations.

A final and important point is that integrated waste management should not be seen as a matter of broad brush solutions. Successful waste management strategies around the world, on the contrary, have generally been achieved through a series of small changes set in an appropriate overall context.

3.1.4 Legislative/Regulatory Approaches

A wide variety of regulatory approaches have been developed around the world. Responsibility for different elements of waste management is variously vested in local, regional, state or national governments. The different waste streams and elements in the total management are grouped in many and varied ways. The extent of regulatory intervention in industrial waste management also varies from minimal to extensive. This reflects the diverse social and political contexts and historical development of waste management.

Each approach has strengths and weaknesses and while much can be learnt from the experience of other countries, it is not possible or appropriate to explore these experiences in detail in these guidelines. As previously stressed, it is important that the hazardous waste management strategies and regulatory frameworks are appropriate to their operating context and are capable of successful implementation. Regulatory systems are covered in the reference material listed at the end of the chapter.

From a review of the regulatory systems and approaches, a number of key elements of successful strategies and issues that need to be addressed in assessing and developing waste management strategies can be identified.

These include:

- Definition and categorisation of waste.
- Definition of responsibility for wastes and waste management.
- Regulation or direct participation in waste management of facilities.
- Enforcement powers.
- Training.

Definition of Wastes: it is important to clearly define and categorise wastes and waste streams so that there is no ambiguity as to the responsibility for and appropriate management of waste.

Many different systems of waste classification have been developed by regional, state and national governments. At the international level the OECD has proposed a comprehensive system of classification. UNEP has also produced a waste classification system.

Categorization is more difficult than for other hazardous materials as the materials are often mixtures of materials which may also have different hazards attached to them. Categorisation also has to recognise that the hazardousness of wastes is in part a function of the appropriateness of their management.

Waste classification systems to be useful need to be able to aid in monitoring of hazardous waste generation and movement

- aid in ensuring appropriate management of hazardous wastes
- aid the assessment of waste management strategies and systems.

They need to be compatible with other hazardous materials classifications and regulatory systems and with the broader regulatory and administrative context.

Classifications need to cover composition, physical state, packaging/containment and type of hazards.

One particularly important reason for a robust waste classification system is the tracking of wastes from production through transport and storage to final treatment or disposal. In the absence of a classification system or a loosely administered one the discrepancies in waste description are likely to lead to errors and abuses. For the purposes of area studies, the limits placed by the exclusion of wastes from existing classification systems should be disregarded.

Responsibility: as important as classification is the question of responsibility for management of particular wastes and ownership of the wastes. There have been many examples around the world of problem wastes transferred from generators to other parties who do not manage the waste properly. Much resultant damage to the environment and to health has occurred.

Unless wastes can be traced to the generators and the generators and any other handlers of the waste can be held liable for the consequences of releases or unsound management, it will remain advantageous to some to employ inappropriate disposal methods.

In the United States a major piece of legislation, the Resources Conservation and Recovery Act, enshrines the principle of "cradle to grave" responsibility for wastes. Waste generators are liable for any adverse impacts of the wastes regardless of whose acts or omissions cause the impacts.

Whilst this is an important principle and facilitates control of wastes it must not be regarded as sufficient in itself. Liability for impacts is only as good as the capacity to pay for remediation and compensation. There is a limit to every entity's capacity to pay and in many cases effective remediation may be impossible and any compensation inadequate. Measures to ensure safe waste management must therefore go beyond this including fostering commitment to sound waste management by generators and others involved.

As well as responsibility at enterprise/production unit level, responsibility must be accepted at local, regional and national level for wastes generated. Transfer of problem wastes to other areas or countries is becoming increasingly unacceptable and it militates against waste avoidance and minimisation as the waste generation and waste impacts are separated. In some circumstances there is a case for movement but only if better waste management results.

The extent of concern over international movement of wastes is highlighted by the OECD treaty on transfrontier waste movements. The practice adopted by some developed nations in seeking to transfer problem wastes to developing nations is to be condemned both because of the impacts on the people and environment of receiving countries and on the global environment.

Transferring waste generating production activities, whilst possibly offering economic benefits to the new production areas, is not likely to reduce waste generation and improve waste management.

Extent of Direct Involvement: in many countries waste management facilities are wholly or partly owned and/or operated by public sector waste management authorities. Joint public/private ventures are also fairly common. It is argued that such direct involvement is more effective in ensuring high quality of critical waste management operations such as high temperature incinerators. Depending on the circumstances, public perceptions may also be best dealt with by direct involvement rather than external regulation. Again, however, it is the operational effectiveness that matters and the appropriate nature and extent of government involvement must suit the particular context.

Enforcement: all regulation is only as good as compliance. Compliance can be voluntary or due to coercion. Co-operation and real commitment to sound waste management is preferable but regulations also need to be able to be enforced. For this to be the case the powers, resources and the commitment of government must match the regulations.

Training: people cannot implement sound waste management strategies unless they have knowledge of regulatory requirements and sufficient knowledge to be able to implement them. Provision of training at all relevant levels should therefore be a part of the regulatory approach.

3.2 Technologies

Whilst waste management should not be seen as a matter of technological solutions in isolation, the application of technology which is appropriate to the wastes in their technical, economic, social and environmental context is critical. This section very briefly touches on relevant aspects of technologies which may be applicable to elements of waste management within the hierarchy discussed in the previous section.

It must be stressed that the coverage here is very limited. There is an extensive literature on waste technologies. Some aspects of waste treatment in particular have been the subject of many investigations. In the case of treatment of stable organochlorine wastes, such as PCBs and TCDD, for example, there have been numerous comparative assessments of technologies and particularly of high temperature incineration technologies. A selection of relevant literature is included in the list of references.

In judging the appropriateness of a particular technology, regard should be had to new or emerging technologies which may do the job better or more economically. As technology in many areas is undergoing rapid change and community standards and knowledge of the impacts of chemicals change, it is essential to keep options open and take advantage of opportunities to upgrade waste management as they become available. A fixed life for a facility or a periodic review of performance and continued appropriateness may be desirable.

3.2.1 Prevention

Choice of appropriate technology is a critical element in waste prevention. There are two important dimensions to this: the selection of technologies which do not themselves generate hazardous wastes; and, the selection of technologies which do not use as inputs materials or produce products which generate hazardous wastes. In some cases this may involve controls over the use of products such as the banning of organochlorine pesticides and asbestos containing products. In other cases the choice may be at plant level where choices of technology may exist which, while not changing the product, do change steps in the process so that certain waste streams are eliminated.

3.2.2 Minimisation

Many of the same observations hold true for minimisation policies as for prevention. In the case of minimisation, however, the changes may be less dramatic. Selective controls on product use, fine tuning of existing processes etc may prove very effective in reducing waste volumes. An example of this is the case of CFC's where under the Montreal Protocol and subsequent international agreements production and use is being phased out and substitutes, such as LPG in aerosols, are being used. There remains, however, an acceptance of the use of CFC's, for the time being at least, in metered dose aerosols for the treatment of asthma and similar ailments.

Improvements in efficiency of processes to give higher yields of the desired material and lower yields of byproducts may offer much scope for waste minimisation.

An element of waste minimisation may be concentration as smaller volumes of more highly concentrated wastes may be preferable to a larger volume of contaminated material.

