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Guidelines for integrated risk assessment and management in large industrial areas

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

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FOREWORD

Industrial development is essential to raise the standard of living in all countries. This requires the building of refineries, power stations and other large industrial complexes. However, human health can be affected, directly or indirectly, by routine discharges of waste from industrial installations. The environment is adversely affected by emissions from power stations and the accumulation of industrial wastes. Releases of toxic materials can have disastrous effects on both health and the environment. A series of major industrial accidents in the 1970s and 1980s highlighted the need for better management of risks in routine industrial operations and from accidents.

Past efforts to cope with these risks, if any, have been largely piecemeal. Some plants are well equipped to manage environmental hazards while others are not. Some risk management studies have concentrated on occupational hazards and some on threats to the environment such as pollution, while others concentrated on contingency planning for major accidents. Very few have considered all risks.

If risks can be assessed and managed on a comprehensive basis, then scarce resources can be deployed more effectively and industrial development can be facilitated. Developing countries, in particular, have much to gain from adopting a sound approach to management of the risks associated with industrial development.

The IAEA, the United Nations Environment Programme (UNEP) within the framework of the Awareness and Preparedness for Emergencies at Local Level (APELL), the United Nations Industrial Development Organization (UNIDO) and the World Health Organization (WHO) decided in 1986 to join forces in order to promote the use of integrated area wide approaches to risk management. An Inter-Agency Programme, which brings together expertise in health, the environment, industry and energy, all vital for effective risk management, was established.

The Inter-Agency Programme on the Assessment and Management of Health and Environmental Risks from Energy and Other Complex Industrial Systems aims at promoting and facilitating the implementation of integrated risk assessment and management for large industrial areas. This initiative includes the compilation of procedures and methods for environmental and public health risk assessment, the transfer of knowledge and experience amongst countries in the application of these procedures and the implementation of an integrated approach to risk management. The purpose of the Inter-Agency Programme is to develop a broad approach to the identification, prioritization and minimization of industrial hazards in a given geographical area.

The UN organizations sponsoring this programme have been involved for several years in activities aimed at assessment and management of environmental and health risks, prevention of major accidents and emergency preparedness. These Guidelines have been developed on the basis of experience from these activities, to assist in the planning and conduct of regional risk management projects. They provide a reference framework for the undertaking of integrated health and environmental risk assessment for large industrial areas and for the formulation of appropriate risk management strategies.

This report has been developed over a number of years with contributions from a large number of authors. It was reviewed in detail during an International Workshop in Tel Aviv, Israel, 18-22 November 1991, held specifically to review the Guidelines. It was subsequently restructured, revised augmented as recommended at the Tel Aviv meeting. On 12-16 September 1994 an IAEA Technical Committee Meeting was called to review experience obtained in the use of the draft guidelines and to make final revisions to thereport. Representatives from Croatia, Egypt, Finland, Greece, India, Israel, Latvia, Netherlands, Philippines, Russia, Switzerland and the United Kingdom attended the September 1994 meeting.

EDITORIAL NOTE

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1. INTRODUCTION

1.1. BACKGROUND

There is worldwide a growing awareness and concern of governments, communities and industry about the risks 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 health and environmental risks are now recognized as essential elements for orderly economic and social development.

Three important emerging issues are particularly significant:

– The need to optimally allocate resources in the health and environmental risk management process. That is, the need to prioritize all relevant risks and to direct management strategies towards achieving the highest benefits from the resource expenditures in the risk control and management processes.

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

– The importance of integrating all elements in the health and environmental risk management strategy: locational, technical, organizational, legislative, social and economic. These elements are complementary and cannot be considered in isolation.

These issues are particularly significant when dealing with an extended geographical area with conflicting demands and pressures for industrial development and urbanization.

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

The integrated risk assessment approach is based on the notion that all health and environmental risks within an area should be systematically identified, analyzed and assessed in such a way that rational choices can be made about which risks should be reduced, weighing the social and economic costs of such risks, and the costs of risk reduction.

The **integrated risk management** approach is based on the notion that all options of risk management: locational, preventive, mitigative, protective and institutional should be explored such that the resources committed in the safety management process are utilized in the most effective way.

1.2. PURPOSE OF GUIDELINES AND AREAS OF APPLICATION

The main purpose of these guidelines is to provide practical guidance and a reference framework for the undertaking of integrated health and environmental risk assessment studies and for the formulation and implementation of co-ordinated health and 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 already a number of published guideline documents dealing with various aspects of health and environmental risk assessment. It is not the aim to duplicate these documents. The integrated risk assessment approach, however, necessitates a 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 management approach also necessitates the formulation of overall co-ordinated strategies involving multi-dimensional elements including technical, locational, social and economic considerations. These aspects require specialized methodologies. These guidelines therefore refer to existing documentation where appropriate, but in addition provide specialized guidance to address the integrated risk assessment approach on an area-wide basis.

The methods and techniques of integrated health and environmental risk assessment and management presented in these guidelines 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 significance in terms of social and economic developments. Two situations may apply: The study area may include existing hazardous activities or it may be the subject of conflicting demands for developments and environmental protection, particularly in terms of future land use planning. Within that context, major areas of applications include:

- Assessment of existing health and environmental risks in a large industrial area including the prioritization of those risks that need to be managed or reduced;
- The formulation of integrated risk management strategies, including the prioritization of implementation measures and 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;
- Influencing institutional and legislative actions with respect to hazardous and polluting industries.

1.3. THE CONCEPT OF INTEGRATED RISK ASSESSMENT AND MANAGEMENT

Policy makers are often confronted with 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, water and air will not be irreversibly damaged for future generations. Only decisions made in such a way can support sustainable development of an area.

The case may also be that serious risks to people and the environment already exist in a particular area 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 hazards which were assessed, the risks to which they are exposed 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 policy-making process may also be ill-founded if certain risks are ignored. Many accidents and environmental catastrophes could likely have been avoided with a broader and more thorough approach to risk assessment and management.

Although the integrated risk assessment and management approach necessitates the consideration of all risks, the level of detail 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 guidelines.

A truly integrated risk assessment should take into consideration all forms of risks to all people in the given area. However, such a broad study would be too complex and is generally not practical to be undertaken. Therefore, some limitations of the study are needed. These guidelines only consider some risks from some types of industrial activities. It depends on the particularities of a given area whether this limitation is adequate or whether other risks are more important. The methodology which is described in these guidelines is, in principle, also applicable for other risks, although different data would be needed.

Integrated risk management also necessitates efficient co-ordination between all 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. The question of risk communication is extremely important and it is essential that those not familiar with the concept of risk and its assessment are properly informed.

1.4. NATURE OF HEALTH AND ENVIRONMENTAL RISKS

1.4.1. Types and sources of risk

Most human activities and many natural phenomena are possible sources of risk. Although there is no single authoritative source of acceptable definitions of the terminology used in risk assessment, 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 magnitude of that loss. In the context of these guidelines, the following constitute the most relevant types and sources of risk, see also Fig. 1.1, to be considered:

- **Continuous emissions** to air, water and land from fixed installations, including those of an industrial, commercial or residential nature are one type of hazard. Transportation systems including motor vehicle emissions can also be considered to constitute a source of continuous emissions. Large-scale agricultural use of fertilizers, insecticides and herbicides have the potential to contaminate groundwater, rivers, lakes and soils and can be considered a form of continuous emission. Continuous emissions can also occur from waste disposal facilities.
- **Accidental releases** of materials from fixed installations have the potential to cause serious harm to the public and the environment. Serious accidents resulting from the transportation of hazardous materials can also result in severe consequences for the public and the environment. In this context, transportation includes the transfer of material by rail, road, pipeline and ship. Waste disposal facilities can also be subject to accidental releases.
- **Natural hazards** such as earthquakes, storms, flooding and volcanic eruptions can have a direct impact on human health and may also increase the likelihood of accidental releases from fixed installations and transportation systems. Natural hazards may therefore constitute an important source of risk to be considered in the assessment process.

1.4.2. Targets of risk

Targets of risks are, firstly, the people living in the study area under consideration. 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.

Health risk

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

Environmental risk

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

FIG. 1.1. Categorization of health and environmental risk

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 an industrial installation can destroy 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 an area.

1.4.3. Dimensions of health and environmental risk

An integrated approach necessitates considerations of the different categories of risks and nature of impacts. Fig. 1.1 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 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 or due to latency period);
- Non-fatal effects (injuries, diseases) of either an immediate or delayed nature.

In relation to health and environmental risk, categorization of risks can be made on the basis of extent: local, regional or global; and on the duration of the effect: short, medium or 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 mining operations is one such example; widespread loss of species in an area is another.

2. PROJECT PROPOSAL AND MANAGEMENT PLAN

2.1. OUTLINE OF THE PROJECT PROCESS

Fig. 2.1 shows the methods and procedures for health and environmental risk assessment and indicates where the relevant information for each stage can be found in these guidelines.

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.** This includes 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. A separate document has been produced by the IAEA [1] for the classification and prioritization of risks from major accidents in process and related industries, to aid this process.

Step 2: **Conduct of Health and Environmental Risk Analysis Studies**. This includes: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 and analysis of transportation related risks.

Step 3: **Conduct of Infrastructure and Organizational Safety Analysis.** This includes the analysis and evaluation of emergency planning provisions, including prevention and protection facilities off-site and on-site; environmental monitoring infra-structure in the area; and the review and analysis of institutional and regulatory provisions.

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

2.2. PROJECT PLANNING

There are a number of facets in which an integrated area-wide risk assessment project differs from other projects. Firstly, the number of parties involved is relatively large and therefore, a description of the project and the organizational and management aspects thereof require 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 health and environmental risks relies on a number of assumptions. Therefore the quantified results should be interpreted with care and all the uncertainties exposed. To ensure orderly and efficient progress of the study a number of procedural steps should be followed.

2.2.1. 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 plan, including the timetable, and identify the required financial, human and other resource requirements.

(b) The initiating organization should ensure that all the relevant industry and government organizations are involved. These organizations should decide on the conditions under which

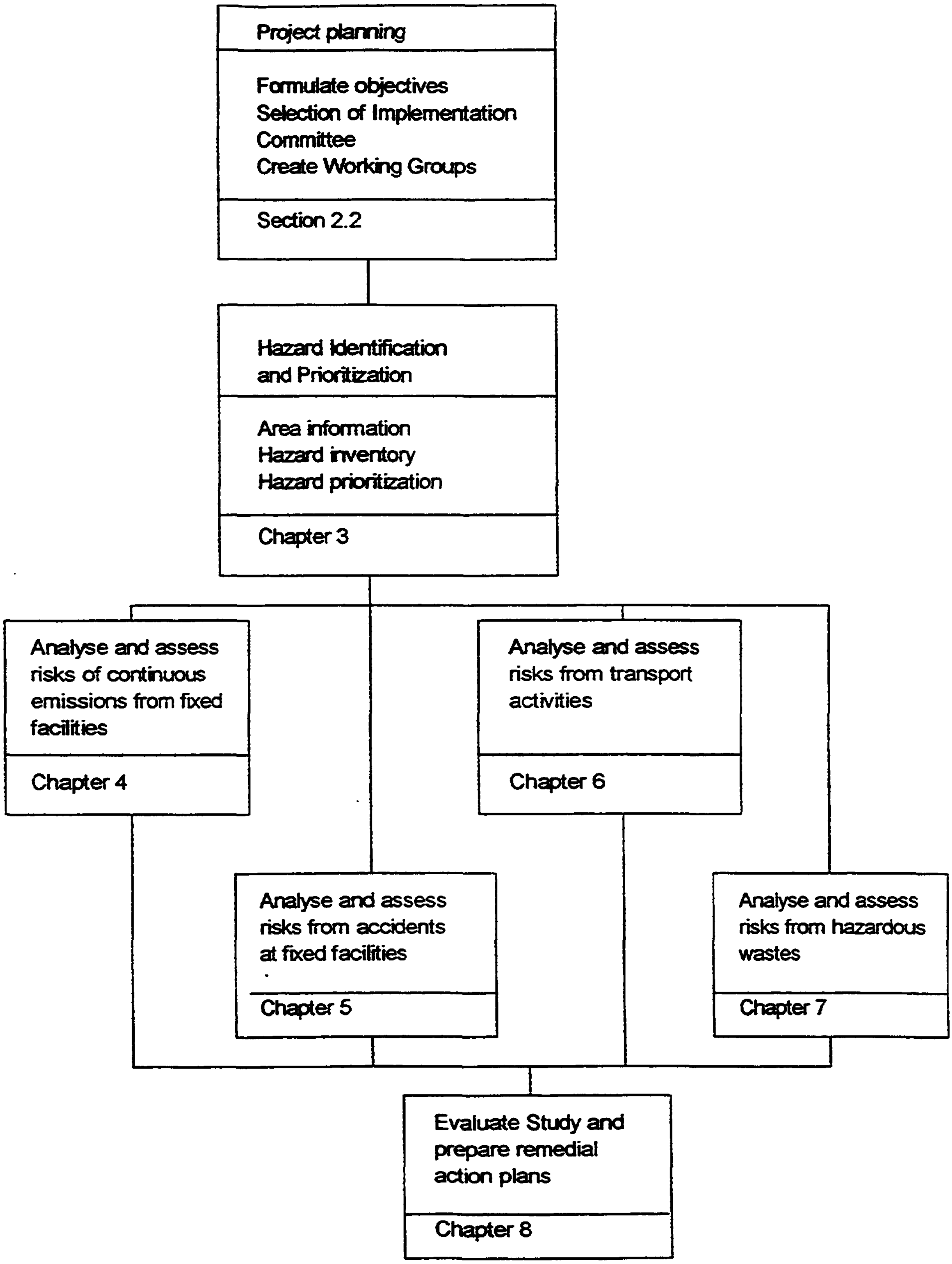


FIG. 2.1. Methods and procedures for health and environmental risk assessment

they wish to participate and on whether the proposed objectives and the draft study plan 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. Industry participation in these studies is seen as essential and every attempt should be made to ensure the co-operation of industry from the outset. 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.

(c) A Steering Committee for the project should be established by the participating organizations, specifying its responsibilities and terms of reference. For the execution of the project an Implementation Committee will assume responsibility.

(d) The Implementation Committee should formulate the project proposal into a detailed working project plan and establish working groups to carry out the various analyses. The working groups should undertake the various analyses associated with the project. If external consultants are necessary, the Implementation Committee should make tenders for the work and approve contract awards.

(e) The Implementation 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 organizational arrangements for such a study are shown in Fig. 2.2.

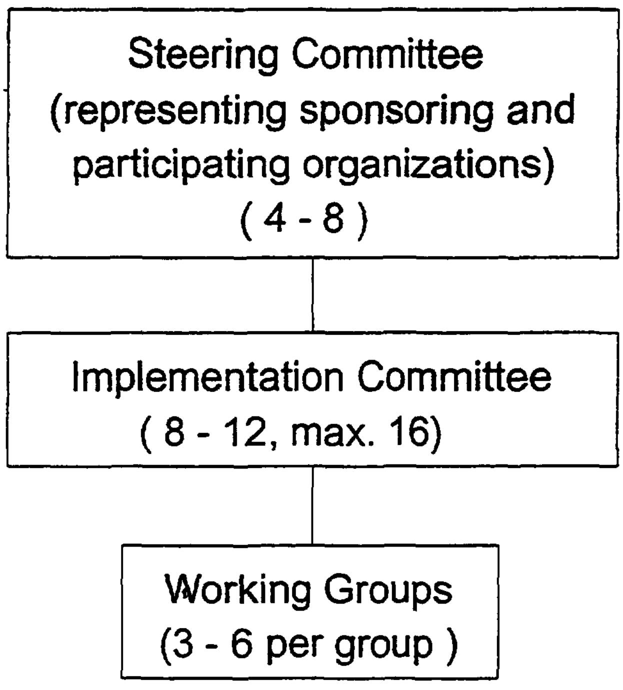


FIG. 2.2. Organizational arrangements for an integrated risk assessment study

2.2.2. Formulating the objectives and project proposals

In most cases, the main objective of the study is to formulate a completely integrated health and 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 area) will vary, depending on the precise needs of the particular area. 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.

Appendix I outlines the main elements to be included in formulating a proposal for a regional risk management project. 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.
- The financial, human, equipment and other resources needed to undertake the study.
- Organizational charts 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 (see Figs 2.3, 2.4, 2.5).

2.2.3. Area study problem formulation

It is obvious that the first step in performing a study is the most difficult and at the same time the most important one. Thus, it could be very significant that the Implementation Committee at the early beginning of the project development (before it is going to define purpose and objectives of the project) makes certain efforts to define the scope of the project i.e. what is reasonably to be analyzed within the integrated area risk study: normal operation of industrial facilities (which means continuous emission to air, water and soil); accidents in the stationary industrial facilities (which means accidental releases in air, water and soil); emissions due to traffic; traffic accidents; problems related to waste management (industrial waste, municipal waste, hazardous waste and soil, surface and ground water pollution); hazardous materials transportation (railway, road, ship, pipeline); noise and odor, etc. Also, the types of risk to be assessed need clarification: health risk (individual or societal risk; risk to the workers or to the public; mortality or morbidity risk; immediate or delayed); or perhaps environmental risk should be taken into consideration.

It is also important to define in advance (if possible) what kind of methodologies, i.e. computer codes will be applied and how many and what kind of databases should be established. Depending on the choices between all these options made by the Implementation Committee the project goals and human, financial and other resources can be assessed and planned, as well as the provisional time schedule and some milestones of the project preparation can be set. Of course, limited resources have a feedback to the already defined scope of the project. Balance between these two aspects is of high importance for the further project development.

To make a proper decision related to the scope of the project, the results of previously performed studies and analyses in the field should be available to the Implementation Committee. It is one of the basic requirements which should be satisfied.

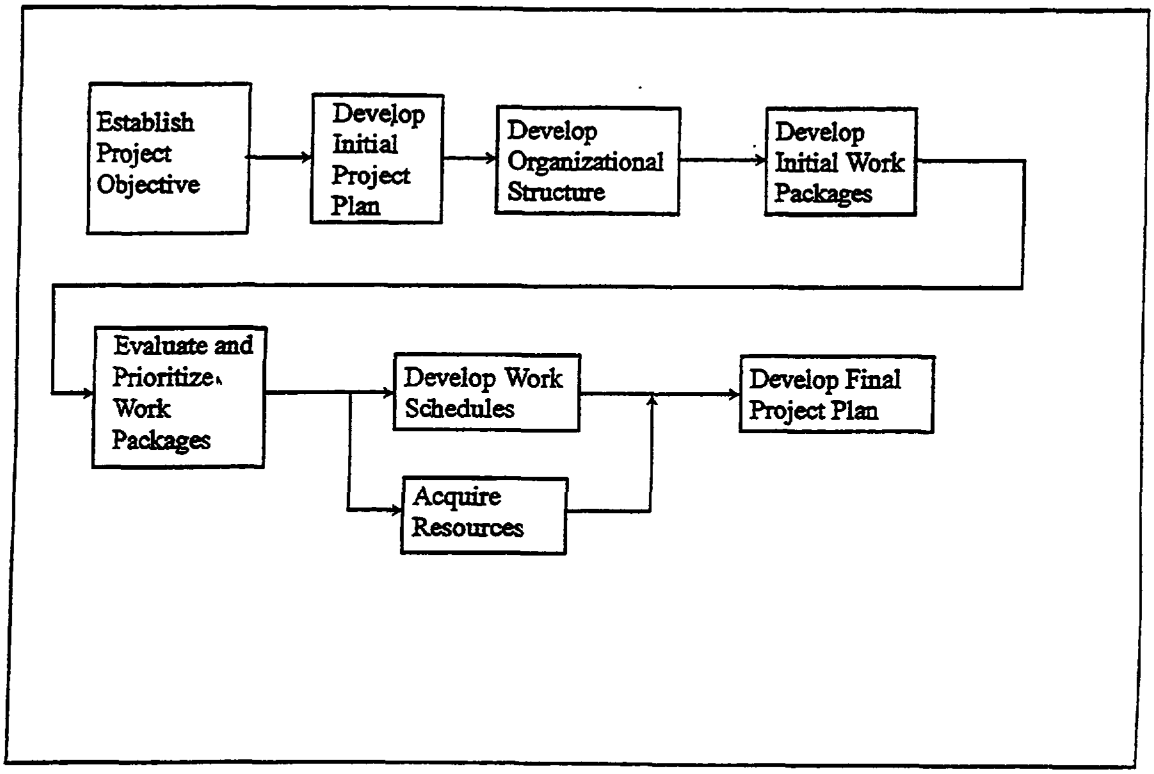


FIG. 2.3. Project planning

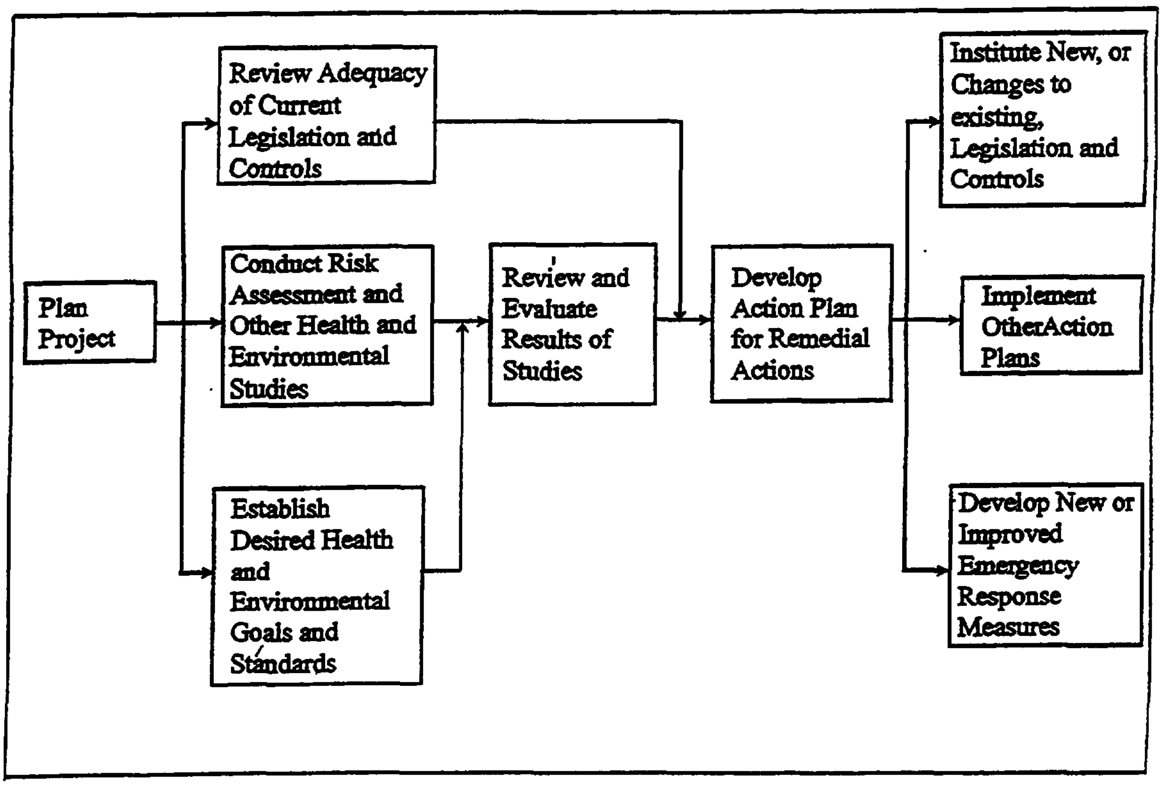


FIG. 2.4. Project management

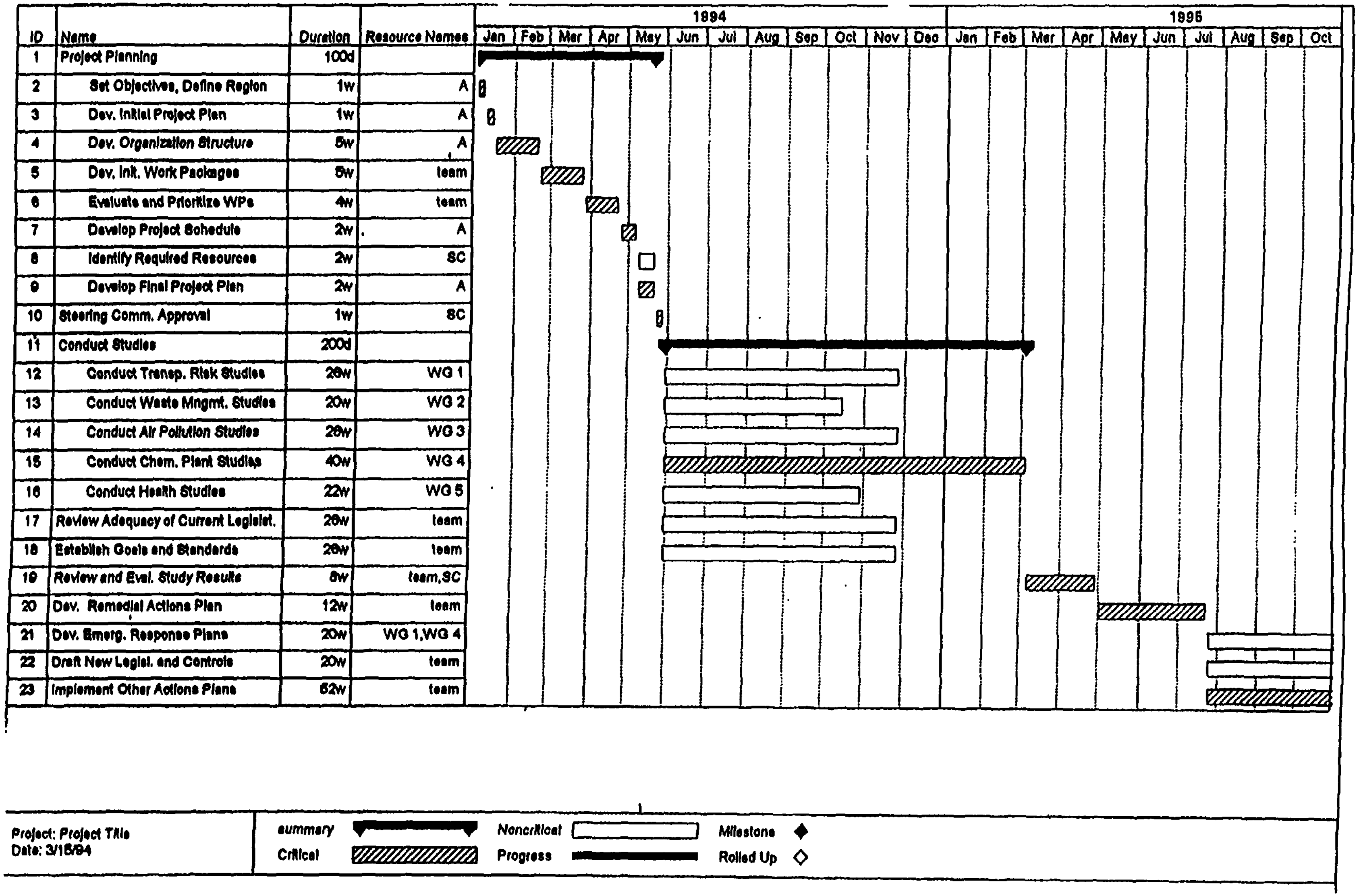


FIG. 2.5. Example of a regional risk management project schedule

2.2.4. Selection of participating organizations

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

Because of the wide-ranging nature of the integrated risk assessment and management process, it is essential that all relevant organizations participate in the study. In all cases, both industry and representatives from relevant government authorities must be involved.

For example, if 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 is possible. However, there is less chance of such a policy actually being implemented.

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

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; in particular those that 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 often appropriate that one or more national government authorities participate.

Another consideration 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, etc. 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 Implementation Committee. It may also be appropriate to involve local community or environmental 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, 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 resource (e.g., financial, human) contributions.

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

2.2.5. Necessary human, financial and other resources

Only when the objectives and extent of the study project are defined, is it possible to provide estimates of the human, financial and other resources needed. Other requirements may include computers, software and environmental measuring and monitoring facilities. Human resources are usually more easily available from the participating organizations than from hired consultants and this should be encouraged in order to develop and extend their knowledge and capabilities. 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, in line with the objective of expertise transfer.

Usually it is sufficient to have one or two modern personal computers or workstations available. Also, it is also not appropriate to purchase expensive measuring or monitoring equipment until 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.

2.2.6. Steering Committee

The Steering Committee should be composed of senior-level representatives from all participating organizations. These individuals should have significant decision-making authority in areas such as policy formation, resource allocation and action plan implementation.

2.2.7. Implementation Committee

When the study project has been defined and the participating organizations, through their Steering Committee, have approved its objectives and scope, and have made decisions concerning human, financial and other resources, then responsibility for the execution of the study falls on the Implementation Committee. Thereafter, the Implementation Committee should make all further routine decisions and direct the course of the study. Interim reports should be regularly presented by the Implementation Committee to the Steering Committee.

All participating organizations, especially those which contribute significant resources or valuable information, should be invited to take their place on the Implementation Committee. The representatives should preferably be experts with wide experience. Leaders of working groups should also be represented on the Implementation Committee.

The size of the Implementation Committee should not be too large. The optimum number is eight to twelve people, the maximum 16 people. The Implementation 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 Implementation Committee should be done in such a way that the Implementation Committee can act with authority and expertise. The Steering Committee must be able to rely on the Implementation Committee for almost all the day-to-day 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 Implementation 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

THE IMPLEMENTATION COMMITTEE
SELECTION OF THE TEAM: • 8 - 12 people (optimum), 16 people (maximum) • Broad knowledge and experience • Includes leaders of working groups • Representatives of different interests
TERMS OF REFERENCE:
• Overall responsibility for the day-to-day progress of the study to completion • Steer the project in line with the objectives agreed by the Steering Committee • Make adjustments where necessary • Establish and guide working groups • Review working group reports • Prepare final strategy with recommendations • Ensure appropriate consultations

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 Implementation 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 Implementation 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 Implementation Committee should also have a secretary with some knowledge of the environmental sciences, with experience in taking 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.

2.2.8. Working groups

The analysis and assessment of different issues should be carried out by one or more working groups under the guidance of the Implementation 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 sub-studies 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 sub-studies with a view to allocate 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 collected by more than one working group.

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 sub-studies, e.g.

environmental sciences, biology, ecology, chemistry, chemical engineering, mechanical engineering, civil engineering, toxicology, epidemiology, safety science and risk analysis, meteorology, physical planning, economy, legislation, administration, 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 Implementation Committee, so that they can be carried out by working groups of the size of three to six people.

2.2.9. Reporting

The Implementation Committee is responsible for the execution of the study and should report on the final results. 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 Implementation Committee should only be 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 Implementation 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 Implementation 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 progress points written down. The general progress report can be made by way of verbal presentation to the Implementation Committee. The purpose of such progress reports is to brief the members of the Implementation Committee on the activities that have been carried out by the working groups 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 Implementation Committee that has to decide on these matters.

The progress reports of the working groups 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 Implementation 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 Implementation Committee should be short. It should refer to the final report for all details, but should contain the main conclusions and recommendations of the Implementation Committee, to be approved by the Steering Committee.

For complex studies with several working groups and final reports, the Implementation Committee has to decide if it will collect these reports and send them with a covering report of the conclusions and recommendations to the Steering Committee, or if it will send each report together with its own separate covering report, with, possibly, an additional integrated final report of the Implementation Committee at the end of all sub-studies.

2.2.10. Evaluation

Three forms of evaluation are recommended for an area-wide integrated risk assessment study. During the course of the study, the Implementation 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 the 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 which were not covered well enough by the study or which need to be updated.

3. HAZARD IDENTIFICATION AND PRIORITIZATION

3.1. FACTORS TO BE CONSIDERED IN THE SELECTION OF THE STUDY AREA

The crucial first step in an area-wide risk assessment and management project is the delineation of an appropriate study area. The appropriate basis for area selection will depend on the particular circumstances of each case. The study area is defined as the area where the emissions from the industrial area may significantly affect human health and the environment. Although absolute rules for choosing a study area cannot be given, experience on the dispersion of pollutants through different media will help to define the study area. Several factors should be considered:

- The study area should be selected for its physical and industrial/economic characteristics, although administrative and national boundaries may be used if necessary.
- Strict boundaries should not be drawn before the initial hazard analysis is completed, as the area which may be affected will not have been identified.
- Transport systems for the movement of hazardous materials should only be considered within the study area.
- Some risk sources will have potential for effects well beyond the immediate area. In certain cases consideration should be given to see if the analysis needs to take account of local effects and separately of wider regional effects.
- Community concern may also be a factor to be considered.

3.2. BASIC INFORMATION ON THE AREA

Background information on the study area is normally required. The desirable set of information includes:

(i) General Environmental Quality

- Air - Average and high concentrations of SO_2, NO_x, CO, TSP (total suspended particulates) and other pollutants of concern in industrial, urban and rural areas;
- Water - General water quality including drinking water;
- Soil - Deposits of acid, nitrates, fluorides, heavy metals.

(ii) Geographical and Socio-economic 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.

It should be noted that the listing in (i) and (ii) above is by way of indicative examples and is by no means exhaustive.

3.3. INVENTORY OF POSSIBLE HAZARDS

3.3.1. 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.

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

Biochemicals, Biotechnology 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 ammunition, 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 principal materials are not by themselves hazardous, such as brickworks and glassworks, but may involve the storage of significant quantities of fuel, the utilization of solvents and cleaning materials which are hazardous.

- Metal works (carbon monoxide, NO_x);
- Paint (hydrocarbons);
- Brick works (fuel, fluorides);
- Glass works (fluorides);
- Shipyards (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: the main hazards are explosions, fire, air pollution, waste, use of explosives.

- Oil;
- Gas;
- Coal;
- Metal;
- 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, vinylchloride, acrylonitrile);
- Solvents;
- Biocides;
- Fertilizer production (ammonia, ammonium nitrate, NO_x, hydrogen);
- Acids, alkalis;
- Detergents;
- Bulk chemical production;
- Ammonia production;
- Chlorine production.

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

Power Generation and Distribution: Electric generation systems are based on:

- Coal/peat;
- Oil;
- Gas;
- Nuclear;
- Biomass (wood, wastes);
- Hydroelectricity;
- Wind;
- Solar energy.

SO_2 and NO_x emissions are of concern in case of fossil fuel or biomass fuelled power plants. Also dusts and wastes containing heavy metals can form a hazard. Many plants store chlorine for the conditioning of cooling water. Radiological hazards are primarily connected with nuclear power plants, but should also be considered for fossil fuel plants.

Transformer/Switchyards: where transformer oils containing PCBs are involved they also could represent 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).

PETROCHEMICALS, CHEMICALS AND RELATED INSTALLATIONS

1. (a) Installation for the production of organic or inorganic chemicals using for this purpose, in particular:
   - alkylation
   - amination by ammonolysis
   - carbonylation
   - condensation
   - dehydrogenation
   - esterification
   - halogenation and manufacture 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 .

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.

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;
- Ships, tank cleaning, etc. (remaining 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.

3.3.2. Basic Information on Activities

In order to be able to identify possible hazards of the activities listed in the previous section, 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 emissions and water emissions: 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;
- Surrounding land use (activities, main roads and dwelling areas).

(b) Transport of Hazardous Materials

The UN list of hazardous materials can be used as the basis information to identify transported 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.

3.4. HAZARD IDENTIFICATION AND PRIORITIZATION

In some situations it may be possible, and more expedient, to use the procedures described in the manual for the Classification and Prioritization of Risks from Major Accidents in Process and Related Industries [1]. The methods and procedures outlined in the Manual apply to the risks of major accidents with off-site consequences from fixed installations handling, storing and processing hazardous materials; and transport of hazardous materials by road, rail, pipelines and inland waterways. The types of risk being considered are risk of fires, explosions and releases of toxic substances to the public outside the boundaries of hazardous installations. The risk to workers (occupational risk) and the risk of accidents to the natural environment are not included. With the information collected in the previous steps an initial hazard identification can be carried out. For this the form as shown in Table 3.1. should be filled in for each activity and for each hazard aspect. The hazard aspects are divided into two main categories: hazards from accidents and other abnormal occurrences and hazards from normal operation. The subcategories of hazard are: acute fatalities, long term health effects, property damage and major economic damage, biophysical damage through the media air, water or soil.

For each entry one of the following labels should be given: **"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 can be based on the listing of notifiable installations in the Directive of the Council of the European Communities (see Annex I) and on the threshold quantities specified, e.g., in the Dutch Labour Directorate (see Table 3.3.)

- Prioritize activities for further analysis based on the location of selected hazardous activities relative to populated areas. The basis is a distance vs. quantity tabulation and a hazard index approach described in section 3.4.3.

3.4.1. Hazards from accidents and other abnormal occurrences

(a) Acute Fatalities

The total quantity of each hazardous material at the facility under investigation or in one transport unit is taken into account. It should be noted that for nuclear facilities an assessment giving all the information required should be made available separately. Nuclear facilities will not therefore need to be considered in the initial hazard identifications process.

Step 1. If the quantity is equal or greater than the quantity prescribed in the CEC Directive, use label "yes"; otherwise label "no". Annex I 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 threshold quantity values for different substances.

- Flammable substances > 10 000 kg
- Explosive substances > 1 000 kg
- Toxic substances: based on LC_{50}
- Toxic substances: use [1]ERPG[1)], IDLH[2)], TLV[3)].

Table 3.2 provides the relationship between the threshold quantity and LC_{50}. Examples of toxic substances and threshold quantities are given in Table 3.3. A list of toxic substances derived from the Emergency Response Planning Guidelines is provided in Table 3.4.

If the quantity of substance is equal or greater than the threshold quantity from above, label "yes", otherwise label "no", in doubt "maybe".

(b) Health 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 label "yes", otherwise "no".

- Structural damage/loss including corrosive and other effects on paints etc.;
- Contamination;
- Infrastructure loss/costs;

ERPG[1)]: Emergency Response Planning Guidelines [2].
IDLH[2)]: Immediately Dangerous to Life or Health [3].
TLV[3)]: Threshold Limit Values, see publications on national occupational limits.

TABLE 3.1. INITIAL HAZARD IDENTIFICATION

Facility/Activity	HAZARDS DUE TO ACCIDENTS AND OTHER ABNORMAL OCCURRENCES				HAZARDS FROM NORMAL OPERATION			
	Acute Fatalities	Long-Term Health	Property Damage	Biophys. Air, Water, Land	Long-Term Health		Biophys. Air, Water, Land	

TABLE 3.2. MODEL CALCULATION OF THRESHOLD QUANTITY OF TOXIC SUBSTANCES

LC_{50} IHI-rat, 1 h mg/m3	Physical condition at 25°C	Threshold quantity Kg
LC ≤ 20 (4h)	not applied	1
20 , LC≤ 100	gas liquid HV liquid (MV) liquid (LV) solid	3 10 30 100 300
100 <LC≤ 500	gas liquid (HV) liquid (MV) liquid (LV) solid	30 100 300 1000 3000
500 <LC≤ 2000	gas liquid (HV) liquid (MV) liquid (LV) solid	300 1000 3000 10000 - *)
2000 <LC≤ 20000	gas liquid (HV) liquid (MV) liquid (LV) solid	3000 10000 - *) - *) - *)
LC> 20.000	not applied	-

HV = high volatility, 25 C < boil pt < 50 C
IHI = initial hazard identification
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 3.3. EXAMPLES OF TOXIC SUBSTANCES AND THRESHOLD QUANTITIES USED IN THE HAZARD INDEX SYSTEM

Substance	Threshold Quantity (Kg)	Toxicity-Data	Boiling Point °C
Acrolein	300	LC_{50}: 109.7 mg/m³ 1H	53
Acrylonitrile	-	LC_{50}- 1 hour between 3 g/m³ and 5 g/m³	77
Aldicarb	1	LD_{50} ORL-RAT = 1 mg/kg	indep.
Ammonia	3000	LC_{50}: 11590 mg/m³ 1H	-33
Arsine	30	LC_{50}: 369 mg/m³ 1H	-55
Azinphos-methyl	300	LC_{50}: 69 mg/m³ 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/m³ 1H	>100
Hydrogencyanide	100	LC_{50}: 163 mg/m³ 1H	26
Dichloroethane /1.2-	-	LC_{50}: 28 g/m³ 1H	84
Dichlorovos	1	LC_{50}: 15 mg/m³ 4H	indep.
Dieldrin	1	LC_{50}: 3.8 mg/m³ 1H	indep.
Diethyl-s-ethionylmethyl-fosforthioaat/0.0-	1	LD_{50} ORL-RAT= 1mg/kg	indep.
Diethyl-s-(ethylthiomethyl)-thiofosfaat	1	LD_{50} ORL-RAT = 250 μg/kg of body mass	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/m³ 1H	11
Fluor	30	LC_{50}: 185 ppm/1H	-188
Hydrogenfluoride	300	LC_{50}: 1276 ppm/1H	20
Formaldehyde	300	LC_{50} 1-hour between 600 and 1000 mg/m³	-21
Phosphine	30	LC_{50}: 361 mg/m³ 1H	-88
Phosgene	3	LC_{50}: 38 mg/m³ 1H	8
Furan	100	LC_{50}: 120 mg/m³ 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

TABLE 3.3. (cont.)

Substance	Threshold Quantity (Kg)	Toxicity-Data	Boiling Point °C
Monocrotofos	3000	LC_{50}: 162 mg/m³ 1H	125
Oxamyl	3000	LC_{50}: 170 mg/m³ 1H	solid
Ozon	1	LC_{50}: 4.8 ppm/4H	indep.
Parathion	1000	LC_{50}: 210 mg/m³ 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/m³ 1H	-21
Nitrogenmonoxide	300	LC_{50}: 924 mg/m³ 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 µg/kg	indep.
TEPP	1	LD_{50} ORL-RAT = 0,5 mg/kg	indep.
Tetraethyllead	10000	LC_{50}: 850 mg/m³ 1H	>100
Triethylenemelamine	1	LD_{50} ORL-RAT = 1 mg/kg	indep.
Sulphurdioxyde	3000	LC_{50}: 5.14 g/m³ 1H	-10
Carbonsulphide	-	A concentration of 20.5 g/m³ during 1 hour no lethality	
Hydrogensulphide	300	LC_{50}: 898 mg/m³ 1H	-60
Sulphuric acid	-	LC_{50}: 3.6 g/m³ 1H	280

- Factors of strategic significance, crucial plant loss;
- Crops and stock losses;
- Social dislocation.

(d) Biophysical Damage (Air/Water/Soil)

If the following type of damage could occur fill in label "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.

3.4.2. 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 wastes.

TABLE 3.4. EMERGENCY RESPONSE PLANNING GUIDELINES, REF.[2]: TOXIC SUBSTANCES

ERPGs according to AIHA [2]			
CHEMICAL	ERPG-1	ERPG-2	ERPG-3
Acrolein	0.1 ppm	0.5 ppm	3 ppm
Acrylic acid	2 ppm	50 ppm	750 ppm
Allyl chloride	3 ppm	40 ppm	300 ppm
Ammonia	25 ppm	200 ppm	1000 ppm
Benzyl chloride*	1 ppm	10 ppm	25 ppm
Bromine	0.2 ppm	1 ppm	5 ppm
1,3-Butadiene	10 ppm	50 ppm	5000 ppm
n-Butyl acrylate**	0.05 ppm	25 ppm	250 ppm
n-Butyl isocyanate*	0.01 ppm	0.05 ppm	1 ppm
Carbon disulfide	1 ppm	50 ppm	500 ppm
Carbon tetrachloride**	20 ppm	100 ppm	750 ppm
Chlorine	1 ppm	3 ppm	20 ppm
Chlorine trifluoride**	0.1 ppm	1 ppm	10 ppm
Chloroacetyl chloride	0.1 ppm	1 ppm	10 ppm
Chloropicrin	NA	0.2 ppm	3 ppm
Chlorosulfonic acid	2 mg/m^3	10 mg/m^3	30 mg/m^3
Chlorotrifluoroethylene	20 ppm	100 ppm	300 ppm
Crotonaldehyde	2 ppm	10 ppm	50 ppm
Diketene	1 ppm	5 ppm	50 ppm
Dimethylamine	1 ppm	100 ppm	500 ppm
Epichlorohydrin	2 ppm	20 ppm	100 ppm
Ethylene oxide*	NA	50 ppm	500 ppm
Formaldehyde	1 ppm	10 ppm	25 ppm
Hexachlorobutadiene	3 ppm	10 ppm	30 ppm
Hexafluoroacetone**	NA	1 ppm	50 ppm
Hydrogen chloride	3 ppm	20 ppm	100 ppm
Hydrogen cyanide*	NA	10 ppm	25 ppm
Hydrogen fluoride	5 ppm	20 ppm	50 ppm
Hydrogen sulfide	0.1 ppm	30 ppm	100 ppm
Isobutyronitrile	10 ppm	50 ppm	200 ppm
Methyl alcohol*	200 ppm	1000 ppm	5000 ppm
Methyl chloride**	NA	400 ppm	1000 ppm

TABLE 3.4. (cont).