An example which illustrates both these elements is solvent recovery from heavy ends and sludges in solvent production. Yields are higher and the volume and hazardousness of residual waste is reduced.

3.2.3 Reuse and Recycling

Recycling or reuse of hazardous wastes is an important component of waste management strategies as it involves the conversion of the "waste" physically, chemically or conceptually from a waste to a useful material. Recycling or reuse may involve on-site or on-line processes or the transfer of the waste to another site or process or the collection of wastes from outside source for processing and use on-site. Simple measures like re-using quench or washing waters can be very effective.

One consideration favouring the development of industrial complexes is the opportunity to utilise what would otherwise be waste streams. Careful planning to achieve maximum integration of facilities is worthwhile in this regard. The development of shared waste treatment facilities can also be beneficial, particularly if planning ensures maximum compatibility.

Changes in technology may be required to achieve such recycling or reuse of materials. In other cases the critical element may be the identification of opportunities and markets for wastes. Waste exchange programs have a role to play in this regard. Successful programs have been undertaken in a number of instances. Notable examples include programs in the Netherlands (initiated in 1972) and Canada.

Waste exchange programs, in addition to environmental gains may offer substantial economic gains through payments for "wastes" or reductions in disposal costs.

3.2.4 Treatment

Waste treatment technologies are many and varied. They may involve physical, chemical or biological processes or a combination of these. The processes can be typified as:

- reducing waste volume - through, for example, dewatering or solvent recovery;
- separation of constituent parts - through distillation, settlement or other physical or chemical separation, for example, mine tailings settlement;
- conversion to another less hazardous or useful material - for example neutralising acids and use of fungus or bacteria to break down organochlorine;
- stabilisation to prevent subsequent hazardous reactions, leaching etc - for example heavy metal sludge stabilisation with flyash and cement prior to landfill and vitrification/synroc type proposals for radioactive wastes.

Incineration is a physical-chemical treatment process. It is covered separately, however, owing to its importance and the controversy which often surrounds its use.

The appropriate treatment technology depends on the nature of the waste stream, the options for use or disposal of residual wastes, and other factors.

Inappropriate technology may well be relatively expensive and ineffective. At worst the hazard or risk may be increased if the wrong technology is used. In practice a particular waste stream may go through a number of processes. For example, aqueous waste from metal coating works may be separated by settlement of suspended matter, the resulting sludge may be further dewatered by heating and/or pressing and/or solvents recovered by evaporation and then the resultant sludge or solid material stabilised prior to land fill.

3.2.5 Incineration

Incineration is widely used for disposal of general household and commercial wastes, particularly in areas where landfill sites are scarce. It is also widely used for waste flammable liquids and for wastes containing halogenated substances including PCB contaminated oils and dioxin contaminated wastes. Most incineration operations are land-based fixed installations, however, mobile facilities and ship board incineration has been used for some classes of wastes.

Incineration is generally ranked well down the preference order of waste management options. It usually involves some discharges to atmosphere and leaves residues which may require further treatment or disposal to landfill. Incineration however may be the best option. It may be superior for example to landfill or storage. Like other options, therefore, it should be assessed on its merits.

Incineration method offers an immediate solution to a large numer of waste disposal (e.g. the volume is reduced by 90%), while the treatment is complete and does not take years for biodegradation. Maintenance of the correct temperature for combustion and regulation of the air input ensures complete combusion with minimal risk of noxious materials passing out with the flue gas. Modern technologies associate a scrubbing process which ensures that flue gas emission falls within acceptable limits. The correct temperature for the incineration is essential in many ways: dioxins production will be avoided, the integrity of the furnace walls will be maintained etc. Because the largest danger in the process is one of the uncontrolled burning, sometimes the entire process is computer monitored.

Ocean incineration in particular is usually regarded as an inferior option. Shipboard operation presents additional technical problems due to the pitch and roll of the ship. Inspection and control is also more difficult.

As with other waste technologies, it is critical that the particular waste is matched with the incinerator technology. It is also necessary to ensure that the gaseous and particulate stream from incineration is cleaned before release to atmosphere and that waste gas cleaning and ash residues are appropriately disposed of.

Issues which may be of concern in assessing risks from incineration include: consistency of waste feedstock; physical characteristics of the wastes (solids and liquids present different problems); the stability of combustion conditions; residence time of wastes; the possibility of incomplete combustion due to cold spots, shortage of oxygen, insufficient energy value of the wastes; reliability of off- gas cleaning systems etc. Monitoring systems for critical performance parameters and the composition of waste gases and residues need to be evaluated.

Of particular concern has been the question of dioxins and furans in emissions of incinerators burning domestic and hospital wastes as well as facilities expressly for halogenated wastes. As it appears that these materials are generally formed in the gases as they cool it is necessary to consider the effectiveness of rapid off-gas cooling etc.

Both technologies induce specific on-site hazards. For the case of incineration one has:

- entanglement with machinery such as conveyors: guarding is crucial;
- noise: monitoring is needed and provisions made to comply with existing legislation;
- dust, airstream helmets and respirators are provided;
- work in hot areas (e.g. inspection and maintenance) requires special protection equipment.

3.2.6 Waste Compaction

This method is costly in practical terms and a large component in this cost is the transport. Compressed wastes is then transferred to a container for transportation to a landfill site. Modern equipments (e.g. containers) hold around 14 tonnes of waste, compared to 4-5 tonnes in a dustcart; in this case only one trip to the tip instead of three are needed.

3.2.7 Landfill/Marine Dumping

Whilst landfill is generally regarded as an option best avoided, it is still required in many waste management operations. Even where other treatment methods are used, residues may need to be landfilled. Judgement as to the appropriateness of landfill operations should be based on a careful assessment of the waste stream, waste management options, the suitability of the soil and surface water and groundwater vulnerability and importance. Control to ensure inappropriate wastes are excluded is particularly important for landfill operations.

Landfill is a cheap and direct method used in waste treatment, aside from complaints about it being an eyesore, a source of dust etc. This method generated considerable media and public interest over problems with landfill gas. By using such a procedure, gas is generated by aerobic, microbial decomposition of the organic component of the waste. A gas mixture is produced, typically 38% nitrogen, 1% oxygen and sometimes hydrogen sulphide and ammonia. Risks of noxious leachates contaminating the ground water exist. Due consideration for the underlying geology when a site is commissioned should eliminate this hazard.

Measures can be taken to reduce the likelihood of hazardous components, reaction products etc being released to the environment. Pretreatment or fixing of wastes to reduce solubility/leachability may be necessary. Equally there is extensive experience with different types of "secure" and "sanitary" landfills using an array of measures such as concrete or clay beds, multiple layers of plastic sheeting, capping etc. Monitoring techniques to detect any loss of containment are also well developed.

Landfill operations typically require ongoing monitoring and maintenance. In considering relative costs and risks of different waste management options, the continuing costs of landfill must be included as must the risks of loss of containment of the wastes and the "sterilization" of land. Regard should be had to impact of natural events such as earthquakes and floods on the integrity of landfill.

Spreading of wastes on land either as a liquid (irrigation spreading) or as a solid is another form of land based disposal. For some wastes, such as those high in nutrients and low in other hazardous constituents, this may be particularly appropriate and can contribute to increased forestry or agricultural output.

Dumping at sea may be more difficult to control than landfill. It also is difficult to monitor impacts and generally very difficult to undertake any remedial action if problems are shown. Sea dumping may however be appropriate for some wastes particularly those substances which are naturally in the sea but are hazardous when concentrated by industrial processes e.g. some salts and radioactive mineral sands. Extreme care however needs to be exercised in such cases to ensure that the wastes are not significantly contaminated with other materials.

3.2.8 Long Term Storage

Long term storage is generally regarded as the least satisfactory option. Depending on the waste it may be expensive and have significant potential for release through failure of containment, fire or natural events such as floods.

Where an appropriate alternative technology is not available, storage may be the best option. Also in the case of some wastes, most notably radioactive wastes with half lives of weeks to tens of years, such storage may render the waste safe for disposal by other means.

Consideration should also be given to the fact that secure landfill is a form of storage and that other forms of storage may be easier to maintain. For drummed wastes, for example, the condition of the drum can be checked and redrumming carried out where necessary in accessible storage. Similarly the condition of containment can be inspected for signs of deterioration rather than relying on detection of leaks through monitoring.

3.3 Location of Facilities and Perceptions

Hazardous waste storage, treatment and disposal facilities are often regarded by people living or working in their vicinity as highly undesirable. Risks from such facilities are often perceived to be disproportionately high. The disposal of halogenated wastes such as PCB's and TCDD ("dioxin") and radioactive wastes, in particular, are susceptible to this adverse perception.

The establishment of new facilities and the continued operation of existing ones can be made very difficult due to this perception. The public perception can thus lead to practices which are sub-optimal. In the assessment of hazardous waste management and the recommendation of management strategies and policies these perception issues must be recognised and dealt with. Solutions proposed which are not capable of implementation can prolong unsound practices rather than improving waste management.

It is important that the risk and other impacts of proposed facilities are understood, that the proposals are subjected to site and operation specific environmental impact assessment, including hazard analysis and risk assessment, and that public perceptions are taken into consideration. The cultural and social context of the proposals must be fully appreciated.

It is also important that new proposal assessment processes are seen to be compatible with the assessment and control of existing facilities and that adequate provision is made for operational and organisational safeguards. In particular, monitoring of on-site operations and the surrounding environment - air, soil, surface water and groundwater - may be appropriate. Provision for community access to the facility and information on an on-going basis may be beneficial.

3.4 Hazardous Waste Transportation

For hazardous wastes, as with other hazardous materials, the transportation phase, including loading and unloading, is generally the phase where incidents are most likely to occur. Releases during transportation have the added dimension of variable location which makes impact assessment more complex and effective emergency response more difficult. Uncertainties as to the composition and physical state of the wastes are also a factor here, for example the concentrations and range of hazardous contaminants may vary depending on the source and the operations undertaken. Similarly a "sludge" may be almost solid or quite liquid. Incidents involving incompatible materials due to lack of care in cleaning vessels between loads, carrying mixed loads and multiple road transport vehicle collisions or multiple rail car accidents are also a complicating factor.

The transfer of waste from waste generating facilities to waste storage and treatment/disposal facilities and other transfers in the total waste management process (e.g. from storage to treatment facilities) is also the stage where wastes can be deliberately or inadvertently diverted to inappropriate disposal.

During transport as well, each load may pass a wide variety and density of different land uses e.g. schools, hospitals, residential areas, water supply facilities etc and potentially sensitive environments e.g. rivers and wetlands.

The hazard analysis and risk assessment for hazardous waste should be carried out as an integrated part of the overall hazardous materials transportation risk assessment. That analysis should have regard to the particular characteristics of waste discussed in this chapter including:

- the need to follow waste from "cradle to grave";
- the need to assess the quality of waste control systems in the transport phase;
- the possible benefits of alternative transport modes;
- the identification of sensitive land uses and environmental features;
- the identification of routes used and assessment against alternative routes;
- the need to take account of hazardous wastes being transferred into the region as well as out of it;
- the need to relocate waste generators.

3.5 Conclusions

The approach and methodology for the wastes component of the study are basically the same as for the other industrial facilities, transport operations etc covered in earlier chapters. It is necessary to consider all possible sources of hazardous wastes and all waste streams to ensure that all the hazards associated with wastes in the study area are identified. It is necessary to assess all phases of waste management - generation, transport, storage and treatment or disposal and to set the technical issues in the social, political and economic context. Analysis of the regulatory framework and controls should be automatically incorporated.

It is essential that recommendations arising out of the study do not borrow uncritically from other countries. Each area will have its own characteristics and it is through the identification and understanding of the specific requirements that sound recommendations can be developed. Solutions must be developed through defining problems carefully and drawing selectively on the experience and the technology available around the world to develop appropriate integrated waste management systems.

(B) Management of Road Transportation of Hazardous Materials

3.1 Principles of Safety Management for the Transportation of Hazardous Materials

The tools, techniques and criteria for the traffic, land use safety and economic assessment of transportation routes for hazardous materials have been highlighted in Chapter (5), Volume (2) of the guide. Figure (3.2) highlights the main components of the assessment process, which is to be used as the basis of transportation safety management.

There are two main aspects for the management of transportation risks:

(i) Technical and operational safety controls on the road tankers and hazardous materials containers.

(ii) The formulation and implementation of routes for the transportation of hazardous substances with due regard to land use and environmental safety and transportation economics.

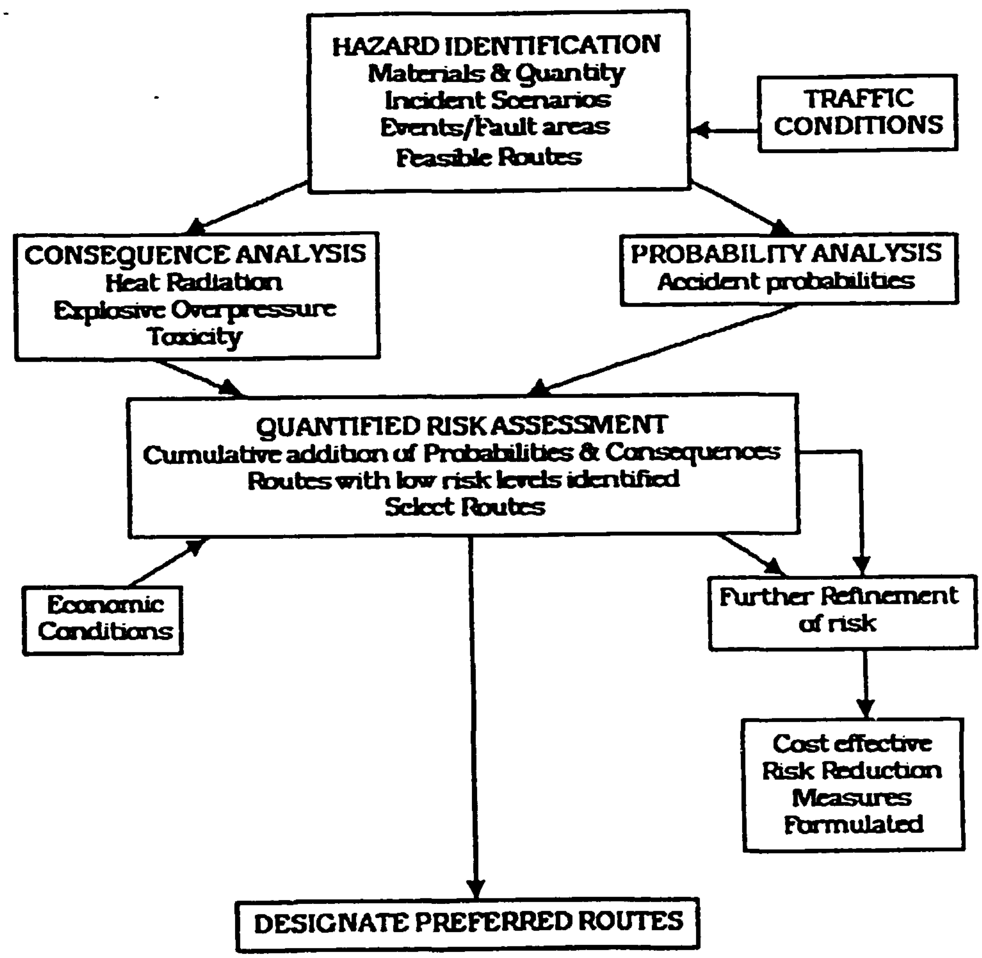
Both factors above must be considered in a complementary manner. Relying on technical safety controls in isolation cannot eliminate the risks. The adoption of routing mechanisms is an essential element of the overall risk management strategy for hazardous material transportation.