ERPGs according to AIHA [2]			
CHEMICAL	ERPG-1	ERPG-2	ERPG-3
Methyl iodide	25 ppm	50 ppm	125 ppm
Methyl mercaptan	0.005 ppm	25 ppm	100 ppm
Monomethylamine	10 ppm	100 ppm	500 ppm
Perfluoroisobutylene	NA	0.1 ppm	0.3 ppm
Phenol	10 ppm	50 ppm	200 ppm
Phosgene	NA	0.2 ppm	1 ppm
Phosphorus pentoxide	5 mg/m^3	25 mg/m^3	100 mg/m^3
Sulfur dioxide	0.3 ppm	3 ppm	15 ppm
Sulfuric acid (Oleum, sulfur trioxide and sulfuric acid)	2 mg/m^3	10 mg/m^3	30 mg/m^3
Tetrafluoroethylene	200 ppm	1000 ppm	10 000 ppm
Titanium tetrachloride	5 mg/m^3	20 mg/m^3	100 mg/m^3
Trimethylamine	0.1 ppm	100 ppm	500 ppm
Vinyl acetate	5 ppm	75 ppm	500 ppm

* Set 8 (under consideration by AIHA)
** Set 9 (under consideration by AIHA)
NA not applicable

(a) Health Effects

- Air: Major pollutant gases such as SO_x, NO_x, CO, O_3, NH_3, HCL, hydrocarbons, carcinogens such as benzene, benzo(a)pyrene, toluene, fluorine, H_2S, dusts, particulates and fumes, CFCs and radioactive materials;
- Water: Biocides, heavy metals, phosphates, acids, nitrates, fertilizers, 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".

(b) 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 grounds).

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

(c) Biophysical Damage

As for accident situation.

3.4.3. 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.

3.4.3.1. Accidents

(a) Acute Fatalities

Step 1: If the activity occurs within the distance from populated areas indicated in Table 3.5. label "yes". Otherwise label "maybe" and proceed to step 2.

Step 2: For activities labelled "maybe" from step 1 above, calculate the Potential Hazard Index (PHI) as a function of distance to the nearest population area. Fig. 3.1. indicates the relevant relationships to be applied.

TABLE 3.5. CRITERIA OF DISTANCE FROM POPULATED AREAS[a] (FIRST DWELLINGS)[b]

Industrial Activity			Distance from populated areas (m)
Stationary installations	flammable substances and/or explosives		< 1000
	specifically:		
	• petrol station		< 50
	• LPG station		< 100
	• pipeline with flammable liquids		< 50
	• storage of cylinders (25-100 kg)		< 100
	toxic substances		< 10000
	specifically:		
	• cooling installation		< 100
	• storage of pesticides for retail		< 50
Transport	LPG, by:	rail/road	< 200
		water	< 500
	petrol, by:	rail/road	< 50
		water	< 200
	oil, by:	rail/road	< 25
		water	< 100
	toxic substances, by:	rail/road	< 3000
		water	< 3000

[a] The values are related to the maximum possible quantities (and maximum toxicity for toxic substances) that exist in normal industrial practice.

[b] Adapted from Ref. [1].

Installations in buildings | Storage

Combustibles $\alpha = 10$, $T = 1$ | Explosive materials $\alpha = 100$, $T = 1$ | Toxic materials $\alpha = 1000$, T = threshold

$$PHI(d) = \alpha \; Q / T d^3$$

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 metres

T: the threshhold quantity which varies with LC50 (see Tables 3.2 and 3.3)

FIG. 3.1.Potential hazard index

If $PHI(d) < 1$ label "no"
If $PHI(d) \geq 1$ label "yes"

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

(b) 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.

3.4.3.2. Normal Operation

The ambient concentrations of major pollutants are compared with the levels given in the WHO guides for air and water, Tables 3.6. and 3.7. This is done for industrial, urban and rural areas. If a level exceeds the concentration as given in the WHO guides, an important hazard has been identified.

Furthermore, the total emission in the area can be calculated from the data on the number of emitters and the quantities each of them emits. The population density is taken into account to determine approximately the number of people affected by too high ambient concentrations. For a worst case accident scenario extremely bad meteorological circumstances are to be assumed. Thus, a rough quantification of the damage per year due to the different pollutants considered in the analysis can be obtained.

TABLE 3.6. WHO AIR QUALITY GUIDELINES VALUES FOR INDIVIDUAL SUBSTANCES BASED ON EFFECTS OTHER THAN CANCER OR ODOR/ANNOYANCE GIVEN IN REF. [4].

Substance	Time-weighted average	Averaging time
Cadmium	1-5 ng/m³ 10-20 ng/m³	1 year (rural areas) 1 year (urban areas)
Carbon disulfide	100 μg/m³	24 hours
Carbon monoxide	100 mg/m³ [a] 60 mg/m³ [a] 30 mg/m³ [a] 10 mg/m³	15 minutes 30 minutes 1 hour 8 hours
1-2 Dichloroethane	0.7 mg/m³	24 hours
Dichloromethane	3 mg/m³	24 hours
Formaldehyde	100 μg/m³	30 minutes
Hydrogen sulfide	150 μg/m³	24 hours
Lead	0.5-1.0 μg/m³	1 year
Manganese	1 μg/m³	1 year
Mercury	1 μg/m³ [b]	1 year
Nitrogen dioxide	400 μg/m³ 150 μg/m³	1 hour 24 hours
Ozone	150-200 μg/m³ 100-120 μg/m³	1 hour 8 hours
Styrene	800 μg/m³	24 hours
Sulfur dioxide	500 μg/m³ 350 μg/m³	10 minutes 1 hour
Tetrachloroethylene	5 mg/m³	24 hours
Toluene	8 mg/m³	24 hours
Trichloroethylene	1 mg/m³	24 hours
Vanadium	1 μg/m³	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 3.7. WHO DRINKING-WATER QUALITY GUIDELINES FOR INORGANIC AND ORGANIC CONTAMINANTS AND PESTICIDES OF HEALTH SIGNIFICANCE GIVEN IN REF.[5]

Contaminant	Guideline Value
Aldrin and Dieldrin	0.03 µg/l
Arsenic	0.01 mg/l
Benzene	10 µg/la
Benzo[a]pyrene	0.7 µg/l
Cadmium	0.003 mg/l
Carbon Tetrachloride	2 µg/la
Chlordane	0.2 µg/l
Chloroform	200 µg/l[a]
Chromium	0.05 mg/l
Cyanide	0.07 mg/l
2,4-D	30 µg/l[b]
DDT	2 µg/l
1,2-Dichloroethane	30 µg/l[a]
Fluoride	1.5 mg/l
Gamma-HCH (lindane)	2 µg/l
Gross alpha activity	0.1 Bq/l
Gross beta activity	1 Bq/l
Heptachlor & heptachlor epoxide	0.03 µg/l
Hexachlorobenzene	1 µg/l[a]
Lead	0.01 mg/l
Mercury	0.001 mg/l
Methoxychlor	20 µg/l
Nitrate	50 mg/l (N)
Pentachlorophenol	9 µg/l
Selenium	0.01 mg/l
Tetrachloroethene	40 µg/l[a]
Trichloroethene	70 µg/l[a]
2,4,6-Trichlorophenol	200 µg/l [a,b]

[a] These guidelines 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 (ie., 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 adaption.

3.5. SELECTION OF HAZARDS FOR FURTHER ANALYSIS

The initial hazard identification process carried out according to section 3.4. gives the first identification of the hazardous activities in the region to be studied. In principle all activities with label entries "yes" or "maybe" should be investigated further. In practice, the limitations of the resources available will determine the number of activities to be studied, the depth of these studies and the timescale involved. It will be necessary therefore to evaluate and prioritize analyses in the light of the nature and extent of the hazards involved, the resources required and the time necessary to carry them out. As environmental impacts may also have a significant effect on the health of the population, they should be considered additionally.

Further examination of the hazardous activities so far identified may reveal that some activities present unacceptable hazards for which clear remedies are apparent. Remedial actions could be proposed for these activities without further studies being made at the time.

Additional simple consequence analysis of those activities posing the highest risk in terms of their inventory of hazardous materials or their location relative to areas of high population density will give rise to further indicators of priority.

The next stage is to assess the resources required for the study of each activity.

Examination of the hazards posed and the resources required will then permit to rank the activities thus identified in order of priority. With this completed it will be possible to develop work schedules, to acquire the needed resources and develop the final project plan.

Some hazardous activities, because of their lower priority, will not attract resources nor further studies. It is however important that these activities are not forgotten but marked for consideration at some future date when either further resources become available or their hazard ranking increases as the risks from the current higher priority hazardous activities are reduced.

4. ANALYSIS AND ASSESSMENT OF CONTINUOUS EMISSIONS FROM FIXED FACILITIES

4.1. INTRODUCTION

Continuous emissions include: pollutants routinely released into the atmosphere from stacks, tailpipes and fugitive emissions from vents, open burning, etc.; pollutants discharged to surface water from outfall pipes or channels, routine overflow from waste ponds or lagoons and spread sources such as run-off from urban roadways products or agriculture; emissions to ground water from soilfill leachate, percolation from surface ponds and lagoons, leakage from pipelines and discharges from injection wells. Products released to water, soil or air which result in the occurrence of adverse effects in humans or the environment are pollutants.

Continuous emissions generally lead to exposures that can create chronic, long-term effects. Acute health effects may also result. Extended meteorologic inversions, for example, lead to acute exposures and acute effects from routine emissions if adequate provisions are not taken. Usually continuous emissions to water can yield chronic effects only but there can be exceptions. Exceptions, for example, are contaminant concentrations which have been built up in river sediments over long periods and may be released during storms that stir up these sediments, resulting in acute, high-level exposure.

Emission sources have to be characterized and compared with the relevant emission standards concerning air, water and soil pollution. As far as the effects are concerned, once the receptors have been identified, the transport of the pollutants from the source to the receptor has to be defined and calculated and the dose-response relationships to the receptor assessed. Owing to the probabilistic character of the transport process, exposures to the receptors are obtained in terms of figures with probabilities. The estimated risk to the receptor, i.e. certain damage affected by a certain probability, is calculated and compared with the relevant risk acceptance criteria. If the criteria are not met, the pollution abatement process in the plant has to be adapted in an iterative procedure. Figure 4.1 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 4.2.

The second step is to identify receptors and characterize the dispersion of pollutants from source to receptor, either through the use of mathematical models or the use of measurements if available. This is discussed in sections 4.3 and 4.4. The procedure 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 steps are meant 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 4.6 for environmental effects. An overview of environmental guidelines and standards is given in Appendix II.

4.2. 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, the World Health Organization WHO, as given in Refs [6,7,8,9], the United Nations Environment Program, Ref.

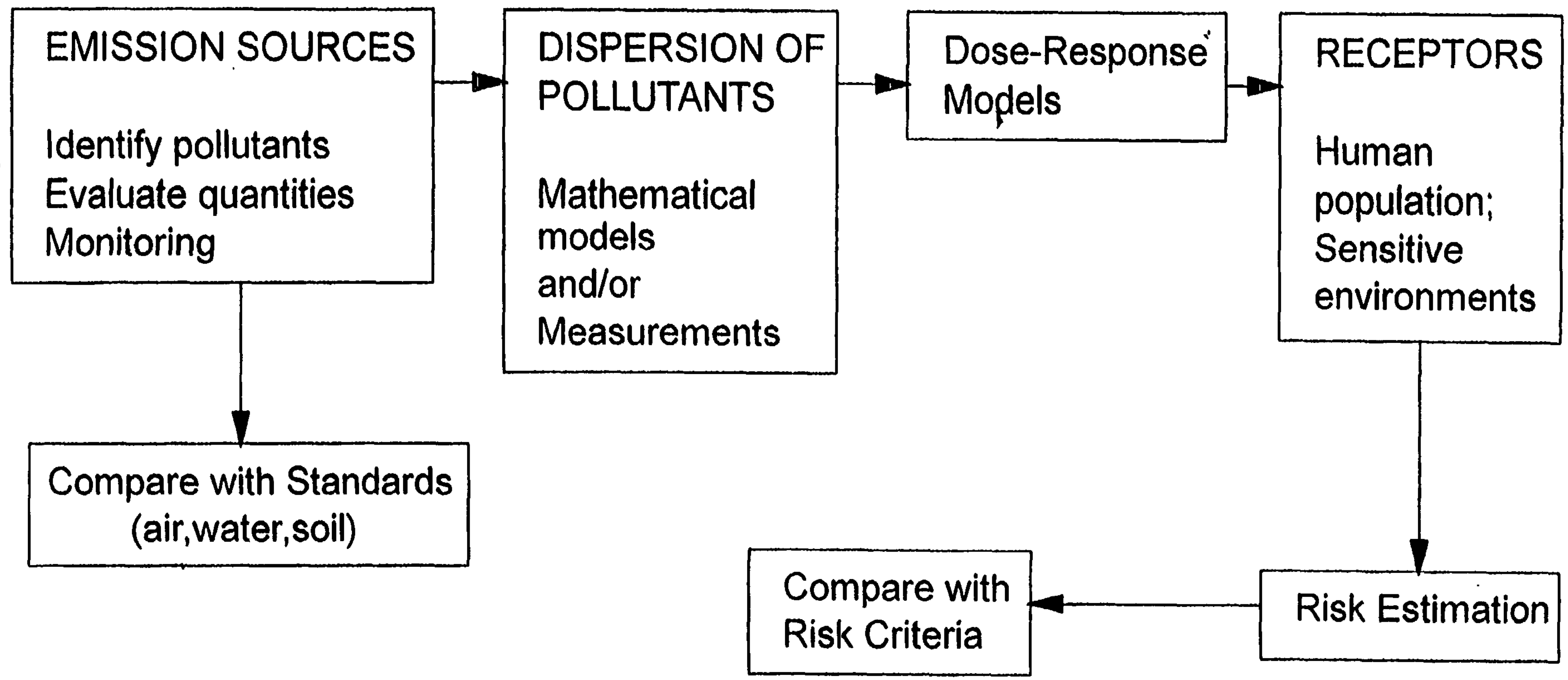


FIG. 4.1. The general assessment framework

STEP 1: Identify sources of continuous 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 pollutants by means of conversion factors and the efficiency figures of the controlled pollution equipments.

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

2.4. Use expert judgement.

STEP 3: Select a pathway for analysis organized according to the receiving media: air, water, soil.

STEP 4: Using models calculate dispersion values in the receiving media and add background values if necessary

4.1. If **air** is the medium where dispersion of pollutants occurs, then calculate concentration of pollutants under given weather conditions, according to step 5, and add background air pollutant concentrations (see subsection 4.4.2). Go to step 6.

4.2. If **water** is the medium where dispersion of pollutants occurs, then calculate concentration of different pollutants at some time instance and at a distance from the source of pollution and add background water pollutant concentrations if necessary (see subsection 4.4.3). Go to step 6.

4.3. If **soil** is the medium, evaluate the soil content of pollutants and add background contents if necessary. 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 one and about 50-80 km dispersion from a point source in simple regional and meteorological conditions use simple Gaussian Plume Models.

5.2. For complex geographical and meteorological conditions use Complex Plume Models.

STEP 6: Use either air quality, water quality and soil quality standards or dose-response relationships to estimate the risk to the population; evaluate the health impacts.

STEP 7: Use analytical methods, critical load concepts <u>or</u> expert judgement for environmental impact assessment.

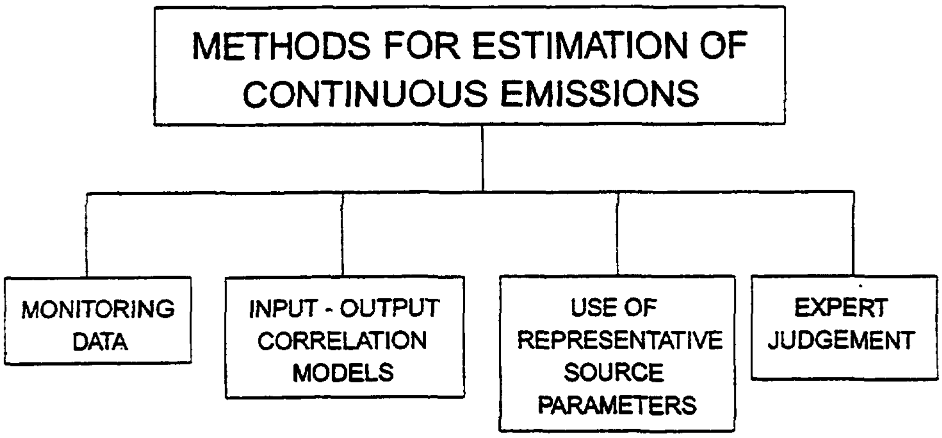


FIG. 4.2. Methods for estimation of continuous emissions

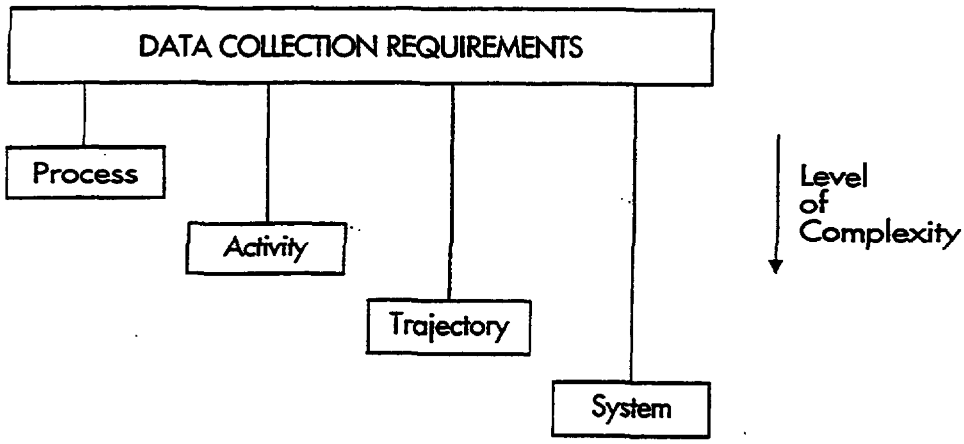


FIG. 4.3. Data collection requirements

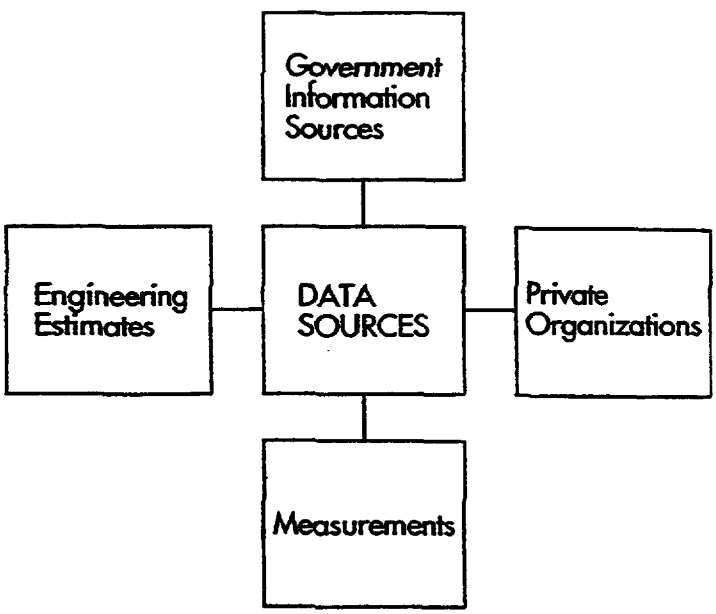


FIG. 4.4. Data sources

[10], and others e.g. OECD, Ref. [11], 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.

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 Fig. 4.2.

The **first method** consists of the collection of monitoring data from an operational source. In such a case monitoring equipments are used either on a continuous or intermittent basis to provide data specific to the process unit in question. Monitoring, however, requires substantial time and effort and may be neither technically nor economically feasible in many cases. Furthermore, if data are not collected for an extended time period, they may not be representative of the true emission characteristics because of time and process dependent variations.

A **second approach** is based on using theoretical or empirical equations correlating operating parameters to input values. Stoichiometric estimates may be, however, erroneous because of inadequate specifications, poor understanding of the process or insufficient knowledge.

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

In addition to the preceding approaches or as a **fourth approach**, if previous methods do not apply, expert judgment may be called upon.

The following subsections highlight information relevant to these methods, including 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 emission factors.

4.2.1. Data reporting protocols

4.2.1.1. 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 are 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 particular 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 areas given in Fig. 4.3.

Moreover, data collection should pay due consideration to the specificity of the products released from the emission source, their environmental impacts and to existing standards, e.g.:

(1) pollutants that quantitatively dominate the waste streams (e.g. carbon dioxide from oil- or gas-fired steam electric power plants);
(2) index pollutants (e.g. biochemical oxygen demand (BOD) or sulfur oxides);
(3) pollutants for which there are environmental standards (e.g. lead in the atmosphere);
(4) pollutants for which there are acute (e.g. hydrogen sulfide) or chronic (benzo(a)pyrene) health effects;
(5) pollutants that are emitted routinely (e.g. noble gases from nuclear power plants).

Emission coefficients may be derived using simple point estimates or 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 the fuel;
(ii) moisture, sulphur, ash, and trace element content of the fuel;
(iii) thermal efficiency of the boiler;
(iv) temperature of the exiting gases;
(v) type and characteristics of the emission-control equipment.

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

4.2.1.2. Format

In the technical literature many formats are used to express emission data for different processes. In principle the following units could be used:

(i) mass of pollutant per mass of fuel (kg/kg);
(ii) mass of pollutant per mass of product (kg/kg);
(iii) mass of pollutant per unit time (kg/s);
(iv) mass of pollutant per unit of volume (kg/m^3);
(v) mass of pollutant per unit of energy input or output (kg/J).

Reporting protocols differ, due to historical and regulatory reasons. In the USA and at OECD [11] emissions are regulated as pollutant mass per unit of energy input (kg/J) or as pollutant mass per unit of volume (kg/m^3). Emission standards for non-combustion sources associated with industrial activities span the range of reporting protocols listed above.

4.2.2. Data sources

Information can be collected from government and private organizations, from compiled literature, from new engineering estimates or from new measurements (see Fig. 4.4). As noted by WHO[12] "A major task of the study team is to locate all major government information sources and to extract the required data from them." Table 4.1 presents a list of possible sources of information. Undoubtedly, a sizeable portion of the required information available from these organizations will be in an unpublished form. Therefore, some efforts will be needed to extract, process and classify the useful information. The major difficulties with unpublished data consist in determining which data is needed and then in data interpretation. 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 a way of ensuring 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.

In the event that the agencies listed in Table 4.1 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, SO_x, NO_x) and water (e.g. TDS, BOD, pH) pollutants can be derived from several summary documents. Emission data on many industrial processes for conventional pollutants have been evaluated by WHO and by the US Environmental Protection Agency (EPA) to establish air and water pollutant emission standards. Tables 4.2 and 4.3 summarize the industries and pollutants examined in the EPA efforts. EPA efforts have also been focused on some toxic chemicals, see Table 4.4.

More detailed characterization efforts may be required for any of the following reasons:

(i) development of site-specific case studies;
(ii) analysis of site specific energy systems (e.g. peat or dung) or industrial activities that are not widely used;
(iii) emission coefficients for non-conventional (e.g. toxic or hazardous) pollutants.

In such cases the data gathering efforts may need to be focused on technical literature published by various research (e.g. US Department of Energy) or regulatory organizations (e.g. US Environmental Protection Agency) as well as by equipment manufacturers.

4.2.3. Compilation of US emission factors

Table 4.5 gives emission coefficients for five conventional air pollutants (i.e. SO_x, NO_x, CO, HC, and TSP) for a range of energy systems. These are compiled from a report prepared for the US Department of Energy. Detailed documentation needed to define the basis for these numbers is 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. heating value, sulphur and ash content);
(iii) pollution control equipments have different impacts (e.g. efficiency or types of pollutants scrubbed).

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

4.2.4. Emission standards for energy facilities in OECD countries

Table 4.6 gives emission standards for electric generating plants for OECD countries [11]. The base reporting protocols for these coefficients vary among the different countries. As discussed by OECD, simply reporting the standards on one uniform basis (e.g. ng/J input) may introduce errors 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 4.1. POSSIBLE SOURCES OF INFORMATION[12]

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 animal production Air, water and solid waste pollution control authorities
Fuel consumption	Ministry of energy Ministry of industry Internal revenue agencies Refineries or 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

TABLE 4.2. INDUSTRIES FOR WHICH NEW SOURCE PERFORMANCE STANDARDS FOR AIR POLLUTANTS HAVE BEEN DEVELOPED BY THE U.S. ENVIRONMENTAL PROTECTION AGENCY

Industry	Pollutants Regulated
Fossil-fuelled steam generators	TSP, SO_2, NO_x
Incinerators of capacity larger than 50 TPD	TSP
Portsoil cement plants	TSP, Opacity
Coal preparation facilities	TSP, Opacity
Nitric acid plants	NO_x, Opacity
Primary aluminum smelters	F, Opacity
Sulfuric acid plants	SO_x, Acid Mist, Opacity
Asphalt concrete plants	TSP, Opacity
Sewage sludge incineration	TSP, Opacity
Iron and steel plants	TSP, Opacity
Electric arc furnaces	TSP, Opacity
Ferro alloy production facilities	TSP, CO
Secondary brass and bronze ingot	TSP, Opacity
Kraft pulp mills	TSP, Total Reduced Sulfur
Petroleum refineries	TSP, Opacity, CO, SO_2
Storage vessels for petroleum	VOC
Secondary lead smelters and refining	TSP, Opacity
Primary copper, lead and zinc	TSP, SO_2, Opacity
Phosphate fertilizer industry	F
Grain elevators	TSP, Opacity
Ammonium sulfate manufacture	TSP, Opacity
Lead acid battery manufacture	Pb, Opacity
Stationary gas turbines	NOx, SO_2,
Glass manufacturing	TSP
Phosphate rock plants	TSP, 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	TSP, Opacity
Rotogravure printing	VOC
Bulk gasoline terminals	VOC
Beverage can coating	VOC

Acronyms: TSP = Total Suspended Particulates; VOC = Volatile Organic Carbon; TPD = Tons per Day

Source: Ref. [13]

TABLE 4.3. INDUSTRIES FOR WHICH PRETREATMENT AND EFFLUENT GUIDELINES AND STANDARDS FOR WATER POLLUTANTS HAVE BEEN DEVELOPED BY THE U.S. ENVIRONMENTAL PROTECTION AGENCY

Industry	Pollutants Regulated
Beet sugar	BOD, TSP, pH
Cane sugar	BOD, TSP, pH
Fiberglass insulation manufacturing	Phenol, COD, BOD, TSP, pH
Sheet, plate and laminated glass	TSP, pH, O&G, P, F, Pb, Ammonia
Rubber processing	TSP, O&G, pH, BOD, COD
Asbestos manufacturing	COD, TSP, pH
Meat products	BOD, TSP, O&G, Fecal Coliform, Ammonia
Phosphate manufacturing	TSP, Phosphorus, As, pH, F
Fruit & vegetable processing	BOD, TSP, pH
Plastics & synthetics	BOD, COD, TSP, pH, Cr, Zn, Phenols, O&G
Nonferrous metals	TSP, F, Ammonia, Al, Cu, COD, pH, O&G, As, Cu, Pb, Cd, Se, Zn
Timber products	BOD, TSP, pH, Phenols, O&G, Cu, CR, As
Organic chemicals	COD, BOD, TSP, pH, Phenols, Cyanide
Leather tanning & finishing	BOD, TSP, O&G, Cr, pH, Sulfide
Petroleum refining	BOD, TSP, COD, O&G, pH, Phenols, Ammonia, Sulfide, Cr
Pulp, paper & paperboard manufacturing	BOD, TSP, pH, Pentachlorophenol, Trichlorophenol, Zn
Builders' paper & roofing felt	BOD, TSP, pH, Pentachlorophenol, Settleable Solids, Trichlorophenol
Iron & steel manufacturing	TSP, O&G, Ammonia, CN, Phenols, pH, Benzene, Naphthalene, Benzo(a)-pyrene, TRC, Pb, Zn, Ni, Cr, Tetrachloroethylene
Textiles	BOD, TSP, COD, O&G, Cr, pH, Phenol, Sulfide, Color, Fecal Coliform
Steam electric power plants	TSP, 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, TSP, BOD
Offshore oil & gas extraction	Produced water, deck drainage, Drilling muds, Drill cutting, Well treatment, Sanitary, Domestic, Produced sand
Mineral mining & processing	pH, TSP, F, Fe
Coal mining & processing	Fe, Mn, TSP, pH, Settleable Solids
Pharmaceutical manufacturing	CN, COD, BOD, TSP, pH
Metal finishing	CN, Cd, Cr, Cu, Pb, Ni, Ag, Zn, TTO, O&G, TSP, pH

TABLE 4.3. (cont.)

Industry	Pollutants Regulated
Coil coating	Cr, CN, Zn, Fe, O&G, TSP, pH, P, Mn, TTO
Porcelain enameling	Cr, Pb, Ni, Zn, Al, Fe, O&G, TSP, pH, Ammonia, Phenols, CN
Copper forming	Cr, Cu, Pb, Ni, Zn, O&G, TSP, F, pH, TTO, Cd, As
Aluminum forming	Cr, CN, Zn, Al, O&G, TSP, pH, TTO,
Ore mining & dressing	TSP, Fe, pH, Al, COD, As, Zn, Ra226, NH, U, Cd, Cu, Pb
Explosives manufacturing	COD, BOD, TSP, pH, O&G
Gum & wood chemicals manufacturing	BOD, TSP, pH
Photographic processing	Ag, CN, pH
Pesticide manufacturing	COD, BOD, TSP, Organic Pesticides, pH
Electroplating	CN, Pb, Cd, Ni, Cr, Zn, Total Metals, TSP, pH Ag, TTO
Dairy processing	BOD, TSP, pH
Grain mills	BOD, TSP, pH
Canned & preserved seafood	BOD, TSP, O&G, pH processing
Cement manufacturing	TSP, Temperature, pH
Feedlots	Fecal Coliform, BOD
Soap & detergent manufacturing	BOD, COD, TSP, O&G, pH, Surfactants
Fertilizer manufacturing	P, F, TSP, Ammonia, N
Phosphate manufacturing	P, F, pH, TSP
Ferroalloy manufacturing	TSP, Cr, Mn, pH, CN, Phenols, Ammonia
Asbestos products manufacturing	TSP, pH, COD
Electrical & electronic components	TTO, F, pH, As, TSP
Inorganic chemicals	TSP, pH, Zn, Hg, Cu, Pb, Ni, Cl, TOC, CN, Cr, Fe, COD, Se, Ba, Sulfide, Ag

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

Source: Ref. [13]

TABLE 4.4. POLLUTANTS AND ACTIVITIES FOR WHICH HAZARDOUS AIR POLLUTANT EMISSION STANDARDS HAVE BEEN DEVELOPED BY THE U.S. ENVIRONMENTAL PROTECTION AGENCY

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 waste water treatment plant sludge

Vinyl Chloride

- Plants which produce ethylene dichloride by reaction of oxygen and hydrogen chloride, vinyl chloride by a 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

Source: Ref. [13]

TABLE 4.5. EMISSION COEFFICIENTS FOR CHOSEN AIR POLLUTANTS FROM VARIOUS ENERGY TECHNOLOGIES IN TONS/10^{12} BTU (1 BTU = 1055J, 1 TON = 907 KG)

To recalculate for metric tons/GW ∘ year use the coefficient

$$n\,\frac{TONS}{10^{12}BTU} = 27n\frac{MT}{GW{\cdot}a}$$

$$(MT = 1000\ kg,\ a = 365\ days)$$

TECHNOLOGY	AIR POLLUTANTS					COMMENTS
	SO_x	NO_x	CO	HC	TSP	
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 UF_6
Gaseous Diffusion	197.00	51.80	1.30	0.50	51.80	Enrichment to 4% U235
Gas Centrifuge Enrichment	0.46	0.37	0.01		0.02	Enrichment to 2-4% U235
Fuel Fabrication	1.10	0.28	0.01			UF_6 to UO_2 fuel elements
Commercial Waste Repository	0.27	0.42	0.38	0.03	0.02	Construction & Operations Emissions

TABLE 4.5 (cont.)

TECHNOLOGY	AIR POLLUTANTS					COMMENTS
	SO_x	NO_x	CO	HC	TSP	
COAL						
Eastern Underground Mining Emissions	0.03	0.31	0.08	0.02	0.02	With preparation plant; diesel
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		
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
Coal-Oil Power Plant	1297.	648.00	40.00	18.00	144.00	40/60 mix (by wt) coal/oil
Fluidized Bed Bituminous	1440.	366.00	56.00	15.00	138.00	Steam plant with emission controls
Fluidized Bed, Subbitumen	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 coals	850.00	850.00	60.00	18.00	42.00	Mine-mouth steam plant; emission controls
Coal-Fired Plant, western coals	600.00	850.00	90.00	30.00	40.00	Conv. steam plant; emission controls

TABLE 4.5 (cont.)

TECHNOLOGY	AIR POLLUTANTS					COMMENTS
	SO_x	NO_x	CO	HC	TSP	
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-domes 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 platforms 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 DWT 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/BIOMASS						
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

Source: Ref.[14].

TABLE 4.6. COMPARISON OF NATIONAL EMISSION STANDARDS FOR FOSSIL ELECTRICITY GENERATING PLANTS[1]

Fuel/Country	Pollutant (ng/J= g/GJ)		
	TSP	SO_x	NO_x
Solid			
Australia	105		
Belgium	147		
Canada	43	258	258
Denmark	63		
Germany	21	148	333
Greece	56		
Japan	42	230	259/173
Netherlands	20	230	270
New Zealand	52		
Sweden	15	100	280
United Kingdom	48		
United States	13	520	260
Liquid			
Australia			
Belgium		740	
Canada	43	258	129
Denmark	36		
Germany	18	168	167
Greece	56		
Japan	18	203	99
Netherlands			
New Zealand			
Sweden		100	
United Kingdom			
United States		340	210
Gas			
Australia			105
Belgium			
Canada	43	258	86
Denmark			
Germany	2	10	106
Greece	56		
Japan	15	165	37
Netherlands			
New Zealand			
Sweden			
United Kingdom			
United States		340	86

[1] Adapted from Ref.[11]

Sample Calculations to Develop Emissions from Coal-Fired Power Plants

Step 1: Coal feed rate required on a daily basis for electricity production

$$B = P.h.q$$

where: B - coal feed rate [t/day]
P - average electric power [MWe]
h - daily number of hours of operation of the power plant [h/day]
q - specific energy consumption, kg of coal equivalent per kWh which for bituminous coal is

$$q = (0.35 - 0.40)\ [kg_{c.e}/kWh]$$

Case 1: Sulphur Oxide (SO_x) - Combustion in Furnace

Step 2: Calculate the SO_x emission factor for the bituminous coal combustion without emission control equipment

$$E_{so_x} = 17.24\ S\ [kg_{so_x}/t_{coal}]$$

where: S - sulphur content of the burnt fuel [%]

Step 3: Calculate the daily SO_x uncontrolled emissions due to coal burning without control equipment

$$S_u = E_{so_x}.B\ [kg_{so_x}/d]$$

Step 4: Calculate the daily sulphur emissions with control equipment

$$S_c = S_u\ (1-a)\ [kg_{so_x}/d]$$

where: a - scrubber efficiency

4.3. ESTABLISHING ENVIRONMENTAL TRANSFERS OF POLLUTANTS TO SENSITIVE RECEPTORS

To estimate human exposure to hazardous substances investigation has to concentrate on:

- the sources and mechanisms for pollutant release to the environment;
- the transfer of pollutant through the environment;
- human exposure to the contaminated medium;
- the pathways of the pollutant.

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 (dermal, inhalation, eating, drinking, etc.) define the pathways that must be evaluated.

Numerical Example:

If:

$$P = 400\ MWe;\ h = 24\ hours/d$$

$$q = 0.37\ kg_{c.e}/kWh$$

$$S = 3\% \qquad a = 0.8$$

then:

$$B = 400\ MWe \times 10^3\ \frac{kWe}{MWe}\ x\ 24\frac{h}{d}\ x\ 0.37\ \frac{kg_{c.e}}{kWh}\ \frac{10^{-3}t}{kg} = 3552\ \frac{t_{coal}}{d}$$

$$S_u = 17.24\ x\ 3\ \frac{kg_{so_x}}{t_{coal}}\ x\ 3552\ \frac{t_{coal}}{d}\ \frac{10^{-3}t}{kg} = 184\ \frac{t_{so_x}}{d}$$

$$S_c = 184\ t_{so_x}\ (1-0.8) = 36.8\ \frac{t_{so_x}}{d}$$

Case 2: TSP - Pulverized Coal Boilers

Step 2: Calculate particulate emissions

$$E_p = 7.25\ A\ [kg_p/t_{coal}]$$

where: A - ash content in the fuel

Step 3: Calculate the daily uncontrolled particulate emissions

$$P_u = E_p.B\ [kg_p/d]$$

Step 4: Calculate the daily controlled particulate emissions

$$P_c = 7.25 \cdot 10^{-3}\, A \cdot A_f \cdot B \cdot (1-e)\ [t_p/d]$$

where: A_f - fraction of fly ash in the ash of the coal (usual value: 0.80)
e - efficiency of the control device
(e.g. electrostatic precipitator)

Numerical Example:

If:

$$B = 3552\ \frac{t_{coal}}{d}$$

$$A = 0.08$$

$$A_f = 0.80$$

$$e = 0.995$$

then:

$$P_u = 7.25\ x\ 0.08\ kg_p/t_{coal}\ x\ 3552\ t_{coal}/d\ x\ 10^{-3}\, t_p\ /kg_p = 2.06\ \frac{t_p}{d}$$

$$P_c = 7.25 \cdot 10^{-3}\ \frac{t_p}{t_{coal}}\ 0.08\ x\ 0.8\ x\ 3552\ t_{coal}/d\ (1-0.995) = 8.24 \cdot 10^{-3}\ t_p/d = 8.24 \frac{kg}{d}$$

As a rule, pathways are considered to provide estimates of population-average exposures and maximum individual exposures. Each realistic pathway from source to receptor represents a unique mechanism of exposure. In considering exposure, especially following accidents, it is easy to become overwhelmed with considerations of "what-if" scenarios which postulate extreme combinations of unlikely pathways and events. But little is accomplished by analyzing potential exposure of exceedingly low probability. The most extreme exposure 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 define the highest conceivable exposures to be considered for evaluation. It is not useful for estimating actual health risk, since no such person normally exists and the results are only defining a hypothetical upper boundary of the exposures.

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 be quantitatively meaningful (i.e. its probability or its consequences are high enough to be worthy of attention).

Table 4.7 shows some typical maximum exposure points that might be evaluated.

The selection of areas to be actually evaluated has to be made in each case according to specific criteria.

The transfer of pollutants depends on:

- the medium into which they are initially released;
- the physical and chemical properties of the pollutants;
- the transfer from one medium to another.

TABLE 4.7. TYPICAL CONTACT POINTS FOR DETERMINING MAXIMUM EXPOSURE FROM CONTINUOUS EMISSIONS

Medium	Exposure Area	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	On-site	Dermal, ingestion
	Immediately adjacent to site (if restricted)	Dermal, ingestion
	Nearest cropsoil	Ingestion (food)

The first two factors can be determined directly from the emission source inventory, which is normally organized by receiving medium (air, water, soil). The physical and chemical characteristics of the pollutants determine their transferability among media. The specific transfers depend on the magnitude of transfer between different media e.g. transfer between air and soil, 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 soil. After emission into the air heavy particles deposit rapidly to nearby surfaces on soil or water. Lighter particles travel farther and deposit at lower rates. Gases may be absorbed 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 absorption 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 soil 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 cannot 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 and models need only to be appropriately linked at the loss-source term.

4.4. ENVIRONMENTAL DISPERSION MODELS

In the absence of direct measurements of exposures produced by specific emissions, quantification of the pollutant concentrations 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 computerized 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 pollutants are released;
- chemical and physical characteristics of the pollutants released;
- medium of transport;
- geophysical characteristics of dispersion;
- chemical and physical changes during transport;
- matching of model output to information needed in the application;
- availability and cost.

Transport medium and pollutants 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 impacts on a lake demands 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 need 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 necessary.

The conditions of release that must be considered cover a wide range, including physical and chemical form of the pollutant, 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, also to a harmless form, or from a harmless form to a toxic one. Analysts must determine whether this is applicable 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. Transferal 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.

4.4.1. 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 effects and eventually synergetic effects;
- establishing relationships between local and regional short and long-term effects;
- simultaneous evaluation of several different sources of risk;

- assessment of risks over time;
- uncertainty analysis.

Various environmental dispersion or transport models are available. 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;
- terrestrial and aquatic food-chain models.

Selection of a suitable model must depend on the aims of the regional risk management project in which it will be used and on an in-depth evaluation of the parameters and implementation requirements as well as verification of the adequacy of predicted results.

4.4.2. 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 source.The final outputs of dispersion models are derived from emissions and atmospheric dispersion conditions, but they can be quite different according to the nature of the problem.

A distinction has to be made between models for accidental releases which use a very short time scale and those for continuous releases which refer to average meteorological and emission conditions.

Some meteorological dispersion models can be expressed in simple mathematical formulae. They can be lists of equations to be calculated by hand, using PCs or more complex models run on micro computers. The simplest models can be run with little experience, the more complicated ones need considerable skill and experience. These complex models are normally not applied for routine risk assessment.

Most of the atmospheric dispersion models are deterministic. Risk assessment assumes a probabilistic approach. This is achieved by using sets of emission values and of dispersion conditions each of which are affected by probabilities. The model output is consequently also probabilistic.

4.4.2.1. Gaussian plume models

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.

Gaussian plume models are commonly used. 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. If there are area 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.

A broad range of more complex Lagrangian and Eulerian 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.

4.4.2.2. Physical models

Models of a region with precise representation of topography make it possible to simulate wind and temperature patterns and the exact behaviour of one or several plumes. Such models are able to provide qualitative results that may be compared with sophisticated computer plume behaviour models.

4.4.2.3. 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 an area 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.

4.4.3. Aquatic dispersion models

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

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

- stationarysubsurface waters
  flowing subsurface waters

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 cannot estimate concentrations as a function of source strength.

4.4.3.1. 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.

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.

(a) 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 and possibly long 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.

(b) 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, in Ref.[15] has developed a simple equation that can be used to estimate the loading of nutrient 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.

The regime of water flows in lakes can be very complicated with some parts of the water really stagnating while other parts are flowing like rivers without mixing with the surrounding waters. For this reason simple calculations assuming complete mixing and using materials - balance equations may be completely misleading.

In addition, the water in the lake is strongly stratified. In large and deeplakes this stratification is completely disturbed according to the season.

Extreme prudence has to be exerted if pollutants or heat are considered to be discharged into the lakes.

4.4.3.2. Subsurface models

Contamination of subsurface aquifers is modeled in two phases:

- vertical transport through the unsaturated zone;
- 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 aquifer, 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.

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

Groundwater flow modeling requires powerful computer models and the availability of a great number of data. Hydrogeological data may be obtained from cores taken in boring and from classical hydraulic tests (pumping, water injection, water table level measurements etc.). These tests should possibly be complemented with more specialized tests such as water sample chemical analyses, temperature measurements, tracing substances flow measurements, isotopic sampling e.g. for O^{18} deficit measurement, H^3 content, etc.

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 amidst large industrial areas, are the cause of environmental impacts due to normal or accidental conditions.

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 by the principal elements of:

- 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 analyst's ability to account for them adequately in the coefficients supplied to the models. Much professional judgment is required.

There are basically two types of models used for simulating ground water flows. According to the scope of the investigation and the data available, direct models are used. In these models the physical data of the aquifer and water boundary conditions are entered while flows are calculated. Conversely, when the aquifer data is uncertain, an inverse model can be used in which the permeability (or transmitivity) of the rock structure is calculated from flow data actually measured or assumed for simulation purpose.

4.4.4. 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.

A number of conceptual and computerized models has been developed for assessing human exposures to harmful toxic substances in foods. 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 i.e. 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 with 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 is usually assumed to reduce 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.

4.5. ESTIMATES OF DOSE-RESPONSE RELATIONSHIPS

4.5.1. Background

The need to quantify dose-response curves 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 generallyadopted consists of hazard identification, followed by parallel steps of exposure assessment and dose-response assessment, which are brought together in risk characterization, see e.g., Ref.[16].This section is concerned with dose-response assessment, i.e. the evaluation and quantitative characterization of the relationship between the level of exposure and the health-related response, as given in Ref.[17]. It differs from other parts of risk assessment in that it is often developed independently of the application on which the risk assessment focuses, using data from other sources. A single dose-response assessment can be applicable to several risk assessment projects.

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 dataof 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, Ref.[18], 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 the 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.

Effect models 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 the certainty that above some threshold level of exposure harm will occur. In this case the harm will be a monotonically increasing function of the exposure, see Fig. 4.5.

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, shown in Fig. 4.6.

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.