3.6.1 Technical and Operational Safety Controls

These include design, operational and legislative controls, amongst which are:

- Safety design of the road tanker
- Containment characteristics, including design and construction of containers, drums and cylinders
- Maintenance of the road tanker and of the containers, including inspection procedures
- Labelling of contents to national/international standards (e.g. U.N. classification) including placarding
- Formalized updated emergency procedures
- Formalized handling, loading and unloading procedures
- Regular training of drivers.

Figure 3.2. DYNAMIC TRANSPORT RISK



3.6.3 Routing for Hazardous Materials Transportation

The following criteria apply:

- Selection of route with no mandatory prohibiting factors on legal or physical ground
- Selection of routes with the least frontage of special sensitive environments or special land uses such as schools, hospitals or for which emergency evacuation is readily more applicable relative to others
- Selection of routes with the least risk of accidents (Assessment procedures in Chapter 5, volume, indicates that roadways with the smallest adjacent population as well as accident rates, will have the lowest risk values)
- Selection of routes with the least economic transportation costs to operators, including delays
- Selection of routes with the best traffic flow characteristics: least congestion, higher traffic flow.

3.7 Evaluation of Alternative Routes

Based on the three main criteria of: land use safety; economic and traffic, it may be possible to classify the various routes, for each criteria - say in terms of:

A = most preferred routes
B = acceptable routes
C = least preferred routes or routes that should be avoided.

The selection of the various routes based on the above classification may be distinctively clear, so that differentiation is possible on the ground of all criteria. In other cases, conflicting results for the different criteria, e.g. a route may be found preferred on safety grounds, but least preferred on economical ground, may be the case. For such situations, it would be necessary to rank the criteria in order of priorities on a base by case basis.

PROCEDURAL GUIDE FOR INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

VOLUME III

ELEMENTS OF INTEGRATED RISK MANAGEMENT FOR LARGE INDUSTRIAL AREAS

CHAPTER 4

INSTITUTIONAL AND STRATEGIC AREA RISK MANAGEMENT

Chapter 4: INSTITUTIONAL AND STRATEGIC AREA RISK MANAGEMENT

The locational and land use safety planning aspects of hazardous and polluting industries are essential elements of the risk management process. Risks cannot be entirely eliminated, and in most cases there will always be a residual risk outside the boundaries of the industrial installation. It is necessary to formulate and implement locational planning safety guidelines and strategies to complement technical and operational safety and environmental controls, as an integral component of the overall risk management process. This aspect has been neglected in the past resulting in significant land use safety conflicts in many countries, both in developed and developing economies. This chapter addresses the issue of location safety management of hazardous and polluting industries and surrounding land uses.

An overview of legislative and institutional mechanisms is also presented as other components of integrated risk management.

4.1. Locational Safety Planning as a Component of Integrated Environmental Risk Management

4.1.1 The Issues

There has a historical lack of land use planning criteria, guidelines and practices concerning the siting of major installations of a hazardous and polluting nature relative to urban areas or environmentally sensitive ecosystems. Conversely, many cases could be cited where extensive residential and commercial urban developments have been allowed to develop and encroach in close proximity to hazardous or polluting industries and their associated activities. Such situations exist worldwide, in almost every city, both in developed and developing countries, resulting in significant land use safety conflicts.

The main reason behind such land use safety conflicts is that, in the past, the decision-making process concerning the location of hazardous and polluting industries and surrounding land uses, relied almost entirely on technical and engineering standards and controls. That approach was based on the belief that such engineering controls can adequately cope with all hazards and risks within the boundaries of the plant. Little recognition was given to the nature and type of surrounding land uses and to the role of land use planning in the management of risks.

4.1.2. Principles of Land Use Safety Planning and Management

Increase in environmental and safety awareness, spurred by an increasing number of reported industrial accidents with major off-site consequences to people, property and the environment, have contributed to a fundamental recognition of the practical technological and economic constraints and limitations of engineering and technical environmental pollution and safety controls when applied in isolation.

It must be acknowledged, that hazards and risks from activities involving pollutant emissions and hazardous materials cannot be entirely eliminated. There will always be a 'residual' risk which in most cases will extend beyond site boundaries. It is essential to understand the nature and extent of this residual risk and to formulate and implement land use strategies and controls to cope with it.

Decisions concerning the location and continuous operations of hazardous and polluting industries are therefore to a large extent, land use planning decisions. Properly implemented, land use safety and environmental planning become an essential and integral component of the hazard and risk management. In this process, land use safety conflicts are prevented by identifying, analyzing and quantifying hazard and risks and managing such risk through both technical controls at the source as well as ensuring compatible land uses.

The basic land use safety planning principle relates to the provision of physical buffer zones or separation between hazardous and polluting industries and sensitive land uses and other natural environmental areas. In this way, physical separation complements technical controls at source to manage the risk. However, the determination of such separation distances is not (and should not be) limited to technical issues in isolation. There are broader social and economic considerations that should also be considered and taken into account in the locational aspects of hazardous installations and surrounding land uses. Firstly, the physical dimensions of buffer zones greatly vary depending on several parameters, mostly the nature of the facility and its environmental and safety controls. A uniform standard separation distance rule may not be possible in this regard, but each case should be looked at on its own merit. Secondly, in the decision making process for the derivation of such buffer zones, various economic and social trade-offs, cost and benefit considerations need to be considered. An overall strategic approach ought to be adopted between industrialization, urbanization, cost of pollution and safety controls, land sterilization, etc. As such, the issues involved are not of local significance only, but extend as well to strategic issues of national importance.