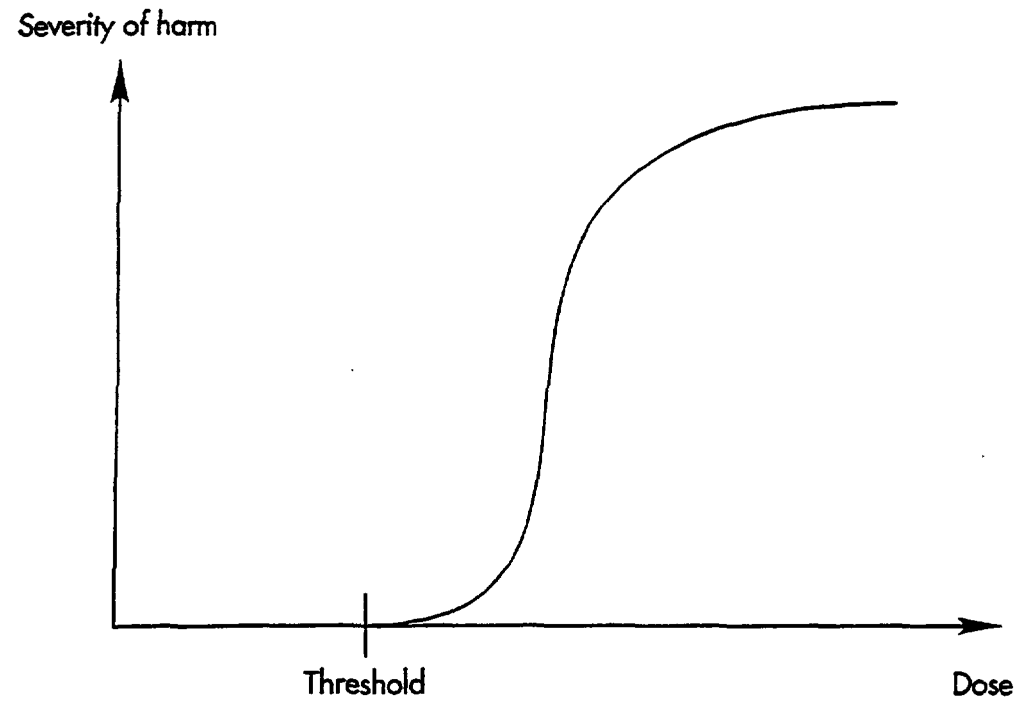


FIG. 4.5. Dose-effect relationship

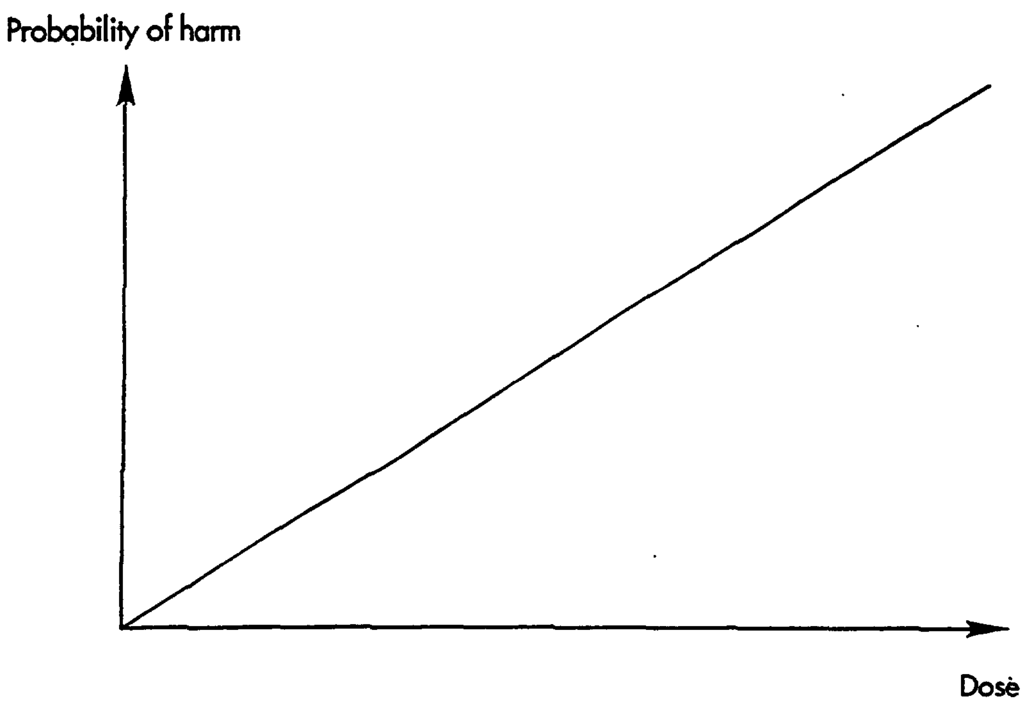


FIG. 4.6. Dose-response relationship

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 minimis level". If the criterion is individual risk, a de minimis 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.

4.5.2. Kinds of exposures: Dose-response implications

4.5.2.1. Exposure and dose

An understanding of dose-response assessment and it's 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 $\mu g/m^3$ 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, as described in Ref.[19]. 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). Therefore, the term dose-response function most commonly indicates an exposure-response function.

Risk assessments must deal with multi-media exposures including air, water, and food-chains. 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. However, 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, since the actual dose to the target organ is difficult to measure. The target tissue itself may be unknown or in question:is it the whole lung or the basal cells of the bronchial epithelium?

An exposure-response function thus incorporates the metabolic, pharmacokinetic 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.

4.5.2.2. Averaging time

Concentrations of pollutants in air vary over time and space. A person standing in one spot is submitted to 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 thelevel immediately dangerous to life or health given, e.g. in Ref.[20]. 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.

4.5.2.3. 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.

4.5.2.4. 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 References [21,22,23].

4.5.2.5. 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, a consideration addressed in Ref. [24]. 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, Ref.[13], are following the concept of "total exposure".

4.5.3. 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.

4.5.3.1. 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.

4.5.3.2. 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.

4.5.3.3. Morbidity

Morbidity is the recognized presence of disease. It is generally expressed as incidence (number of new cases developing annually per 1000 people in a population) or prevalence (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 Ref. [25].

4.5.3.4. 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. The probability of death is one. It is not the fact of death but the unnecessary cutting short of life that is of concern. Expressing the response in terms of years of life lost would help solve the problem regarding the length of life lost. Some examples may help to clarify the problem. An analysis of the benefits of superior ambulance service might count the number of heart attack victims whose lives were saved. Would a victim of multiple heart attacks who was saved, say 3 times, count the same as

3 separate people each saved once? Would saving a 50-year old heart attack victim count equally with saving a 25-year old traffic accident victim? If the 50-year old had an average expectation of 25 years to live and the 25-year old an average expectation of 50 years to live, would saving one 25-year old be an equivalent benefit to saving two 50-year olds? These are questions for risk assessments or policy assessments, not for dose-response per se, but they can never be addressed unless dose-response functions include the necessary detail. The data are often difficult to obtain. Consider the case of air pollution - mortality risks [26]. Even though the London fog of 1952 resulted in 4000 deaths above the normal, decades of study passed before it was demonstrated that the deaths were not all simply a harvesting of people who would have died over the next few days anyway. While it is generally agreed that the deaths were among people with poor adaptive capacity due to serious lung disease, heart disease, asthma, or other advanced chronic disease, the question of whether a few months or 20 years of life was lost to the average victim is still unresolved. No clear determination has been made of the years of life lost per death in macro-epidemiological studies of air pollution mortality, which are more likely to represent chronic effects. In Reference [27] a broad estimate is made that the most likely range was from 5-15 years lost per death with a range that could be as wide as from 1-30 years lost per death.

The difference between the ambulance and the air pollution examples illustrates an important point regarding risk assessment of effects of environmental exposures. Environmental effects are seldom specific. There is no way to distinguish a death or a lung cancer from air pollution from other deaths or lung cancers. Therefore, it is not possible in these cases to gather statistics specifically on the victims of air pollution or other environmental agents. In the ambulance case, one can find out specifically the ages and past medical histories of the victims assisted; in the air pollution case one cannot. Key pieces of information must be estimated indirectly. There are, of course, some environmental agents which produce specific effects, leave characteristic markers or act so quickly that victims can be easily identified. A special case of the latter effect is injury. The victim of an accidental injury is immediately identifiable and detailed statistics on the characteristics of the victim and the circumstances of the injury are frequently available.

4.5.4. 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 US 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, e.g. Refs [21,28,29,30,31,32,33].

4.5.5. 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 phenomena 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 which 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 simplest 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.

4.5.6. 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);
(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.

4.5.7. 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, such as Refs [34,35,36,37].

Reference [38] 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.

Since the use of 95% confidence levels is so ingrained in science and since 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. It is better to present 67% or 80% confidence bounds in which one has confidence, than 95% confidence bounds which 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 for a particular analysis, can draw their own conclusions.

4.5.8. 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.

4.6. 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, the 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 an 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?

4.6.1. Endpoints

The diversity of possible endpoints requires that they be divided into classes as described below:

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, to define the relationship between acidification of freshwater lakes and the resulting impacts on aquatic life it is often sufficient that the latter be indexed solely on the basis of predicted changes in pH of the lake water.

4.6.2. 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 LC_{50}.

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 should include extrapolation errors, which are 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 useful comparative measures 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 in Ref. [39].

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. Such projections should be replaced by 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, ecosystem uncertainty analysis using Monte Carlo simulation, and ecosystem models for extrapolating laboratory toxicological data so that they can be used to estimate risks to populations and ecosystems , see Ref. [40].

Expert judgement: Few, if any, needs for environmental risk assessment can 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. Judgments can be applied to policy making using techniques such as decision theory or analytical hierarchy method. Environmental applications of the latter are described in Ref. [40].

5. ANALYSIS OF ACCIDENTS FROM FIXED FACILITIES

5.1. OVERVIEW

Government, industry and the community now recognize the need to identify, assess and control the risks to both people and the environment 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 industrial safety practices, engineering safety codes and standards, design and operating procedures remain at the core of safety management. The increasing awareness of hazards and accidents, that may result in a significant loss of life and property, has led to 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. Fig. 5.1 is an overall scheme of the risk assessment process, which involves: a system description, the identification of hazards, the development of accident scenarios and events associated with a process operation 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 and that possible events and risks 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 of such accidents actually occurring should be taken into account. Such probabilities and resultant risk levels should reflect the level of design as well as operational and organizational controls available at the plant. Table 5.1 is a summary listing of major chemical accidents/incidents during the period 1950-1988.

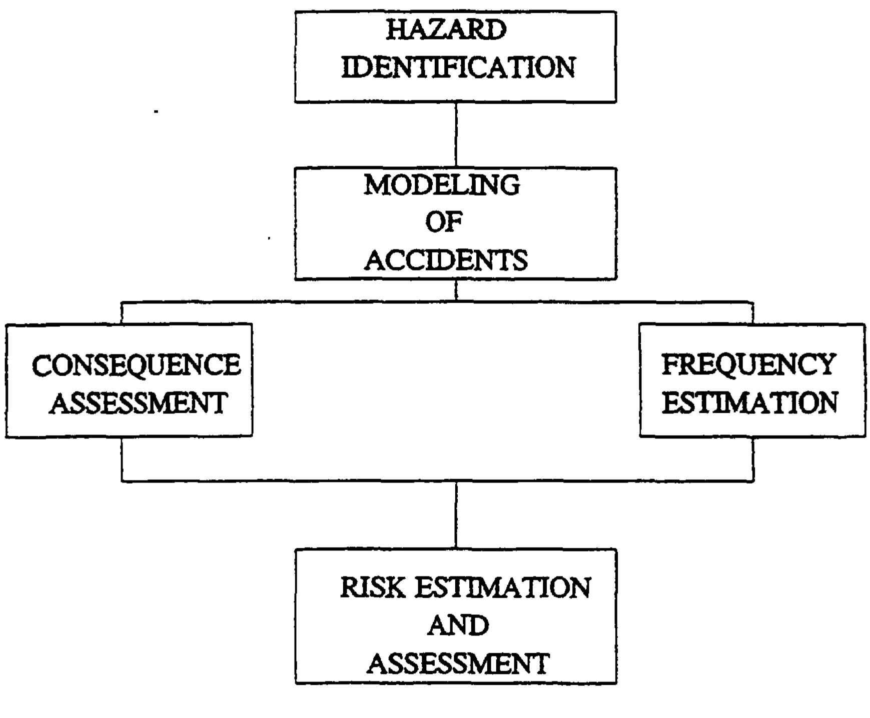


FIG. 5.1. Overview of quantitative risk assessment procedure

TABLE 5.1. 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		Food stuff contamination (oil)	0-Cresyl-phosphate (OCP)	0	2,000[c]	
1960	India	Bombay	Foodstuff contamination (oil)	0-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			2500
		Fort Wayne	Rail accident	Vinyl chloride			4500
		Michigan	Foodstuff contamination (livestock)	PBBS	0	333	
		Greensburg	Rail accident	Chlorine	0	8	2000
1974	UK	Flixborough	Plant (explosion)	Cyclohexane	28	89	3000
	USA	Decatur	Rail accident	Isobutane	7	152	
		Wenatchee	Rial accident (explosion)	Monoethyl ammonium	2	112	
		Houston	Rail accident (explosion)	Butadiene	1	235	

TABLE 5.1. (cont.)

YEAR	COUNTRY	LOCATION	TYPE OF ACCIDENT/INCIDENT	CHEMICAL(S) INVOLVED	OUTCOME		
					Deaths	Injuries[a]	Evacuated[b]
1975	German Dem. Rep.	Helmstetten	Warehouse	Nitrogen oxide			10000
	Netherlands	Beek	Road accident (explosion)	Propyulene	14	104	
	USA	Eagle Pass	Road accident	LPG	17	34	
		Niagara Falls	Rail accident	Chlorine	4	176	
	Italy	Seveso[d]	Chemical plant (explosion)	Dioxin (TCDD)/2,4,5T	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			10000
1978	German Dem. Rep.	Regensburg	Factory fire	Nitrogen oxide	0	40	2000
	Italy	Manfredonia	Plant	Ammonia			10000
	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	Missisauga	Rail accident	Chlorine/propane/butane/toluene			220000
	China, Taiwan	Yucheng	Foodstuff contamination (oil)	PCBs/PCDFs	0	1900[c]	
		Three Mile Island	Reactor failure	Radionuclides			200000
		Crystal City	Warehouse	Pesticides			6000
		Crest View	Rail accident	Ammonia/chlorine		14	4500
		Memphis	Storage	Parathion	0	0	200

TABLE 5.1. (cont.)

YEAR	COUNTRY	LOCATION	TYPE OF ACCIDENT/INCIDENT	CHEMICAL(S) INVOLVED	OUTCOME		
					Deaths	Injuries[a]	Evacuated[b]
	USSR	Novosibirsk	Plant accident		300		
1980	India	Mandir Asod	Plant explosion		50		
	Malaysia	Port Kelang	Explosion/fire	Ammonia/oxyacetylene	3	200	3000
	Spain	Ortuella	Explosion	Explosives	51		
1980	UK	Barking	Plant fire	Sodium cyanide		12	3500
	USA	Muldraugh	Rail accident (derailment)	Vinyl chloride		4	6500
		Sommerville	Rail accident	Phosphorous trichloride		343	23000
		Garland	Rail accident (derailment)	Styrene	0	5	8600
		Newark	Rail accident (fire)	Ethylene oxide			4000
1981	Mexico	Montana	Rail accident (derailment)	Chlorine	29	1000	5000
	Puerto Rico	San Juan	Rupture in factory	Chlorine		200	2000
1981-1983	Spain	Madrid	Food contamination (oil)	As yet uncharacterized	340	20000[c]	
1981	USA	Geismar	Plant	Chlorine		140	
		Castaic	Plant	Propylene		100	
	Venezuela	Tacoa	Explosion	Oil	145	1000	
	Viet Nam	Saigon	Contaminated product (talcum powder)	Warfarin	177[a]	564[a]	
1982	Canada		Rail accident	Hydrofluoric acid	0	0	1200
	USA	Livingstone	Rail accident	Fuel oil			3000
		Vernon	Plant	Methyl acrylate		355	
		Fitchburg	Factory	Vinyl chloride	0	0	3000
		Taft	Explosion	Acrolein			17000
	Venezuela	Caracas	Tank explosion	Explosives	101	1000	
1983	Nicaragua	Corinto	Tank explosion	Oil			23000
	USA	Denver	Rail accident	Nitric acid		43	2000
1984	Brazil	Sao Paulo	Pipeline explosion	Gasoline	508	3	
	India	Bhopal	Chemical plant (leakage)	Methyl isocyanate	2500	50000[c]	200000

TABLE 5.1. (cont.)

YEAR	COUNTRY	LOCATION	TYPE OF ACCIDENT/INCIDENT	CHEMICAL(S) INVOLVED	OUTCOME		
					Deaths	Injuries[a]	Evacuated[b]
	Mexico	St. J. Ixhuatepec	Tank explosion	Gas	452	4248	31000
	Matamoras	Fertilizer factory	Ammonia			200	3000
	Pakistan	Garhi Dhoda	Explosion (gas-pipe)	Natural gas	60		
	Peru	Callao	Pipeline explosion				3000
	USA	Middleport	Plant	Methyl isocyanate		110	
		Sauget	Plant	Phosphorous oxychloride		125	
		Linden	Plant	Malathion		161	
1985	*India*	*Bombay*	*Industrial accident (pipe burst)*	*Chlorine*	1	110	
		New Delhi	Industrial accident (leakage)	Sulphuric acid	0	49	5000
	Mexico	Guadalajara	Rail accident (leakage)	*Sulphuric acid*	*0*	*49*	*5000*
	USA	Institute	Fire	Aldicarbe oxime		140	
		Peabody	Plant	Benzene	1	125	
1986	Ukrainian SSR	Chernobyl[d]	Nuclear reactor (explosion)	Radionuclides	31	300	135000
1987	China	Guangxi province		Methyl alcohol	55	3600	
		Shanxi	Drinking water contamination	Ammonium bicarbonate	0	15400	
	USA	Wilson country	Rail accident	Sulphuric acid	0	0	3000
		Nanticote	Factory fire	Sulphuric acid	0	0	18000
		Ohio	Road accident	Phosphorous trichloride	0	6	2000
		Confluence	Rail accident	Propane gas	0	0	1000
1988	USSR	Yaroslavl	Rail accident		0	34	2000

[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 1000 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 malpractice (e.g. uncontrolled chemical waste disposal or misuse of chemicals).
Data have been taken from Refs[41,42,43,44,45,46].

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.

As risk analysis technology has matured and become a more important tool in planning and safety investment decision-making, the pressure for quality in such studies has increased. Key themes include:

Staff	–	competent, formally trained
Tools	–	validated, approved
Data	–	traceable
Documentation	–	auditable

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 of risks. The most significant advantage in this regard relates to the optimum allocation of priorities in risk reduction in that the assessment process provides a clear identification and recognition of hazards and as such enables the allocation of relevant and appropriate resources to the hazards control process. The quantified risk assessment process also provides a useful tool for risk communication.

5.2. HAZARD IDENTIFICATION AT THE PLANT LEVEL

5.2.1. Introduction

The first and most essential step in any risk assessment is the identification of all relevant hazards and initiating events applicable to a particular plant or operation. In all cases it is necessary to establish:

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

This component of the analysis, termed 'Hazard Identification`, involves consideration of all situations where potential harm may exist in order to identify those which are hazardous. In the next procedural step, termed 'Modeling of Accident Scenarios', the identified hazardous situations will be analyzed systematically to assess which events could transform this potential to an accident. Once an accident scenario has been established, 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. Fig. 5.1. 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.

It must be noted that there is no 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 to complement each other. Relevant screening may be an important part of this process and this is a decision to be made by the project manager.

5.2.2. Objectives

Hazard identification is a corner stone in the assessment of safety of an installation. It is essential to have a clear understanding of the type and nature of hazardous incidents associated with the operation 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, since, 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 but screening may also be appropriate.

(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) enables 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 including the management of future change.

(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.

5.2.3. System description

The first task of the risk assessment process involves gathering all necessary and available information about the installation to be analyzed. This includes information concerning the design, construction and operation of the plant and normal and/or emergency situations. The information will be not only in the form of relevant documentation (e.g. pids, procedure manuals, log books) but also in the form of experienced plant personnel. Complete understanding about the function of the installation is absolutely necessary for a realistic risk assessment and this is not possible without the participation of an analysis team involved in the design, operation and maintenance of the plant.

5.2.4. Initiating event selection and establishment of plant response

Hazard identification involves assessment of all events that can initiate a course of events which may eventually lead to the release of hazardous material to the environment. These events are called initiating events. Following the onset of an initiating event the various engineered protection and/or safety systems of the installation are called upon to mitigate the event and keep the installation in a safe state. This step of the risk assessment process aims to determine all possible initiating events and to establish and understand the response of the installation both in terms of hardware and human actions.

In order to complete this task the analysts should combine information about past experience (both from the particular installation and from other similar installations) and techniques that can help to identify events which may initiate accidents. Review of past experience in the form of historical data concerning accidents all over the world and that of the installation itself should be the first step in this procedure.

An enormous quantity of accident reports exist. The information available is often limited to whatever was recorded at that time and particularly when based on eyewitness reports it can be extremely unreliable. A variety of databanks have been set up to store and process this type of information. Examples are the MHIDAS database operated by the UK Safety and Reliability Directorate/Health and Safety Executive, the FACTS database operated by TNO - The Netherlands Organization of Applied Scientific Research - and the compilation of events by the Commission of the European Communities published by the Joint Research Center at Ispra. Review of the events reported in these databases will provide those that are applicable to the installation under analysis.

This review of the past experience should be followed by an analysis of the installation in order to identify additional initiating events and assess the response of the installation to those already identified. Of particular help can be techniques used for overall qualitative assessment of the plant safety. These techniques can be divided into two categories:

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" checklist
- Failure mode and effects analysis (FMEA)
- Master logic diagram

Appendix III provides detailed information on each of these methods.

Once the initial list of the initiating events has been compiled the next step consists of the determination of the safety functions and the systems that serve these functions. Safety functions and systems are incorporated in the design of the facility to prevent and/or mitigate the possible consequences of the initiating events. Furthermore it is important to identify other systems whose mission is to support the function of the safety systems e.g. the electric power supply of a cooling system. These systems and their potential failures will be used later in the modeling of accident scenarios.

5.2.5. Grouping and screening of initiating events

The objective of this step is to group together all the initiating events that provoke the same response from the plant, therefore requiring the same safety functions and the corresponding systems. Only one accident model (e.g. event tree) is required for all initiating events in the same group. Furthermore, the groups of the initiating events can be screened on the basis of their expected frequencies. Extremely unlikely accident initiators can be excluded from further analysis. When in doubt, however, the screening is better to be postponed until after the assessment of the consequences of the accident in order to avoid excluding highly unlikely accidents with very severe consequences.

5.3. MODELING OF ACCIDENT SCENARIOS

Some initiating events might lead directly to the release of a particular amount of hazardous material to the atmosphere. In this case the analysis may proceed with the consequence assessment step as described in Section 5.4. If, however, a number of safety systems as well as human actions can successfully mitigate the initiating event then, in order to have a release of hazardous material, a combination of failures need to follow.

Techniques for modelling the response of the installation following the onset of an initiating event falls into the category of logic diagrams. These are techniques that try to model the logical combination of simpler events into composite events. For accident modelling the predominantly used techniques consist of a combination of event tree and fault tree analysis.

5.3.1. Event tree analysis

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 determination and quantification of a sequence of events which can result in the occurrence of potential accidents. Event trees use 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 consequence estimation.

Event trees starting with an initiating event and proceeding to the release of hazardous material can be called "pre-accident" event trees. Event trees starting with the release and examining the development of the physical phenomena following the release are called "post-accident" event trees.

Pre-accident event trees can be used to evaluate effectiveness of plant protective systems and operator actions against the occurrence of an accident initiator. 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. See Fig. 5.2.

Other event trees as those shown in Figures 5.3 and 5.4 lead directly to the undesired physical phenomenon (e.g. fire).

In all cases however, the heading or constituent events in an event tree will be a hardware failure (system failure), a human action or a physical phenomenon. Branching at each mode of the event tree (which is not necessarily binary) is done to the extent that it is necessary to uniquely determine the result of the accident sequence. For example, in the case of a cooling system consisting of two compressors, if the function of only one compressor will lead to a different damage state than that of the failure of both compressors, three branches will be necessary to depict the three alternatives: both compressors operating; one compressor operating; no compressor operating. Alternatively, one could use two headings: Compressor A; Compressor B. This tends to explode the size of the event trees.

In general it is recommended to develop event trees only up to the point where the nature of the accident sequence is uniquely determined. In the previous example, if loss of one compressor would mean effectively loss of the cooling function then only one "event" should be considered with the title "cooling system".

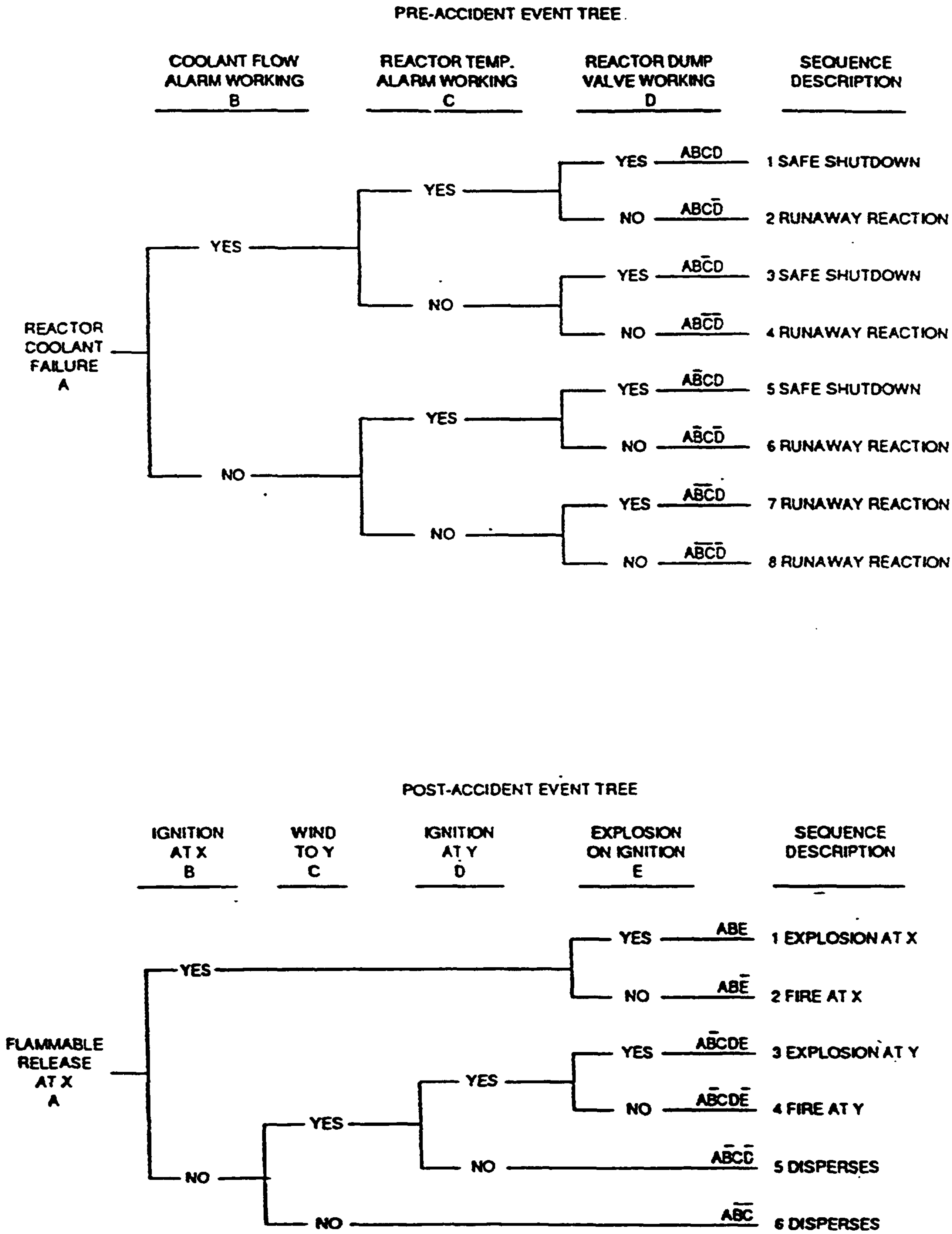


FIG. 5.2. Examples of pre-incident and post-incident event trees

5.3.2. Binning of accident sequences in plant damage states

Accident sequences leading to the same consequences should at this point be binned into plant damage states. A plant damage state uniquely defines the conditions that affect the type of releases of hazardous material from the installation. Ultimately the frequencies of the accident sequences belonging to the same plant damage state will be combined to determine the frequency of this state which in turn will characterize the frequency of the corresponding consequences.

5.4. CONSEQUENCE ANALYSIS FOR ACCIDENTAL EMISSIONS

5.4.1. Introduction

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 which have 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 ionizing radiation, asphyxiants, very cold substances (cryogens) and corrosive substances. However, it is not intended to consider these in the context of the guideline document.

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.

The outcomes may cause death, injury, property damage or 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.

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.

It is the responsibility of the project managers to assess impact criteria and assure their consistent application throughout the whole exercise. Model evaluation groups are being set up (e.g. in the CEC) to structure representative overall approaches. In the absence of absolute information, a representative range of source terms should be assumed.

The overall approach is illustrated in Table 5.2. Each of the steps involved are addressed by the following sections.

A brief description of the approaches to methods of consequence analysis for accidental emissions are given in the remainder of this section while more details about the physical models can be found in Appendix IV.

Before presenting the various methodologies and procedures for the estimation and calculation 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 hazards that can occur at installations handling hazardous materials.

TABLE 5.2. OVERALL APPROACH TO CONSEQUENCE ESTIMATIONS

Determine accident scenarios
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 death, injury, structural damage, environmental harm, etc.

5.4.2. Site topography and population distribution

Meteorological conditions and other topographical characteristics that affect the consequences of the accident must be established before applying the appropriate physical models and estimating the consequences of the accident. Furthermore the population distribution around the site should be established for assessing the societal risk (see section 5.6.2).

5.4.3. Flammable releases

5.4.3.1. Explosions

These can be dense-phase explosions, confined or partially confined 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 fertilizer. This mixture tended to

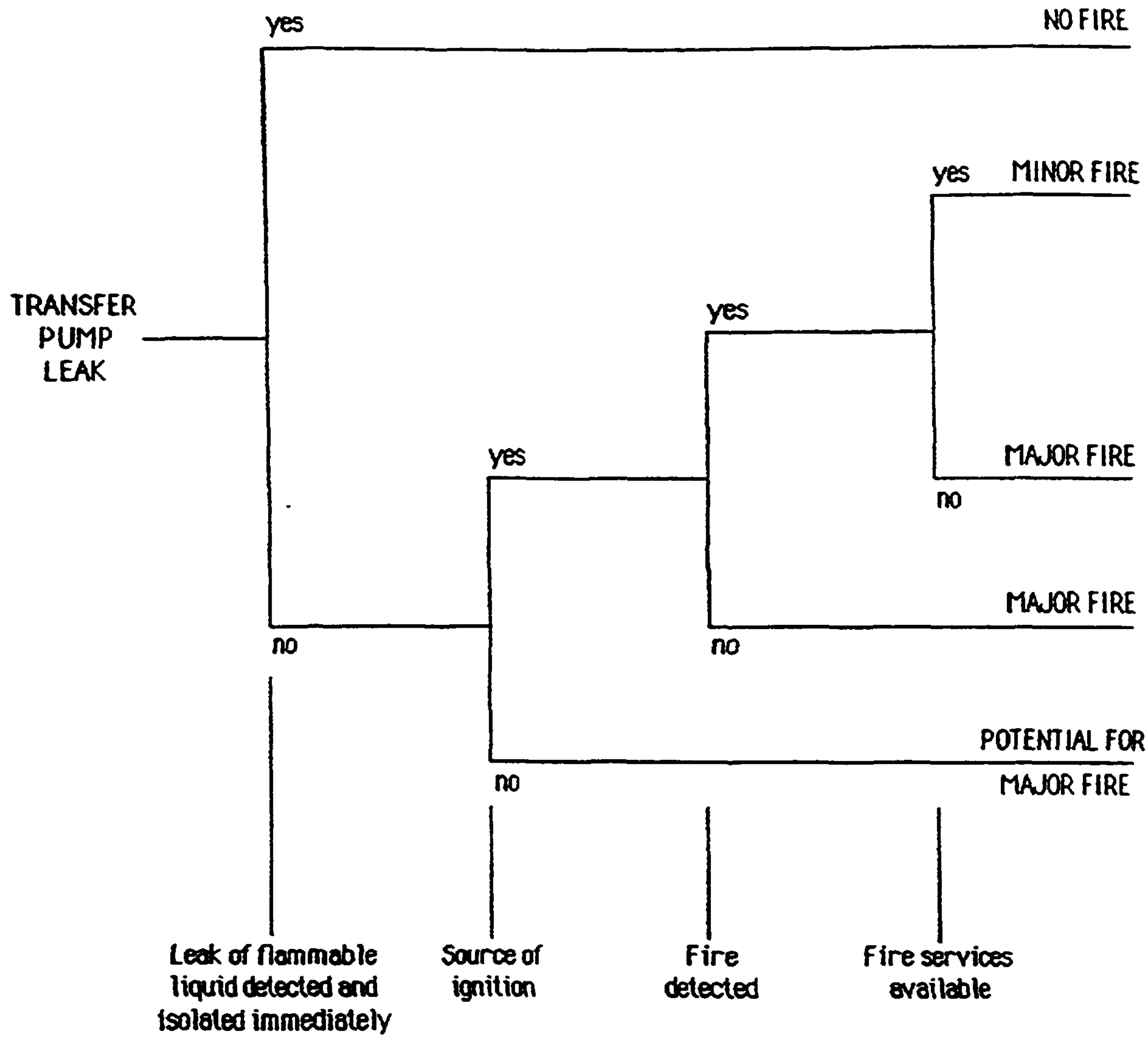
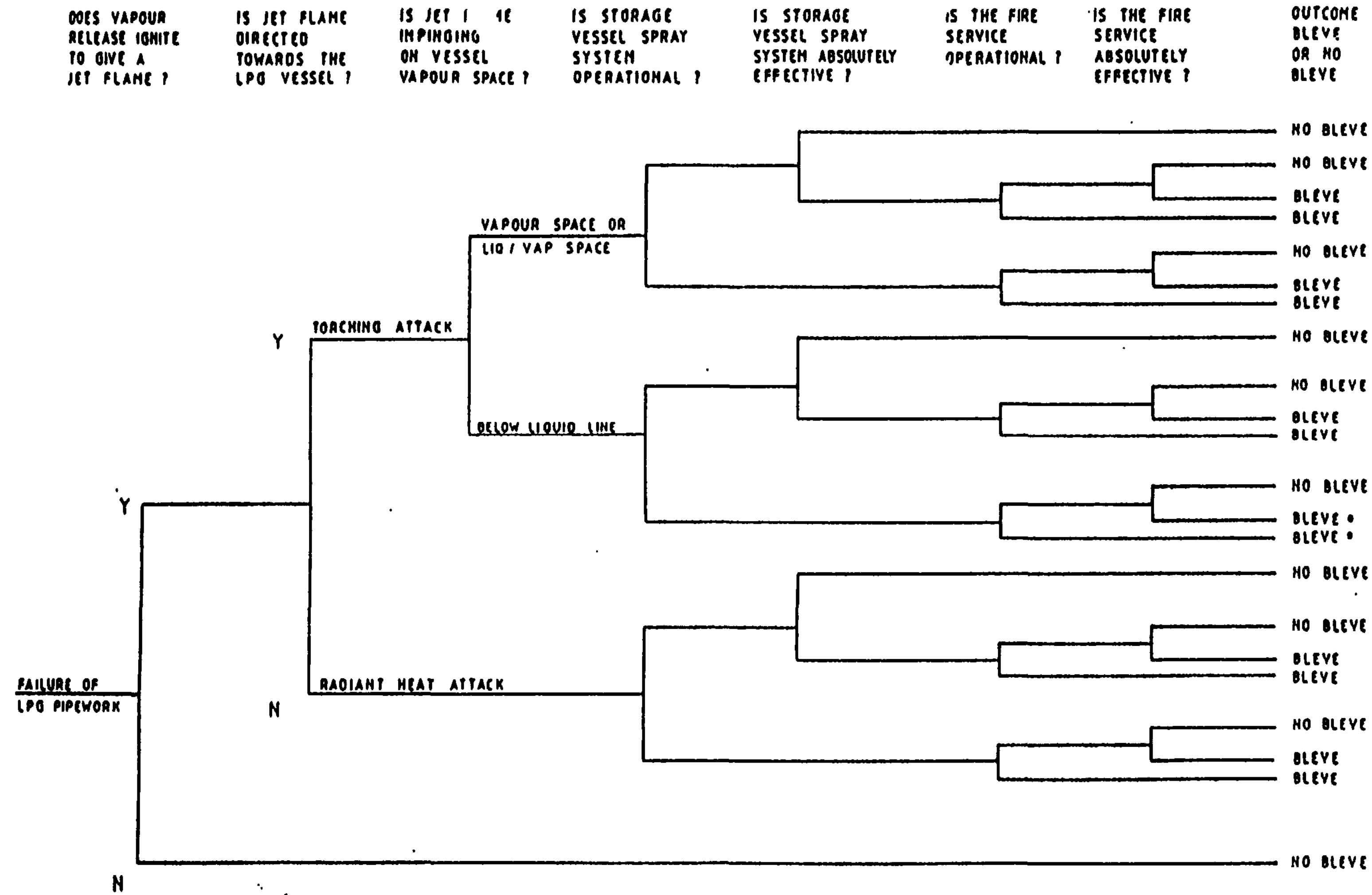


FIG. 5.3. Simplified event tree example



BLEVE (ACRONYM FOR BOILING LIQUID EXPANDING VAPOUR EXPLOSION)

* This situation arises when liquid level drops below torch point.

FIG. 5.4. Event tree indicating how the failure of LPG vapour pipework can develop towards a BLEVE of an LPG storage vessel

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 m 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 and the presence of some confinement or obstructions. 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 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 one of the reactors 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) 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 Westwego 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.

5.4.3.2. 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) torch fire or BLEVE.

(i) Boiling Liquid Expanding Vapour Explosions (BLEVE)

A BLEVE describes the sudden rupture of a vessel containing liquefied flammable gas under pressure. The primary cause is usually an external flame impinging on the shell of a vessel above the liquid level, weakening the container and leading to sudden shell rupture. The pressure burst and the flashing of the liquid to vapour creates a pressure 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 fireball. 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 in a pipeline transporting LPG from a refinery. A cloud of vapour was formed and ignited. There were several violent BLEVEs (7 or 8) and numerous smaller ones.

These BLEVEs and the fires that followed killed at least 500 people, injured more than 7 000 others and about 60 000 persons had to be evacuated. Out of the original 48 'bullet' type storage vessels only 4 remained on their supports. One of them weighing about 20 t was found 1200 m away. There were also 6 spherical storage vessels on the site, of which the 4 smallest ones 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 m away. However poor quality, flimsily constructed housing had been allowed to encroach to within 100 m of the site boundary.

(ii) 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 vaporize 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. An exception to this is the 'boil over' incident during storage of hazardous substances. Products of combustion from pool fires may also provide a hazard.

(iii) 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 depending on the mode of release. When ignition occurs, the flame front races or 'flashes' through the cloud very quickly. It is also possible that the flame may accelerate to a sufficiently high velocity for an explosion to occur. 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. Under certain circumstances a flash fire can lead to vapour cloud explosion.

(iv) 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. An example is the jet-fire torching from a safety valve on top of a 50 t 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.

5.4.4. 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 susceptibility 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.

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 pressurized 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, Louisiana, USA in 1961, in which between 27 and 35 t of chlorine were 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 and 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 ruptured 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 pressurized 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 sterilizing about 4 km^2 of land for agricultural use. 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.

5.4.5. Consequence assessment

The physical models discussed in the previous section and in Appendix IV 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. However, environmental effect models development is still in its infancy and existing approaches contain great uncertainties. A good overview of people and property effects modelling is given in Ref.[47].

5.4.5.1. Effects of hazardous material dispersion (toxicity effects)

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 (see Appendix IV). The effects of these are 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 man, 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 susceptibility. 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 substances 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. The methods used to calculate the effect of toxic releases on the environment from continuous releases are also applicable to calculate the effects of accidental releases.

There are a large number of references which give useful information on the methods of predicting the likelihood that a release will cause serious injury or death. A number of common substances have been examined in depth. In the UK, chlorine was considered by the Major Hazards Assessment Panel [48], and associated publications have given an extensive review of the animal data for man, see e.g. Ref. [49]. The same group has also reviewed ammonia, [50].

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. The probit equation 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 = measure of the percentage of people affected
a,b, and n = constants
C = concentration (ppm)
t = exposure time (min)
$(C^n t)$ = quantity known as toxic load.

Values of the constants for the lethal toxicity probit equation for a number of the more common chemicals along with further details are given in Appendix IV.

A probit quantity (P) has a mean of 5 and a standard deviation of 1. 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 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. It is important to ensure that correct and compatible units are used.

5.4.5.2. Effects of thermal radiation

Similar probit functions have been developed for the effects of thermal radiation where instead of the 'toxic load' the thermal load is used. Further details are given in Appendix IV.

5.4.5.3. Explosion effects

Explosions effects are caused by the blast overpressure. Details on these effects on people and structures are given in Appendix IV.

5.4.6. Mitigating effects

The objective of this section is to draw attention to some of the factors which may mitigate against the consequences of incidents involving hazardous materials. The omission of mitigating effects in a risk assessment will nearly always lead to an overestimation of the numbers of casualties. There are considerable uncertainties in estimating the factors that account for evasive actions. For these reasons many risk assessments do not consider the role of mitigating effects such as sheltering and evacuation - in such cases the possibility of having overestimated the number of casualties should be acknowledged.

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 may be less serious than predicted due to topographical factors, physical obstructions and to evasive actions taken by people. Such evasive actions can include evacuation, sheltering and medical treatment. These are briefly described thereafter.

5.4.6.1. 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 [51,52].

5.4.6.2. 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 in relation to building types and human behaviour [53]. The effects of sheltering depend on:

- The nature of the hazard - shelters can have a beneficial 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.

- The time available - 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 recognized 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.

5.4.6.3. Medical treatment

The effectiveness of training and the availability of equipment for emergency 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.

5.5. ESTIMATION OF THE FREQUENCY OF ACCIDENTS

5.5.1. Introduction

This section describes the methodological step of estimating the frequency of accident sequences identified in the previous steps (see Section 5.3 and Appendix III) for which the consequence analysis (see Section 5.2.) has shown can lead to non-negligible consequences. The strengths and weaknesses of the analytical techniques and the data requirements for quantification are examined, with comments on possible future developments. Accuracy and uncertainty in these estimates are considered and the implications for use of the techniques, together with the potential benefits and limitations, are discussed.

5.5.2. Event definition

Careful definition of events to be quantified is an important stage in the analysis. It is particularly vital for a full analysis where the probabilities and consequences of the various possible events are to be combined to produce an overall quantitative risk estimate. Risk analysis is an iterative process; initially a coarse estimate of the consequences of events is made to identify which of the dangerous events would be sufficiently damaging to be included in a more detailed study.

In a case where loss of containment is the major concern the breakdown of event probability against size of release is necessary to couple probability and consequences. This is not usually treated as a continuous function since the possible releases tend to be characteristic of the particular plant, i.e. the dimensions of the equipment and the conditions such as pressure and temperature under normal and fault conditions. Similar releases are usually grouped together in order to achieve the coupling of events with the appropriate consequences of the overall risk analysis. The coupling of event probabilities and consequences is considered further in Section 5.6.

In this section the possibility of an occurrence of an event is generally referred to as a "probability". This quantity may indeed be a probability and therefore dimensionless. However, in many circumstances it will be expressed as a frequency of occurrence over a specified time interval, e.g. a year or a plant lifetime. It may be possible to relate such a frequency to a finite number of occurrences over a sufficiently long time: for example a large number of events over a relevant timescale are taken to be indicative that an event will occur during a more limited period.. As we shall see in Section 5.6.3 the distinction between dimensionless probability values and frequency values is important where these numbers are used in combination. Because it is not always possible to be definite about which way a particular value should be expressed, some authors use the term "likelihood" to express the possibility of something happening, leaving it open as to whether a probability or a frequency should be used depending on the circumstances. There are two basic approaches.