The conclusion is made therefore that the location of hazardous and pollution industries and of surrounding land uses and of associated compatibility issues should be made within the broader context of environmental, safety, economic, social and overall planning issues. It is essential to agree on a planning strategy for the area. The strategy must recognize the technological and economic constraints of accommodating industry and urban developments 'across the road' from each other. Environmental planning policies and strategies should be developed on a case by case basis to guide industrial as well as all other forms of developments.

4.1.3. Locational Safety Planning for Existing Situations

Existing land use environmental and safety conflicts are those most prevailing (relative to potential conflicts from proposed new developments) and offering the most difficult challenges to rectify. As land use patterns develop, it becomes very difficult to relocate industry or people. The most effective strategy is to prevent land use safety conflicts from developing from the onset by formulating and adopting strategies, guidelines and criteria for the location of industrial and other land uses, that ensure environmental and safety compatibility.

In the case of existing situations the main basic immediate strategy is that of managing the risks within the existing constraints of land use patterns. A longer term strategy should also be formulated that aim at rectifying land use safety conflicts. The following procedural/strategic steps are relevant:

(i) An environmental study should be undertaken for the whole study area including studies on air pollution, water pollution, solid wastes. The study should identify, on a cumulative basis, the health and environmental effects and delineate areas and people most at risk.

(ii) A hazard analysis and quantified risk assessment for hazardous installations and transportation systems should be undertaken for each plant (as applicable) and cumulatively for the whole area. Resultant risk levels both in terms of individual and societal risk should be compared with agreed criteria or targets. People and property and various land uses most at risk should be delineated.

(iii) Based on the above, it is possible to identify environmental systems, land uses (residential, commercial, recreation, etc.), and number of people and properties exposed to the highest risk from both normal emissions and accidents from the operations of industry in the area. The studies should also identify the major contributors to the total risk. Based on such information, an overall land use safety plan may be formulated for immediate-short term implementation.

(iv) The **immediate-short term strategic elements** should include the following four essential components:

- Reduced risk at the source, with emphasis on technical controls for the major risk contributors, and wherever economically and technically feasible. A comprehensive risk reduction programme should be formulated and implemented at each facility. As a minimum, there should not by any further increase in total risk. This may necessitate no further increase in any industrial activities of a hazardous or polluting nature in the immediate - short term.

- **Control the number of people and sensitive land uses,** exposed to risk. No further increase in residential densities in the areas most affected by the total risk should be allowed. Increase in people related activities within the most affected areas should be strictly controlled to ensure no increase in the number of people exposed to high risk.

- **Mitigate the consequences of major hazards** with a priority emergency plant for the area mostly affected by the risk. A comprehensive emergency plan and procedures should be formulated with specific reference to the type of hazards in the area. People in the affected area should be made aware of the hazards and emergency/evacuation procedures to follow in case of accidents.

(v) **A long-term strategic plan** for the area should be formulated on the basis of an integrated approach that include consideration of environmental, health, safety, social and economic factors. The plan should be based on national needs and preferences for the area and should specify a long term planning outlook for the area in terms of either continuation and controlled expansions of industrial activities or urban developments and intensification.

The implementation of the long term strategic plan should be based on the following elements:

(a) **Industrial Oriented Strategy**

- Any intensification of existing industry or introduction of new industry in the area should be allowed only if it can be demonstrated at an early stage of development application that no cumulative increase in existing risk levels will result from the development. A decrease in some activities may have to be implemented to achieve this objective. This will ensure that the area affected does not increase.

- Whilst no intensification in residential developments should be undertaken, every opportunity should be taken to encourage re-development or re-location of residents in the area mostly affected by risk.

(b) **Urbanization Oriented Strategy**

- This strategy is based on encouraging residential and people related land uses in preference to industry. In this case, no developments of a hazardous industrial nature should be allowed. A stringent programme for risk reduction should be implemented and industry should be encouraged to relocate.

- Intensification of residential developments in the area mostly affected by risk should not be undertaken until risk reduction measures have been implemented.

(vi) Criteria and guidelines for the location, assessment and decision making process for industrial, residential and other forms of land use in the area should be formulated as part of the implementation process for the above strategies.

Strategic Elements of Land Use Safety Planning for Existing Situations

<u>Immediate - Short Term Strategy</u>

- Reduce Risk at source (emphasize on major risk contributors): Technical and operational controls; stringent controls on any new developments. Risk reduction programmes

- No increase in number of people exposed to risk above agreed criteria: planning controls to ensure no further intensification in the risk affected areas

- Mitigate the consequences of Major Hazards: Comprehensive emergency planning and procedures for the areas most at risk.

<u>Long - Term Strategy</u>

- Based on National Priorities and Needs, select industry oriented strategy or urban oriented strategy

- For industry oriented strategy: industry development subject to no increase in cumulative risk; no intensification of residential development; long-term relocation of people

- For urban oriented strategy: no intensification in industrial developments and overall re-location strategy

- Criteria and guidelines for the location and assessment of land uses based on above principles.

4.1.4 Locational Safety Planning for Proposed Development

The formulation and implementation of criteria, guidelines, zoning controls, assessment policies and practices as an integral component of the decision making process for the location and development approval of new hazardous and polluting industries and proposals for development of other land uses in the surrounding of such industries, are the most effective measures to prevent land use safety conflicts. The integration of planning as complementary to technical risk controls at the source is the most cost effective risk management strategy for all concerned. The approaches outlined hereafter as examples of comprehensive controls over the locational aspects of new proposed developments of a hazardous nature (similar principles apply to industrial developments of a polluting nature) and of land uses in their surroundings. In all cases, an overall regional environmental plan for the whose area should be prepared. The plan should specify policies, guidelines and criteria for various land uses.

(i) **Environmental Impact Assessment Procedures**

Development proposals of a hazardous or polluting nature, particularly those proposing to locate near sensitive land uses or environment, are the subject of environmental impact assessment procedures in many countries. These procedures require the preparation of Environmental Impact Statements (EIS) and associated studies as part of the decision making process to allow or not the proposed development. Two approaches are mostly used in different countries: (i) a range of developments (including those of a hazardous and polluting nature) are specified by regulations and an EIS is necessary for these irrespective of their proposed location. (ii) The decision is made on a case by case basis as to whether an EIS is required, taking into account various factors including the zoning of land, size and nature of the development.

The EIS and its associated assessment process is a powerful tool that greatly assist in ensuring that, at an early stage of development, resultant risks are compatible with the various land uses in the locality. The process also ensures that technical safety and environmental controls at the source complement locational siting considerations.

At the EIS stage, the proponent is requested to demonstrate that the proposed development at the proposed location will not result in significant increases to overall risk levels at existing land uses.

This is done by undertaking a preliminary hazard analysis and quantified risk assessment, identifying all relevant hazards and indicating cumulative risk levels to surrounding land uses. An assessment of resultant cumulative risk levels and their implications for, and impact on, land uses and the environment should be undertaken with particular emphasis on the locational suitability of the proposed development, accounting for proposed safety measures.

(ii) **Zoning Controls based on Safety Separation Distances**

Different countries pursue the implementation of safety separation distances using arrangements appropriate to their particular legislation. An approach in the use of zoning controls on the land where planning permission can only be obtained for developments that are permissible within that zoning. the zoning is determined accounting for principles of safety separation distances between hazardous and polluting industry and other types of land uses. In many cases the permissibility of a type of development within a particular zoning does not mean that planning permission would be granted automatically. Environmental Impact Assessment and other procedures are often still required to make a decision on the merit of the particular case of development. An important consideration is the degree of separation which is necessary. Ideally, one could calculate the worse-case accident occurring at the works and permit development only outside its hazard range. For most countries, and particularly for toxic hazards where the consequences could, at worst, extend for several kilometres, such a policy would blight large areas of land at considerable cost both to the area and the country.

An alternative approach is to undertake a hazard analysis and quantified risk assessment to predict the risk to an occupance of the proposed development, and then to decide whether such a risk is tolerable. This approach requires considerable sophistication in analysis and computation techniques. A middle approach, which has been endorsed by the United Kingdom Advisory Committee on Major Hazards, is to try to arrange a separation of developments from major works. This will achieve almost complete protection from the more common but relatively minor accidents and, in addition, worth-while but not complete protection from the severe but very rare major events. Based on this approach, Table 4.1 gives suggested approximate separation distances for a range of major hazard works. These distances should be regarded as tentative and would need to be considered under local circumstances to decide on their applicability large, more detailed assessment work may be necessary in most cases by way of a detailed quantified risk assessment.

(iii) **Categorization of Development and Notification Requirements**

In deciding on the separation required from a works, it can be helpful to categorize the proposed development. This will enable individual development decisions to be made within the framework of a consistent approach. Categories of development can take account of a number of relevant factors in deciding on whether to permit development, e.g. amount of time individuals spend in the development, ease of implementing an emergency plan, vulnerability of occupants of the development (old people more vulnerable to thermal radiation). One broad categorization which has been widely used is based on three general categories:

Category A:	Residential, including houses, hotels, flats;
Category B:	Industrial, including factories (unless they have high-density employment), warehouses;
Category C:	Special, including schools, hospitals, old people's homes.

Other types of developments can then be added to the most appropriate of these categories, e.g. theatres/cinemas and shopping centres could be included in Category A. In Table 4.1 and as a first approximation, the separation distances given should be considered as follows:

TABLE 4.1 Suggested approximate separation distances for major hazard works

Substance	Largest tank size (t)	Separation distance (para. 7.3) (m)
Liquefied petroleum gas, such as propane and butane, held at a pressure greater than 1.4 bar absolute	25- 40	300
	41- 80	400
	81-120	500
	121-300	600
	More than 300	1 000
	25 or more, only in cylinders or small bulk tanks of up to 5 te capacity	100
Liquefied petroleum gas, such as propane and butane, held under refrigeration at a pressure of 1 4 bar absolute or less	50 or more	1 000
Phosgene	2 or more	1 000
Chlorine	10-100	1 000
	More than 100	1 500
Hydrogen fluoride	10 or more	1 000
Sulphur trioxide	15 or more	1 000
Acrylonitrile	20 or more	250
Hydrogen cyanide	20 or more	1 000
Carbon disulphide	20 or more	250
Ammonium nitrate and mixtures of ammonium nitrate where the nitrogen content derived from the ammonium nitrate exceeds 28 % of the mixture by weight	500 or more	See note [1]
Liquid oxygen	500 or more	500
Sulphur dioxide	20 or more	1 000
Bromine	40 or more	600
Ammonia (anhydrous or as solution containing more then 50 % by weight of ammonia)	More than 100	1 000
Hydrogen	2 or more	500
Ethylene oxide	5-25	500
	More than 25	1 000
Propylene oxide (atmospheric pressure storage)	5 or more	250
(stored under pressure)	5-25	500
	More than 25	1 000
Methyl isocyanate	1	1 000
Classes of substances not specifically named		
1. Gas or any mixture of gases which is flammable in air and is held in the installation as a gas (except low-pressure gasholders)	15 or more	500
2. A substance or any mixture of substances which is flammable in air and is normally held in the installation above its boiling point (measured at 1 bar absolute) as a liquid or as a mixture of liquid and gas at a pressure of more than 1.4 bar absolute	25- 40	300
	41- 80	400
	81-120	500
	121-300	600
	More than 300	1 000
	25 or more only in cylinder or small bulk tanks or up to 5 te capacity	1 000
3. A liquefied gas or any mixture of liquefied gases which is flammable in air, has a boiling point of less than 0°C (measured at 1 bar absolute) and is normally held in the installation under refrigeration or cooling at a pressure of 1.4 bar absolute or less	50 or more	1 000
4. A liquid or any mixture of liquids not included in items 1-3 above which has a flashpoint of less than 21°C	10 000 or more	250

[1] For bagged ammonium nitrate stored in stacks of 300 t (maximum) a separation distance of 600 m is appropriate. For loose ammonium nitrate, the separation distance is given by–

$$600 \left\{\frac{\text{stack size (t)}}{300}\right\}^{1/3}$$

(a) within the separation distance - no Category C development;

(b) within about two-thirds of the distance - no Category A development;

(c) no restriction of Category B development.

The principles outlined above have also been used as the basis of 'notification' practices, notably in the United Kingdom. The responsibility for granting planning permission for all types of developments in the U.K. rests with the local planning authority. Under applicable regulations in that country, the Health and Safety Executive (HSE) is notified of all installations which meet a criteria of storage (substance and quantity). It then informs the relevant Local Planning Authority and provides a site specific consultation zone (CD). The majority of sites have CDs of 1 km or less in size. Within each CDs, Local Planning Authority are requested to refer to the Health and Safety Executive, for advise, developments that include: any residential development regardless of size; all shops over 250 m^2 gross space; all industrial development over 750 m^2 gross space; all office development over 500 m^2 gross space; any development likely to lead to a significant increase in people close to a hazard. The Health and Safety Executive assesses the hazards implications and advises Local Planning on the appropriateness of the proposed development from a safety viewpoint. It must be noted that such advise is not binding on the local planning authority. The advise is usually in terms of three situations of risk. Negligible risk; where the assessment has shown it to be extremely unlikely that people outside of the factory fence would be killed. Marginal risk; safety reasons in themselves are viewed as not justifying a refusal of planning permission, so safety should be a major consideration. If there are other factors strongly favouring the development, the local Planning Authority is advised to ask the HSE for more detailed explanation/assessment of the risk.

(iv) Specific Guidelines for Classes of Developments

In some countries, notably Australia, the Netherlands and the U.K., specific guidelines for classes of developments particularly chlorine, liquified petroleum gases, flammable storage facilities, specifying safety separation distance and other technical requirements have been issued. A summary of guidelines applicable to LP Gas storage and distribution facilities issued by those countries is at Appendix 4.1.

4.2 Review of Safety Legislation in the Process Industry for Major Hazards Control

This chapter provides an overview of the legislative requirements in selected countries in the field of major hazards control. The main aim is to highlight the relevant practices. The formulation of a specific regulatory framework is a matter for each national authority to consider, based on local circumstances.

United Kingdom

In 1972 the Robens Committee produced a Report which was a precursor to significant legislation in the UK, in that it crystallized the realization for the need for specific and unified control of potentially hazardous industrial installations.