5.5.3. Direct frequency assessment of accident sequences

The first is direct use of statistical data on release frequency or other failure types, sometimes called the "historical approach" or "generic data". Such data is usually defined for specific hole sizes (5 mm, 25 mm, 100 mm, and full bore ruptures are typical for pipes). Attempting to link hole sizes to specific single mechanisms such as flange leaks or critical crack sizes is an attractive explanation for the general public, but the reality is far more complexed as a review of release case descriptions highlights. It is becoming increasingly common to apply "Management Factors" to generic frequency data to account for the overall effectiveness of the Site Safety Management System (SMS). This is an attempt to put back into failure rate data, used in risk analysis, the frequency variation induced by the SMS which the generic averaging process has removed.

An advantage associated with the use of historical event data is that, where the accumulated experience is relevant and statistically meaningful, the assessment will not omit any of the significant routes leading to the event. The data already encompass all relevant contributory aspects including the reliability of equipment, human factors, operational methods, quality of construction, inspection, maintenance, operation, environment, etc. However, routes which may not be relevant to a specific case study will be included, resulting in an over-estimate, which is usually referred to as a "conservative" estimate of the chance of an event. The sample may also include older plants built to a lower standard.

Often the historical data is of such a quality that, while undoubtedly relevant, it is not considered adequate. In this case synthesis must be used and the predicted event probability should be tested against whatever experience exists to judge whether the different approaches produce compatible predictions.

5.5.4. System analysis

The second approach in accident sequence quantification is to break down the event into its contributory factors and causes, using the analytical techniques described in Section 5.3.1. This process is pursued up to the point where data is available, or can be obtained for the contributory sub-events. The overall event probability is then synthesized from the data of these various sub-events. The analytical approach will inevitably be adopted where the historical data are inadequate or simply not available. It may also be adopted where there is a cause for expecting a particular plant, system or item to have a different failure probability from that indicated by historical data.

Sometimes the analytical approach will not succeed in breaking the event down to the point where data is available for all sub-events. In this case judgmental inputs may be required and this has caused suspicion that the technique is not scientifically rigorous. However, the philosophy here is consistent with the basic approach of breaking down the judgement on how likely the event is into smaller areas of more specific judgements which are within the realms of practical experience. The overall outcome is then less sensitive to any one particular judgmental input. An important consideration in the analytical approach is how far to continue the breakdown of the main event.

There are various techniques for modelling mechanisms - logical combinations or a sequence of events - by which an undesired event could occur. Most of these techniques are based on diagrammatic methods known as logic diagrams. The techniques are essentially qualitative in nature, and if appropriate can provide a model for subsequent quantification. In Section 5.2 on hazard identification some of these techniques have already been mentioned and their usefulness in this role should not be underestimated. The distinction between identification techniques and failure logic synthesis techniques is, therefore, somewhat artificial. The comparative, guideword and FMEA methods discussed in Appendix III do not provide a logical framework for the setting down of event causes and effects generated by logic diagrams. However, logic diagrams must start from an event which has been identified by some method.

The techniques are, therefore, complementary. Logic diagrams will not be necessary where the cause and effect relationship is simple. Generally, only a proportion of the identified hazardous events in a study will contain sufficient complexity to require the use of logic diagrams.

Logic diagram techniques are sometimes classified as "top-down" or "bottom-up", according to whether they work back from the undesired event of the contributory causes or follow through initial fault conditions, failures or errors to the various possible conclusions. Most problems may be addressed by any of the more important techniques, considered briefly below. However, each have strengths and weaknesses, depending on the type of problem applied. In particular, when applied as an identification tool a combination of methods are often used to minimize the chance of omissions, which is possible with either approach. It sometimes proves easier to develop the logic using one approach or a combination of approaches, but then clearer to present it using another.

The event trees that might have been developed in the step of hazard identification follow initial causes through to possible outcomes. They can be used to deal with independent and coincident events, but are particularly powerful in portraying event sequences. Event trees are usually applied to binary state systems but can be used for multi-outcome states. Although event trees are often used in their own right and provide easy extension to quantification they are also useful in identifying sub-systems which require fault tree analysis. It is difficult to represent interactions between event states and a separate tree will be required for each initiating event, but then the relationship between different trees must be considered very carefully. Outcomes are related to the specific cause being analyzed and could arise from other causes which would not be shown.

5.5.4.1. Fault trees

Fault trees are the best known and most widely used technique for developing failure logic. The basic process adopted is to select an undesired "top-event" and trace it back to the possible causes which can be component failures, human errors or any other pertinent events that can lead to the top event. This procedure should be followed methodically, identifying immediate precursors to the top event, then the immediate precursors to the sub-events and so on, as shown in Fig. 5.5.

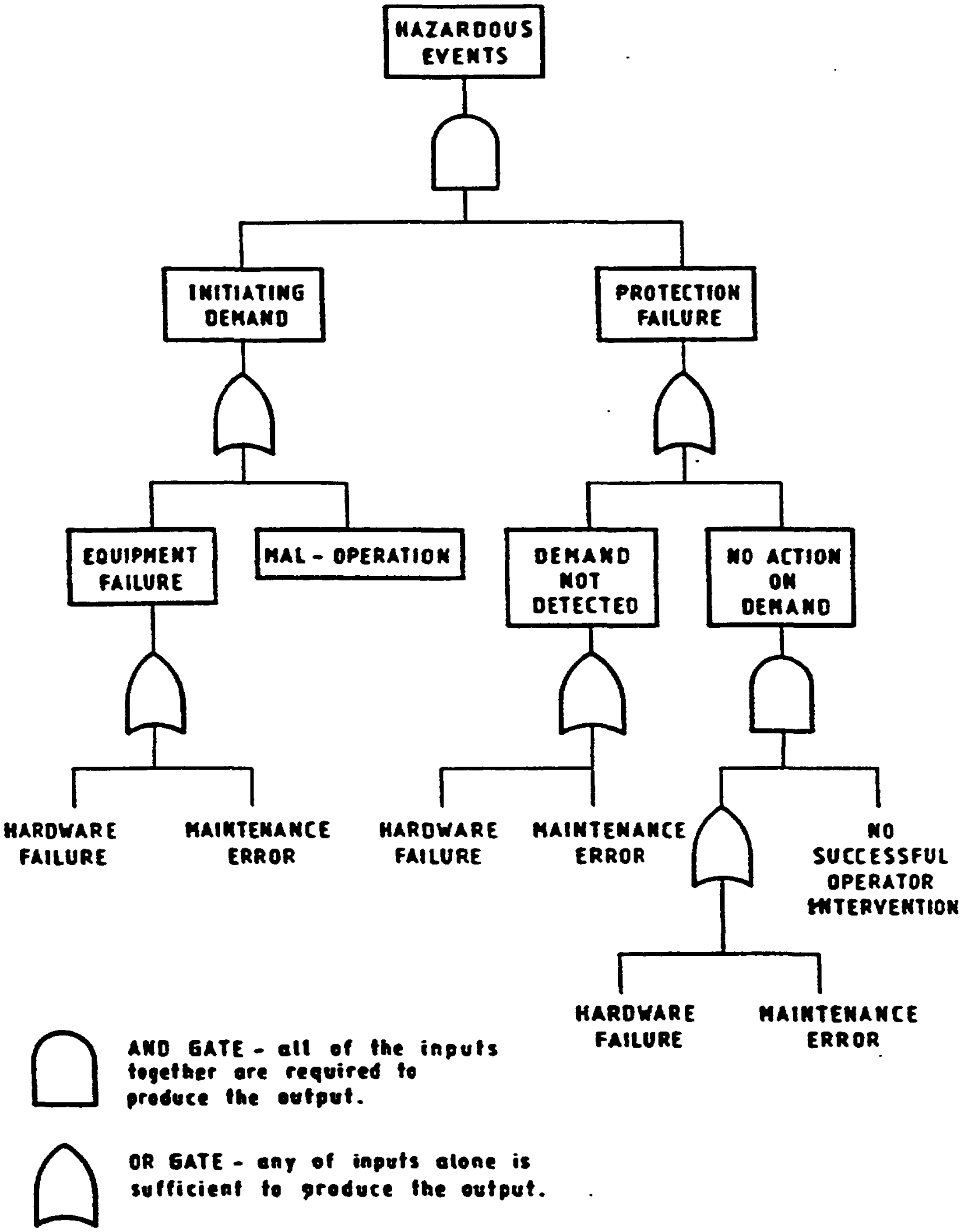


FIG. 5.5. Example used to illustrate the construction of a fault tree

A fault tree is comprised from a complex of entities known as "gates" which, when a logical combination of input conditions are satisfied, produces a specified output which is propagated. The construction of a fault tree follows a defined methodology, but as yet, there is no universally adopted set of symbols, which is unfortunate as fault trees provide a vivid method of communication.

The fault tree is not a model for all system failures or possible causes for system failures as it only includes events which contribute to the top event. A fault tree does not show sequences of events, although some complex gates can be used to illustrate the conditions of the sequence of input events. This can be confusing and often leads to difficulties in evaluating the tree.

A fault tree essentially shows the system states and because of this, other techniques are often more useful in cases where the sequence is likely to be important, as would generally be the case with batch processes. Fault trees may, however, still be used for analysis of sub-systems on batch plants such as protective instrumentation or services.

When compiled rigorously in a "top-down" procedure, certain sub-events may appear more than once in the fault tree. This is not anomalous and does not prevent the tree from being quantified. Attempts to draw the tree without repetition of events in the tree usually leads to the "top-down" approach not being rigorously followed, increasing the chance of omissions. An important feature that the analyst must consider is the possibility of failure from independent items by a single cause. This is considered further in Section 5.5.7.

Fault tree analysis provides an extremely powerful tool which is capable of handling most forms of combinational events. It provides a good basis for quantification and is particularly useful where a small number of major outcomes are of concern, as is usually the case in hazard analysis. Very large trees can result, with a separate tree required for each top-event and relationships between different trees then need to be considered carefully. Only the outcome under consideration is shown but other outcomes from the causes in the tree will not be shown. Transition routes between states are not represented and the technique generally deals with binary states: partial failures and multiple failure modes can cause difficulties.

5.5.4.2 Cause consequence diagrams

Cause-consequence analysis is a technique which combines the ability of fault trees to show the way various factors may combine to cause a hazardous event and with the ability of event trees to show the possible outcome. Sequences and therefore time delays can be illustrated in the consequence part of the diagram. A symbolism similar to that used in fault trees is used to show logical combinations. The technique has considerable potential for illustrating the relationships from initiating events through to the end outcome. It can be used fairly directly for quantification, but the diagrams can become extremely unwieldy. Because of this, cause-consequence analysis is not as widely used as the first two techniques described, possibly because fault and event trees are easier to follow and so tend to be preferred for presentation of the separate parts of the analysis.

5.5.5. Human errors

Some of the events depicted in either the event trees or the fault trees correspond to human actions. The probability of committing these actions by the human involved should be calculated with an appropriate human error analysis technique.

Human Error Analysis consists of 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 lead to an accident. It includes identification of the 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.

5.5.6. Data requirements

The data required for estimating the frequency of the various accidents identified, as described in section 5.3 and Appendix III, and evaluated for their consequences, as described in section 5.4 and Appendix IV, are those that will permit the estimation of the parameters necessary for the quantification of the event trees and the fault trees. They can be distinguished into three categories:

1. Frequencies of initiating events;

2. Probabilities of occurrence of basic events;
3. Human error probabilities.

The first category is used to quantify those initiating events which are leading events in an accident sequence. The second category involves the estimation of parameters of various reliability models used as a model for the basic events in fault trees. As described in section 5.5.4 they provide the necessary input for calculating the probability of top events of fault trees corresponding to the headings of the event trees. Of course, if some headings of event trees have not been further modeled in terms of a fault tree or of another model the probability of the whole system failing will be directly estimated from existing data or expert judgement. The third category of data involves the estimation of the probabilities of human errors that are explicitly modeled in the event trees and the fault trees.

Some types of human error are implicitly included in the reliability data for components. Indeed, it would be very difficult to separate many types of error, including design, installation, inspection, calibration, maintenance and so on, from the data to give a basic hardware failure rate. This means that application of such failure data implies an assumption about operating standards and maintenance regimes which is discussed further below. However, it may not be enough to assume that this approach is adequate and in critical situations specific attention may need to be given to these types of human errors, requiring a data input. It is also important to model carefully the variability of human responses in emergency situations.

Other types of human error are evidently not included in component reliability data, although they would be included in accident data. These include operational errors of omission or commission, such as failing to carry out a task or doing the wrong task, which may precipitate a dangerous situation, and errors in responding to dangerous situations as they arise. Where possible errors of this type are identified as being significant a data input is again required. The error rate observed has been found to be dependent on many factors such as the level of stress, familiarity with an operation or procedure, complexity of the task, training, and situation-specific features.

Several attempts have been made to gather relevant human error data for a variety of tasks under various conditions and levels of stress. Data collection is continuing and the study of human factors has become a very important subject in its own right.

5.5.6.1. Types of data

Data used for estimating frequencies and/or probabilities of events can be distinguished into categories according to their source:

1. Plant specific data;
2. Generic data.

Plant specific data are those originating from the particular installation under analysis. These are the most appropriate data to be used but it is most time consuming and expensive, if possible at all. Generic data are data from various plants gathered in various databases.

High quality event data are very expensive to collect and often a long time elapses before a statistically viable sample has accumulated. Therefore, such data are often regarded as a contributor to reliability information. Reliability data are values of the probability that a system performs as the designer intended. This parameter might just be an overall failure rate or it might be a quantity which can be separated into failure modes and causes.

There are data banks throughout the world which have considerable amounts of information, particularly on the reliability of components in nuclear plants. The data bank operated by SRS (Systems Reliability Service of the UKAEA) probably has the largest single collection of reliability data, drawn mainly from conventional rather than nuclear plants.

Another data bank, a multinational Event Recording Data System (ERDS) is under development by the CEC Ispra establishment. This data bank, intended to assemble in one system data failures from all light water nuclear reactors in Europe, is still only at the prototype stage and is indicative of the international co-operation that is required and can be achieved.

Publications are another source of information. The problem with inserting this type of information into a data bank is that distortion can be introduced by the data bank coding system when data has not been collected specifically for the data bank.

Data collection schemes must be arranged with due consideration for the nature of the events or failures concerned. A different approach is necessary to collect information on relatively frequent occurrences as compared to rare events, and when an extremely large amount of experience may be necessary for the data to be statistically meaningful. In the UK offshore operators are collaborating with HSE to provide a database which will hopefully produce useful and representative offshore failure rate data (OREDA).

5.5.6.2. Sharing and pooling of data

This area is very much in its infancy. Presently, two methods are being pursued, typified by the SRS system and the system being developed by the EUREDATA Association. The SRS method is one of encouraging co-operation of various industries and organizations with similar interests to supply data to a central data bank with benefit to the member organizations. The EUREDATA Association has the intention of drawing together, for the purpose of data acquisition, people of like interests so that exchanges of information and co-operation between the organizations can be collectively agreed. At this stage it is not possible to judge the efficiency of this approach, but the aims are clearly laudable. (See also reference to OREDA in reliability and event data above).

5.5.6.3. Possible future development

There is a great potential for progress given the co-operation of large numbers of organizations. Information sharing schemes and data banks have a vital role to play, as arrangements can generally be made to overcome problems and inhibitions regarding commercial confidentiality. The problem of demonstrating very high reliability, i.e. obtaining a statistically meaningful sample for rare events, will always remain. Data collection may well proceed independently of risk analysis, as much of the data is useful in reliability and availability studies, for which there is generally a keener economic incentive.

Analysis and modelling of data, within the limitations of the data, provide worthwhile results. Current developments which are proving useful include multivariety analysis of failure data, which allows tests to be made for coherence of data and correlation between observed parameters and known attributes. These techniques represent a considerable advance on existing modelling techniques.

5.5.7. Accident sequence quantification

The evaluation of failure logic diagrams i.e. the production of an algebraic expression for the probability of a particular outcome is carried out through application of probability mathematics and in particular the rules of boolean algebra.

Event trees are relatively straightforward to evaluate, as a probability of occurrence can be allocated to each outcome *conditional only* to the precursor event. As there are no logical combinations (gates) the probability of any particular outcome, conditional on the initiating event of the tree occurring, can be obtained by straightforward multiplication.

However, evaluation of logic diagrams which include gates is more complex. When compiled rigorously even simple systems can produce complex fault trees, with some events featuring more than once requiring evaluation by Boolean algebra. Conditions on the input events, e.g. sequence, can pose problems. The algebraic expressions can become unwieldy, making reduction tiresome. In the case of complex systems, for example multiple redundant and standby units with diverse or cross-linked supplies as might be found where extremely high reliability is required, the logic can become so complex as to virtually defy manual evaluation. However, correctly understanding the failure logic and ensuring consistency in the design is obviously crucial. Computer packages are available for evaluation of such fault trees. This introduces a possible disadvantage: that the analyst learns less about the system, or has less "feel" for it. The computer packages identify "minimal cut sets" i.e. groups of basic events, which cause the top event if existing at the same time. The analyst who writes a fault tree "straight down" is usually proceeding directly to this stage and by starting with the minimal cut sets he can increase the chance of errors in constructing the tree.

Over the past few years a number of computer codes have been developed for fault tree analysis (FTA). Fault tree analysis provides an extremely powerful tool which is capable of handling most forms of combinational events. It provides a good basis for quantification and, as is usually the case in hazard analysis, is particularly useful where a small number of major outcomes are of concern. With a separate tree required for each top-event very large trees can result and relationships then need to be considered carefully between the different trees. Finally, only the outcome under consideration is shown in the tree, whereas other outcomes from the causes will not be shown. Transitions routed between states are not represented and the technique generally deals with binary states: partial failures and multiple failure modes can cause difficulties.

Simple fault trees can, of course, be evaluated by "short cut" methods. Typically, simple fault trees are approximately evaluated by multiplication/addition of probabilities at and/or gates. It is important that the analyst should be aware of the possible pitfalls of this approach. It will only work if there are no events occurring more than once in the tree. This encourages the analyst to over-simplify in order to construct a tree which can be quantified in this manner. Also, large probabilities must not be added together: a flammable cloud encountering two ignition sources, with 0.5 probability of ignition at each, is not certain to ignite.

Although in many cases there is no need to use Boolean algebra or computer codes to evaluate fault trees, an advantage of such techniques is the ability to carry out sensitivity analyses, with input data as statistical distributions. The accuracy and availability of data, discussed later, is often such that sensitivity analyses are extremely valuable.

An important point that must be considered in the evaluation of fault trees is common cause/mode failure. Where redundant units are used the system failure probability, calculated by multiplication of the individual unit failure probabilities, is only valid provided that the units are truly independent. The fault tree and the practical situation must be examined to consider susceptibility to common mode failure. Computer codes are available for complex cases where the number of possible combinations has become large: these tools will not perform miracles but will search exhaustively for specified types of common mode failure.

However the tree is evaluated, the inputs must be dimensionally consistent. Probabilities cannot be added to frequencies and multiplication of frequencies produces a meaningless value. This may require manipulations of the data inputs into the required form, for example, the frequency of an event may depend on the frequency of a demand and the probability for failure of a protective system on demand. This failure probability must be determined from failure data of the system expressed as a frequency by using the fractional dead time concept, allowing for testing and repair. This type of common manipulation is discussed in most standard texts which cover the subject.

5.5.7.1. Quantification of accident event trees

Estimation of the frequency of an accident sequence depicted in an event tree entails the estimation of the frequency of the joint event consisting of the branches of the tree that constitute the sequence. In the most simple case this calculation is simply the multiplication of the frequency of the initiating events with the probabilities of the following events. This however, is valid only if the events are statistically independent. Formal quantification requires that the probability of each branch be evaluated conditional on the events preceding this branch in the accident sequence.

When a computer code for analyzing fault trees is available the quantification of the accident sequences can be done with the method of fault tree linking. Fault tree linking is the generation of a large fault tree incorporating accident sequences and system fault trees, in the following steps:

(i) All accident sequences are put into groups leading to the same type of releases.

(ii) For each type of release a large fault tree is created with the top event "occurrence of the particular release". The top event is linked with an "OR" gate which inputs all the accident sequences in the same group.

(iii) Each accident sequence is linked through an "AND" gate with all the event tree events that constitute the accident sequence.

(iv) Each event of the accident sequence is considered a basic event if its probability has been calculated directly (human error, or system failure without further analysis) or it is replaced by the system fault tree that models the systems failure.

The resulting tree can be very large and requires the use of specific codes for its quantification. The resulting "cut sets" represent accident sequences expressed in terms of basic events (simple failures) all resulting in the same type of release. The frequency of the top event is the frequency of the release category to be used in the risk estimation described in section 5.6.

5.6. RISK ESTIMATION AND RISK ASSESSMENT

5.6.1. The combination of consequence and frequency to produce risks

As described in section 5.3 the basis for quantification of risk from an industrial activity is a list of hazardous events or groupings of like events which can be considered to produce similar consequences. The frequencies of these events may be estimated by the techniques described in section 5.5. There may be a range of possible outcomes from each event, depending on the different circumstances which may prevail: for example meteorology, location of people, probability of ignition etc. Each of these circumstances must be defined and assigned a probability. The aggregation of the frequency and consequence analysis can, therefore, be complex, although it is conceptually simple and all analyses follow essentially the same procedure.

Damage causing events must be related to the undesired initiating events: for example, the various possible outcomes arising from a release of flammable material may be modelled using an event tree. The conditional probability for factors such as wind direction towards ignition sources and chance of ignition at each source can then be used to produce a frequency for the damage causing event from the frequency of the initiating event.

The consequences of each damage causing event are assessed using the methods described in section 5.4. and in Appendix IV. The usual approach is to define ranges to selected casualty probabilities from a combination of effect and vulnerability models. These casualty probabilities may be selected and limit ranges to each value estimated: for example, the probability of casualties occurring at various over-pressures could be used in conjunction with an explosion overpressure model to produce radii to selected casualty probabilities. The selection of probabilities will usually depend on the available data underlying the vulnerability model used. The analyst should be wary of using probit type relationships to produce a large number of casualty probability bands as this not only complicates the analysis, but the degree of detail would not be supported by the base data.

Having obtained the frequency and casualty probabilities against range for each damage causing event under consideration, the risk relationships are derived in the following manner. Taking each event in turn, the number of people present in the area covered by each casualty probability band are multiplied by the appropriate casualty probability producing, by summation, the total number of people predicted to be affected by each event. The overall frequency-consequence relationship can then be drawn up from the number affected and the frequency for each event. Expressing the risk in terms of the frequency distribution of multiple casualty events in this way is known as calculating the SOCIETAL RISK.

The INDIVIDUAL RISK at a location is obtained by taking the casualty probability at that location for each damage causing event and multiplying it by the frequency of that event. The individual risk from all such events, and therefore from the activity as a whole, is obtained by summation over all the events.

The final expression of individual and societal risks then incorporates the likelihood and severity of all the outcomes that have been considered and allows for features specific to the plant and to the particular location.

The following three sections illustrate the way in which the calculations can be carried out.

5.6.2. Individual risk

Individual fatality risk is defined as the frequency (probability per unit of time) that an individual at a specific location (x,y) relative to the installation will die as a result of an accident in the installation.

The following components are combined to form the individual fatality risk:

f_i frequency of the i^{th} initiating event that can lead to an accident (i=1,...,I).

P_{ri} conditional probability that the i^{th} initiating event can result in a release of type (r) of a hazardous material or in an event like pool fire, explosion etc (r=1,...,R).

f_r frequency of the r^{th} release category given by:

$$f_r = \sum_i f_i P_{ri} \qquad (r=1,...,R)$$

f_j frequency of the j^{th} type of weather conditions coupled with any other type of uncertain parameter e.g. ignition time (j=1,...,J)

The two sets of uncertain events R and J define a new combined set of random events W, where W=JR, each of which has a frequency f_w:

$$f_w = f_j f_r \qquad (j=1,...,J),(r=1,...,R)$$

$k_w(x,y)$ Level of adverse exposure (e.g. heat, radiation, dose of toxic material) at location (x,y) conditional on the joint event W. This quantity is calculated by the physical models presented in section 5.4.3, 5.4.4 and in Appendix IV.

P_{ck} Conditional probability that an individual exposed to the k^{th} level of the adverse effect will die as a result of that exposure (Casualty Probability).

$P_{cw}(x,y)$ *Conditional probability that an individual at location (x,y) will die given the joint event w.*

Frequencies of accident initiators (f_i) and conditional probabilities of releases (P_{ri}) are calculated at the hazard identification steps and the corresponding quantification. Frequencies f_w and levels of exposure to adverse effects, $k_w(x,y)$, are calculated during the consequence estimation steps.

Conditional probabilities P_{ck} are the result of the dose/response analyses involving probit functions in the consequence estimation step. Given the fact that from an installation a number of initiating events (i) can occur each with the potential of resulting in a number of release types each of which, owing to the weather variability and other uncertainties, can result in a number of consequence levels k, the total individual risk at a location (x,y) is given by:

$$I(x,y) = \sum f_w P_w(x,y)$$

5.6.3. Societal risk

Societal risk proceeds one step further than individual risk by taking into consideration the population size and distribution around the site of the installation. Societal risk is expressed in terms of the so called FN- curves and gives the frequency for the number of fatalities which exceed the number N.

Societal risk is calculated as follows:

d(x,y) is the population density at location (x,y)

N_w is the number of people that will die given the joint event w (w=1,...,W) given by

$$N_w = \sum_w P_w(x,y)d(x,y)$$

where the summation extends over all points (x,y) for which $P_w(x,y)$ and d(x,y) are different than zero.

This process results in W doublets (N_w, f_w) which can then be sorted out to form the cumulative distribution function of N or the FN- curves.

5.6.4. 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 with safety targets or criteria. A judgement can be made on the hazard impacts. 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 other sources.

(b) The analysis should particularly highlight major contributors to risk, i.e. 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.

Verification of results is a critical stage in risk analysis. It is relatively easy to make an error in the calculation sequence and several types of checking are necessary.

(a) Total result:

Is the total individual and societal risk predicted consistent with the historical experience for such facilities.

(b) Major risk contributors:

The top ten to twenty major risk contributors for both individual and societal risk needs to be separately checked in detail. As well as verifying correct analysis, the accident sequence and safeguarding deficiencies are a major deliverable of the risk analysis.

(c) Minor risk contributors:

A task often omitted is the need to check for analysis errors in the minor risk contributors. Important cases can be neglected if the initial analysis has under- estimated the event either in frequency or consequence.

(d) Shape of the individual risk contour:

Does the shape reflect any predominant wind direction, are major isolated ignition sources clearly contributing to the shape, do contours reflect appropriate dominance of non-directional (e.g. BLEVEs) or directional (e.g. flash fire) events?

It is through the process of detailed results checking that errors are removed from the analysis and that the project manager achieves a clear understanding of the full risk picture. Once this is complete, it is possible to compare results against formal criteria and, where appropriate, to develop a range of suitable mitigation measures.

Event frequency modifiers resulting from audit of management systems are discussed in Chapter 8.

6. ASSESSMENT OF TRANSPORTATION RISK

6.1. OVERVIEW AND SCOPE OF APPLICATION

The transport and distribution of hazardous substances, such as petroleum products, liquified petroleum gases, chlorine gas, pesticides, chemicals/petrochemicals, hazardous waste 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. A recent study carried out by the HSE's Advisory Committee on Dangerous Substances (ACDS) on the Major Hazards Aspects of the Transport of Dangerous Substances gives detailed accounts of the methodologies and techniques used in the assessment of transport risks [54].

There are several important features of transport risk that require a different type of analysis to fixed facilities. Such features include:

- the hazard source is not continuously present at any place (except pipelines);
- the exposed population is in close proximity to the hazard (buffer zones are impractical);
- individual risk may be very low (due to occasional exposure) but societal risk may be very high (as the transport vehicle is always affecting someone);
- the level of safeguards is less (bunding, water sprays, fire insulation are impractical);
- immediate availability of specialist knowledge is less (i.e. no foreman or engineers present).

This chapter of the guidelines focuses on the analysis and assessment of transportation routes (road, rail, waterway, harbour and pipelines) 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 network and cumulative traffic implications;** including overall traffic movement, congestion and level of service on used or potential routes, accident rates, route 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 an area 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;

(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 transport network for the transport of hazardous material and the formulation of routes for the safe transport of such material are therefore major objectives.

It should be noted that although this chapter deals mainly with the risks of hazardous materials being transported, when considering the overall system the risks of choosing a particular mode of transport may well be dominated by the risks involved at the loading/unloading facility. These risks can be calculated either as part of the fixed facility assessment or as part of the transport assessment - whichever is the more appropriate for the specific situation.

It should also be noted that, for most forms of transport of hazardous materials, there exists a comprehensive and extensive list of international transport regulations. The results of a transport risk assessment are very specific to that particular assessment and care must be taken to avoid drawing conclusions from a few studies and then generalizing from these, i.e. rail may not always be safer than road, pipelines may not always be safer than rail, etc.

A good screening system for transport risk is given in Ref. [1].

6.2. ANALYSIS AND ASSESSMENT OF TRANSPORTATION RISK AND ENVIRONMENTAL AND LAND USE SAFETY FACTORS

6.2.1. 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 Fig. 6.1):

- Mandatory factors, including legal and physical constraints;

- 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 factors 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.

6.2.2. 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 routes or structures (e.g. tunnels, bridges). Local, state and national transport authorities should be consulted in all cases. Such prohibited routes are obvious first cut alternatives to be eliminated.

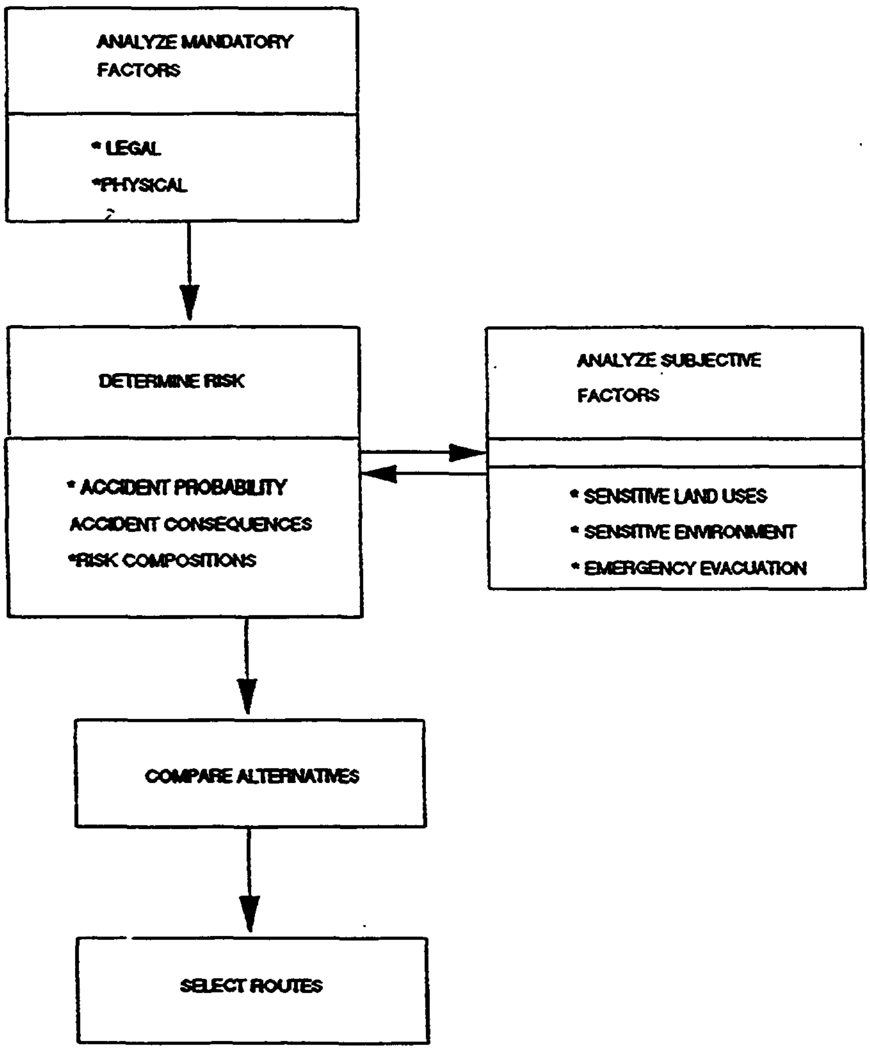


FIG. 6.1. Overall approach to risk comparisons and assessment for hazardous materials transportation routes

6.2.3. 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, routes with the smallest adjacent population as well as accident rates will have the lowest risk values. This population should also include that on the traffic route itself.

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.

6.2.3.1. 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 and the compatibility of the materials being transported and the tank construction (this should include hazardous waste);
- Identify for the various transportation modes (i.e. sea, river, road, rail or pipeline) those materials which have the potential for continuous (routine) releases hazardous to health and the environment;
- Identify for the various transportation modes those materials which pose a threat to health and the environment if released as a result of an accident;
- The storage/transportation 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, etc.) 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 and/or release of toxic substances into the environment, the consequences (effects) of each accident scenario are calculated, usually in terms of heat flux, explosion overpressure and toxic exposure, using thereby mainly consequence modeling tools (see Section 5.4 of this document). Based on estimated effects and population data (densities for land use types along the route and for roadways, people on the route trapped in the blocked up traffic) the number of people that may be affected by the postulated accident, in terms of injuries or fatalities can be determined. The effects on the environment can be determined in a similar manner using the models described in Chapter 4.

It is difficult to set out standard safety separation distances for evacuation and other emergency response following an accident. A better approach is to assess each type and quantity of load for its specific hazardous consequences (e.g. BLEVE, jet fire, pool fire, toxic cloud) for a small number of realistic accident scenarios. The methods described in Chapter 5 are suitable for this purpose, but see also the IAEA Prioritization Scheme [1].

Useful emergency response guidance for a wide range of chemicals is given in the US Coast guard CHRIS Manuals [55]. This applies to both land and marine spillages.

6.2.3.2. Estimations of the probability of transport accidents

The probability of a hazardous materials accident is the likelihood or chance that a vehicle carrying hazardous materials will be involved in an 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. Similar reasoning can be applied to pipeline accidents.

A suggested sequence of steps can be summarized as follows:

(i) **Determine the accident rates on a particular route:** ideally, the most reliable data concerning accident rates would be those associated specifically with hazardous materials transportation tankers in terms of the number of hazardous materials accidents per tanker. 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 local total rates of accidents from relevant vehicles, usually in terms of accidents/vehicles-km, where vehicle-km refers to the total number of kms travelled by all vehicles for which accident statistics are available.

(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 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.

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.

It is necessary in some justifiable circumstances to further introduce a correction factor that reflects physical characteristics of the particular route segment which may increase the probability of an accident on that particular route.

6.2.3.3. Methodology to calculate transport risk

The potential consequences (population and/or property) and accident probabilities for each route segment are multiplied 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 Section 6.2.3.2 above should be further converted to a likelihood or probability of impact. The probability of a hazardous event and release 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.

For the computation of transportation risks along different route segments, based on the cumulative combination of the consequences and probabilities of accidents, the following procedural steps are appropriate:

(a) For each substance (load category) transported establish the range of hazardous events scenarios, the probability of each scenario P_{SC} and the radius of fatality (or injury) effects from each scenario. Figs 6.2, 6.3, and 6.4 are examples of event trees that may be followed. The depth, extent and number of hazardous scenarios will depend on the comprehensiveness of the analysis study. It may be possible for a simplified case analysis to postulate two or three hazardous accident scenarios and assign probabilities and estimate the radius of fatality (or injury) effects for each event;

(b) From the above, estimate the severity index for each category of hazardous load:

- Calculate $P_{sc}\,\pi r^2$ for each hazardous scenario
- Calculate the severity index (S.I.) by summing up $\Sigma P_{sc}\pi r^2$ for all postulated scenarios;

(c) Multiply the severity index for each load category ($\Sigma P_{sc}\pi r^2$) by the probability of a hazardous material accident as determined in section 6.2.3.2.

(d) Multiply the result of step (c) above by the population density along each of the transportation routes under consideration. This is the population risk for the route(s) under consideration for the hazardous load;

Note: 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.

6.2.4. 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.
- 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 be arrived at through community discussion and consensus. These factors are particularly relevant in the assessment process when one alternative is not clearly superior to the others. As such, whether or not the analyst chooses to select and apply subjective factors will depend upon the outcome of the risk calculations and how conclusive the findings are.

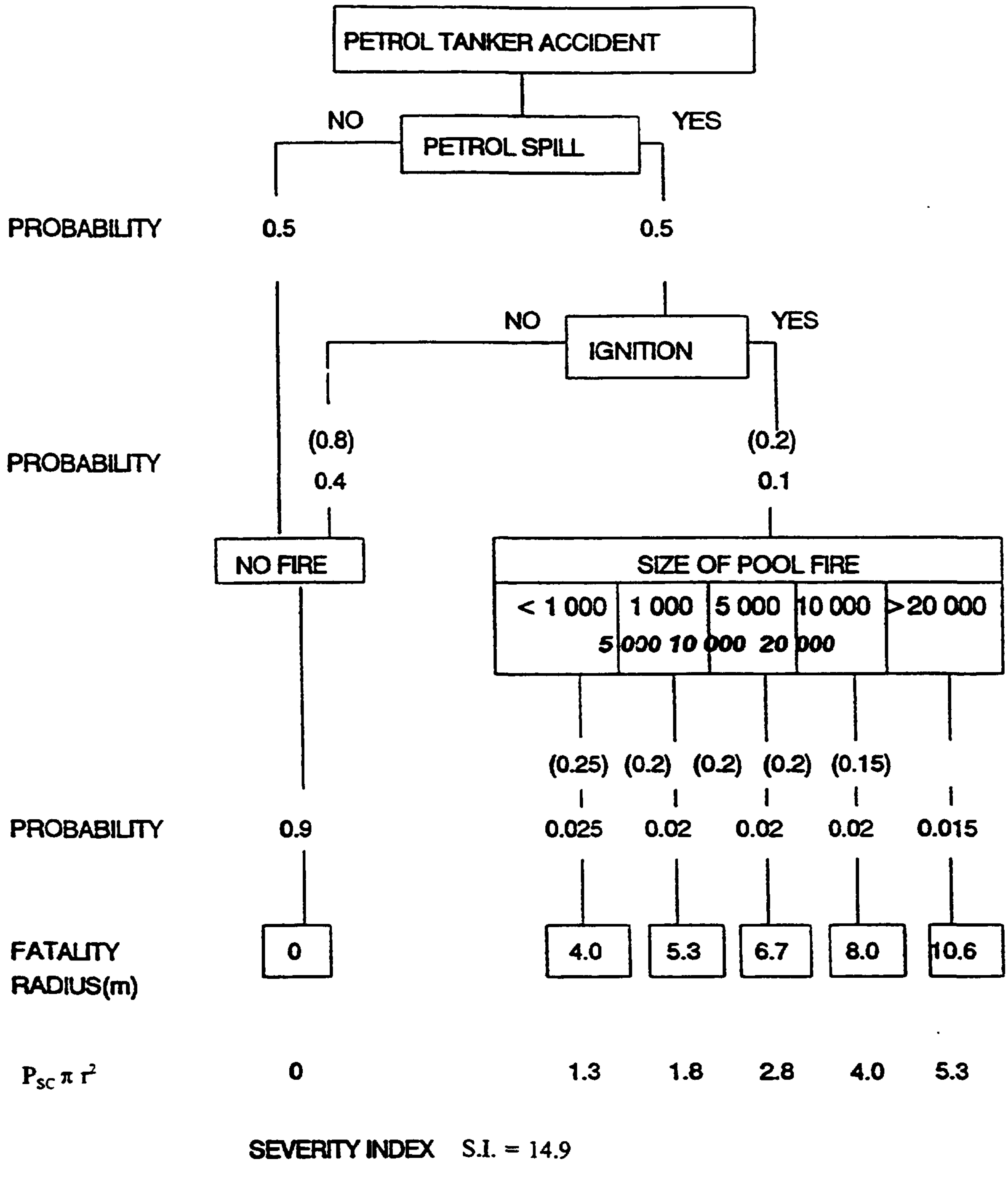


FIG. 6.2. Event tree for petrol tanker accident (Spill size in litres). Extracted from Ref. [54].

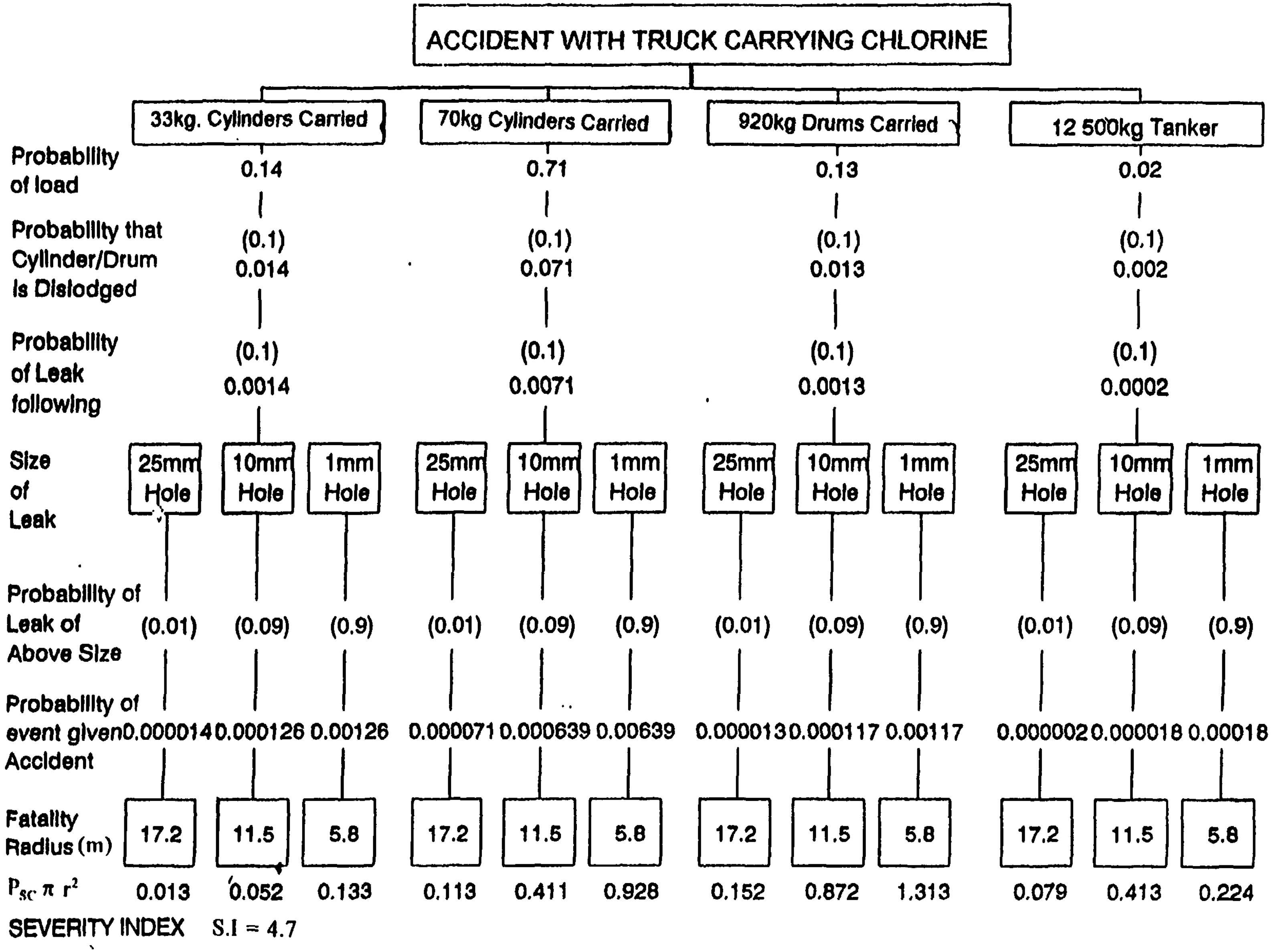


FIG. 6.3. Event tree for accident with truck carrying chlorine. Extracted from Ref. [54].