In response to public pressure and concern following the Flixborough disaster in 1974, the authorities adopted the Robens Committee recommendations. The legislation that enacted the main points was the Health and Safety at Work etc. Act 1974, (HASAWA), which set up a unified authority, the Health and Safety Commission. In general, the legislation:

- established a general duty of care on companies at Board level (a written safety policy is required),
- identified the employer as responsible for both employees and public, (the "etc" in the Act title),
- in addition, imposed duties on employees.

Advisory Committee on Major Hazards (ACMH)

The committee produced three public reports which represent a comprehensive and authoritative exposition of methods and policy issues on industrial major hazards.

In 1976, their first report recommended the adoption of legislation requiring operators to notify the authorities of potentially hazardous installations, based on specified inventories of chemicals (notifiable installations). This would lead to the selection of installations requiring more elaborate risk assessment (HMSO, 1986).

The HSE has the powers now, under HASAWA (1974), to prohibit operations (and operators) considered unsafe and they could require improvements in installations where they were not satisfied. The ACMH further recommended that a realistic program be established by the HSE to bring older existing plants up to new plant standards.

Their second report in 1979 (HMSO, 1979) examined the historical experience and the frequency and consequences of major hazard incidents. This data was seen as generally supporting the levels at which inventories of hazardous substances should be notifiable. The report also:

(a) developed categories of installations which led to the definition of priority sites which would need hazard surveys as those with ten times the notification level of inventory;

(b) outlined a scheme of licensing regulations;

(c) canvassed means whereby planning controls may be applied to new sites and intensified activity at existing sites.

The report also called for more effort in understanding the causes of major incidents.

The Advisory Committee findings were made legislative requirements in the 'Notification of Installations Handling Hazardous Substances, (NIHHS) 1982' and largely adopted intact as the later EEC Seveso Directive. This was enacted in Britain as the 'Control of Industrial Major Accident Hazards Regulations (CIMAH), 1984'.

Experience with CIMAH Regulations

The siting and control of hazardous industry in the UK is in the main, the responsibility of local authorities. The Major Hazards Assessment Unit (MHAU) of the Health and Safety Executive (HSE) can only advise local authorities on the siting of hazardous plants and land use but has no control over the final decision.

Public information on hazardous plants is provided mainly at the local level. Industry liaison with the local safety inspector is encouraged. The implementation of CIMAH is thus seen as an ongoing process, not just a single exercise of submitting a Safety Case.

Important issues with CIMAH are:

- it does not specify the depth of treatment for consequence analyses;
- risk criteria have not been specified;
- transport risks are not included.

Recent Developments

The third and final report from the Advisory Committee on Major Hazards in 1984 set out a practical system based on Quantitative Risk Assessment (QRA) as the best control mechanism, but pointed out the problems which can arise if inflexible fixed criteria for acceptability are employed, (HMSO, 1984).

In particular, the report:

(a) adopted the "reasonably practicable" approach as applicable to the control of major hazards. Instead of setting a particular risk criterion, it proposed that the risk from a hazardous installation to an individual employee or member of the public should not be significant when compared to other risks to which he is exposed in everyday life. Further, the risk from any hazardous installation should, where reasonably practicable, be reduced. It suggested that the likelihood of serious accident of one in ten thousand years was on the borderline of acceptability, bearing in mind the background risks faced everyday by the general public;

(b) recommended that information given to the public should include the nature of hazards which might affect them if control measures fail, emergency arrangements which have been made in advance and what should be done in the event of a major accident;

(c) recommended that hazard surveys should be based on some form of quantitative assessment;

(d) endorsed the full use of technical and managerial techniques available to ensure plant reliability;

(e) recommended the location of plants away from centers of population and the development of guidelines for separation distances;

(f) recommended a unified off-site emergency planning scheme with cooperation between industry and local government;

(g) recommended further education among senior management, further research into the consequences of major incidents and canvassed the need for the storage of data from incidents.

In addition, new approaches to operational safety such as a scheme based on a hazard warning structure was outlined. This is based on 'near miss' or warning incidents and it predicts the closeness of real disasters, rather than waiting for them to occur.

The HSE is moving towards establishing risk probability consequence targets like the Dutch. It has developed a simpler version of the Dutch SAFETI package which is in regular use. Although no specific criteria have been published, it indicates that individual risk of 1 in 10-6 fatalities is acceptable while 1 in 10-3 is intolerable. However, it appears that these criteria will be used only to compare various industries rather than target criteria.

In the area of Transport Risks, an Advisory Committee has been established to examine the routing by rail, road and pipeline for hazardous substances.

Netherlands

The Working Environment Act has contained since 1977, the requirement for a Safety Report (Arbeidsveiligheidsrapport) for specified installations. The legislation applies to new and existing installations. The Labour Inspectorate has issued guidelines interpreting the law including the contents of the Safety Report. It requires not merely a list of substances involved but also the conditions of storage and/or processing and associated details.

There is, in addition, the need to comply with the Nuisance and Air Pollution Laws to protect the population at large; under these laws, construction and operating licenses have to be obtained from the provincial authority. The effects of major accidents on the surrounding population and environment are included(together with any normal emissions) under these provisions. The public is given the opportunity to inspect the license application and draft permit, and lodge objections. Any confidential material, however, can be withheld from such publicly available dossiers at the manufacturer's request.

The Dutch designation system compares a mathematical combination of the threshold quantities under reference conditions (T) the correction factor(s) which account(s) for the physical condition and the process conditions (C) and the phasing factor (F) with the quantity of material present in the installation. This can lead to a designation.

An installation is designated when the amount of dangerous materials present in the installation and multiplied by one or more correction factors is equal or larger than the relevant threshold quantity multiplied by the prevalent phasing factor.

Additional legislation on **External Safety**, specifically concerned with protection of the population outside the operating sites, as is legislation introducing Environmental Impact Reporting and Assessment also apply. As part of the External Safety Policy, the Dutch government has embarked on an extensive research program to obtain insight into three main areas:

- the methodology for the quantification of risks, the possibilities and limitations,
- the attitude of groups concerned with a potentially hazardous activity, their motives and reactions, and
- the handling of these factors in a decision-making process.

It has designed a computerized hazard quantification model along the lines of the Public Vulnerability Model developed by the US Coast Guard for risks associated with the import of dangerous substances in sea harbors. This model has been adapted to the special circumstances in the chemical industry in the Netherlands. It is now operational and includes failure data, dispersion models, meteorologic data, population data and consequence models for the effects of toxic, flammable and explosive materials. The SAFETI package is used as a 'benchmark' to which disputing parties can be referred and as a vehicle for optimizing the siting of plant, routing of hazardous pipelines and improving the safety of the community.

This model is being used in conjunction with both individual and societal quantitative risk criteria, which are quantitatively specified.

Where risk levels are considered unacceptable, risk reduction is achieved by insitu measures, such as plant layout, the use of additional safety devices or less hazardous technology. Zoning controls are used to keep the public apart from hazardous activity. This may include the removal of vulnerable dwellings. The Dutch government will provide compensation funds for such rehabilitation schemes. Risks associated with the transport of hazardous materials may require improvement of the means of transport or zoning or both. In every case, risk reduction measures are undertaken based on their cost effectiveness.