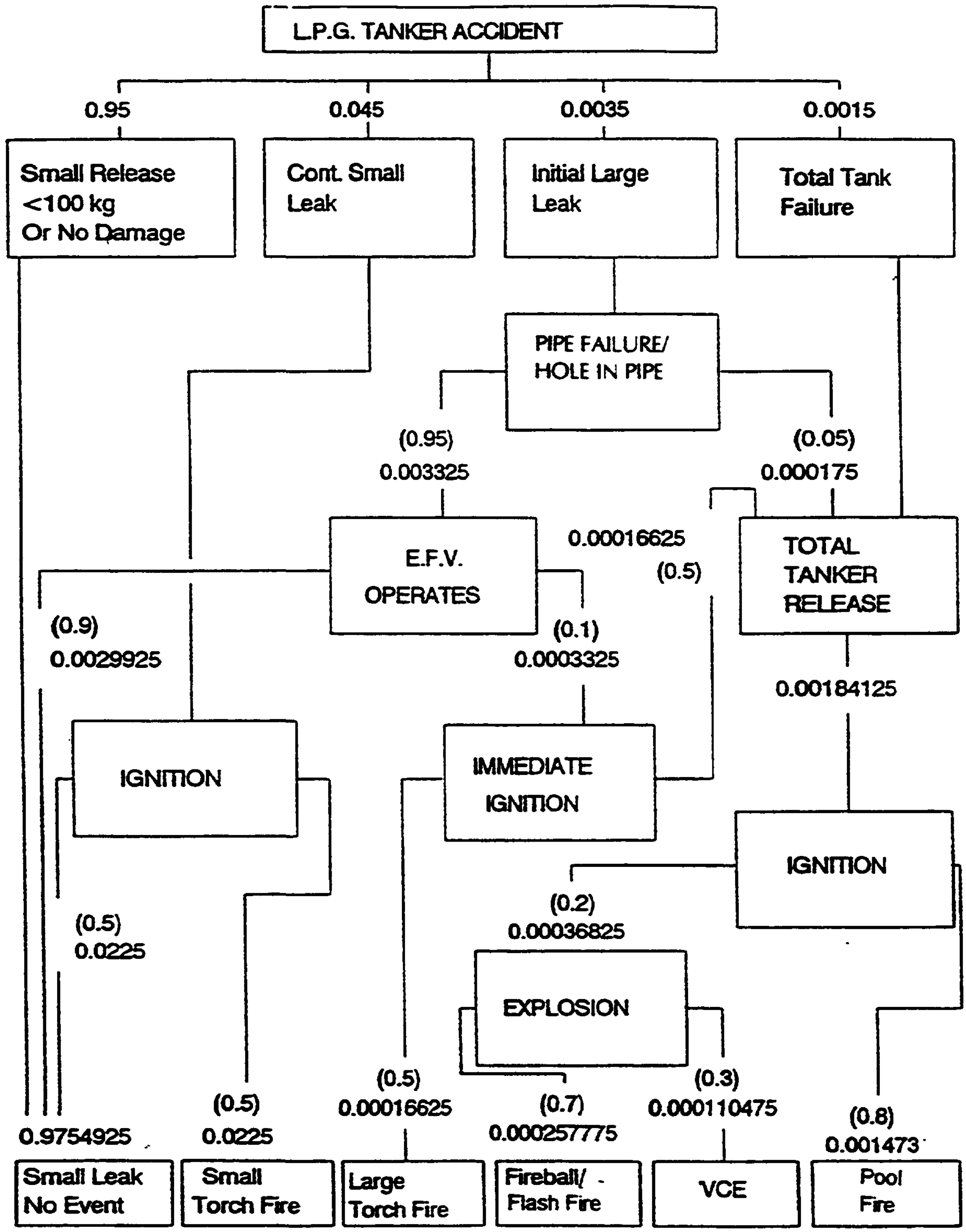


FIG. 6.4. Event tree for LPG tanker accident. Extracted from Ref. [54].

6.2.5. Guidance implementation

The following 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):

....
Special hazardous properties for emergency
response:

....

3. SUBJECTIVE FACTORS (optional)

Explain any of the following subjective factors, as applicable:

Special Population:

....

Special Properties:

....
Emergency response capabilities:

....
Other factors:.

....

RISK ESTIMATION

Segment No.	Probability of a Hazardous Material Accident	Population Density	Hazard Index	Population Risk
....	 x	 x	.... =	....
....	 x	 x	.... =	....
....	 x	 x	.... =	....
....	 x	 x	.... =	....
....	 x	 x	.... =	....
....	 x	 x	.... =	....
....	 x	 x	.... =	....
....	 x	 x	.... =	....
			TOTAL:	

6.3. AN EXAMPLE OF THE ANALYSIS AND ASSESSMENT OF THE TRANSPORT OPERATIONAL AND TRAFFIC FACTORS FOR A ROAD ROUTE

The following traffic factors reflect the ability of a route to effectively and safely move the traffic flows using it:

- Traffic 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.

6.3.1. Traffic volume and composition

The composition of vehicles by size and type is required to assess the roads 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 can 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).

6.3.2. 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 terms 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).

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 6.1 indicates suggested one-way hourly volumes for interrupted traffic flow at different levels 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 Section 6.3.1. may therefore be used to estimate the appropriate level of service of each road under consideration.

6.3.3. 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

TABLE 6.1. EXAMPLE OF ONE-WAY TRAFFIC VOLUMES (PCU)[1] FOR URBAN ROADS AT DIFFERENT LEVEL OF SERVICE (INTERRUPTED FLOW CONDITIONS)

Type of Road Carriageway	Level of Service				
	A	B	C	D	E
2 Lane Undivided	540	630	720	810	900
4 Lane Undivided	900	1050	1200	1350	1500
4 Lane Undivided with clearway	1080	1260	1440	1620	1800
4 Lane Divided with clearways	1140	1330	1520	1710	1900
6 Lane Undivided	1440	1680	1920	2160	2400
6 Lane Divided with clearway	1740	2030	2320	2610	2900

PCU[1] = Passenger car unit, i.e. heavy vehicle volumes are converted into passenger car equivalent.

carriageway with minimum horizontal and vertical curves) and good line of sight should be selected in preference to routes of lesser quality. In situations where for other reasons routes in the latter category were selected they should be upgraded to provide better geometry and, if necessary, the pavement should be reconstructed to cater for increased volumes of heavy vehicles.

6.3.4. 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.

6.3.5. Travel time and travel speed

Travel time for vehicles using a route indicates the congestion points as well as reflects the level of congestion. Travel time information is usually available from transport authorities or may have to be collected by way of field surveys. The National Association of Australian State Road Authorities has suggested an average vehicle travel speed for different levels of service given in Table 6.2. According to this table, travel speeds in the range 25-30 km/hr correspond 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.

6.3.6. Availability of alternative emergency routes

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 6.2. EXAMPLE OF TRAVEL SPEED AND FLOWS FOR DIFFERENT CATEGORIES OF LEVEL OF SERVICE

Level of Service	Type of Flows (km/hr)	Average Overall Travel Speed
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	Forced flow	≤25

6.4. TRANSPORT OPERATIONAL COSTS AND OPERATION 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 basic 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 material needs 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.

Total vehicle operating cost = Unit cost component by distance travelled (cost/km) + Unit cost component by time taken to travel the distance (cost/hr).

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 material is the expected increase or decrease in travel time (the main component that influences 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 material. It is also considered that the distance cost could increase further as long as the travel time was within the 10% margin. For example, a longer distance route could have less congestion thereby resulting in a travel time about the same as the shorter route.

6.5. PIPELINE TRANSPORT

Pipelines share common risk features with both fixed facilities and transport facilities. Physically the pipeline does not move but population separation can be very little and third party interference is hard to prevent (e.g. digging).

It is not possible here to provide a method, but features to consider in the analysis include:

- length of isolatable sections (block valve locations);
- realistic isolation times (manual or remote operated valves);
- leak detection systems (if any);
- depth of cover;
- corrosion protection (wrapping, cathodic protection);
- safety factor (specified minimum yield stress, enhancement at road, river crossings, etc.);
- inspection and maintenance;
- safety management system.

Once all these factors are included a risk analysis of the type defined in Chapter 5 may be carried out. Pipeline failure rate data is available from various sources (CONCANE in Europe and the US National Transportation Safety Board) but these will need to be modified using logic diagrams to account for local factors (e.g. digging, welding standards, etc.). An interesting but confusing aspect of individual risk contents when applied to pipelines carrying flammable gases is that contours appear to shrink in size when entering populated areas. This is due to the many local ignition sources and thus few vapour clouds will reach their full extent before igniting.

7. ANALYSIS OF HAZARDOUS WASTE

7.1. INTRODUCTION

Wastes are generated by almost all branches of industry including industries that produce non-dangerous products, but a few major groups are most likely to produce hazardous toxic wastes which require special treatment. Industries with a high potential for generating hazardous wastes are mainly: inorganic and organic chemicals, petroleum refining, iron and steel, non-ferrous metals (smelting and refinery), leather tanning and finishing, paint and coatings, nuclear facilities, electroplating and metal finishing. A list of the main waste producing industries, the type of waste produced and the potential impacts on health and the environment is given in Table 7.1.

In general, the industrial production system generates products and wastes - it consumes raw materials, energy and manpower. The waste products generated enter some form of waste stream and are moved to the waste management sector for further processing, treatment and ultimately disposal. Fig. 7.1 illustrates the various points at which the generation, storage, handling and transport of hazardous wastes may arise. Fig. 7.2 shows the hierarchy or alternatives in waste management, which involves the following four options:

(a) avoidance at source;
(b) re-cycling of the hazardous waste;
(c) special treatment of hazardous waste;
(d) disposal of the waste.

The chemical plant (or any other process system) will produce wastes that may be recycled in-house. If wastes, either from the plant or process itself or from the re-cycling unit are hazardous, then storage, handling and transport problems will arise when it is transferred to the waste disposal industry as shown on the diagram. Hazardous waste will also arrive from industries which use toxic chemicals which may subsequently appear in liquid, sludge or solid wastes.

It is not only industrial wastes that need to be considered in the integrated risk assessment of the study area concerned but also domestic wastes such as discarded paints, insecticides and aerosol containers can be hazardous and in landfill disposal sites methane may be produced which can present an explosion hazard. Toxic chemicals can also get into ground-water if not properly contained.

The assessment of the risks from all the waste forms produced in a large area of industrial activity will be very difficult and time-consuming and it is recommended that a top-down approach is applied to rank the wastes in order of priority so that those which cause the biggest problem can be identified and dealt with first.

Once the various waste streams have been identified the methods of assessing their effects on health and the environment presented in these guidelines can be applied. For example continuous discharges to the atmosphere or water can be dealt with in Chapter 4 of these guidelines - the consequences of methane explosions from landfill sites can be estimated from section 5.2 and so on.

The objective of this chapter is to define hazardous wastes, to discuss why wastes are treated differently to normal industrial hazardous material and to identify and assess waste generation systems.

7.2. CATEGORIZATION OF WASTES

It is important to clearly categorize wastes and waste streams so that there is no ambiguity as to the responsibility for the appropriate management of waste. Many different systems of waste categorization have been developed by regional, state and national governments. At the international level the OECD [56] has produced a comprehensive system of categorization.

TABLE 7.1. HAZARDOUS WASTE: GENERATING OR HANDLING FACILITIES

Activity	Typical Hazardous Waste	Nature of Hazards	Potential Impacts	Potential Health Impacts
A. Mining				
Coal mining washeries	Spoil heaps/slurry waste waters/dams	Physical impact/pollution	Pollution of water courses landslides/dam failures	Chronic and acute illnesses through intake of pollutants through water supply and food chain
Non-ferrous metal mining (particularly gold)	Spoil heaps/slurry waste dams containing heavy metals/salts, cyanide arsenic etc	Pollution by toxics/physical impact	Contamination of ground and surface waters (runoff and leachate). Aquatic environment damage	Chronic and acute illnesses through intake of pollutants through water supply and food chain
Asbestos mining	Slurry waste heaps high in asbestos	Asbestos fibres/dust	Soil contamination	Chronic and acute illnesses through intake of pollutants through water supply and food chain
Gas and oil extraction	Oily muds/sludges	Pollution/fire	Soil, groundwater and surface water contamination	Chronic and acute illnesses through inhalation and intake of pollutants through water supply and food chain
Uranium mining	Radioactive slurry waste and waters. Other minerals and metals in slurry waste waters	Radiation/pollution	Pollution of water bodies and impact on aquatic and other species	Chronic and acute illnesses through inhalation and intake of pollutants through water supply and food chain
B. Manufacturing				
Gas works	Phenol/mercaptan/cyanide containing sludges	Pollution by toxics and odorous substances	Soil, water and air contamination	Chronic and acute illnesses through inhalation and intake of pollutants through water supply and food chain

TABLE 7.1. HAZARDOUS WASTE: GENERATING OR HANDLING FACILITIES (cont.)

Activity	Typical Hazardous Waste	Nature of Hazards	Potential Impacts	Potential Health Impacts
Oil refineries	Sludges/tars/aqueous waste	Fire/explosion/pollution by toxics	Soil, water and air contamination	Chronic and acute illnesses through inhalation and intake of pollutants through water supply and food chain
Leather production/tanneries	Sludges containing heavy metals	Pollution by toxics	Soil and water contamination	Chronic and acute illnesses through intake of pollutants through water supply and food chain
Coke works	Sludges/tars/solvents	Pollution by toxics	Soil and water contamination	Chronic and acute illnesses through intake of pollutants through water supply and food chain
Aluminium smelters	Fluoride and cyanide containing residues	Pollution by toxics	Surface and groundwater contamination.	Chronic and acute illnesses through intake of pollutants through water supply and food chain
Electro-plating works	Sludges containing heavy metals	Pollution by toxics	Soil and water contamination	Chronic and acute illnesses through intake of pollutants through water supply and food chain
Pharmaceutical works	Halogenous and halogen free solvents	Pollution by toxics	Soil and water contamination	Chronic and acute illnesses through intake of pollutants through water supply and food chain
Asbestos works	Asbestos containing residues	Asbestos fibres/dust	Soil contamination	Chronic and acute illnesses through intake of pollutants through water supply and food chain

TABLE 7.1. HAZARDOUS WASTE: GENERATING OR HANDLING FACILITIES (cont.)

Activity	Typical Hazardous Waste	Nature of Hazards	Potential Impacts	Potential Health Impacts
Metal pickling works	Acid mixtures/sludges containing metal residues	Corrosion/pollution by toxics	Soil and water contamination	Chronic and acute illnesses through intake of pollutants through water supply and food chain
Plastic manufacturing	Sludges/halogenated residues/solvents	Fire/pollution by toxics	Soil and water contamination.	Chronic and acute illnesses through inhalation and intake of pollutants through water supply and food chain
Rubber production/processing	Solvents	Pollution by toxics	Soil and water contamination	Chronic and acute illnesses through intake of pollutants through water supply and food chain
Paint/resin manufacturing	Sludges/heavy metals/solvents	Pollution by toxics/fire	Soil and water contamination.	Chronic and acute illnesses through inhalation and intake of pollutants through water supply and food chain
Coating works	Acids/solvents/metals	Fire/pollution by toxics	Soil and water contamination.	Chronic and acute illnesses through inhalation and intake of pollutants through water supply and food chain
Pesticide production	Pesticides and byproducts/ contaminated filters	Pollution by toxics	Soil, water and air contamination Bioaccumulation and persistence in environment	Chronic and acute illnesses through inhalation and intake of pollutants through water supply and food chain
Non-ferrous metal refining	Slags and sludges containing heavy metals	Pollution by toxics	Soil and water contamination.	Chronic and acute illnesses through intake of pollutants through water supply and food chain

TABLE 7.1. HAZARDOUS WASTE: GENERATING OR HANDLING FACILITIES (cont.)

Activity	Typical Hazardous Waste	Nature of Hazards	Potential Impacts	Potential Health Impacts
Uranium refining and fuel rod production	Radioactive/heavy metal containing sludges and waters	Radiation/pollution by toxics	Soil, water and air contamination	Chronic and acute illnesses through inhalation and intake of pollutants through water supply and food chain
C. Agriculture				
Cropping and animal husbandry including feed lots, piggeries, chicken batteries etc.	Pesticides and manure	Pollution by toxics/infections	Soil, water and air contamination	Chronic and acute illnesses through intake of pollutants through water supply and food chain
D. Medical and Veterinary Facilities				
Hospitals and medical clinics	Infectious waste, radioactive material	Pollution by toxics/micro-organisms/radiation	Soil, water and air contamination	Chronic and acute illnesses through inhalation and intake of pollutants through water supply and food chain
Quarantine stations, abattoirs etc	Infectious wastes	Pollution by micro-organisms	Soil, water and air contamination	Chronic and acute illnesses through inhalation and intake of pollutants through water supply and food chain
E. Waste Management Operations				
Sewage treatment	Bacterial sludges, sludges with heavy metals and organics	Pollution by toxics/micro-organisms	Soil, water and air contamination	Chronic and acute illnesses through inhalation and intake of pollutants through water supply and food chain
Municipal or industrial landfill	Domestic or industrial wastes	Fire/explosion/ pollution by toxics	Soil, water and air contamination	Chronic and acute illnesses through inhalation and intake of pollutants through water supply and food chain

TABLE 7.1. HAZARDOUS WASTE: GENERATING OR HANDLING FACILITIES (cont.)

Activity	Typical Hazardous Waste	Nature of Hazards	Potential Impacts	Potential Health Impacts
Municipal or industrial incinerators	Domestic or industrial waste and sludges	Pollution by toxics	Soil, water and air contamination	Chronic and acute illnesses through inhalation and intake of pollutants through water supply and food chain
F. Energy Production/Distribution				
Power stations/switching/transformer stations	PCB contaminated oil/fly ash (leachate)	Pollution by toxics	Soil and water contamination Bioaccumulation and persistence of PCB in the environment	Chronic and acute illnesses through intake of pollutants through water supply and food chain
Nuclear power plants/fuel production	Fuel/reprocessing residues/ contaminated materials	Radiation	Soil, water and air contamination	Chronic and acute illnesses through inhalation and intake of pollutants through water supply and food chain
G. Transportation				
Vehicle washings, slops from changeovers of products in pipelines	Full range of waste possible/ oil containing waste	Pollution by toxics	Soil and water contamination	Chronic and acute illnesses through intake of pollutants through water supply and food chain

TABLE 7.1. HAZARDOUS WASTE: GENERATING OR HANDLING FACILITIES (cont.)

Activity	Typical Hazardous Waste	Nature of Hazards	Potential Impacts	Potential Health Impacts
H. Military				
Munitions production	Surplus or expired conventional, chemical and biological weaponry	Explosion/fire/pollution by toxics/infections	Contamination of soil, water and air	Chronic and acute illnesses through inhalation and intake of pollutants through water supply and food chain
I. Research Facilities				
Scientific laboratories etc	Wide range of hazardous materials usually in relatively small quantities	Pollution by toxics/infections/radiation	Soil, water and air contamination	Chronic and acute illnesses through inhalation and intake of pollutants through water supply and food chain
J. Construction Industry				
Demolition and excavation	Building and soil material	Pollution by toxics	Soil, water and air contamination	Chronic and acute illnesses are through intake of pollutants through water supply and food chain
K. Accidents and spills				
Deliberate and accidental fires/explosions/spills etc during production, storage and transportation of hazardous materials	Contaminated fire fighting water/soil/"cocktails" of hazardous materials	Pollution by toxics	Soil and water contamination	Chronic and acute illnesses through intake of pollutants through water supply and food chain

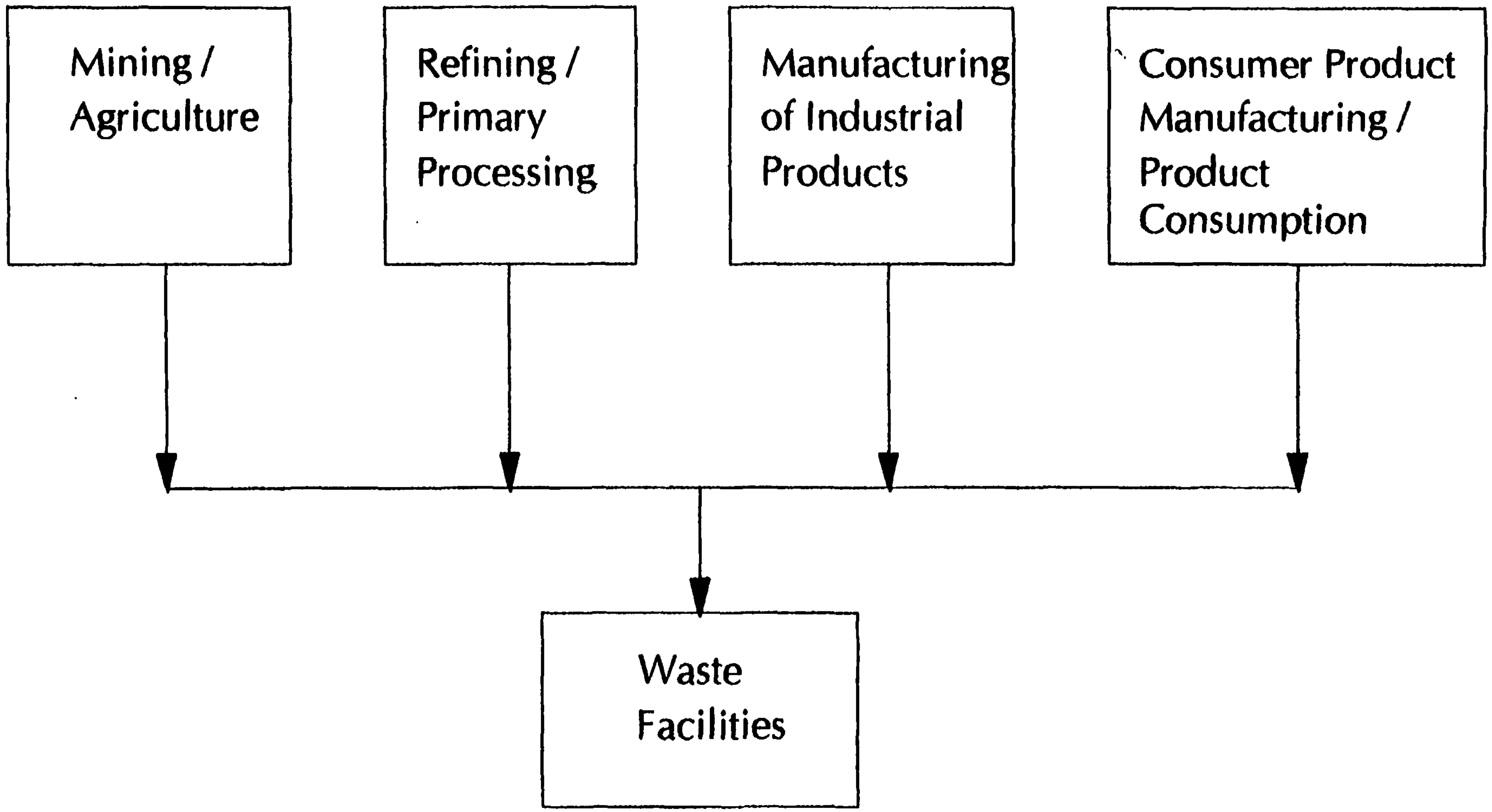


FIG. 7.1. Industries at which waste may arise

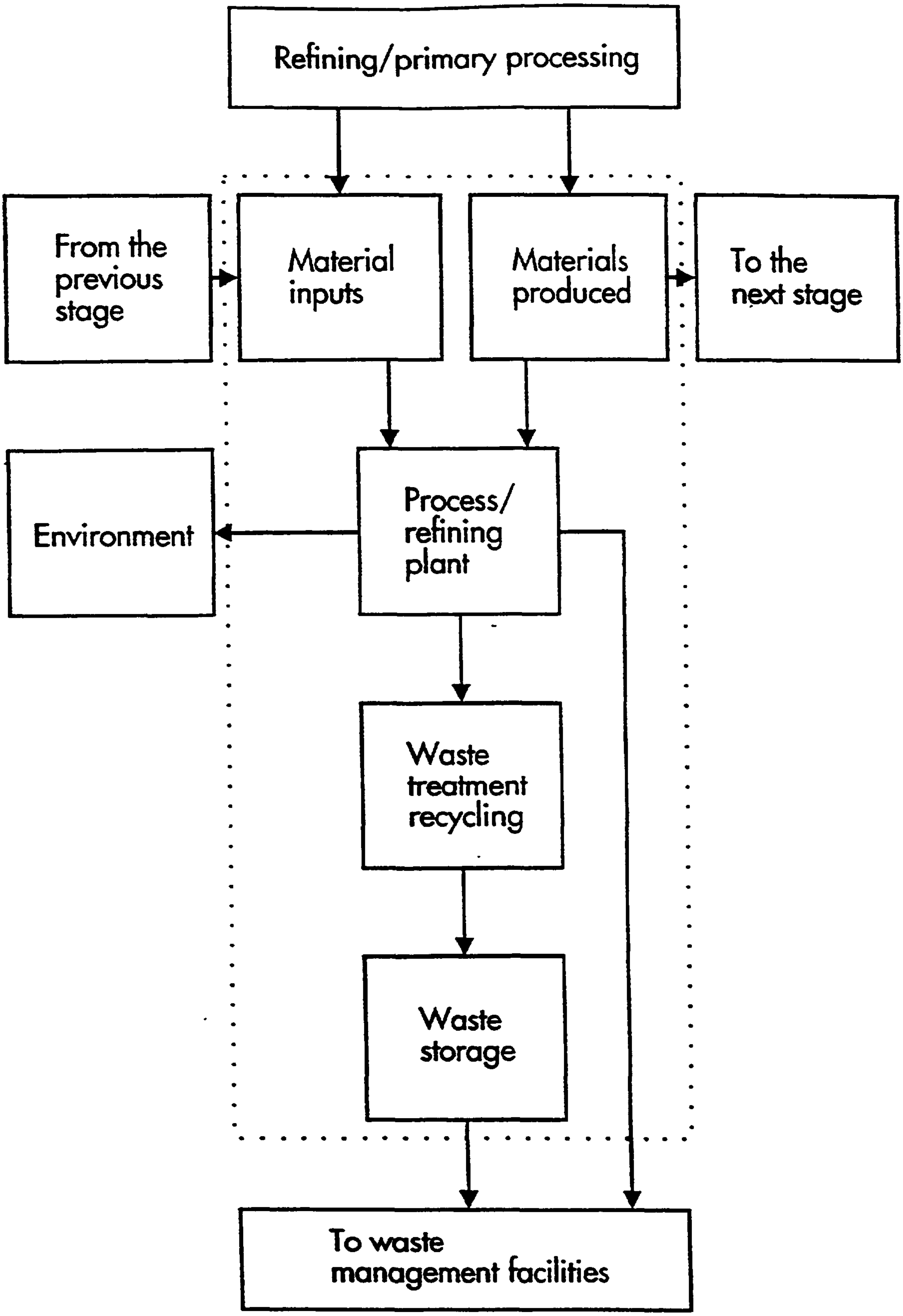


FIG. 7.2. Alternatives in waste management

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. There can also be unexpected reactions between different waste materials and there may also be synergistic effects on man and the environment due to the combination of several otherwise 'harmless' wastes.

To be useful waste categorization systems need to be able to aid in the monitoring of hazardous waste generation and transport. They need to be compatible with other hazardous material categorization and regulatory systems and with the broader regulatory and administrative context. Categorizations also need to cover composition, physical state, packaging/containment and type of hazards. One particular reason for a robust waste categorization system is the tracking of wastes from production through transport and storage to final treatment and disposal. In the absence of a categorization system or a loosely administered one the discrepancies in waste description are likely to lead to error and abuses. For the purpose of these area studies, the limits placed by the exclusion of wastes from existing categorization systems should be disregarded.

The range of waste management strategies and options, economic considerations and regulatory approaches and aspects of the technologies which can be applied within these options form an integral part of the integrated risk management strategy. Problems are associated with the siting of facilities of waste treatment with respect to community perception to waste treatment and transport.

7.3. HAZARDOUS WASTES

7.3.1. 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 generalization 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: It is the negative value of a material that causes it to be classed as waste and not the characteristics of the material. What may be considered a waste in some circumstances can be useful material in others. The situation can change as local, domestic and international demand and supply change and is also dependent on knowledge about demand.

Further, wastes are often mixtures of materials, impure or contaminated materials and this increases the likelihood of accidental inappropriate handling, treatment or disposal. This 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 of risk in the public mind 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.

7.3.2. 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, pollution by toxics and microorganisms leading to chronic or acute health effects, corrosivity, eutrophication, radiation and contribution to climate change.

Wastes of many types can be hazardous if they are not appropriately managed. They include e.g. dangerous liquids, with pH below 3 or greater than 10, which would behave like acids or basic fluids. Domestic garbage, for example, can play a role in spreading disease if it is not treated or disposed of by soil filling. In landfills it can present an explosion hazard if methane produced is confined in and under buildings. Methane also contributes to global warming. It can also contribute to pollution of waterways and ground water through leaching of nutrients, heavy metals, organics etc. If burnt or incinerated 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.

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.

Waste streams will vary greatly from case to case. Different raw materials, different technologies and different waste management practices will all greatly affect the type, form and hazardousness of the waste stream. The general activity descriptors of the first column of Table 7.1 encompass a number of different specific operations and activities. Within each specific activity the waste profile will differ with the attempt of waste avoidance, the technology applied and the waste management approach. Further, many waste streams, as shown in Table 7.1 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 generalized table such as this. The manner of release also critically affects 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, produce acute affects while low level exposures may produce chronic effects. It is essential therefore that the complexities and the diverse range of possible impacts are dealt with by the use of a 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.

7.4. 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 that 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 ascertain that hazards and risks are fully addressed.

7.4.1. Identification

Potentially Hazardous Industrial Facilities: The general hazard identification carried out for the area as described in Chapter 3 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 soil) and solid, liquid or gaseous waste generated (including materials collected in air filtration and scrubbing, and sludges 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 7.1 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 activities 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.

The 'mass balance' 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 is that large scale problems are usually more likely to be identified while relatively small but potentially significant waste streams, particularly very toxic substances, may be missed.

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 are also to be taken into account. As indicated in Table 7.1 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 included 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 organizations (both private and public). Landfill operations should receive particular attention due to their potential to create problems which may only appear many years later.

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 soil and groundwater by waste disposal practices, such as absorption of metal processing wastes in on-site pits, should be factored into 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), type of containment/packaging, transport of wastes compatible with each other, 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.

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.

Categorization and Registration Systems: The identification of waste streams and their fates is much easier where there is a regulatory framework which records them and their movements. 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 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 soil, fresh water (rivers, lakes), drinking water, seawater 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.

7.4.2. Assessment of waste practices and controls

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 organizational 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 4 and 5 of this document. 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. There is no reason why the 'long-term' storage of toxic wastes (long-term indicating no current intention to carry further treatment) should be treated any less thoroughly than the long-term storage of radioactive wastes. 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.

7.5. CONCLUSIONS

This chapter has attempted to provide some broad, general guidance on identification and assessment of hazards and risks arising from wastes in the context of area risk assessment and management. There is a substantial general and specialized literature on hazardous waste issues, management, technologies etc. 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 prejudgment. The holistic, systematic approach proposed should provide a sound basis for hazardous waste management strategies to minimize risk to people, property and the biophysical environment. A guide for such a holistic and systematic approach is provided in the WHO Environmental Technology Series, Ref. [12], which treat, among others, the solid waste management problem.

8. RISK MANAGEMENT

8.1. INTRODUCTION

In Chapter 2 reference was made to the formation of an Implementation Committee. The first task of the Implementation Committee should be to formulate the project proposal into a detailed project plan and establish working groups to carry out the various analyses. The Implementation Committee should accept reports from the working groups and prepare its own covering report which should include consolidated conclusions and recommendations. This consolidated report should be then presented to the Steering Committee for their endorsement of the recommendations and associated action plans for implementation.

The objective of this chapter is to provide guidance in the preparation and presentation of the final report, to assist with setting decision criteria and to help in the preparation of remedial action plans.

8.1.1. General introduction on risk management

Risk management constitutes a system of decisions directed towards what needs to be done in order to reduce unacceptable risks. The problem of choice is in most cases based on economic analysis and every economic analysis is reduced to the question of the optimal utilization of financial resources. Thus, risk management itself is reduced to the problem of selecting risk reduction/elimination measures to bring about maximum risk reduction with the available means.

8.1.2. Presentation of project results

It is recommended that the documentation of the project results be divided into three major parts:

- summary report;
- main report;
- appendices.

The summary report should provide an overview of the Regional Risk Management Project, motivations, assumptions, objectives, scope, results, conclusions and recommendations at a level which is useful to the Steering Committee and participating organizations. The summary report should:

- provide a high-level view of the project;
- communicate key aspects of the study to a wide audience;
- provide a clear framework and guide for the reader or user prior to consulting the main report.

The summary report should also list the contents of the main report and the appendices.

The main report should give a clear and traceable presentation of the complete project. It should include the scope of the project, objectives, implementation, methods used, results, conclusions and recommendations. It is important that areas of uncertainty are identified and highlighted. The appendices should contain detailed data, detailed models and other information which most users will either not need at all or will not need to consult regularly.

The Implementation Committee of the project is usually in a position to make a presentation of the results achieved within the area risk study to the professional public, decision makers as well as to the general public. Presentation of achieved results should be very carefully designed by the Implementation Committee of the project, especially when the representatives of the general public participate in the audience. It is obvious that public relations in this particular case represent extremely sensitive questions because of the different ways risks can be perceived. It should be noted that, for example, the perception of the industrial risks is considerably different from the risk perception in the case of natural disasters.

In general, it is possible to present each type of risk in different ways, but also there is no clear rule which one is more useful. There are several ways to make risk presentations, such as:

- Absolute risk presentation;
- Relative risk presentation;
- F-N graph;
- Risk profile;
- Risk isolines;
- Risk matrix.

Some of these are also illustrated in Figs 8.1, 8.2, 8.3.

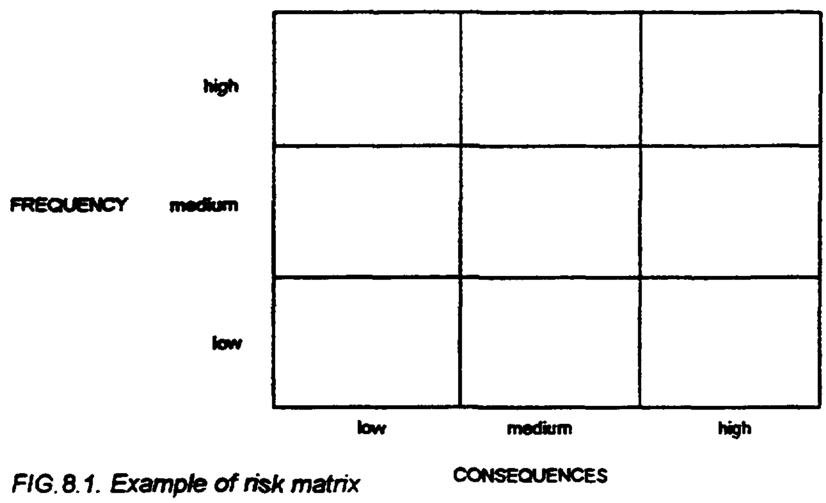


FIG. 8.1. Example of risk matrix

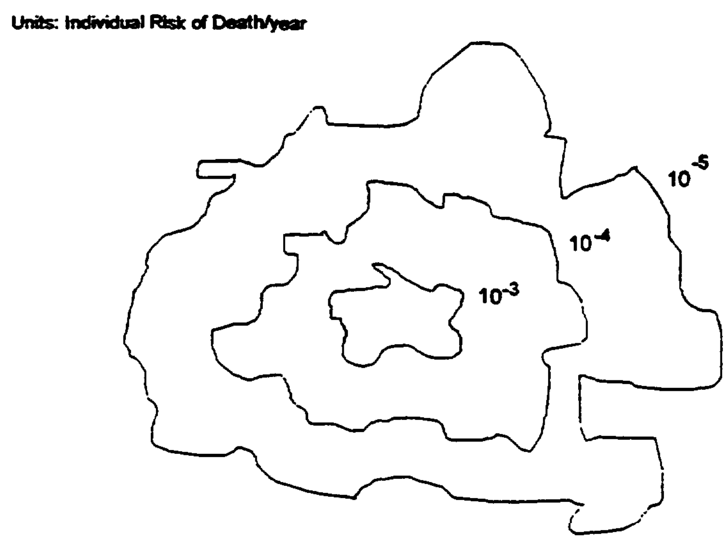


FIG. 8.2. Example of risk isolines

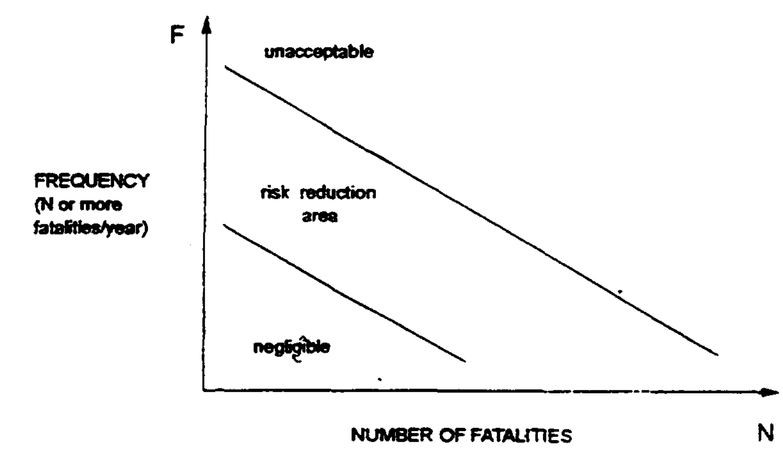


FIG. 8.3. Example of FN graph

8.2. AREA RISK MANAGEMENT

8.2.1. Introduction

As indicated in Chapter 2, the objective of an integrated risk assessment is to identify and analyse all risks of industrial activities to humans and the environment in the project area and to assess the risks in such a way that rational choices can be made about what risks should be reduced in existing situations, weighing the social and economic costs of such risks and the costs of risk reduction. Also, for newly planned industrial developments rational decisions should be made with respect to which risks can be tolerated and what the consequences are for land use and permitted development of the industry in the area. In this section guidance will be given on management of the risks in an area. If necessary a distinction will be made between existing industrialized areas and new industrial developments in an area.

The following steps are distinguished in the area risk management:

- definition of decision criteria for the identified risks in the risk analysis;
- decision analysis on the defined alternative options;
- presentation of the results of the decision analysis for the decision makers and the public.

The above mentioned steps are iterative. One will start defining the decision criteria for the acceptable or tolerable risks. Next it will be assessed if in the present situation (or for the proposed development) the criteria are met. If not, different packages of risk reducing measures will be defined and assessments made on which packages meet the criteria, including the costs of these packages. The result will be that some packages meet the criteria at acceptable costs, other packages at high costs and some do not meet the criteria. It is possible that not one package meets the defined criteria at acceptable costs. Then it will be necessary to set less rigid criteria and the decision analysis can be repeated as indicated in Figure 8.4.

8.2.2. Decision criteria

As with most decision processes, risk management works better if clear criteria are established to guide the decision-making process. Decision criteria can be expressed as 'tolerable' individual or societal risks or as emissions or concentrations where these have been based on health risk considerations. Appendix V provides background and advice on how to establish decision criteria.

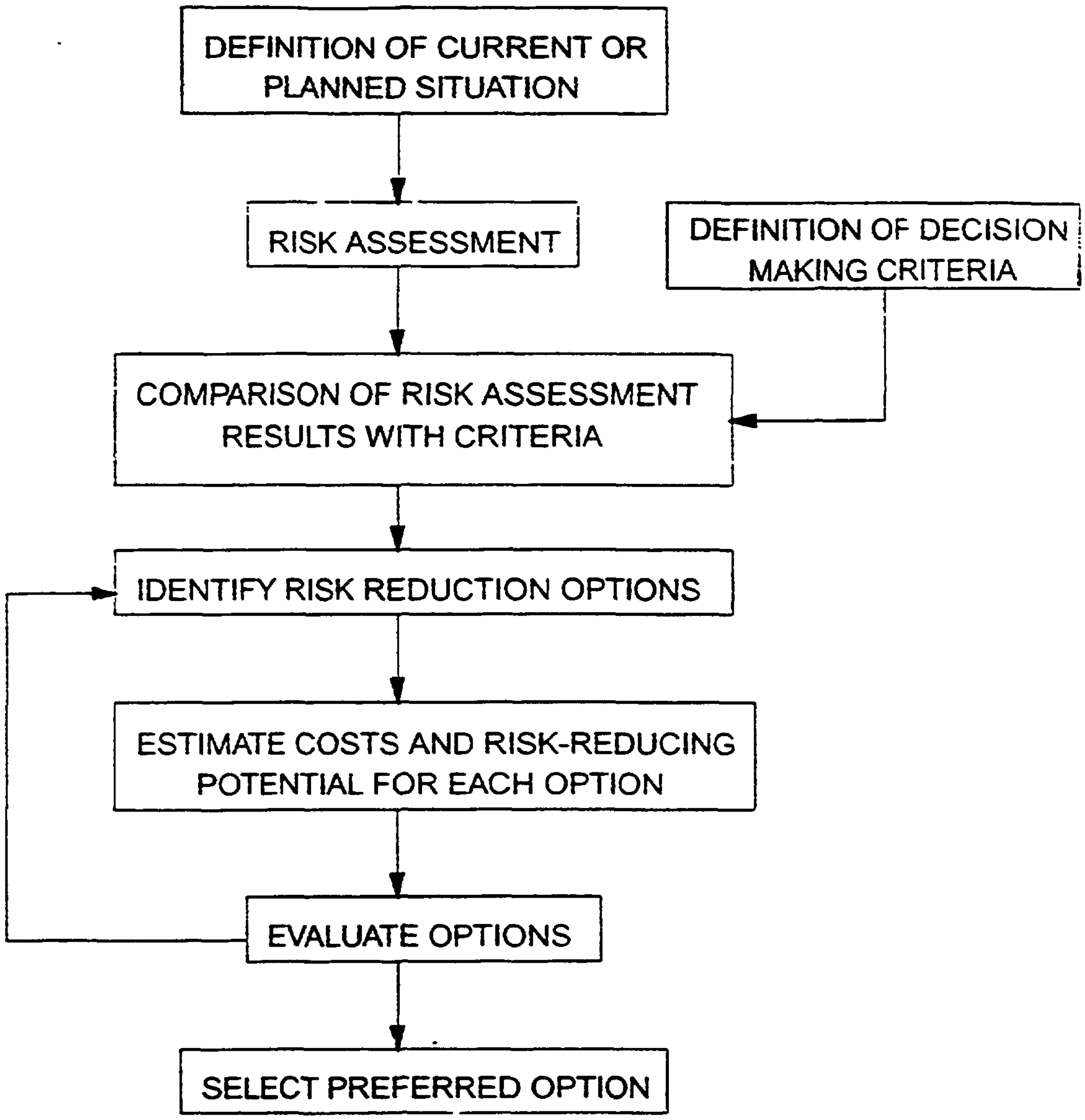


FIG. 8.4. Risk management process

8.2.3. Decision analysis

The risks in an existing area or for a proposed new development of an area can or cannot meet the defined criteria. If not, alternative options will be defined. These alternative options can be:

- For existing industrialized areas different packages of risk reducing measures at the source, restrictions in land use (e.g. not allowing the construction of new houses and other buildings in the area) or mitigating measures (e.g. a well prepared emergency response system).

- For newly planned industrialization in an area, land use planning will be an important tool to reduce the risks for the population. Alternative options can include different packages of required safety measures for the industries, different types of industrialization (production and application of hazardous materials or not) with different associated risks and different degrees of allowed housing in the neighbourhood.

The present situation or proposed development and alternative options will have economic consequences for the industries, authorities and the public. Because of the limited available resources, the associated costs of the options for the authorities and companies should also be assessed. If other aspects than costs are important for the realization of an option they should be included in the decision analysis. Such aspects are for example:

- time schedule required to realize the option;
- availability of the technology to realize the option;
- availability of other areas for housing.

For such a decision analysis several methodologies do exist, such as cost benefit analysis and multi criteria analysis, amongst others. The following steps can be distinguished in these methodologies:

- assess a score for how the risks of the present situation or proposed development and alternative options fit into the framework of the defined risk criteria;
- assess a score for the other aspects like costs, time and other constraints;
- present the scores in a comprehensive way, e.g. in a scoring matrix;
- assess a total score for each option.

An example of such a scoring matrix is presented below (Table 8.1).

TABLE 8.1. SCORING MATRIX

Measure	Present situation	Option 1	Option 2	Option 3
SO_2 (actual concentration divided by the SO_2 criterion)	2.4	1.5	1.0	0.8
Carcinogenic risk (actual risk divided by the criterion)	0.5	0.5	0.5	0.4
Area, km^2, where the individual risk is above 10^{-6}	10	15	5	7
Costs in \$ 10^6	10	50	80	100
Time for realization in years		2	5	10
Availability of other housing areas	yes	no	yes	no

The dimensions of the individual scores to the criteria are not the same. Therefore an assessment of total score based on the scoring matrix is impossible. A total score is only possible if the scores are made dimensionless. This can be done as in the following example: Divide area for 10^{-6} individual risk by minimum area, divide costs by present costs. If additional housing is required in the example, the present situation could only be compared with option 2.

It is not necessary to assess a total score to select the preferred option. Other site specific decision schemes can be developed, for example by defining different classes that indicate at what level a criterion is met on a site in the area. An example of such classes applied in area risk assessments is given below (Table 8.2).

TABLE 8.2. CLASSES IN AREA RISK ASSESSMENTS

Category	Class				
	E	D	C	B	A
Industrial noise in dB(A)	> 65	65-60	60-55	55-50	<50
Individual risk	$> 10^{-5}$	10^{-5}-10^{-6}	10^{-6}-10^{-7}	10^{-7}-10^{-8}	$< 10^{-8}$
Stench in odour units/m^3	> 10	10 - 3	3 - 1	< 1	< 1
Carcinogenic chemicals $\mu g/m^3$	$> 10^{-5}$	10^{-5}-10^{-6}	10^{-6}-10^{-7}	10^{-7}-10^{-8}	$< 10^{-8}$
Toxic compounds percentage of NOAEL	>100	100-10	10-3	3-1	< 1

Note: This table shows one possible approach to the multidimensional integrated risk problem. Other successful approaches exist too.

The classes have to be combined to integral environmental risk classes. An example of such a combination for existing situations is presented below:

TABLE 8.3. ENVIRONMENTAL RISK CLASSES

Integral class	Combination of Classes
I	Only B, classes C,D,E not allowed
II	2 x C, no classes D or E
III	At maximum 3 x C, no D or E
IV	At maximum 1 x D, and at minimum 1 x C or at maximum 4 x C and no D and no E
V	At maximum 2 x D, and no E or 1 x D and 4 x C and no E
VI	3 x D or more, or 1 x E or more

8.2.4. Decision making

The final step is taking the decision for the most preferred option. When the matrix is presented to the decision maker, he can indicate which criteria are important in the final decision. Such criteria could get a greater weight factor or even could exclude certain options. In the example where additional housing was required, this criterion excludes options 1 and 3. All the environmental risks are reduced in option 2, the price for this reduction is high and it will take 5 years. If this is acceptable option 2 has preference; if not, other options should be defined and the risk assessment repeated.

For the site specific approach, restrictions with respect to housing could be defined for the integral environmental classes as in the next table:

TABLE 8.4. SITE SPECIFIC RESTRICTIONS

Class I	No restrictions
Class II	Housing allowed if alternative locations are not available
Class III	As in class II but more restrictive
Class IV	Only replacement of old houses, no increase of number of inhabitants
Class V	As class IV, more restrictive
Class VI	Removal of existing houses

8.3. AREA ACTION PLANS

8.3.1. Introduction

It is the responsibility of the Steering Committee, working with the Implementation Committee, to prepare and approve action plans consistent with the recommendations that have been accepted. The selected preferred options for the future will require risk reduction measures to bring outlier risks to an acceptable level. The possible risk reduction measures available are many and therefore it is essential that structured action plans are prepared which provide clarification for all concerned about:

- the actions required;
- the responsibility for carrying out the actions;
- the costs involved;
- the time-scale to be met.

Risk reduction measures to be considered can fall into a number of categories:

- Preventive measures

– To prevent risks at the source by using alternative technologies/processes;
– Land use planning to avoid people being exposed to high risk levels;
– Transport routing to avoid transport of hazardous materials in populated areas.

- Risk reduction measures

– Source-oriented measures like additional instrumentation in a plant to reduce probability and possible consequences of an accident. Also very important is to improve the safety management in the plant;
– With respect to the environment the risks can be reduced by a proper land use planning.

- Emergency preparedness

– A well-trained emergency service can significantly reduce the number of fatalities from an accident.

These different categories of measures are discussed in more detail in the following.

8.3.2. Preventive measures

8.3.2.1. Generalities

Hazards and risks from activities involving pollutant emissions and hazardous materials cannot be entirely eliminated. There will always be a residual risk which in many cases will extend beyond site boundaries. The consequences of such events depend mainly on the distance between the source of emissions and the sensitive objects (population, environmental sites, groundwater, etc.).

The location of hazardous and polluting activities is therefore an important preventive measure. Safety must become one aspect of land use planning and of all planning related to hazardous activities.

Of course safety is not the only criterion for decisions concerning the location of hazardous activities. 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 areas.

The following paragraphs describe how the safety-related aspects can be taken into consideration in the frame of the overall planning process.

8.3.2.2. Principles of land use planning

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.

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 becomes an essential and integral component of the hazards and risks management. In this process, land use safety conflicts are prevented by identifying, analyzing and quantifying hazards and risks and managing such risks 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 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 evaluated. An overall strategic approach ought to be adopted between industrialization, urbanization, cost of pollution and safety controls, land sterilization, etc.

The conclusion is made therefore that the location of hazardous and polluting industries, 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.

8.3.2.3. Safety distances

Establishing safety distances is often difficult. Especially in densely populated areas there are usually hard conflicts between the interests in using all the territory and the need to provide safety distances. Establishing safety distances therefore always requires a cost effectiveness analysis in order to decide whether source-oriented safety measures to reduce risks are preferable. This cost effectiveness analysis must include not only the market price of the territory involved but the whole social and economic context. Land use planning has always to take the specific conditions of the given case into consideration.

Having said this some general guidelines and criteria can be given for providing safety zones.

Whether safety distances are justified or needed depends on:

- the character of the potentiality affected sites;
- the distance in which hazards can happen as a consequence of an accident;
- the probability of a damage at a certain distance.

(a) Categorization of Development and Notification Requirements

In deciding on the separation required from a site 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 are 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. theaters/cinemas and shopping centres could be included in category A. In Table 8.5 and as a first approximation, the separation distances given should be considered as follows:

(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 United Kingdom 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 CD the local planning authority is requested to refer to the Health and Safety Executive for advise on 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 advice is not binding on the local planning authority. The advice is usually in terms of two situations of risk:

(i) *Negligible risk:* where the assessment has shown it to be extremely unlikely that people outside of the factory fence would be killed.

(ii) *Substantial risk:* where the risks are sufficiently severe that health and safety considerations should be a major issue in any planning decisions. 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.

(b) Hazard Analysis

A hazard analysis must be made for each individual activity in order to determine the distance where hazards can happen. Table 8.5. gives suggested approximate separation distances for a range of major hazards. These distances should be regarded as tentative and would need to be considered under local circumstances.

(c) The Probability of Damage at a Certain Distance

Usually it is not justified to require safety separation distance if the probability of a fatality is less than 10^{-5}. On the other hand, safety separation distances should be established if the probability is higher than 10^{-3}.

These numbers are related to the acceptability criteria for individual risks, taking into consideration the effect of mitigation procedures in the case of an accident.

If the probability is between 10^{-3} and 10^{-5} it depends on the general economic and social situation whether safety distances should be established.

8.3.2.4. Land use 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 which 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 with the aim to rectify land use safety conflicts. The following procedural/strategic steps are relevant:

(i) An environmental study should be undertaken for the whole area in consideration including studies on air pollution, water pollution and solid wastes. The study should identify, on a cumulative basis, the health and environmental effects and delineate areas and people most at risk.

TABLE 8.5. SUGGESTED APPROXIMATE SEPARATION DISTANCES FOR SOME MAJOR HAZARD WORKS

Substance	Largest tank size (t)	Separation distance (m)
Liquefied petroleum gas, such as propane and butane, held at a pressure greater than 1.4 bar absolute	25-40 41-80 81-120 More than 300 25 or more, only in cylinders or small bulk tanks of up to 5 te capacity	300 400 500 600 1000 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	1000
Phosgene	2 or more	1000
Chlorine	10-100 More than 100	1000 1500
Hydrogen fluoride solution	10 or more	1000
Sulphur trioxide	15 or more	1000
Acrylonitrile	20 or more	250
Hydrogen cyanide	20 or more	1000
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	1000
Bromine	40 or more	600
Ammonia (anhydrous or as solution containing more than 50% by weight of ammonia)	More than 100	1000
Hydrogen	2 or more	500
Ethylene oxide	5-25 More than 25	500 1000
Propylene oxide (atmospheric pressure storage) (stored under pressure)	5 or more 5-25 More than 25	250 500 1000
Methyl isocyanate	1	1000
Classes of substances not specifically named		

TABLE 8.5. (cont.)

	Substance	Largest tank size (t)	Separation distance (m)
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 41-80 81-120 121-300 More than 300 25 or more only in cylinder or small bulk tanks or up to 5 te capacity	300 400 500 600 1000 1000
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 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	1000
4.	A liquid or any mixture of liquids not included in items 1-3 above which has a flashpoint of less than 21°C	10000 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:

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

(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, 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 three essential components:

- Reduce risk at the source with emphasis on technical controls for the major risk contributors wherever economically and technically feasible. A comprehensive risk reduction programme should be formulated and implemented at each facility. As a minimum, no developments, industrial or otherwise, should be allowed which may increase the overall 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 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 plan 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 includes 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 in terms of either continuation and controlled expansion of industrial activities or urban developments and intensification.

The implementation of the long term strategic plan should be based on the following elements:

- Industrial Oriented Strategy

  - Any intensification of an existing industry or introduction of a new industry in the area should be allowed only if it can be demonstrated at an early stage of development that no cumulative increase in existing risk levels will result from this new 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 development should be permitted every opportunity should be taken to encourage re-development or re-location of residents in the area mostly affected by risk.

- 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 in circumstances where the necessary distances between the installation and the population cannot be achieved.

  - 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.

It is important to recognize that at many of the above stages the public should be encouraged to participate.

8.3.2.5. Land use 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 may be the most cost effective risk management strategy for all concerned. The approaches outlined hereafter serve 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 whole area should be prepared. The plan should specify policies, guidelines and criteria for various land uses.

(a) 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 give or not give permission to 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 assists 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 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.

(b) Zoning Controls

Different countries pursue the implementation of safety separation distances using the zoning regime or other arrangements appropriate to their legislation. Usually different zones are established for industrial, commercial and residential purposes. New buildings are only allowed if they are in accordance to the respective zone. In this way safety distances between industrial zones and e.g. residential zones can be established.

For establishing the zones it is desirable to undertake additional environmental impact studies.

Before designing new residential zones, the risk exposition of the zone should be considered and residential buildings should not be allowed if the risk is too high unless it is reduced by appropriate safety measures.

In the same way new industrial zones should not be established if the industries which are supposed to be built could be too high a risk for existing or planned residential zones or other sensitive objects in the neighbourhood of this zone.

8.3.2.6. Transportation planning

In many cases risks from transportation of hazardous materials are more important than risks from fixed installations. Transportation planning is therefore an important measure for risk reduction. There are, however, some constraints to be taken into account:

- Theoretically it would be possible to establish safety distances between transportation routes and sensitive objects. However, the main purpose of transportation routes is to connect various populated areas. It can therefore not be completely avoided that transportation routes are crossing through populated areas.
- Usually the main transportation routes already exist and can hardly be removed.
- The international transport regulations indicate that transports of hazardous materials must be allowed if they comply with the safety measures defined in these regulations. It is therefore not possible to forbid such transportations or to demand more source-oriented safety measures.

There are, however, some safety measures which can be taken into consideration:

- Although it is not possible to keep residential zones completely away from transportation routes, this can at least be achieved for terminals and other places where big quantities of hazardous materials are loaded or unloaded. This is often a very important contribution to safety, because a great deal of transportation accidents happen in connection with loading activities.
- Many transportation accidents do not happen because the safety regulations would not be strict enough but because they are not respected by the drivers. Therefore a better control of the drivers by the police is often a very effective mean to reduce the risk.
- Although it is not possible to fully forbid the transport of hazardous material, it can be forbidden on some routes which go through densely populated areas.
- Transportation can also be restricted in time, e.g.:
  - No transportation through cities during rush hour;
  - No transportation by rail through railway stations when there are many people at the station.
- Pipelines should be considered in the same way as fixed installations. Appropriate measures can be taken to limit the risk, e.g. by establishing safety distances between pipelines and populated areas.
- A long term transportation planning should be established with the following elements:
  - estimation of the future amounts of hazardous materials transported through the area;
  - estimation of the possibilities to reduce the amount of transported goods;
  - overview over the existing transportation capacities (rail, road, pipelines, water), including loading terminals;
  - overview over the specially endangered areas and the existing neuralgic points;
  - estimation of the future need for transport capacity;
  - evaluation of the best possible mean to improve the transport capacity based on a risk estimation and a cost-effectiveness-analysis;
- According to such planning measures can be taken in order to:
  - reduce the amount of transported goods;
  - deviate the transportation from more dangerous to less dangerous transportation means;
  - build new transportation capacities with the means which are the least dangerous.

8.3.3. Risk reducing measures

With proper risk management and additional risk reduction measures, the risks of industries or transport of hazardous materials can be reduced.

8.3.3.1. Safety management

It is widely recognized within the process industry that safety management systems have a major influence on failure rates. It has been frequently demonstrated that dramatic improvements in Lost Time Injury rates are possible by large corporations which have adopted rigorous and auditable safety management procedures. Given the very large impact of Safety Management Systems (SMS), there is increasing belief by regulatory bodies in the need to quantify such systems and to consider these in an analogous manner to hardware implications in QRA studies.

A problem with the generic failure rate data used in QRA studies is that it implies the same average value for all sites, regardless of the quality of safety management systems employed. QRA studies need at least to be supported therefore with a reasonable qualitative overview of safety management systems, and preferably some quantitative estimate as well (recognizing that this will be a crude estimate only).

Key source documents in this area include Refs [57, 58, 59].

One of the earliest quantitative systems developed for Modification of Risk (MOR) is the MANAGER technique. This was originally developed by Bellamy with HSE and VROM support and its operational version is described in Ref. [60]. The system uses human performance shaping factors as an underlying basis linked to real accidents.

Other quantitative systems for scoring management systems include STATAS (HSE), ACRONYM (TNO, DuPont, and other), and ISRS (DNV). STATAS has substantial human factors theory underlying (socio-technical pyramid), while ISRS has the largest user base.

Topics to be covered in the safety management system audit vary between audit systems, but the following list is indicative:

- Safety leadership and administration;
- Safety policy and safety culture;
- Incident and accident reporting;
- Formal safety studies and documentation;
- Written procedures;
- Inspection and maintenance;
- Management of change;
- Emergency resources and procedures;
- Human factors influences (control room design, ergonomics, manning levels, etc.);
- Organizational factors (management structures, ability to deal with change, etc.);
- Training.

Typically the results of an audit would be scored relative to a 'generic' typical facility for which generic frequency data would apply directly. For the audited site a so-called Management Factor (MF) would be derived and applied to all frequency data for that site. This method is covered briefly in Ref. [1].

8.3.3.2. Source-oriented risk-reducing measures

A number of technical measures can reduce the probability or effect of a major hazard. Some examples are:

- reduction of the quality of the hazardous material in the process;
- isolation valves to reduce the inventory of a system;
- leak detection systems;
- explosion protection;
- fire protection.

A process review and review of the design of the process should be performed to identify the possibilities of additional risk reduction measures. In Annex III risk reduction measures for fires are described.

8.3.4. Emergency preparedness

In line with a defence-in-depth approach to risk management, it is appropriate for a community to be prepared for industrial accidents (or natural hazards) even though risks have been lowered to tolerable levels by other risk-reducing measures. Emergency preparedness is the name given to this aspect of community protection. Emergency preparedness requires industries and local authorities to work together to develop and exercise response plans so as to minimize the impacts of an industrial or transportation-related accident should it occur. Annex II outlines in detail an approach to this subject concentrating on UNEP's Awareness and Preparedness for Emergencies at Local Level (APELL) approach.

9. REVIEW AND DEVELOPMENT OF LEGISLATION

9.1 LEGISLATION ABOUT MAJOR HAZARDS

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.

9.1.1. Policy

Legislation about safety at work and accident prevention exists in all countries. This legislation aims to protect primarily the workers in industry, but at the same time also to contribute to the safety of the population and the environment. Usually this legislation does not regulate in terms of risk, but may contain technical specifications which sometimes require risk assessments to satisfy the authorities that the necessary margin of safety does exist.

In the last twenty years, however, this legislation has resulted in not being completely satisfactory. Therefore, a new type of legislation is being developed which is based on the probabilistic notion of risk and aims to reduce the risk of industrial activities. The main steps in order to achieve these goals are:

- the owners of installations with hazardous materials are obliged to notify the authority about the amount of the substances and the safety measures;
- the competent authority can require a quantitative and/or qualitative risk analysis;
- if the risk is considered too high, the authority can order supplementary safety measures or close down the facility;
- the owners of installations have to establish an internal emergency plan;
- the governmental bodies are responsible for preparing external emergency plans;
- the public must be informed about the risk;
- in case of an accident the authorities and the potential victims must be notified;
- in many countries principles for siting hazardous activities have been established;
- a strict liability is often proposed or introduced as a means to internalize the external costs of risk.

9.1.2. Review of legislation

The above mentioned principles have mainly been established by the European Union in a Council Directive on the major-accident hazards of certain industrial activities (see Annex I), which was partly based on the UK Health and Safety at Work etc. Act [61]. The purpose of the Directive was to ensure the introduction of legislation in this area in all Member States in accordance with the objectives given in the Directive and the establishment of related procedures by competent authorities to implement its provisions.

The Directive has been implemented by all Member States of the European Union by specific national legislation.

9.1.3. 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 [61] (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.

9.1.3.1. 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 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, Ref. [62].

The Health and Safety Executive has the powers now, under HASAWA [61], 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 Health and Safety Executive to bring older existing plants up to new plant standards.

The second report in 1979, Ref. [63] 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), Ref. [64]. The EU Directive was enacted in Britain as the "Control of Industrial Major Accident Hazards Regulations (CIMAH), see Ref. [65].

9.1.3.2. Experience with CIMAH regulations

The siting and control of hazardous industry in the UK is primarily 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.

9.1.3.3. 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, Ref. [66].

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 a 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 co-operation 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 Health and Safety Executive 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 an individual fatality risk of 1 in 10^{-6} 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.

9.1.4. Netherlands

The Working Environment Act has since 1977 contained the requirement for a Safety Report (Arbeidsveiligheidsrapport) for specific 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 applies. 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;
- the handling of these factors in a decision-making process.

The Dutch government has also designed a computerized 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 of 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 a plant, routing of hazardous pipelines and improving the safety of the community.

This model is being used in conjunction with both individual and societal risk criteria, which are quantitatively specified.

Where risk levels are considered unacceptable, risk reduction is achieved by in situ 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 a 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.

9.1.5. Belgium

Legislation on hazardous 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.

9.1.6. Republic of Ireland

The Public Health Act of 1978, 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.

9.1.7. 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.

9.1.8. Luxembourg

The legislative mechanism is based on a 1979 law and on regulations listing and classifying all industrial establishments which could present hazards or nuisance affecting the safety, health and comfort of the workers or 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 EU Council Directive on Major Accident Hazards.

9.1.9. Germany

The Law "Störfall-Verordnung" (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 (two appendices list the industrial activities and the 142 substances concerned). This law came into power in September 1980 imposing on industry the obligation, amongst 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 ensuing emergency;
- information on the consequences of an accident.

After the German unification the Industrial Initiative for Environmental Protection was founded. 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.

9.1.10. 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 a 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.

9.1.11. Switzerland

The "Störfall-Verordnung" from 1991, based on the environmental protection act from 1983, is in principle similar to the EU Council Directive. There are however, some important particularities:

- it is also applicable for installations with micro-organisms and for installations with hazardous waste as well as for transportation routes (railway, roads, Rhine) through which hazardous materials are transported;
- concerning installations with chemical substances the limits for application of the Störfall-Verordnung are lower than the ones of the Council Directive;

- all owners of installations subject to the Störfall-Verordnung have to make a short report which indicates the worst case scenario. This allows the authority to make a prioritization and to require a risk analysis from the installations which could cause severe damages.

9.1.12. United States of America

Although there have been several chemical industry incidents in the United 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, 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 the aftermath of the Bhopal accident in India in 1984 regulatory efforts dealing with prevention of major chemical plant accidents started to increase. The Environmental Protection Agency (EPA) initiated a programme in 1985 to encourage community planning and preparedness concerning major releases of hazardous materials. The Clean Air Act Amendments signed in 1990, which contain provisions for accidental release prevention, mandate the EPA to create regulations for facilities possessing listed chemicals above a threshold quantity. The extensive risk management plans required must contain three specific components:

- a hazards assessment of a worst case accident;
- an accident prevention programme;
- an accident response programme.

At the same time that EPA began to intensify their major accident prevention effort the Department of Labour's Occupational Safety and Health Administration (OSHA) began performing detailed inspections of chemical plants. It became obvious that OSHA needed new regulatory standards to establish consistent regulations on accidental release prevention. This led to the release of the report on Process Safety Management of Highly Hazardous Chemicals [67]. Concerned facilities must develop and implement a process safety management (PSM) system which must be maintained over the lifetime of the facility and is mainly concerned with protection of workers.

In general, significant advances have been made in the development and application of accident prevention strategies by several industry groups. The American Institute of Chemical Engineers, for example, created its Center for Chemical Process Safety which published a large number of technical guidelines. Furthermore, Recommended Practices on Process Hazard Management were issued by the American Petroleum Institute, see Reference [58].

9.1.13. International Organizations

The most active international organizations in the field of controlling major hazards have been the United Nations Economic Commission for Europe (UNECE), the International Labour Organization (ILO) and the Organization for Economic Co-operation and Development (OECD) as described in [68].

The 1992 UNECE convention covering Transboundary Major Accidents is based on the same principles as the EU Council Directive (see Annex I). It stresses the need for international consultation and information exchange about dangerous activities and accidents as well as the principle of equal access and treatment in administrative and judicial matters.

A Code of Practice on Major Accidents was published by the ILO in 1991. After consultations and negotiations with Member States and the European Community a convention, covering pipelines and the extractive industries, was adopted in June 1993.

The OECD has recently completed a programme dealing with various aspects related to major accidents. These areas include:

- the role of human factors in plant operations;
- food management practice;
- information to the public;
- the role of workers in accident prevention and response;
- the role of public authorities in preventing major accidents;
- the role of public authorities in land use planning.

The use of economic instruments in environmental policy was recommended by the OECD in 1991. Following this principle a draft convention on the regime of strict liability for hazardous activities in Europe was formulated by the European Council.

9.2. *LEGISLATION ABOUT ENVIRONMENTAL IMPACTS*

9.2.1. Policy

The emergence of environmental policy in the industrialized countries over the 20 years from 1972 to 1992 has been described in Reference [69] and is characterized by the following main features:

(1) A recognition of the need for policies to take more account of environmental impacts and constraints. Environmental impact has been a feature of development control in most developed countries.

(2) An increased recognition of the need for cross-sectoral policies. Links between environment, energy, transport and technology policies have been strengthened.

(3) Replacement of formerly largely reactive approaches to pollution control by anticipatory and preventive ones. During the last two decades there has been an increasing focus on pollution abatement at source. The *precautionary principle,* which broadly demands that, if an activity or substance clearly carries a significant risk of environmental damage, it should either not proceed or be used, or should be adopted only at the minimum essential level and with maximum practical safeguards, is now widely recognized. Also widely recognized is the *polluter pays principle* which essentially states that the costs of pollution should not be externalized. An industry or municipality should itself bear the costs, without subsidy, of the actions needed to meet environmental standards and avoid environmental damage. Screening of potentially hazardous substances before their introduction to the general market has become more stringent, partly as a reaction to the unforeseen impacts of persistent organochlorine pesticides and chlorofluorocarbons. The concept of "critical loads" (defined as the maximum amount of pollutant an ecosystem can stand without stress) has increasingly come to guide policy. Such critical loads have been defined for water, air and soil pollution and relate to a large number of harmful substances.

(4) Increasing interest in economic instruments as an incentive to energy and materials efficiency and pollution control.

(5) Increasing promotion of energy efficiency, energy conservation and environmentally sound processes in industry, transport and domestic environments.

(6) Recognition of the international and often regional nature of many environmental problems with an increasing broadening of the response.

(7) Increased attention to public information and participation. It has become evident that the most effective way of ensuring the success of environmental policies is to involve all sectors of the community in the discussion of their objective and to inform the public about the state of the environment and the actions being taken to protect it.

(8) Better environmental science and monitoring. These are the foundation of sound policy and public understanding. Through them the loop between policy implementation and effect can be closed.

(9) Increased concern about global climate change due to anthropogenic CO_2 emissions. The climate convention adopted in Rio has the main objective to stop and reduce the quantities of CO_2 emitted worldwide.

9.2.2. Review and development of legislation

There has been a major evolution of environmental law in the industrialized countries since 1970. In recent years the character of the legislation has changed to bring about a more integrated and cross-sectoral series of policies and increasingly to apply, within the territory of individual countries, international obligations.

Much national environmental legislation has been concerned with regulating activities that have the potential to cause environmental hazard. Such regulations concern, for example, the containment of toxic substances in storage, in use and in transportation: the authorization of discharges to the environment and the setting of standards for emissions.

The emergence of an increasing body of legislation and regulation has been paralleled by changes in the way in which legal instruments are interpreted and enforced in a number of countries. The public has acquired an increasing right to challenge the way in which departments of government and official agencies carry out their functions and this move, to make public authorities accountable to the public at large through the courts for the achievement of national policy goals in the environmental field, is a development that has clear implications for the future.

Institutional responsibility for the environment in industrialized countries is commonly divided between the national and the state/district/municipal/local authority levels. Moreover there are commonly decisions at both these levels between departments with overall responsibility for setting technical standards, granting operational consents, levying charges, monitoring performance and prosecuting infringements.

The governmental sector has no monopoly of institutions concerned with the national environment. During the last 20 years there has been an increasing emergence of self-regulation institutions within industry, linked to the development of new and environmentally compatible technologies in which sectors of industry have commonly co-operated. A third institutional development has been the massive growth in non-governmental organizations, usually in the form of groups whose business it is to demand higher standards of environmental performance, protect particular regions or interests or draw attention to inadequacies of performance.

At a national level, the early 1970s were characterized in many developed countries by a sudden initiative to incorporate what were then perceived as new environmental concerns within the mandates of existing sectoral ministries. This was done in Sweden (Ministry of Agriculture), The Netherlands (Ministry of Health) and Germany and Finland (Ministry of the Interior), see Ref. [70]. In some countries, including the United Kingdom and France, new ministries were formed by bringing together pre-existing sectoral departments. In other countries, including the United States, Japan, Norway, Canada, France, Australia and New Zealand, more specialized environment ministries were created. Toward the end of the 1980s there was increasing concern within governments over the inadequacy of having sectoral Departments of Environment established alongside others, when it was apparent that the environment was actually the natural capital of nations, the foundation of the quality of life and prosperity and influenced by all the various sectoral activities, Ref. [71]. Many governments have therefore established new machinery to better co-ordinate the activity of the sectoral departments. A survey of 101 countries by UNEP shows that by 1991/2 nearly all industrialized countries surveyed had established a ministry or department concerned solely or principally with environmental protection and natural resource management, see Ref. [69].

In many industrialized countries (notably the United States, Australia, Switzerland, Germany, Canada and to a lesser extent the United Kingdom, France, Austria and the Nordic countries), provinces, cantons and states within the unitary state have substantial responsibility for setting goals for environmental protection and for enforcing standards and regulations. In a number of countries there has been a debate about the proper balance between the central or federal government and the state or provincial administrations. The conclusion seems to be that the broad strategy has to be national, but worked out through a dialogue involving the components of the state and that while standards and policies must be applied everywhere, the enforcement mechanism is often most effectively decentralized. Making this machinery work means establishing effective consultation within the countries, often down to local community and village level and the need to empower local communities to take more direct care of their own environments is being increasingly stressed e.g. in Ref. [72].

In the industrial field, Chambers of Commerce, national business councils and specialized industrial organizations are playing an increasing part in environmental policy. Some such organizations are concerned with promoting products perceived to be superior in energy use or environmental impact, while others seek to represent industrial sectors in dialogue with government. In Canada, for example, the Canadian Manufacturer's Association has produced a policy paper which describes sustainable development as both, a challenge and an opportunity for industry, while the Canadian Chamber of Commerce has established a task force for the environment and machinery designed to stimulate and guide national industry. The need for technological transformation is appreciated in many countries and within sectors of industry and will therefore be a growing area in the future, as described in Ref.[73].

A dramatic feature of the last 20 years has been the growth in non-governmental organizations concerned with environmental affairs. For example, the aggregate membership of the major environmental organizations in the US increased from under three million in 1971 to over nine million in 1990. The figures for the UK are even more startling - a combined membership of under half a million in 1971 grew to over 3.6 million in 1990. Another recent trend has been the recognition by governments of the need to involve all these institutions - governmental and non-governmental alike - in the discussion of the national policy. In Canada, round tables that involve government, industry and the non-governmental environmental movement have been established at both, national and provincial levels. A similar mechanism has been established in Australia for a national study of ecologically sustainable development. In general there is an increasing preparedness for discussions between the governmental sector, as the regulator of action and the establisher of overall policy for the environment, the industry, as the source of the invention and technological advance that will be needed in order to maintain quality of life while minimizing environmental impact and the waste of resources, and the environmental non-governmental movement, with its extensive scientific knowledge and commitment and ability to mobilize public opinion.

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Appendix I

GUIDELINE ON CONTENT OF REGIONAL RISK MANAGEMENT PROJECT PLAN

This Appendix provides general guidance concerning the range of information to be addressed when formulating a Project Plan for a regional risk management project. The details of such information would vary for different situations and conditions. Some sections may not be able to be completed in detail at the early stages of a proposal.

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- 2.1.3. Climate
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- 2.1.5. The Labour Force
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- 2.1.7. Industry
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2.2. REGULATORY CONTEXT

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3.1. OBJECTIVES AND EXPECTED OUTPUT

3.2. INDUSTRIES AND TRANSPORTATION ROUTES

- 3.1.1. Transport Systems
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3.6.1. Acceptable Risk Criteria
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- Agencies
- Universities
- Research Organizations
- Consulting Engineering

4.2. IMPLEMENTATION COMMITTEE AND WORKING GROUPS

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7. DEFINITION OF WORK PACKAGES

- As prepared by Working Groups and approved by Implementation Committee

8. PROJECT SCHEDULE

REFERENCES

Appendix II

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 in Ref. [II.1]. 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 aiming at these guideline values, taking into account also other factors such as specific environmental, social, economical 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 information that are at their basis.

II.1. GUIDELINES FOR AIR QUALITY

Tables II.1 - II.6 show air quality guideline values or carcinogenic risk estimates for organic and inorganic substances recommended by WHO for Europe. The emphasis in the guidelines is based on exposure. The starting point for the derivation of guideline values based on effects other than cancer (Tables II.1 and II.2) 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 in Ref. [II.2]. 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 (Tables II.3 and II.4). 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".

Table II.5 in 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);

TABLE II.1. WHO AIR QUALITY GUIDELINES VALUES FOR INDIVIDUAL SUBSTANCES BASED ON EFFECTS OTHER THAN CANCER OR ODOR/ANNOYANCE [II.1]

Substance	Time-weighted average	Averaging Time
Cadmium	1-5 ng/m³ 10-20 ng/m³	1 a (rural areas) 1 a (urban areas)
Carbon disulfide	100 μg/m³	24 h
Carbon monoxide	100 mg/m³ [a] 60 mg/m³ [a] 30 mg/m³ [a] 10 mg/m³	15 min 30 min 1 h 8 h
1,2, -Dichloroethane	*0.7 mg/m³*	*24 h*
Dichloromethane	3 mg/m³	24 h
Formaldehyde	100 μg/m³	30 min
Hydrogen sulfide	150 μg/m³	24 h
Lead	0.5-1.0 μg/m³	1 a
Manganese	1 μg/m³	1 a
Mercury	1 μg/m³ [b]	1 a
Nitrogen dioxide	400 μg/m³ 150 μg/m³	1 h 24 h
Ozone	150-200 μg/m³ 100-120 μg/m³	1 h 8 h
Styrene	800 μg/m³	24 h
Sulfure dioxide	500 μg/m³ 350 μg/m³	10 min 1 h
Tetrachloroethylene	5 mg/m³	24 h
Toluene	8 mg/m³	24 h
Trichloroethylene	1 mg/m³	24 h
Vanadium	1 μg/m³	24 h

[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.

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 II.6 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 synergetic effects are at present insufficient for establishing guidelines.

TABLE II.2. GUIDELINES VALUES FOR COMBINED EXPOSURE TO SULFUR DIOXIDE AND PARTICULATE MATTER[a] [II.1]

	Averaging time	Sulfur dioxide ($\mu g/m^3$)	Reflectance assessment black smoke[b] ($\mu g/m^3$)	Gravimetic assessment	
				Total suspended particulates (TSP)[c] ($\mu g/m^3$)	Thoracic particles (TP)[d] ($\mu g/m^3$)
Short term	24 h	125	125	120[e]	70[e]
Long term	1 a	50	50	-	-

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

[b] Nominal $\mu g/m^3$ units assessed by reflectance. Application of the black smoke value is recommended only in areas where coal smoke from domestic fires is the dominant component of the particulates. It does not necessarily apply where diesel smoke is an important contributor.

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

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

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

TABLE II.3. CARCINOGENIC RISK ESTIMATES BASED ON HUMAN STUDIES [II.1]

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.

II.2. GUIDELINES FOR WATER QUALITY

Table II.7 shows WHO guideline values for various substances or contaminants in drinking water. 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

TABLE II.4. RISK ESTIMATES FOR ASBESTOS [II.1]

Concentration	Range of lifetime risk estimates	
500F*/m^3 (0.0005F/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 II.5. RATIONALE AND GUIDELINE VALUES BASED ON SENSORY EFFECTS OR ANNOYANCE REACTIONS USING AN AVERAGING TIME OF 30 MINUTES [II.2]

Substance	Detection threshold	Recognition threshold	Guideline value
Carbon disulfide in viscose emissions			20 μg/m^3
Hydrogen sulfide	0.2-2.0 μg/m^3	0.6-6.0 μg/m^3	7 μg/m^3
Styrene	70 μg/m^3	210-280 μg/m^3	70 μg/m^3
Tetrachloroethylene	8 mg/m^3	24-32 mg/m^3	8 mg/m^3
Toluene	1 mg/m^3	10 mg/m^3	1 mg/m^3

TABLE II.6 GUIDELINE VALUES FOR INDIVIDUAL SUBSTANCES BASED ON EFFECTS ON TERRESTRIAL VEGETATION [II.1]

Substance	Guideline value	Averaging time	Remarks
Nitrogen dioxide	95μg/m^3 30 μg/m^3	4 h 1 a	In the presence of SO_2 and O_3 levels which are not higher than 30 μg/m^3 (arithmetic annual average) and 60 μg/m^3 (average during growing season), respectively
Total nitrogen deposition	3 g/m^2	1 a	Sensitive ecosystems are endangered above this level
Sulfur dioxide	30 μg/m^3 100 μg/m^3	1 a 24 h	Insufficient protection in the case of extreme climatic and topographic conditions
Ozone	200 μg/m^3 65 μg/m^3 60 μg/m^3	1 h 24 h averaged over growing season	
Peroxyacetylnitrate	300 μg/m^3 80 μg/m^3	1 h 8 h	

TABLE II.7. WHO DRINKING-WATER QUALITY GUIDELINES FOR INORGANIC AND ORGANIC CONTAMINANTS OF HEALTH SIGNIFICANCE [II.1]

Contaminant	Guideline Value
Aldrin/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-Dichloroethylene	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
Tetrachloroethylene	10 μg/l [a]
Trichloroethylene	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 the 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] The value may necessitate adaptation due to local or climatic conditions.

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 substances 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, see Ref. [II.3].

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.

II.3. HEALTH EFFECTS OF VARIOUS POLLUTANTS

It is useful to include short information on the health effects of exposure to various concentrations in air of some pollutants. Tables II.8 - II.12 regard health effects of sulphur dioxide and sulphate, sulphur dioxide and particulate matter, nitrogen oxides, carbon monoxide and ozone. Tables II.13 and II.14 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 II.8. HEALTH EFFECTS OF SULPHUR DIOXIDE AND SULPHATE [II.4]

Concentration			
SO_2 µg/m^3	Sulphates µg/m^3	Averaging Time	Health Effect
300-400	NA	24 h	Increased mortality
365	8-10	24 h	Aggravation of symptoms in elderly
180-250	6-10	24 h	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

TABLE II.9. SYNERGETIC EFFECTS OF SULPHUR DIOXIDE AND SUSPENDED PARTICULATE MATTER [II.4]

Concentration			
SO_2 µg/m³	SPM µg/m³	Averaging Time	Adverse Effect
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

TABLE II.10. HEALTH EFFECTS OF NITROGEN OXIDES [II.4]

Average NO_2 Concentration µg/m³	Health Effects	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 difference in various measures of pulmonary function	Central City vs. suburban policemen in Boston
96 vs. 43	No difference in various measures of pulmonary function	Seventh Day Adventists in Los Angeles, San Diego
20-70	Twofold excess in acute respiratory disease compared to unexposed group	Czechoslovakian children aged 7-12
10	Excess in acute respiratory disease ranging from 11 to 27%	USSR 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 USSR 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

TABLE II.11. HEALTH EFFECTS OF CARBON MONOXIDE [II.4]

CO concentration µg/m³	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

TABLE II.12. RELATIONSHIP OF OZONE AND PHOTOCHEMICAL EXPOSURE TO HUMAN HEALTH EFFECTS AND RECOMMENDED ALERT AND WARNING SYSTEM LEVELS [II.5]

Recommended Episode Levels	Ozone and Photochemicals Oxidants (ppm)	Duration of Exposure	Health Effects
Emergency	0.70	2.0 h	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 h	Measurable biochemical changes in blood sera enzyme levels and in red blood cell membrane integrity; some subjects become physically ill and unable to perform normal jobs for several hours.
	0.37	2.0 h	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 h	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 become 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 h	Biochemical changes in blood sera enzyme levels.
Yellow alert	0.10	1 h	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 h 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.

TABLE II.13. HEALTH EFFECTS OF SELECTED TOXIC TRACE AIR POLLUTANTS, ORGANIC COMPOUNDS [II.6]

Pollutant	Major Health Effects
Acryronitrile (CH_2-CH-C-N)	Dermatitis; hematological 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 ($C_2H_2CI_2$)	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.
Methylane chloride (CH_2CI_2)	Nervous system disturbances.
Polychlorinated bi-phenyls (PCB) (coplanar)	Spontaneous abortions; congenital birth defects; bioaccumulation in food chains.
Polychlorinated dibenzo-dioxins furans	Birth defects; skin disorders; liver damage; suppression of the immune system.
Polycyclic Organic Matter (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 hematopoietic tissues.
Tetrachloroethylene (C_2CI_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_2HCI_3)	Impairment of psychomotoric functions; skin and eye irritation; injury to liver and kidneys; urinary tract tumors and lymphomas.
Vinyl chloride (CH_2-CHCI)	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 hematopoietic system.

TABLE II.14. HEALTH EFFECTS OF SELECTED TOXIC TRACE AIR POLLUTANTS, METALS [II.6]

Pollutant	Major Health Effect
Arsenic (As)	Lung cancer; dermatological disorders, incl. ulcerative dermatitis; hematological 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 blood forming 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.
Thalium (Tl)	Bioaccumulation; toxic to plants and animals.
Vanadium (V)	Respiratory irritation; asthma; nervous disturbances; changes in the blood formula.

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Appendix III

STEPS AND TECHNIQUES FOR HAZARD IDENTIFICATION

This appendix provides a brief description of some of the most frequently used methods in support of hazard identification.

III.1. METHODS FOR HAZARD IDENTIFICATION

- **Process/Safety Checklists:** checklists are used to identify hazards and examine compliances of otherwise 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 the system or plant; they lead to a "yes-or-no" decision about compliances 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 the appropriate background and responsibilities. When a comprehensive review is undertaken it is referred to as a safety audit/review, a process review or a 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, equipment 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 and "What if?" questions.

- **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 of 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. The Dow Index has recently been extended to apply to toxic risks.

- **Preliminary Hazard Analysis:** the method is designed to recognize early hazards and focuses on hazardous materials and major plant elements since only few details on the plant design and possibly no information on the procedures would be available. The method consists of formulating a list of hazards related to the 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 and Operability Studies:** 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 start up; to minimize extensive last minute modifications and ultimately to ensure trouble-free long term operation.

HAZOP studies are systematic techniques and were developed using a multi-disciplinary 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;
- Be managed in a competent manner;
- Be operated and maintained in accordance with good practice and in line with the design intent;
- Protective systems will be tested regularly and be kept in good working order.

The HAZOP procedure was originally described in Ref [III.1] but a more up-to-date description can be found in Ref. [III.2]. In simple terms, the HAZOP procedure gives 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 is 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 experiences 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 necessary experience, knowledge, skill 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.

- **"What If" Checklists:** 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 and Effects Analysis (FMEA):** is a tabulation of the system/plant equipment, it's failure modes as a description of how equipment fails (open, closed, on, off, leaks etc.) and the effect of failure modes (e.g. system response of an accident resulting from equipment failure). FMEA requires the knowledge of a system/plant function; it does not apply to a combination of equipment failures that leads to accidents. The result of using the method is qualitative and consists in a systematic reference listing of system/plant equipment, failure modes, and it's effects. The method is especially useful in the analysis of very critical processes but can be extremely time consuming if applied on too broad a scale.

- **Master Logic Diagrams:** this is a logic diagram similar to a fault tree but without the formal boolean structure that characterizes the latter. One starts with the general undesirable event (e.g. release of toxic material to the environment) and proceeds in a deductive "top-down" approach to define causes of the events identified in the previous level. Events at a particular level will find their causative factors in events at the immediate lower level. A precise connection with an "AND" or "OR" logic is not, however, necessary. Eventually at the lowest level of this tree there will be events that have the potential to trigger chains of events leading to the top undesirable event.

A comparative description of these methods is summarized in Table III.1.

III.2. GUIDANCE ON IMPLEMENTATION

The appropriateness and relevance of any one particular technique of hazard identification largely depends 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 can 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. A guidance framework of the most appropriate techniques for various situations is given in Table III.2.

The application of hazard identification methods can be both time consuming and expensive so that some sections of the plant will receive a more detailed study than others. The depth of study depends upon the appraisal of the inherent hazards from the various sections of the plant. In the case of a highly sensitive reactor system the hazard identification study may be very detailed and often supplemented by a reliability analysis of the control system using a method such as fault tree analysis. On the other hand a water treatment plant might only be reviewed for operability and personnel protection. Therefore, the depth and scope of a study is determined by the organizations' perception of the hazards as a process and their appraisal of the need to control them.

In stressing the need to identify hazards as early as possible in the development of a process, and especially at the process design stage, the impression may have been given that hazard identification ends when the design specification has been approved. In fact, approval of design means only that "at the time of the study the study team believed that, provided the plant is constructed and operated in accordance with their recommendations, the plant will be acceptably safe". The first uncontrolled change during construction or the first unapproved modification during operation negates this approval. Consequently hazard identification is a continuing ingredient for safe operation and should be applied, sometimes in a very simple form, to control any changes from the original intentions of the designers.

TABLE III.1. TECHNIQUES OF HAZARD IDENTIFICATION

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 operation; 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-no' decision about compliance with standards/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, organizational safety systems, emergency procedures	– For a complete review, team needs access to plant descriptions, piping and instrumentation diagrams, flowcharts, 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
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 an 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

TABLE III.1. (Cont.)

Techniques of Hazard Identification	General Description	Data and Requirements	Output
Preliminary Hazard Analysis	Examine preliminary design to determine hazards related to materials and processes, components and interfaces as well as organizational 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 as a useful presentation tool
Failure Mode and Effects 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 modes 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
Hazard Operability (HAZOP)	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	A comprehensive identification of possible deviations, their consequences, causes and suggested actions
"What If?" Analysis	Systematic examination of a process of operation, using "what if" prompt to suggest an initiating event, a failure from which an undesirable event sequence could occur	– Process flow sheets, pilot plans, PIDS – two qualified analysts An identification of deviations with their consequences and recommended actions	An identification of deviations with their consequences and recommended actions

TABLE III.2. 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	A	B	B	C
Preliminary Hazard Analysis	A	C	C	B
Hazard Operability Studies	B	A	B	A
'What if' Checklist	A	B	B	A
Failure Mode and Effects Analysis	C	B	A	B
Fault Tree Analysis	C	A	A	A
Event Tree Analysis	C	A	A	A
Cause-Consequence Analysis	C	B	A	B
Human Reliability Analysis	C	A	A	A
A- Best suited	B- Could be used	C- last suited (not advised)		

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Appendix IV

MODELS FOR MAJOR HAZARD INCIDENTS

IV.1. PHYSICAL MODELS

IV.1.1. Release or Discharge Rates

The objective 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 depends 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 flammable liquefied gases stored under pressure, the contents of the vessel which has catastrophically 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 wind stream 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. IV.1.

These effects can be summarized as follows:

(a) Gas/Vapour discharge results from:

- 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.

(b) Two-phase discharge results from:

- a hole in a pressurized 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).