Commission of the European Communities

The impetus for legislation to control hazardous industry came in the wake of the Seveso disaster in 1976 resulting in the so called 'Seveso Directive', largely modelled on the UK Advisory Committee Reports. This Directive which was passed by the EEC in 1982 (enacted in UK in 1984) refers both to the storage and production of hazardous materials. The Directive requires further controls over large quantities of the hazardous materials listed in the NIHHS regulations and extends controls to other similar hazardous and toxic substances (Directive, 1982).

General Requirements

There are two general requirements. The first requires the person in control of any industrial activity where a major accident might occur to be able to provide at any time evidence which shows that major accident hazards have been identified; that steps have been taken to prevent such accidents, and that persons working on site have been provided with the information, training and equipment necessary for their safety.

The second general requirement requires manufacturers to inform the 'competent authority', i.e. in the UK the HSE, immediately of any major accident. Further information will also be required on the effects of the accident, the emergency measures taken and of any steps taken to alleviate medium or long-term effects and to prevent a recurrence of the accident. This requirement is not linked to any threshold level. This information about major accidents will be passed on to the European Commission who are to establish a register of major accidents for the use of Member States.

Special Requirements for Larger Installations

There are major requirements applying to installations classified as presenting a special potential for a major accident. These fall mainly on the manufacturer who must:

(a) produce a written report (or 'safety case') on the hazards and their control;

(b) prepare an emergency plan for dealing with accidents and emergencies at his site, and

(c) provide information to people who might be affected by an accident.

In addition a competent authority is required to draw up an emergency plan for dealing with the off-site effects of major accidents.

The Directive requires people who are liable to be affected by a major accident to be informed of the safety measures and of the correct behavior to adopt in the event of an accident.

Annexes to the Directive specify a number of substances with associated treshold quantities as basis for notification and special requirements. The large threshold quantities necessitate a written 'safety case' report and the preparation of emergency procedures. It is understood that the date of June 1994 has been set as the deadline for the completion of notifications of existing installations in Europe.

4.2.4 Belgium

Legislation on insanitary, noxious or dangerous factories requires a license for the building and operation of plants classified on the basis of listed sectors.

The Regulation is aimed primarily at protecting the workers, but the application for a license under this regulation must, apart from technical details of the installation, also include information covering measures to prevent, or reduce the consequences of, accidents affecting the surroundings of the installation.

The application and the authority's decision are displayed for public inspection and, in certain cases, communicated in writing to those in the immediate vicinity of the establishment.

In addition, the provincial authorities may require a Safety Survey, whose extent they determine themselves. Currently the EEC Directive is being incorporated into the Labour Law.

4.2.5 Republic of Ireland

The Public Health Act of 1878, the Alkali Act of 1906 and the Local Authorities Acts 1963 and 1976, provide for licensing dangerous establishments (determined according to emissions). They also empower planning authorities to require an environmental impact report in addition to plans and general technical data on the facility. The planning procedure is public. To this extent, there is some control of hazardous installations; any measures that are deemed necessary can always be imposed by planning authorities on a case by case basis.

4.2.6 Italy

The beginning of implementing the EEC Directive on Major accidents within Law 833 is the Presidential Decree of 1982 on fire prevention. This requires the company concerned to carry out a safety survey before a new plant or a new process is put into operation. Other decrees covering protection of health, of the environment, etc. are expected in due course.

4.2.7 Luxembourg

The legislative mechanism is based on a 1979 law and regulations listing and classifying all industrial establishments, which could present hazards or nuisance affecting the safety, health and comfort of the workers or of the general public, or endanger the environment.

Such establishments have to be licensed by the Inspectorate of Labour and Mines. The application for a license must include information about the type and location of the establishment, plants and processes to be operated, the approximate quantities of products to be manufactured or stored, the measures planned to prevent or mitigate the danger of nuisance which the establishment might cause, and the approximate number of workers employed. These provisions thus cover much of what is required by the EEC Directive on Major Accident Hazards.

4.2.8 Germany

The Law "Störfall-Verordung" (Decree on the control of disturbances) was published in 1980 with the aim of providing protection against major hazards from industrial activities: fire, explosion, and the release of certain substances (2 appendices list the industrial activities and the 142 substances concerned). This law came into power in September 1980 imposing on industry the obligation, among others, to have a "Safety Analysis" (Sicherheitsanalyse) available for the competent authority.

The Regulation of 1981 detailing the application of the "Störfall Verordnung) defined the "Safety Analysis" as including:

- description of the installation and the process, including the characteristics of the process under normal operating conditions;

- description of parts of the installation significant from the point of view of technical safety, the possible sources of hazard and hypothetical causes of an accident;

- chemical analysis/composition of the substances involved;

- a description of measures concerned with safety, limitation of the consequences of the disturbances and consequent emergency;

- information on the consequences of an accident.

After the German unification, in order to provide help towards self-help it founded the Industrial Initiative for Environmental Protection in the GDR. This body promotes the exchange of experts from companies and consultancy on specific environmental solutions. Germany is comprehensively regulated in the environmental field, the existing limit values and regulations are of a preventative nature. The objectives of the German environmental policy and associated legislation are:

- introduction of environmental protection as a constitutional policy;
- multimedia environmental protection (e.g. liability for environmental damage, environmental impacts statements);
- producing revised legislation on effluent charges, waste management, federal emission control, measures for soil protection, etc.

4.2.9 France

In accordance with the laws of 1976 and 1977 (Protection of Nature and Impact on the Environment respectively), the competent authorities may examine the hazards presented by normal as well as abnormal operation involving certain raw materials, intermediates or products with the view of mitigating such hazards.

For installations requiring a license, the application (which is available to the public for inspection) must include a safety study, maps of the surrounding area and plans of the installation, an impact study, a description of emergency resources, and an account of the provisions for hygiene and safety. The final decision is published by means of notices, and announcements in local newspapers.

The Code de Travail (Labour Law) contains provisions regarding fire and explosion hazards at work which cover requirements relating to the construction of installations, operating practices and procedures aimed at the protection of workers in the event of accidents. The Decree of 1979 on safety training, which also forms part of this Code, strengthens the provisions for informing workers, particularly as regards procedures in the event of an accident.

4.2.10 The United States

Although there have been several chemical industry incidents in the States, the one of most concern to the public was the Love Canal episode, when a toxic waste dump so heavily polluted a waterway that leaks and spills finally made the surrounding area uninhabitable. As the full impact of the extent of the problems emerged, so legislation for control and clean up of problem sites was enacted (Toxic Substances Control Act 1976) and through the Superfund, techniques and expertise were developed to deal with the problems.

In terms of legislation for control of major industrial hazards the main contribution from the States has been the Department of Transportation (DOT) regulations in 1976 which specified separation distances from major refrigerated LNG storage of some 2 km, based on a worst credible event of a ten minute release calculated on a proprietary model (US Department of Transportation, 1976).

4.3 Institutional Overview for Integrated Risk Management

PROCEDURAL GUIDE FOR INTEGRATED HEALTH AND ENVIRONMENTAL RISK ASSESSMENT AND SAFETY MANAGEMENT IN LARGE INDUSTRIAL AREAS

VOLUME III

ELEMENTS OF INTEGRATED RISK MANAGEMENT FOR LARGE INDUSTRIAL AREAS

CHAPTER 5

INTEGRATED RISK MANAGEMENT