(c) 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 pressurized 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 Ref. [IV.1] which

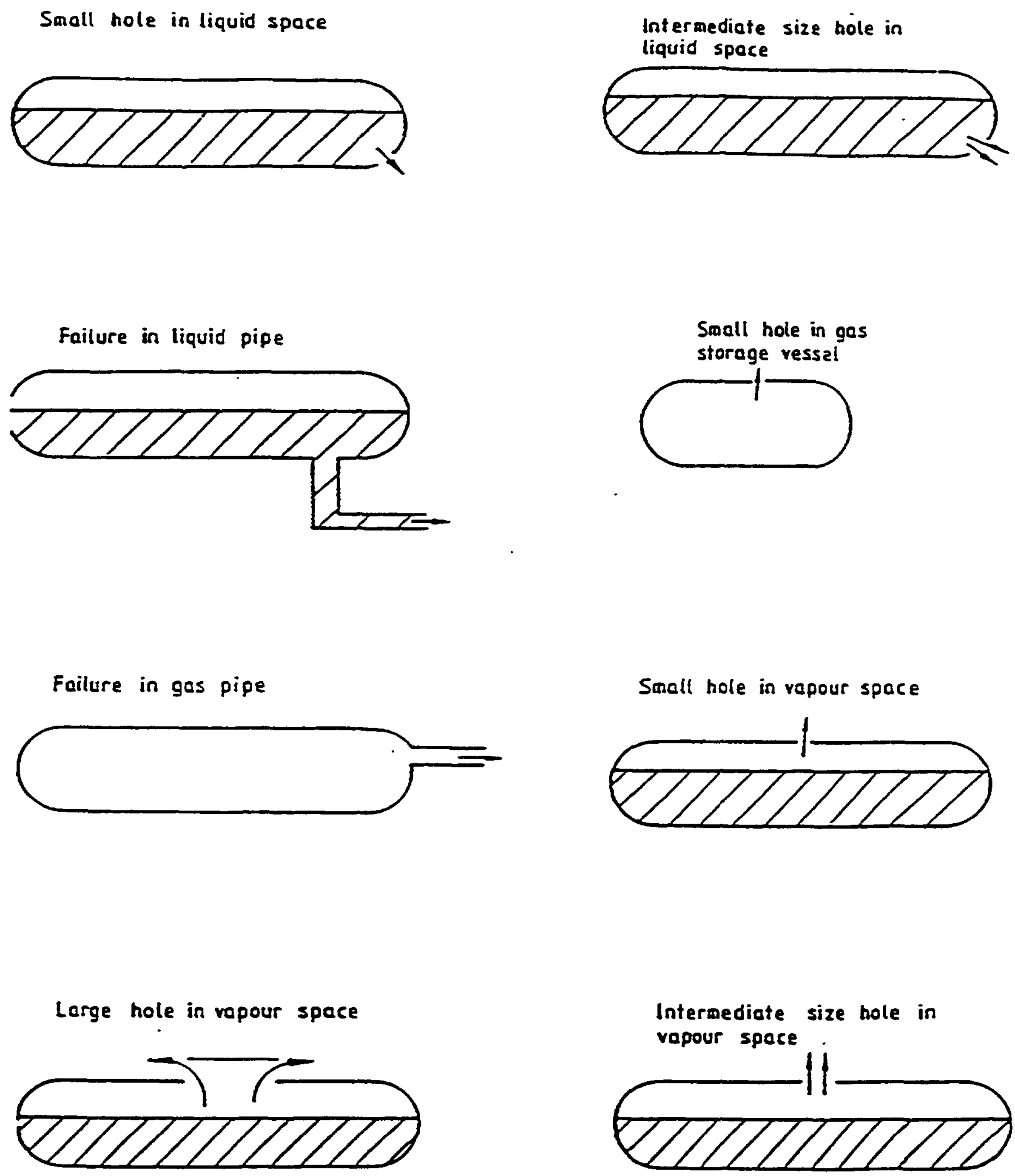

FIG. IV.1. Location of discharge positions, from Ref. [IV.2].

lists example base cases for a range of hole sizes and Refs [IV.2, IV.3, IV.4, IV.5] Relief valve discharges can be determined by reference to the AIChe/DIERS work in Refs [IV.6, IV.7].

Fig. IV.2 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.

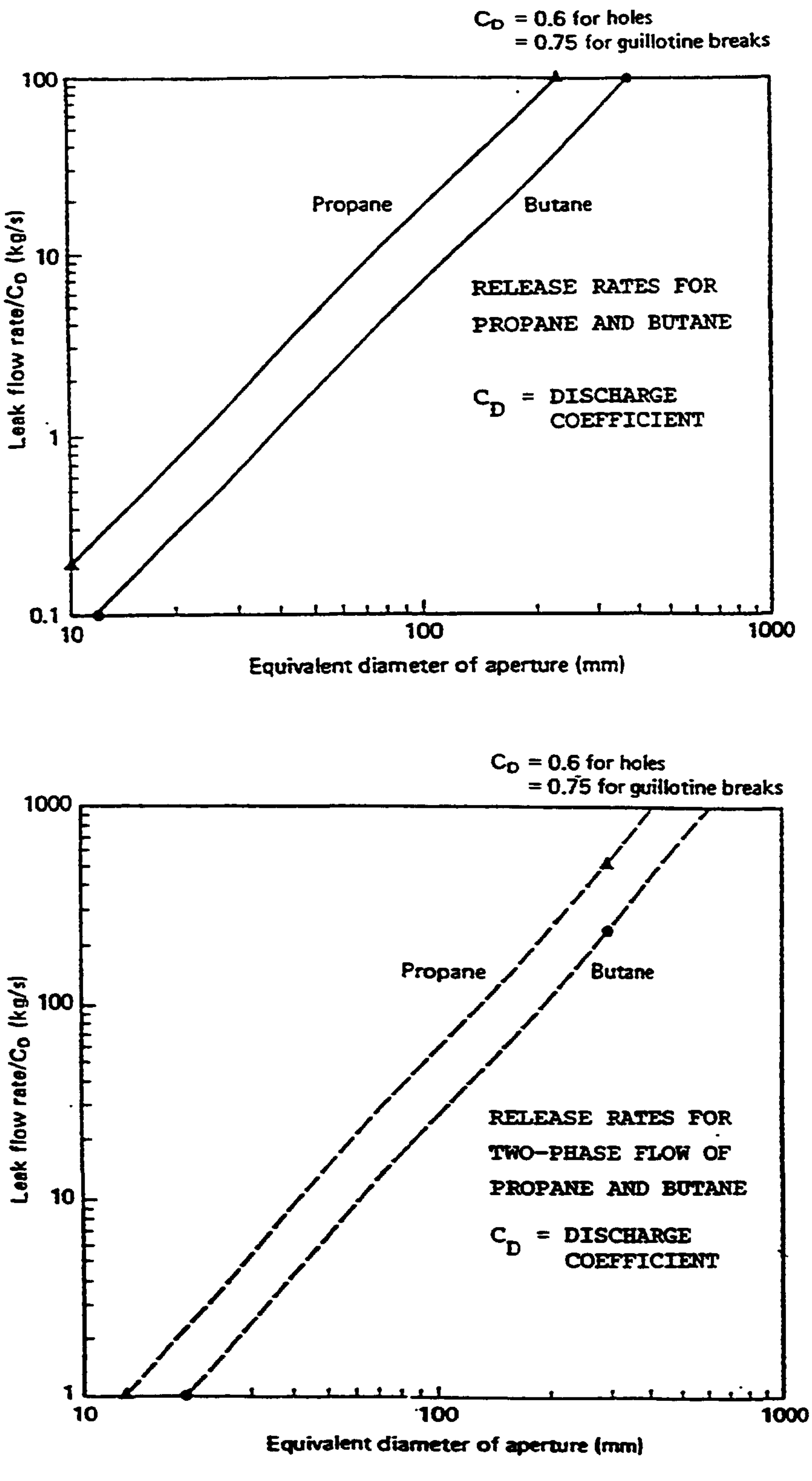

FIG. IV.2. Release rates for propane and butane, Ref. [IV.8]

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

PHAST (Technica, UK/USA)
SUPERATOMS (AD Little, USA)
RAMSKILL (SRD, UK)
CHARM (Radian Corporation, USA)

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

(i) Gas discharge

The following, taken from Ref. [IV.8], describes 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);
- Γ = 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:

$$G_v = C_d \frac{A\ p}{G} Y$$

where:
- G_v = gas discharge rate (kg/s);
- C_d = discharge coefficient;
- A = hole area (m^2);
- c = sonic velocity of gas at temperature T, $c = (RT/M)^{1/2}$;
- 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:

subsonic flow

$$Y = \left\{ \frac{2\Gamma^2}{\Gamma-1} (p_a/p)^{2/\Gamma} \left[1-(p_a/p)^{(\Gamma-1)/\Gamma} \right] \right\}^{1/2} \qquad \text{for } (p/p_a) \leq r_{crit}$$

sonic flow

$$Y = \Gamma \left\{ \frac{2}{\Gamma+1} \right\}^{(\Gamma+1)/2(\Gamma-1)} \qquad \text{for } (p/p_a) \geq r_{crit}$$

(ii) Liquid discharge

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

$$G_1 = C_d A\delta[2(p - p_a)/\delta + 2gh]^{1/2}$$

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) the flow is assumed to remain liquid while it is escaping through the break. Immediately after, it flashes to vapour for the fraction:

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

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 0.2; none, of course, if $f_v = 0$; for values included in this range, a linear relationship could be considered.

A major area of effort has been devoted to the prediction of aerosol formation of non-flashing liquids entrained in the vapour phase of a release. Simple estimates have been provided in Ref. [IV.9] where doubling the flash fraction is suggested and more recently in Ref. [IV.10] where 5 times the flash fraction is suggested. Thus if $f_v \geq 0.2$ then all the liquid is entrained and none if $f_v=0$, with linear interpolation used in between. Better estimates of entrainment can be calculated based on surface tension, density and other physical parameters characterizing the release. Subsequent rainout can greatly reduce the size of the initial vapour cloud and this can be estimated based on predicted droplet size.

(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 length 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 reported in the World Bank Manual, Ref. [IV.11], 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 throat 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:

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

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:

$$G_m = C_d\ A_r\ .\ [\ 2(p-p_c)/v_m]_{1/2}$$

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).

Discussion:

Gas and liquid phase discharge calculation methods are well founded and are readily available from many standard references. However, many real releases of pressurized liquids will give rise to two-phase discharges which must be taken into account. A simplified approximate method has been developed in Ref. [IV.12].

IV.1.2. Airborne 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 and 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 which leads to aerosol formation and 'dense' effects (e.g. LNG or ammonia).

Dispersion models require the background meteorological regime to be specified. This will usually be in the form of a wind-rose (wind speed and direction probabilities) and atmospheric stability information (A-unstable, D-neutral, F-stable). If no data are available, it is typical to assume a uniform wind distribution and two weather classes D5m/s and F2m/s.

Meteorological data needs to be of adequate duration to be representative, usually one year or greater is recommended. Such data is readily available at low cost from the UK Met office or the USA NOAA for a large number of airports worldwide. Wind rose data can be highly variable over relatively short distances especially in hilly terrain and thus care is required where the met station is well separated from the site under review. Often, however, there will be no other reasonable alternative.

(i) 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. 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 vaporization rate of a pool is the product of the average local vaporization rate and the pool area. However the local vaporization rate is in itself largely dependent 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.

Pool vaporization 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;
- 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 dependent on the nature and type of surface involved and is difficult to model in a generic manner.

The sheer diversity and complexity of the physical phenomena (heat and mass transfer effects) which conspire to determine pool vaporization rates have made numerical solutions to the problem necessary. Hand calculation methods can be used as shown in [Ref. IV.3], but accurate estimates need sophisticated computer models. The most recent and thorough of these is GASP in Ref. [IV.13]. 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 those in Refs [IV.14, IV.15].

(ii) 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 (see section 4.4.2). Descriptions of neutral or positively buoyant gases and the way in which they disperse are given in Refs [IV.16, IV.17] and in the TNO Yellow Book, Ref. [IV.18].

Hand calculations to estimate the dispersion of neutral or positively buoyant clouds are still common in chemical process plant risk assessment but most models do use computerized techniques. A good review of these models is given in Ref. [IV.19].

A brief description of Gaussian dispersion models has been already reported in section 4.4.2.

(iii) Negatively buoyant gases (dense gas dispersion)

The importance of dense gas dispersion has been recognized 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 than neutral or positively 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, Refs [IV.20, IV.21]. 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 pressurized 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 in Ref. [IV.19]. A number of codes are available, with some dealing only with instantaneous releases, others only with continuous releases, whilst others 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.

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

DOW INDEX MODEL FOR TOXICS
CHARM (Radian Corporation, USA)
DEGADIS (US Coastguard)
HEGADAS (SHELL)
DENZ/CRUNCH (SRD, UK)
HASTE (ERT, USA)
SLAB (Lawrence-Livermore National Laboratory, USA)
PHAST (Technica, UK)
TRACE (SAFER CORPORATION, USA)
DRIFT (SRD, UK)
SUPERATOMS (AD Little)

The USA has completed, and the CEC are proceeding with overall comparative model validation. It must be appreciated by now that the subject of dense gas dispersion is a very specialized, 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 computer model are realistic. There is no easy short-cut to carrying out dense gas dispersion calculations. 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 Ref. [IV.1] and in Ref. [IV.22]. Figs IV.3 and IV.4 show 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 (5m/s and 2 m/s, respectively). These curves were derived with the use of the SRD computer code CRUNCH, Ref. [IV.23].

Discussion

The strength of most of the dense gas dispersion models is their inclusion of the important mechanisms of gravity slumping, air entrainment and heat transfer processes. Their main weakness is the difficulties encountered with estimating the source term and the fact that a degree of skill is required by the user.

IV.1.3. Aquatic Dispersion Models

Environmental impact of accidental spills of hazardous liquids is not well worked out except for certain special cases (e.g. oil spills in coastal locations) which have received special attention.

In other cases a simple approach may be all that is possible. This must address the source term (spill size and immediate containment) and then translate this into the aquatic environment. The methods discussed in Section 4.4.3. for continuous emissions will be a good starting point.

IV.1.4. Fires

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

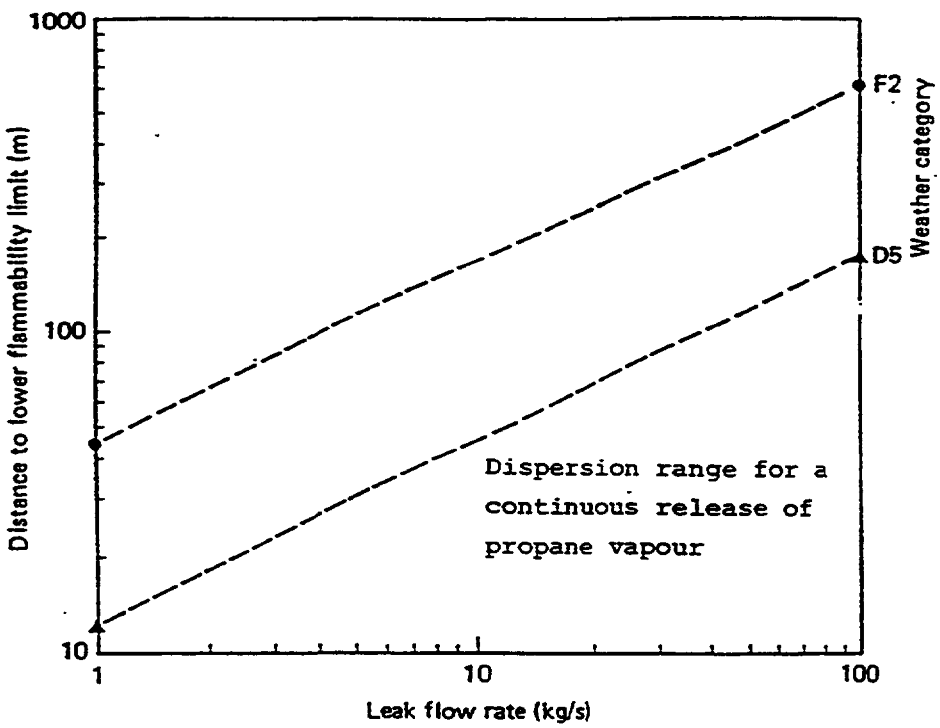

FIG. IV.3. Dispersion range for propane, Ref. [IV.23]

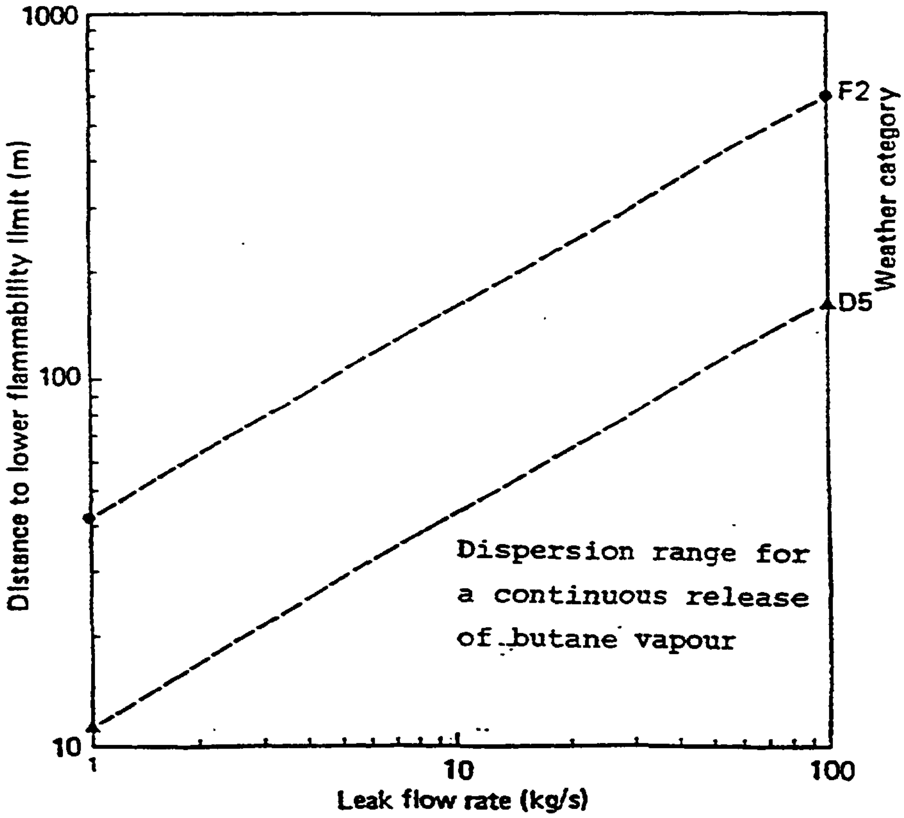

FIG. IV.4. Dispersion range for butane, Ref. [IV.23]

(i) **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/minutes.

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:

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

where:
- I = incident radiation per unit area; (ignoring transmissivity)
- R = distance from the source
- f = the fraction of the heat of combustion assumed to radiate in all directions from the notional centrepoint source (often around 0.3)
- 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 particles 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 is the reason why the normal procedure is to use the solid flame 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) Ref. [IV.24];
- 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, see Refs [IV.18, IV.25, IV.26, IV.27].

Pool fires have been studied for many years and the empirical equations used are well validated. The treatment of smoky flames is still difficult, also flame impingement effects are not simulated.

(ii) Jet fire: Jet fire modelling has received considerable experimental attention in recent years, mainly by Shell, due to escalation problems on offshore oil platforms. Useful references include [IV.28, IV.29, IV.30, IV.31]. The API method is relatively simple. An example of its application to an LPG jet flame is given in Figs IV.5 and IV.6. which show the flame length and the distance to a given level of thermal radiation against the flow rate. As in pool fires flame impingement effects are not simulated.

(iii) 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, 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 and ruptures. As a result of the vessel failure the pressurized 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 Refs [IV.18, IV.32, IV.33].

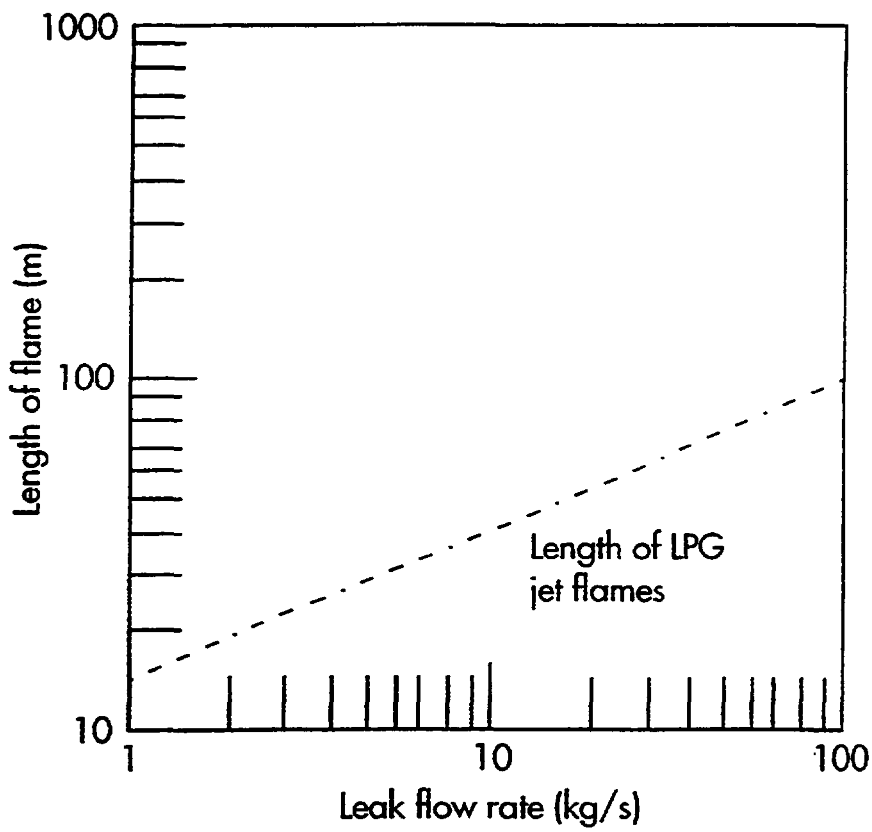

FIG. IV.5. Jet fire modeling - length of flame

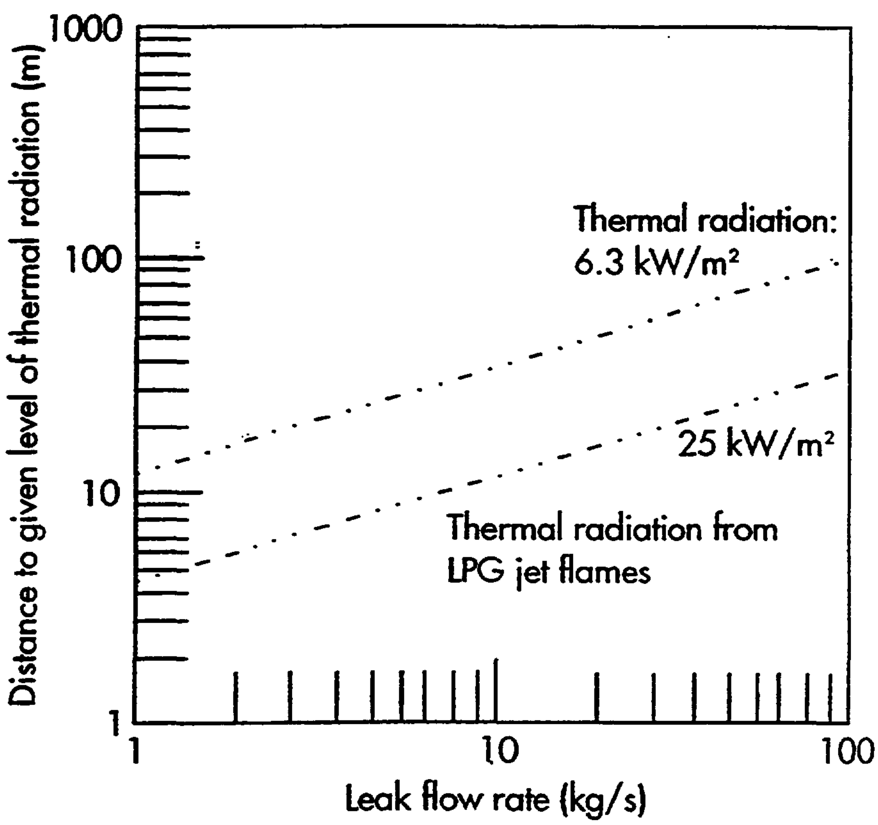

FIG. IV.6. Jet fire modeling - distance of thermal radiation

Discussion

BLEVE dimensions and durations have been studied by many authors and the empirical basis consists of several well-described incidents, as well as many smaller laboratory trials. The use of a surface emitted flux estimate is the greatest weakness, as this is not a fundamental property.

IV.1.5. 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. A good overview of this topic is given in Ref. [IV.18].

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. IV.7. 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.

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.

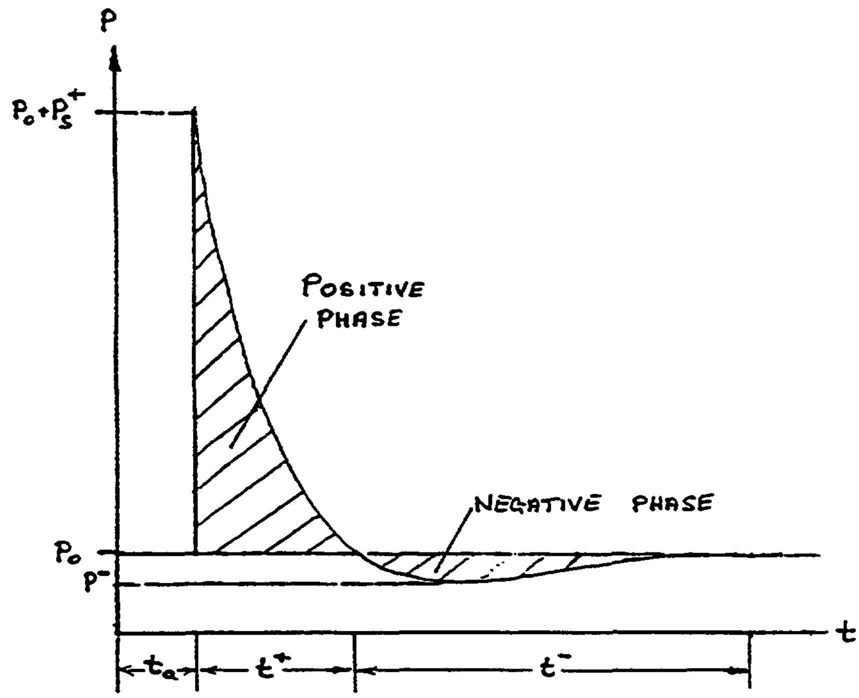

FIG. IV.7. Idealized structure of a blast wave, Ref.[IV.35]

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 such an explosion is characterized 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, see Refs [IV.33, IV.34]. The pressure profile due to thermal effects for a totally confined explosion is shown in Fig. IV.8.

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 materials such as some organic peroxides which are used as propellants for military purposes. Condensed phase explosions are the type which most closely approximate that of the idealized blast wave structure described earlier in that it is characterized by an abrupt pressure rise, a short (1 to 10 ms) positive phase duration and a very high 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.

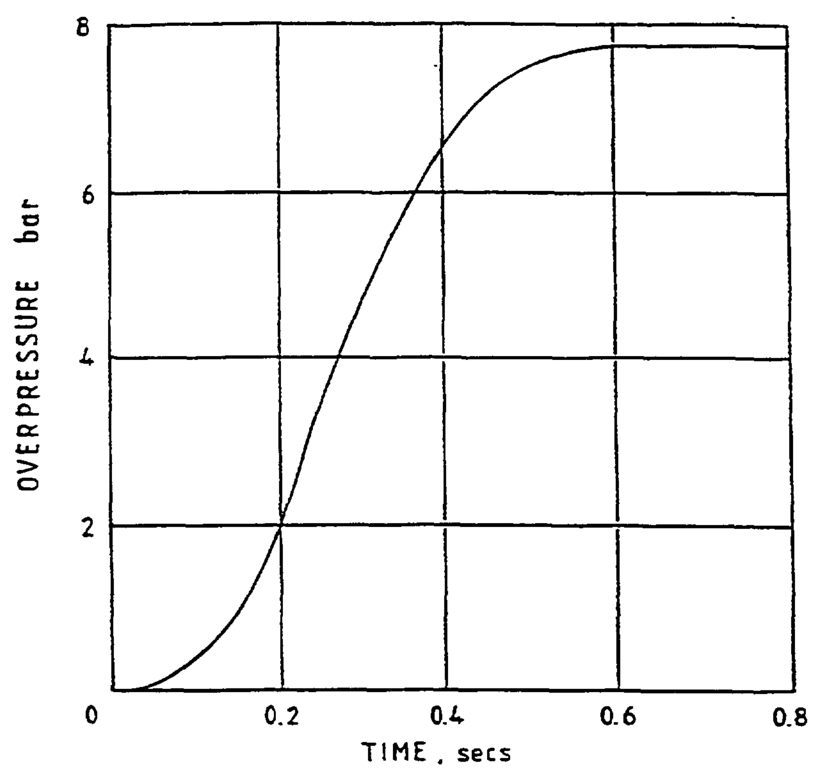

FIG. IV.8. The pressure-time profile for a totally confined stoichiometric propane - air mixture

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, Ref. [IV.35]. The method is under review to take account of improved understanding of the underlying mechanisms of flame acceleration in partially confined structures. A number of people also use a model developed by TNO, Ref. [IV.18], 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 explosives varies from about 60% to 130%, however as a first approximation it can be assumed that 1 equivalent tonne of high explosive will produce the same blast energy as 1 tonne 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, see Ref. [IV.36].

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

where: R = distance (m) from the source of the explosion
W = charge weight (kg TNT).

Fig. IV.9 which relates peak overpressure to scaled distance, is an example of the TNT blast relationship. Ref. [IV.35] explains the application and use of the TNT equivalence approach.

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 in Refs [IV.35, IV.37]. 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 of the explosion. The TNO multi-energy method, presented in Ref. [IV.38], is now considered to give results which are much more representative of those observed in actual explosions and to match theory. This model is very well regarded.

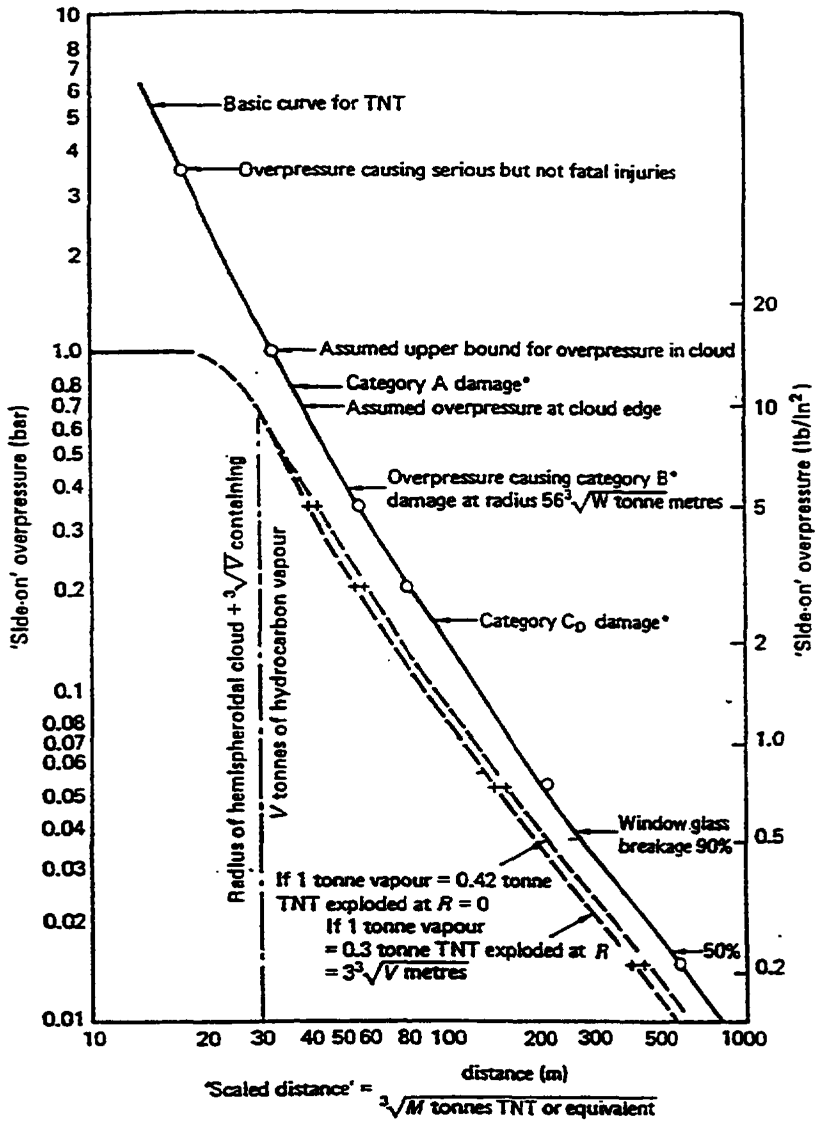

FIG. IV.9. Relationship between peak overpressure and "scaled distance", Ref.[IV.35].

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 are the codes FLACS which was developed by the CMR at Bergen, Norway, and CHAOS, developed by British Gas, UK.

Discussion

The TNT equivalent model as described is relatively easy to use. Neither this nor the TNO model is solidly based on theory, but they both predict well the observed VCE incidents. One difficulty is that in the TNT approach some expertise is required in selecting the explosion yield. The other weakness of the TNT model is the substantial physical difference between detonations and VCE deflagrations. The TNO correlations model is based on actual VCE incidents and employs one of two defined explosion yields, but it is limited to flammable models of medium reactivity.

IV.1.6. 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. Generally, in risk terms, due to the small area affected, fragments are not a major issue; but they can be a public perception problem. 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 Refs [IV.36, IV.39, IV.40, IV.41]. 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.

IV.2. EFFECTS 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. However, environmental effect models development is still in its infancy and existing approaches contain great uncertainties. A good overview of people and property effects modelling is given in the TNO Green Book, Ref. [IV.42].

IV.2.1. 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 man, 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 susceptibility. 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 substances 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. The methods presented in chapter 4 of these Guidelines to calculate the effect of toxic releases on the environment from continuous releases are also applicable to calculate the effects of accidental releases.

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 Major Hazards Assessment Panel and associated publications have given an extensive review of the animal data for man. Refs [IV.43, IV.44]. The same group has also reviewed ammonia, Ref. [IV.45].

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. The probit equation 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 IV.1 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:

$$P_T = -35.9 + 1.85 \log_e(C^2 t)$$

The important factor in the determination of the effects of toxic material is to study the known data about the material in question, see Refs [IV.46, IV.47] and the monographs for Chlorine, Ammonia and Phosgene. In any case, before interpreting 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 in Refs [IV.42, IV.48]. But there are also databases many of which are now computerized and some of which are on Compact Disc-Read Only Memory, Refs [IV.49, IV.50].

It should be noted however that the information on dose-response relationships necessary to apply a probit function is only available for the chemicals shown in Table IV.1., information on a few other chemicals is slowly becoming available. In circumstances where chemicals other than those listed in Table IV.1 are involved or where a rapid result is required, it may be necessary to make use of established toxicological criteria. Some are listed below:

- Emergency Response Planning Guidelines (ERPGs) for air contaminants issued by the American Industrial Hygiene Association (AIHA). Over 40 ERPGs have been developed, for 3 different levels of impact, all for 60 minutes of exposure.

- Immediately Dangerous to Life or Health (IDLH) Levels established by the National Institute for Occupational Safety and Health (NIOSH). NIOSH has published IDLH concentrations to be used as acute toxicity measures for common industrial gases. An IDLH level represents the maximum airborne concentration of a substance to which a healthy male worker can be exposed for as long as 30 minutes and still be able to escape without loss of life or irreversible organ system damage. Because IDLHs were developed to protect healthy worker populations they must be used with caution when applied to sensitive populations.

TABLE IV.1. CONSTANTS FOR LETHAL TOXICITY PROBIT EQUATION, Ref.[IV.3]

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

Note: These values should be used with caution. They contain uncertainties and are subject to regular review and updating/change.

- Emergency Exposure Guidance Levels (EEGLs) and Short-Term Public Emergency Guidance Levels (SPEGLs) issued by the American National Academy of Sciences/National Research

Council. An EEGL is defined as a concentration of a gas, vapour or aerosol that is judged to be acceptable and that will allow exposed individuals to perform specific tasks during emergency conditions lasting from 1 to 24 hrs. SPEGLs are defined as acceptable concentrations for exposures of members of the general public . These are generally set at 10 to 50% of the EEGL and are calculated to take account of the effects of exposure on sensitive populations. Their advantage over IDLH values are that they have been developed for a range of exposure times and consider the effects on sensitive populations.

– Threshold Limit Values (TLVs) established by the American Conference of Government Industrial Hygienists (ACGIH) including Short Term Exposure Limits (STELs) and ceiling concentrations. The STELs are designed to protect workers from acute effects resulting from exposure to chemicals. They are however designed as limits on exposure excursions lasting up to 15 minutes.

The use of established toxicity measures such as ERPGs, IDLH, EEGLs, SPEGLs and TLV/STEL is usually a simpler approach than the probit model - and is also applicable over a wider range of chemicals. However the results are more difficult to interpret when the release is over a different time period to that published.

IV.2.2. 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 response (to turn and run away) and the existence of solar radiation exposure in sunny climates. Fig. IV.10 from Ref. [IV.26] shows a simple relationship

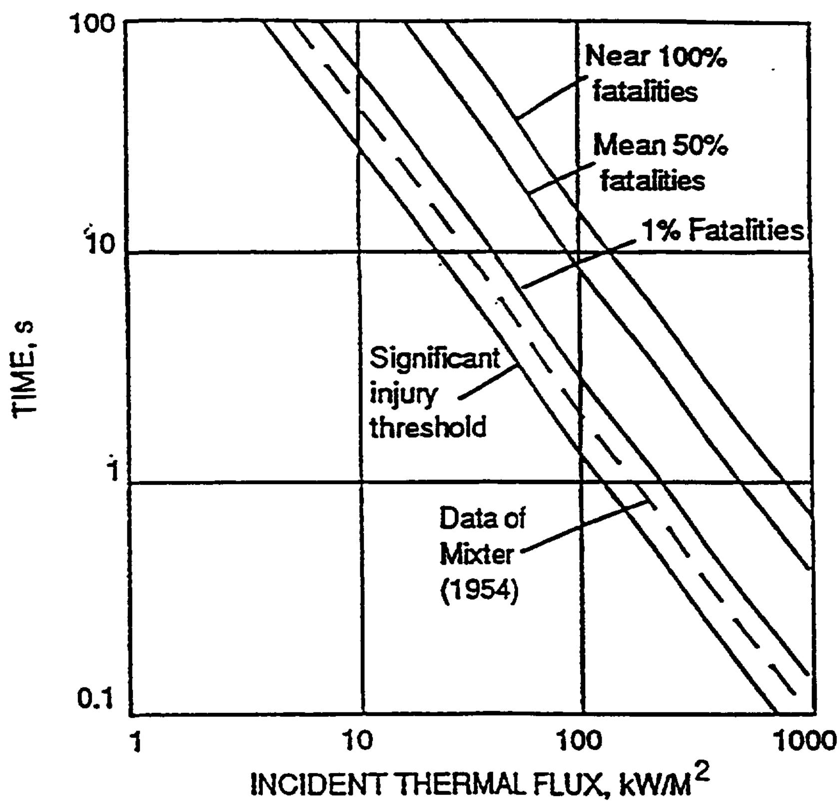

FIG. IV.10. Fatality and injury levels for thermal radiation, Ref. [IV.26] between incident thermal flux, time and damage (injury/fatalities). A probit model was developed, see Ref. [IV.51], to estimate the injury levels for a given thermal radiation dose from pool and flash fires based on data from nuclear tests:

$$P_r = 14.9 + 2.56 \log_e (t\, I.\ 10^{-4})^{4/3}$$

where: P_r = Probit (measure of the percentage of people affected)
t = exposure time in sec.
I = thermal radiations intensity (W/m^2)

This normally should be used only with care and not applied to long exposure doses.Table IV.2 indicates the consequence effects of heat radiation on people and property.

TABLE IV.2. CONSEQUENCE EFFECTS OF HEAT RADIATION ON PEOPLE AND EQUIPMENT, Ref. [52]

INCIDENT FLUX (kW/m^2)	DAMAGE TO EQUIPMENT	DAMAGE TO PEOPLE
35	• Damage to process equipment • Cellulosic equipment will pilot ignite within one minute exposure	• Significant chance of fatality for people exposed instantaneously • Likely fatality for extended exposures
23	• 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	• Chance of fatality for instantaneous exposure
12.6	• Minimum energy to ignite wood with 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	• Significant chance of fatality for extended exposure • High chance of injury
4.7		• Causes pain if duration is longer than 20 sec. • Possible injury after 30 sec. exposure
2.1		• Minimum to cause pain after 1 min.
1.2		• Causes no discomfort for long exposure

Discussion

Thermal effect models are simple and are based on extensive experimental data. The main weakness arises if duration of exposure is not considered. Thermal effect data relates to bare skin and it is necessary to take account of the effect of clothing and sheltering.

IV.2.3. 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.

There have been a number of different approaches developed 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 also been investigated in depth. The effects of explosion overpressure on people and buildings are indicated in Table IV.3.

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.

TABLE IV.3. 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 to 8 bars
50% lethality	3.5 to 5 bars
Threshold lethality	2 to 3 bars
Severe lung damage	1.33 to 2 bars
50 % eardrum rupture	2 to 2.33 bars (over 20 yrs. of age)
50 % eardrum rupture	1 to 1.33 bars (under 20 yrs. of age)

Note: Great caution should be exercised in the use of probits for modelling consequence effects from explosion overpressure in a non-nuclear event.

Discussion

The strength of explosion effect models is their solid base of experimental data and the general simplicity of the approach. Attention has been drawn to the fact that people may be killed indoors due to building collapse at a much lower overpressure than outdoors due to overpressure alone. Explosions in built-up areas are rarely uniform in effects. VCEs are often directional and this effect is not accounted for in many current effect models.

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Appendix V

BACKGROUND ON DECISION CRITERIA

V.1. HEALTH RISK CRITERIA

V.1.1. 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, downhill 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. Tables V.1 and V.2 indicate a range of various voluntary and non-voluntary risks to which people are generally exposed as the result of various activities.

TABLE V.1. EXAMPLES OF SOME ANNUAL INDIVIDUAL MORTALITY RATES: 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

TABLE V.2. EXAMPLES OF SOME ANNUAL INDIVIDUAL MORTALITY RATES: 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
Lightning	1×10^{-7}	0.1 in one million

The increased societal awareness of the need to protect the environment, the complexity of modern industries and their potential to cause accidents with 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 appendix is to provide a general guidance concerning the setting and applications of such criteria.

V.1.2. 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.

Tables V.3 and V.4 outline 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.

TABLE V.3. CATEGORIES OF 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

TABLE V.4. CATEGORIES OF ENVIRONMENTAL RISK

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

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 long term 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 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 appendix refer to the latter type.

To date, emphasis has been placed 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 encompassing overall quantified risk criteria have been established for long term chronic exposure to chemicals from on-off or repeated accidental exposures. For the long term effects of chemicals, the assessments have until now relied mostly on translating animal test 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 ecosystems, including the issue of irreversibility and/or recoverability of damage make it difficult to establish 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.

V.1.3. 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 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 immediate 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).

V.1.4. 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.

V.1.5. 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 a `tolerable' level of risk, the notion of risk `tolerability' 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 those which may be tolerated in relation to both the costs and benefits associated with the activities under consideration. Social and economic considerations therefore become 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) in which 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. Fig. V.1 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, Ref. [V.1].

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 inevitably 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/no-go rules, hence they are shown as hatched zones. 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. In all cases it should be recognized that the criteria developed should be guidelines only and not treated as absolute rules.

V.1.6. Individual Risk Criteria

Individual risk is usually defined as the probability per year that any one 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 are 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 effected;
- 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 V.5 provides an overview summary of risk criteria suggested or adopted by different national authorities. Selected examples are presented hereafter.

TABLE V.5. 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	$<1 \times 10^{-6}$ 1×10^{-3} 1×10^{-6} to 1×10^{-3}	Risk acceptable Not acceptable Compare risks, detriments, costs and benefits
1989	HSE, UK	$<1 \times 10^{-6}$ $<0.3 \times 10^{-6}$ 10×10^{-6} No numerical criteria justified for group risk	Risk acceptable Sensitive land uses may not be acceptable
1989	Dutch National Environmental Policy Plan	1×10^{-6} 1×10^{-8} 1×10^{-6} to 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

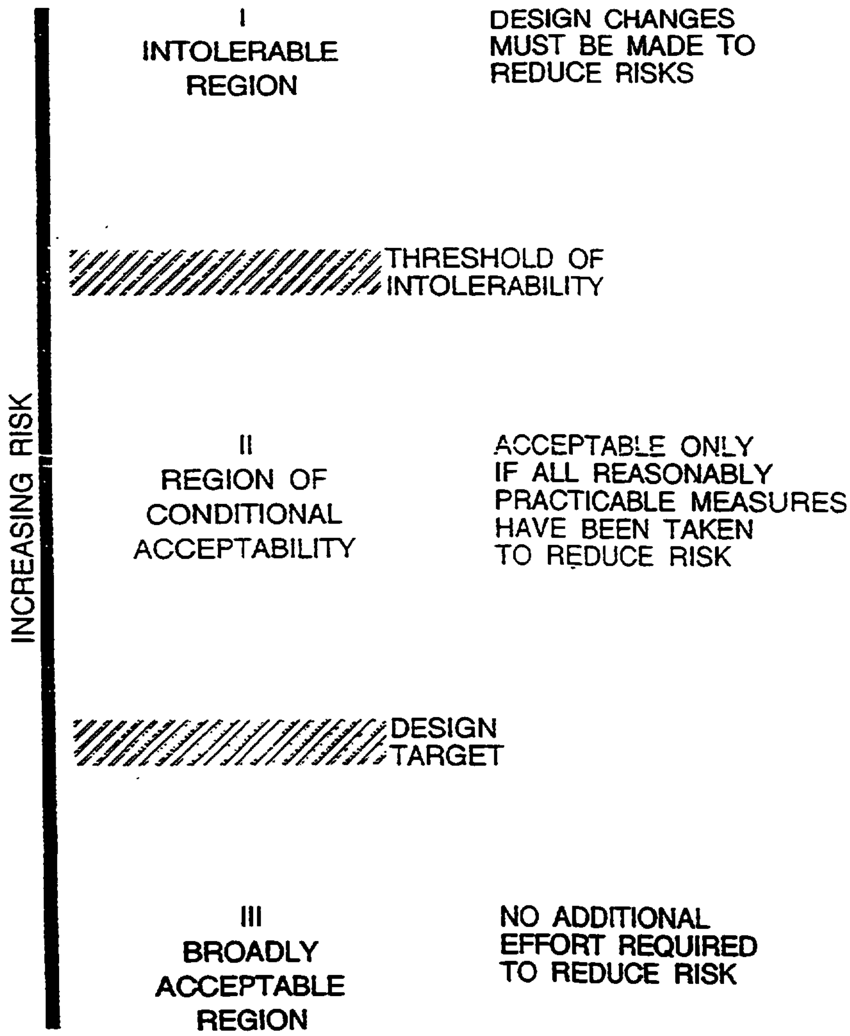

FIG. V.1. Regions of risk

V.1.7. 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 a 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 address 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, wherever possible, be contained within the boundaries of the installation.

d) 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.

V.1.8. 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 appendix 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 emphasizes 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 risk criteria in terming plants which exceed the suggested 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 that a tighter locational and technological standard is applied now than at earlier times. In the case of existing industry, compliance with 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 as 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 arises 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 a cumulative impact of developments.

g) In a large industrial complex risk criteria should also provide for the potential of accident propagation. The risk of an accident at 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.

An example to illustrate how to define criteria for an area risk assessment is given in Table V.6.

TABLE V.6. EXAMPLE OF A SET OF CRITERIA FOR AN AREA RISK ASSESSMENT

Emissions in Water	Pesticides	< 0.03 µg/l
	Nitrate	< 10 mg/l
	Lead	< 0.05 mg/l
	Other criteria can be derived from Table II.7.	
Air Emissions	SO_2	< 500 µg/m^3
	Toluene	< 8 µg/m^3
	CO	< 100 mg/m^3
	Other criteria can be derived from WHO Air Quality Guideline Values (see Table II.1)	
Major Hazards		< Individual risk 10^{-6}
Carcinogenic Risk		< 10^{-6}

REFERENCE

V.1. HEALTH AND SAFETY EXECUTIVE, The Tolerability of Risks from Nuclear Power Stations, HSME, London (1992).

Annex I

THE COUNCIL DIRECTIVE (82/501/EEC AND AMENDMENTS 87/216/EEC,88/610/EEC) ON THE MAJOR-ACCIDENT HAZARDS OF CERTAIN INDUSTRIAL FACILITIES

The Directive is concerned with industrial activities which involve or may involve substances that are particularly dangerous in certain quantities, with the prevention of major accidents and the limitation of their consequences for man and the environment. The general presentation is in the form of "Articles", some of which will be given below in a shortened version to permit better understanding of the related tables.

ARTICLE 1: Definitions

(a) **Industrial activity** means:

- any operation carried out in an industrial installation involving, or possibly involving, one or more dangerous substances and capable of presenting major-accident hazards, and also transport carried out within the establishment for internal reasons and the storage associated with this operation within the establishment,
- any other storage.

(b) **Manufacturer** means:

- any person in charge of an industrial activity;

(c) **Major accident** means:

- an occurrence such as a major emission, fire or explosion resulting from uncontrolled developments in the course of an industrial activity, leading to a serious danger to man, immediate or delayed, inside or outside the establishment, and/or to the environment, and involving one or more dangerous substances;

(d) **Dangerous substances** means:

- for the purposes of Articles 3 and 4, substances generally considered to fulfil the criteria laid down in Table I-1.
- for the purposes of Article 5, substances listed in Table I-3.

The indicative criteria for dangerous substances are the following:

(a) *very toxic substances*

(i) substances which correspond to the first line of Table I-1.

(ii) substances which correspond to the second line of Table I-1. 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*

(i) are the substances showing the values on line three of Table I-1. of acute toxicity and having physical and chemical properties capable of producing major accident hazards.

TABLE I-1. CRITERIA FOR TOXIC SUBSTANCES

Toxicity Case	LD_{50} (oral) mg/kg body weight	LD_{50} (cutaneous) mg/kg body weight	LC_{50} mg/l (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 or rabbits
LC_{50} by inhalation (four hours) in rats

(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);

(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*

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

ARTICLE 3:

Member States shall adopt the provisions necessary to ensure that, in the case of any of the industrial activities specified in Article 1, the manufacturer is obliged to take all the measures necessary to prevent major accidents and to limit their consequences for man and the environment.

ARTICLE 4:

Member States shall take the measures necessary to ensure that all manufacturers are required to prove to the competent authority at any time, for the purposes of controls, that they have identified existing major-accident hazards, adopted the appropriate safety measures, and provided the persons working on the site with information, training and equipment in order to ensure their safety.

ARTICLE 5:

1. Without prejudice to Article 4, Member States shall introduce the necessary measures to require the manufacturer to notify the competent authorities.

– if in an industrial activity as defined in Article 1 (a), first indent, one or more of the dangerous substances listed in Table I-3. are involved, or it is recognized that they may be involved, in the quantities laid down in Table I-3. such as:
  - substances stored or used in connection with the industrial activity concerned,
  - products of manufacture;

- by-products; or
- residues;

– or if in an industrial activity as defined in Article 1 (a), second indent, one or more of the dangerous substances listed in Table I-2. are stored in the quantities laid down in Table I-3.

The notification shall contain the following:

(a) information relating to substances listed, respectively, in Table I-2. and Table I-3., that is to say:

- the stage of the activity in which the substances are involved or may be involved;
- the quantity (order of magnitude);
- the chemical and/or physical behaviour under normal conditions of use during the process;
- the forms in which the substances may occur or into which they may be transformed in the case of abnormal conditions which can be foreseen;
- if necessary, other dangerous substances whose presence could have an effect on the potential hazard presented by the relevant industrial activity;

(b) information relating to the installations, that is to say:

- the geographical location of the installations and predominant meteorological conditions and sources of danger arising from the location of the site,
- the maximum number of persons working on the site of the establishment and particularly of those persons exposed to the hazard,
- a general description of the technological processes,
- a description of the sections of the establishment which are important from the safety point of view, the sources of hazard and the conditions under which a major accident could occur, together with a description of the preventive measures planned,
- the arrangements made to ensure that the technical means necessary for the safe operation of plant and to deal with any malfunctions that arise are available at all times;

(c) information relating to possible major-accident situations, that is to say:

- emergency plans, including safety equipment, alarm systems and resources available for use inside the establishments in dealing with a major accident,
- any information necessary to the competent authorities to enable them to prepare emergency plans for use outside the establishment,
- the names of the person and his deputies or the qualified body responsible for safety and authorized to set the emergency plans in motion and to alert the competent authorities.

2. In the case of new installations, the notification referred to in paragraph 1 must reach the competent authorities a reasonable length of time before the industrial activity commences.

3. The notification specified in paragraph 1 shall be updated periodically to take account of new technical knowledge relative to safety and of development in knowledge concerning the assessment of hazards.

4. In the case of industrial activities for which the quantities, by substance, laid down in Tables I-2. and I-3. as appropriate, are exceeded in a group of installations belonging to the same manufacturer which are less than 500 meters apart, the Member States shall take the necessary steps to ensure that the manufacturer supplies the amount of information required for the notification referred to in paragraph 1, having regard to the fact that the installations are a short distance apart and that any major-accident hazards may therefore be aggravated.

The quantities given in Tables I-2. and I-3. relate to the storage of dangerous substances and/or preparations at any place, installation, premises, building or area or land, isolated or within an

TABLE I-2. LIST OF SUBSTANCES FOR THE APPLICATION OF ARTICLES 3 AND 4

	Substances or groups of substances	Quantity (tonnes) ≥ for application of articles 3 and 4
1.	Acrylonitrile	20
2.	Ammonia	50
3.	Chlorine	10
4.	Sulphur dioxide	25
5.	Ammonium nitrate (1)	350
6.	Ammonium nitrate in the form of fertilizers (2)	1 250
7.	Sodium chlorate	25
8.	Oxygen	200
9.	Sulphur trioxide	15
10.	Carbonyl chloride (Phosgene)	0,750
11.	Hydrogen sulphide	5
12.	Hydrogen fluoride	5
13.	Hydrogen cyanide	5
14.	Carbon disulphide	20
15.	Bromine	50
16.	Acetylene	5
17.	Hydrogen	5
18.	Ethylene oxide	5
19.	Propylene oxide	5
20.	2-Propenal (Acrolein)	20
21.	Formaldehyde (concentration ≥ 90%)	5
22.	Bromomethane (Methyl bromide)	20
23.	Methyl isocyanate	0,150
24.	Tetraethyl lead or tetramethyl lead	5
25.	1,2 Dibromoethane (Ethylene dibromide)	5
26.	Hydrogen chloride (liquefied gas)	25

(1) This applies to ammonium nitrate and mixtures of ammonium nitrate where the nitrogen content derived from the ammonium nitrate is greater than 28% by weight and aqueous solutions of ammonium nitrate where the concentration of ammonium nitrate is greater than 90% by weight.

(2) This applies to straight ammonium nitrate fertilizers which comply with Directive 80/876/EEC and to compound fertilizers where the nitrogen content derived from the ammonium nitrate is greater than 28% by weight (a compound fertilizer contains ammonium nitrate together with phosphate and/or potash).

TABLE I-3. LIST OF SUBSTANCES FOR THE APPLICATION OF ARTICLE 5

Substance	Quantity (for application of Article 5)	CAS number[1)]	EEC number[2)]
Group 1: Toxic substances (Quantity ≤ 1 tonne)			
Aldicarb	100 kilograms	116-06-3	006-017-00X
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	
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 metal, oxides, carbonates, sulphides, as powders	1 tonne		
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
00-Diethyl S-ethylsulphinylmethyl phosphorothioate	100 kilograms	2588-05-08	
00-Diethyl S-ethylsulphonylmethyl phosphorothioate	100 kilograms	2588-06-09	

TABLE I-3 (cont)

Substance	Quantity (for application of Article 5)	CAS number[1)]	EEC number[2)]
00-Diethyl S-ethylthiomethyl phosphorothioate	100 kilograms	2600-69-3	
00-Diethyl S-isopropylthiomethyl phosphorodithioate	100 kilograms	78-52-4	
00-Diethyl S-propylthiomethyl phosphorothioate	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	
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
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-Fluorocrotic acid, salts	1 kilogram		
4-Fluorocrotic acid, esters	1 kilogram		
4-Fluorocrotic 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		

TABLE I-3 (cont)

Substance	Quantity (for application of Article 5)	CAS number[1)]	EEC number[2)]
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	
Hydropen 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	150 kilograms	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 metal, oxides, carbonates, sulphides, as powders	1 tonne		
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
Pensulfothion	100 kilograms	115-90-2	015-090-00-7
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
Phosgene (Carbonyl chloride)	750 kilograms	75-44-5	006-002-00-8
Phosphamidon	100 kilograms	13171-21-6	015-022-00-6
Phosphine (Hydrogen phosphide)	100 kilograms	7803-51-2	
Promurit (1-(3,4-Dichlorophenyl)-3-triazenethio-carboxamide)	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

TABLE I-3 (cont)

Substance	Quantity (for application of Article 5)	CAS number[1)]	EEC number[2)]
Selenium hexafluoride	10 kilograms	7783-79-1	
Sodium selenite	100 kilograms	10102-18-8	
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-Tri(cyclohexyl)stannyl -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
Allyelamine	200 tonnes	107-11-9	612-046-00-1
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	25 tonnes	7782-50-5	017-001-007
Ethylene dibromide (1,2-Dibromoethane)	50 tonnes	106-93-4	602-010-00-6
Ethyleneimine	50 tonnes	151-56-4	613-001-00-1

TABLE I-3 (cont)

Substance	Quantity (for application of Article 5)	CAS number[1)]	EEC number[2)]
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	7783-06-04	016-001-00-4
Methyl bromide (Bromomethane)	200 tonnes	74-83-9	602-002-00-3
Nitrogen oxides	50 tonnes	11104-93-1	
Propyleneimine	50 tonnes	75-55-8	
Sulphur dioxide	250 tonnes	7446-09-5	016-011-00-9
Sulphur trioxide	75 tonnes	7446-11-9	
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	2500 tonnes	6484-52-2	
Ammonium nitrate in the form of fertilizers	5000 tonnes		
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	
Dibenzyl peroxydicarbonate (concentration ≥ 90%)	50 tonnes	2144-45-8	
Di-sec- butyl peroxydicarbonate (concentration ≥ 80%)	50 tonnes	19910-65-7	

TABLE I-3 (cont)

Substance	Quantity (for application of Article 5)	CAS number[1)]	EEC number[2)]
Diethyl peroxydicarbonate (concentration ≥ 30%)	50 tonnes	14666-78-5	
2,2 Dihydroperoxypropane (concentration ≥ 30%)	50 tonnes	2614-76-8	
Di-isobutyl 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	
Liquid oxygen	2000 tonnes	7782-44-7	008-001-00-8
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	
Cyclotrimethylene trinitramine	50 tonnes	121-82-4	
Diazodinitrophenol	10 tonnes	7008-81-3	
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

TABLE I-3 (cont)

Substance	Quantity (for application of Article 5)	CAS number[1)]	EEC number[2)]
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
N-Methyl-N, 2,4,6 -N-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	
Styphinc acid (2,4,6-Trinitroresorcinol)	50 tonnes	82-71-3	609-018-00-9
1,3,5-Triamono-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
Group 5: Flammable substances			
Flammable substances as defined in Article 1, para (c)(i)	200 tonnes		
Flammable substances as defined in Article 1, para (c)(ii)	50000 tonnes		
Flammable substances as defined in Article 1, para (c)(iii)	200 tonnes		

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.

establishment or group of stores belonging to the same manufacturer where the distance between the stores is not sufficient to avoid, in foreseeable circumstances, any aggravation of major accident hazards. These quantities apply in any case to each group of stores belonging to the same manufacturer where the distance between the stores is less than 500 m.

The quantities to be considered are the maximum quantities which are, or are liable to be, in storage at any one time.

Annex II

AWARENESS AND PREPAREDNESS FOR EMERGENCIES AT LOCAL LEVEL (APELL)

II-1. FRAMEWORK OF THE APELL PROCESS

The Industry and Environment 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 local community 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 the 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 extent 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 the key organizational step to make the APELL process work.

The main goal of APELL is to protect the community against loss of life and damage to property and the environment.

- Establishing an emergency response plans in the local area.
- Integrating industry emergency plans with local emergency response plans in a single plan.
- Involving members of the local community in the process of the overall emergency response plan.
- Providing information on the hazards involved in industrial operations on the site, and the measures taken to reduce these risks.

II-1.1. 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 information on hazards and risks from the local plant manager. 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." A 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 attract the attention of industry and government and represent the concerns of the community on hazardous activities. Fig. II-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 to develop a unified and co-ordinated approach to emergency response planning and communication with the community (see Fig. II-2).

- **National Governments:** have the responsibility of organizing, maintaining and reviewing plans for an adequate level of preparedness in emergency conditions. They are encouraged to establish a climate conducive to the implementation of the APELL process.

II-1.2. Scope and Content of APELL

Specific issues have to be addressed in emergency preparedness planning according to the APELL 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 assure that potential overlaps in planning are avoided;

- identify the specific community points of contact and their responsibilities in an emergency situation;

- identify the equipment and materials available at the local level to respond to emergencies;

- identify organizational structure for handling 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 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.

It should be clear that the Co-ordinating Group has not itself a direct operational role during an emergency, but is preparing the various parties involved to be ready and know their tasks should an accident occur.

The practical experience of dealing with emergency situations leads to a ten step approach for the APELL process for planning for emergency preparedness. The corresponding flow chart for implementation is given in Fig. II-3.

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

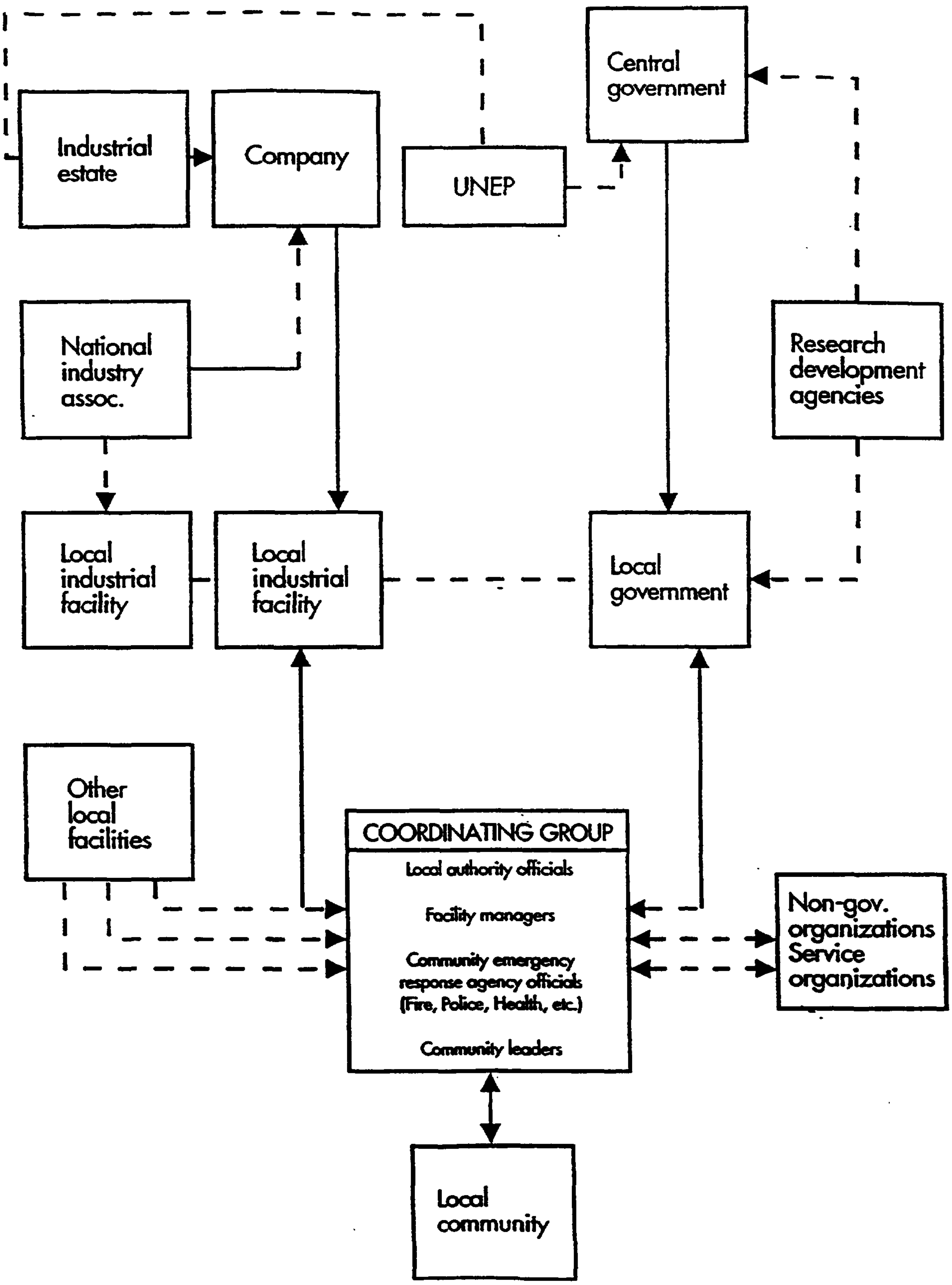

FIG. II-1. APELL information and organization flow chart

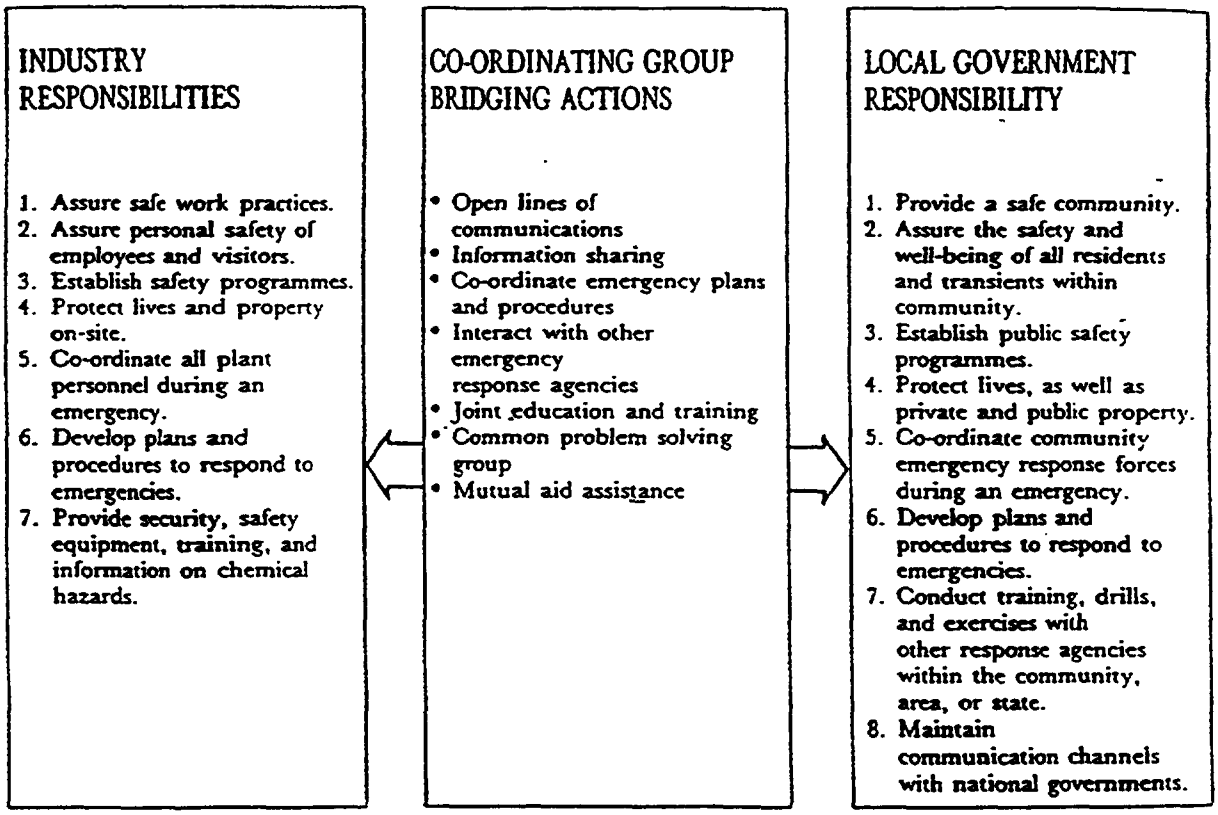

FIG. II-2. Responsibility bridge

equipment and facilities assessment capabilities, protective action procedures, post-emergency procedures, training and 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 the 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 Fig. II-4. The APELL process recommends status reports for industry as well as for local authorities.

II-2. EMERGENCY PLANNING AND PROCEDURES AT THE SITE LEVEL

II-2.1. 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 site. 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 possible to 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 and arrangements to achieve this should be clearly stated. 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.

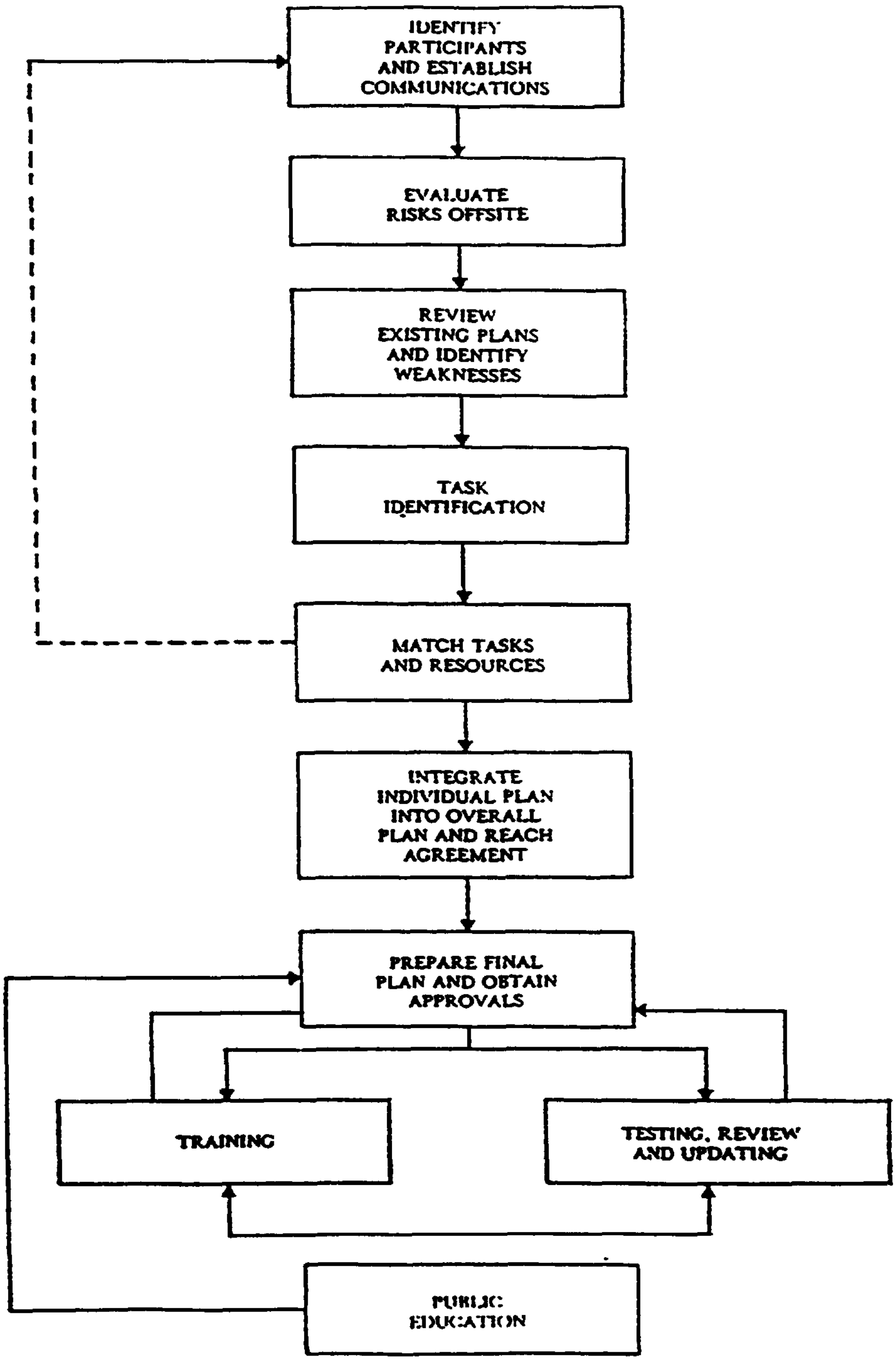

FIG. II-3. Community emergency plan implementation flow chart

II-2.1.1. Essential Elements of Emergency Plans

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;

	Regional				Local Governments (Country/City/Town)							Other (Industrial/Institutional					
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

FIG. II-4. Emergency response plan evaluation matrix

- 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.

II-2.1.2. Principles Applying to Emergency Plans

The following principles apply to the development of an emergency plan and must be incorporated in the plan.

Emergency 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: Fig. II-5 shows in a generalized form the stages in a planned emergency response. The elements in Fig. II-5 should be taken into account in drafting the company plan.

II-2.2. Scope and Content of Emergency Plan

The following information should ideally be included in the formalized emergency plans (see box).

Scope and Content of an 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 Site Plan*

A brief description of the facility covered by the plan should be included together with appropriate site layout.

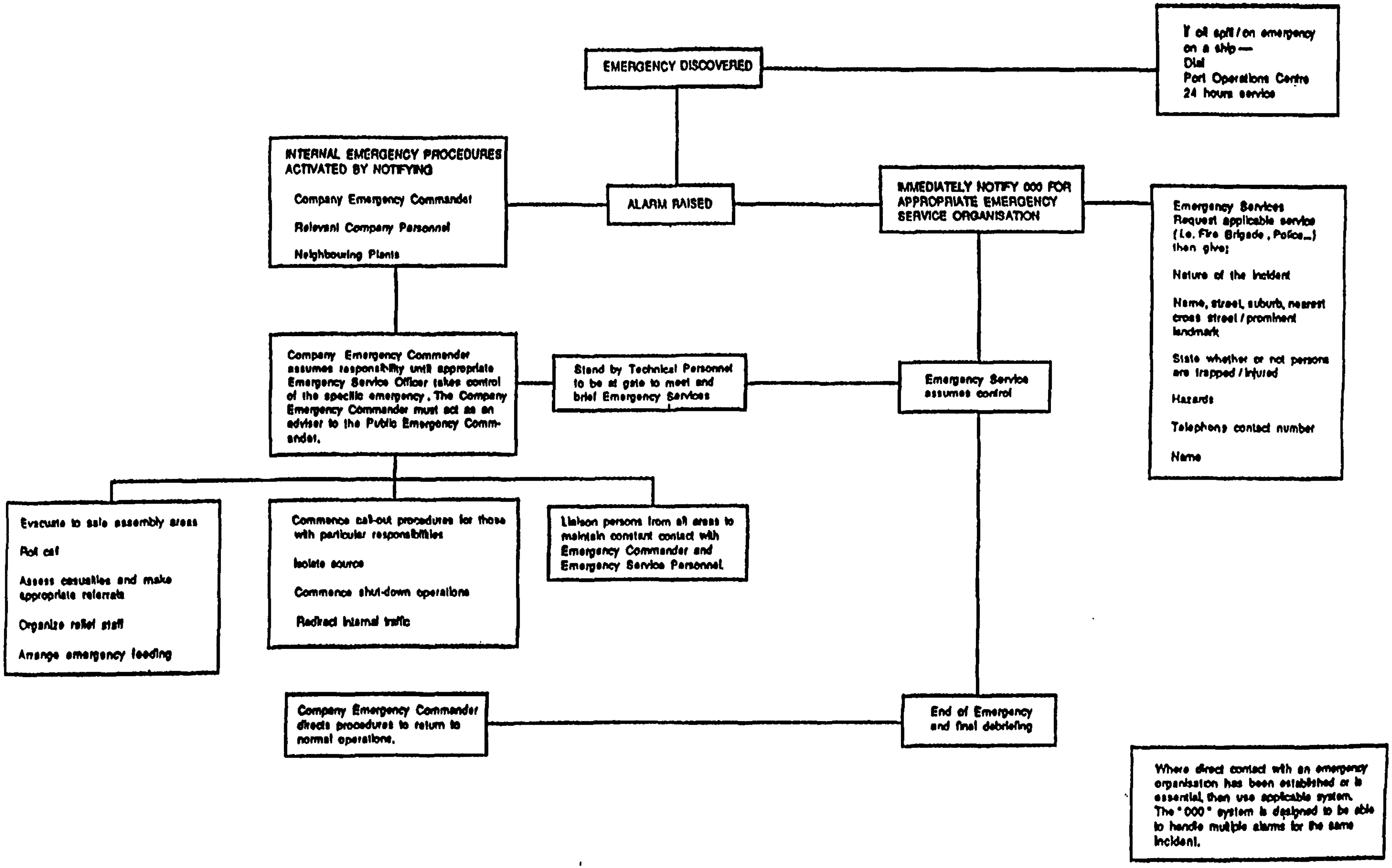

FIG. II-5. Stages in emergency response

(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 in doubt, the 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 the site or on 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 prepared 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 its 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 Accident and Emergency Response*

The types of accidents and emergencies are the crux of the plan. If they are not properly identified the plan cannot be developed on a sound base.

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: (which initiate other on-site events)

Flood, grass fire, bush fire
Earthquake
Cyclones, wind and electric 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 (see Chapters 3 and 5). 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. The intrinsic safety of the 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 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 indicate 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 the alarm should always be activated first and then the doubt clarified.

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 the level of emergency.

The section on alarm initiation 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 alarm is 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 of alarm testing and recording by person within organization.

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 Fig. II-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 center.

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 be necessary. 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 Fig. II-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/her 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 the functions may be combined.

(ix) *Interaction with Emergency Services and Relationships to Existing Plans and Procedures*

Some important general elements of interaction are described in the following.

In any emergency, internal roads must be free of vehicles not involved in handling the emergency. Access <u>must</u> be clear for large service vehicles at all times. 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 external emergency authorities.

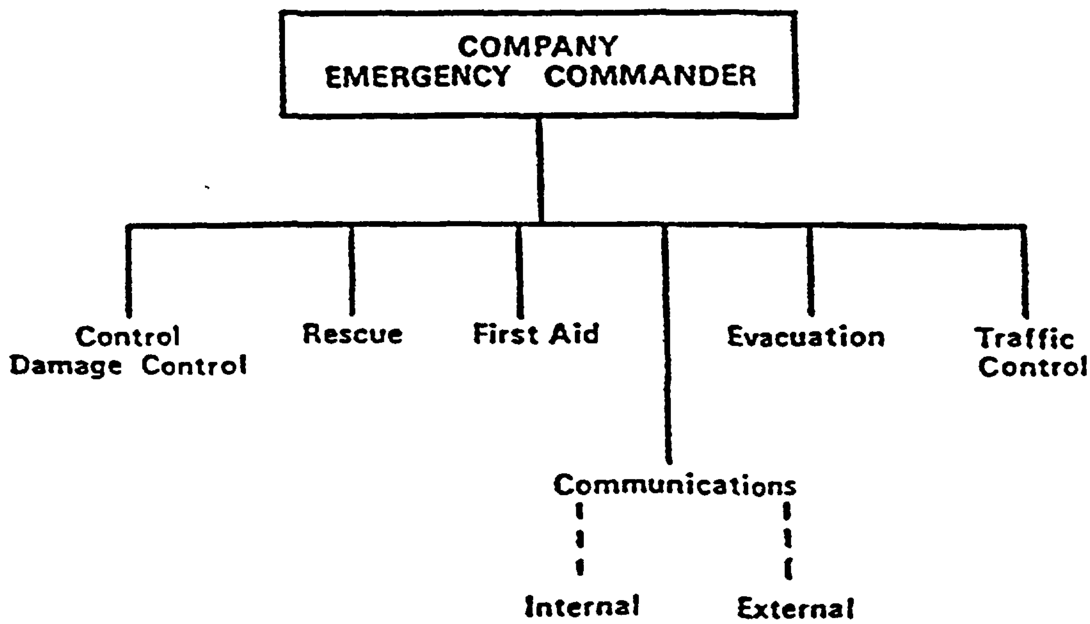

FIG. II-6. Functions of company emergency commander

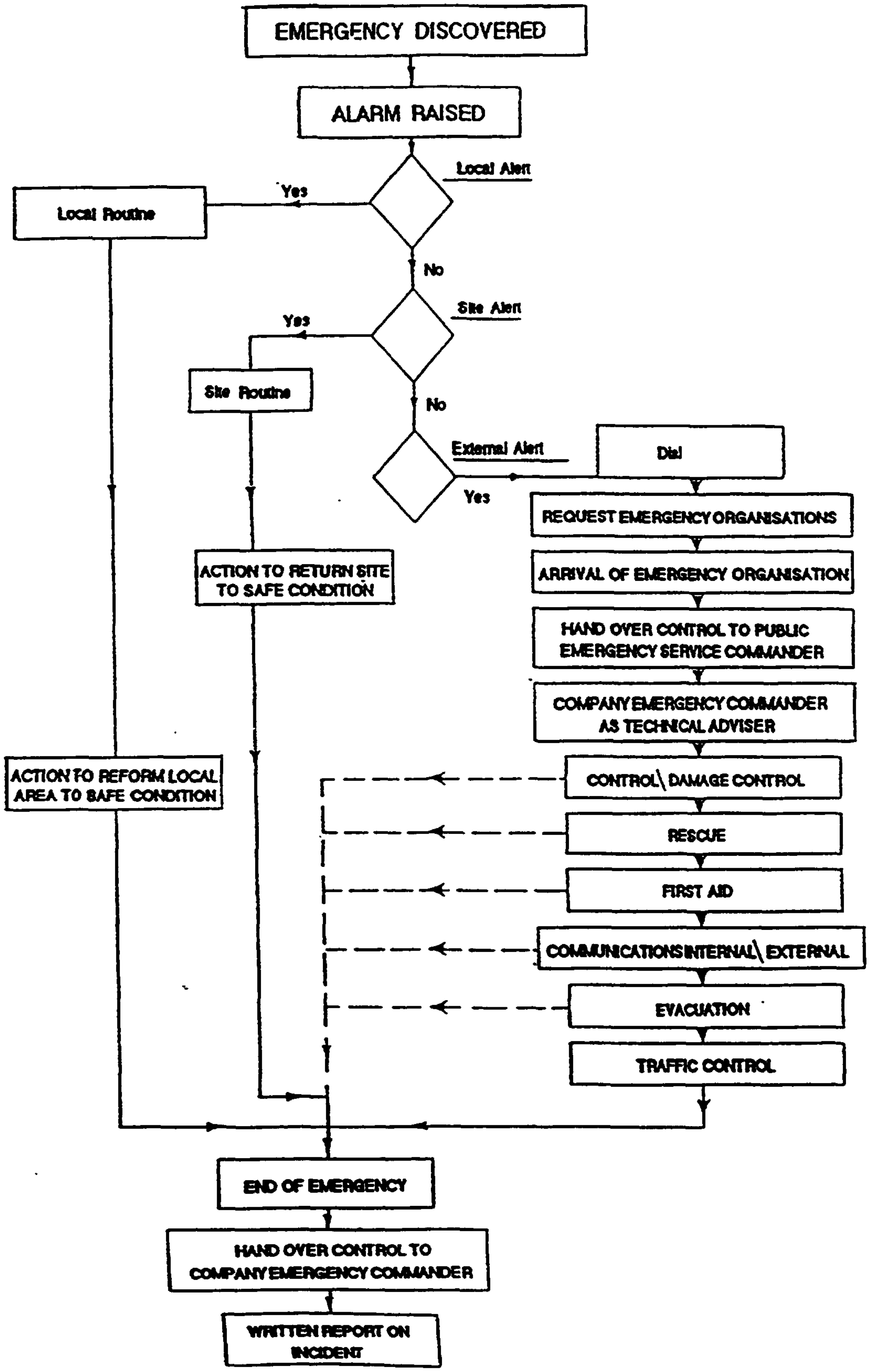

FIG. II-7. Sample emergency organization flow chart

If the emergency operations control centre 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 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, where necessary, the public emergency services, 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

All 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 means for internal and external communications available.

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 must be established.

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 spokesperson for radio and television. This spokesperson may require training to discharge adequately 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 coroner's 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 the 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 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 regular amendments 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 amendments and the frequency of periodic review. It should indicate 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 are considered. This list is also necessary to ensure that revisions and updates are provided to everyone holding the plan.

Typical components of a plant emergency plan whereas a chemical plant's emergency plan draws upon all of the site's disciplines, it is top management's leadership role, by example, that is of prime importance to long lasting success.

Accident prevention programmes must be firmly in place. they include technology selection, plant design, construction, and operation as well as operator selection and training. Prevention must be backed up with an emergency plan involving all site people and co-ordinated with the local community. The plans should be tested under hypothetical conditions at least annually. Each test should be documented.

Every industrial site should have positive answers to the following questions:

- Has site management considered all potential emergency types and decided what to do, for example, in the case of toxic gas release, fire, explosion, severe weather, utility failure, bomb threats, etc.?
- Is there a formalized emergency plan, is it up to date, what is the last revision date?
- Who is responsible for keeping the plan up to date?
- Are tests run regularly? What frequency? Are they documented?
- Does the plan consider emergencies in neighboring plants?
- Does the site have an effective emergency alarm system?
- Does the site have an emergency control centre and backup?
- Does the centre have adequate communication devices, underground drawings, personnel lists, etc.?
- Does the site have access to adequate emergency control equipment above that which is available at the plant?
- What is the system to inform emergency crews of the potential emergency scene hazards? (toxicity, reactivity, etc.)?
- Are emergency block valves, including underground key service shut-off valves to each plant identified and accessible in an emergency?
- Have those pieces of process equipment been identified that require back up power in the event of power failure what about emergency lighting for key plants laboratories and buildings?
- Has the site identified a public relations contact man for emergencies?
- Are vital records secured from possible loss?
- Are first responders trained adequately in medical and first aid?
- Are on- and off-site medical resources and facilities inventories, trained and involved in emergency planning and practice?

II-3 EMERGENCY PLANNING AND PROCEDURES ON AN INDUSTRIAL AREA BASIS

II-3.1 Overview

Emergency procedures and plans at the site 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 off-site area planning is the responsibility of the civil authorities although the management of the various sites involved can clearly assist.

The plan should specify how the company's emergency response operates in relation to the various emergency services.

- Related Plans and Procedures
- The Operational Plan
  - Alerting Procedures
  - Command
  - Control Centers
  - Access to Technical Information
  - Response
  - Evacuation
  - 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 adequacy of response resources and response capacity in the area 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 which 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) *Co-ordinating Group*: The formulation, administration, implementation, update and review should be undertaken by the APELL Co-ordinating Group comprising representatives of all relevant organizations, ideally: emergency service organizations (police, fire brigade, ambulance), industry (operating plants in the area), health authorities, local councils and community groups. In addition to the preparation of the overall plan, the group should be responsible for its continuous update. The group also has the responsibility for vetting and reviewing the individual industry plans and other sub-plans and for ensuring consistency with other related plans.

(v) *Plant Area Characteristics*: The subject area and its characteristics should be comprehensively described in the emergency plan document, with associated support maps. Information to be considered includes 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 to comprehensively identify and quantify, as far as possible, the type, scale and nature of possible events requiring emergency response, the nature and scale of impacts and the required response. In addition, the plan should contain a comprehensive and systematic set of hazardous incident scenarios and the consequences, the magnitude and nature of harm, to both people and environment, should be computed.

Emergency situations can broadly be divided into three categories:

(i) hazardous materials incidents; (ii) natural events; (iii) incidents caused by man-made technology. From the inventory and location of hazardous materials and processes in the area, it is possible to estimate the area of fatality or 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 during the production of combustion products, 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 relate to and refer wherever possible to other emergency plans or procedures applicable to the area. 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 document 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 stated.
- **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 Centers:** to be established and specified in the plan. The function of these center(s) is to act as the center for communication and co-ordination during emergencies.
- **Access to Technical Information:** access to accurate data on the chemicals at the time of an incident is essential. The operating plan should make provisions for the location and access to updated data sheets and relevant information.
- **Response:** the operating plan should specify response actions 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 response 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 an 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 Co-ordinating Group should maintain an up-to-date resource list to be maintained in the site plans and in related plans and procedures. The adequacy 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' exercises 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 reviews of particular scenarios should be conducted from time to time.

II-3.3. Co-ordination of On- and Off-Site Emergency Plans

Liaison between site management and the civil authorities should ensure that:

- There is a properly co-ordinated set of plans which will be effectively controlled;
- Works procedures are in harmony with plans developed by outside authorities;
- Outside services understand the nature of the risks and have appropriate knowledge, equipment and materials to deal with them;
- The equipment of the works and outside services is compatible;
- The personnel of the works and outside services who are likely to have to co-operate in an emergency already know each other;
- The appropriate type and number of outside services reach the scene promptly.

Annex III

FIRE PREVENTION AND PROTECTION

III-1. INTRODUCTION

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 area level where cumulative infrastructure requirements should be considered. The basic principle is that each industrial facility handling hazardous materials should accommodate adequate design, equipment, 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 relevance and appropriateness of fire prevention and protection measures.

An adequate level of fire protection at the plant level however, cannot 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 area with a concentration of hazardous plants, where cumulative requirements need to be considered. The adequate provisions of fire prevention and protection infrastructure at an area level should complement on-site plant level provisions and be an integral part of the overall safety management process.

This Annex provides an overall guidance as to the safety management aspects of fire protection and prevention at both the plant and the area levels.

III-2. 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 a 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 alone.

Defining the hazard potential of an area, plant and/or operation 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 an area 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 Fig. III-1.

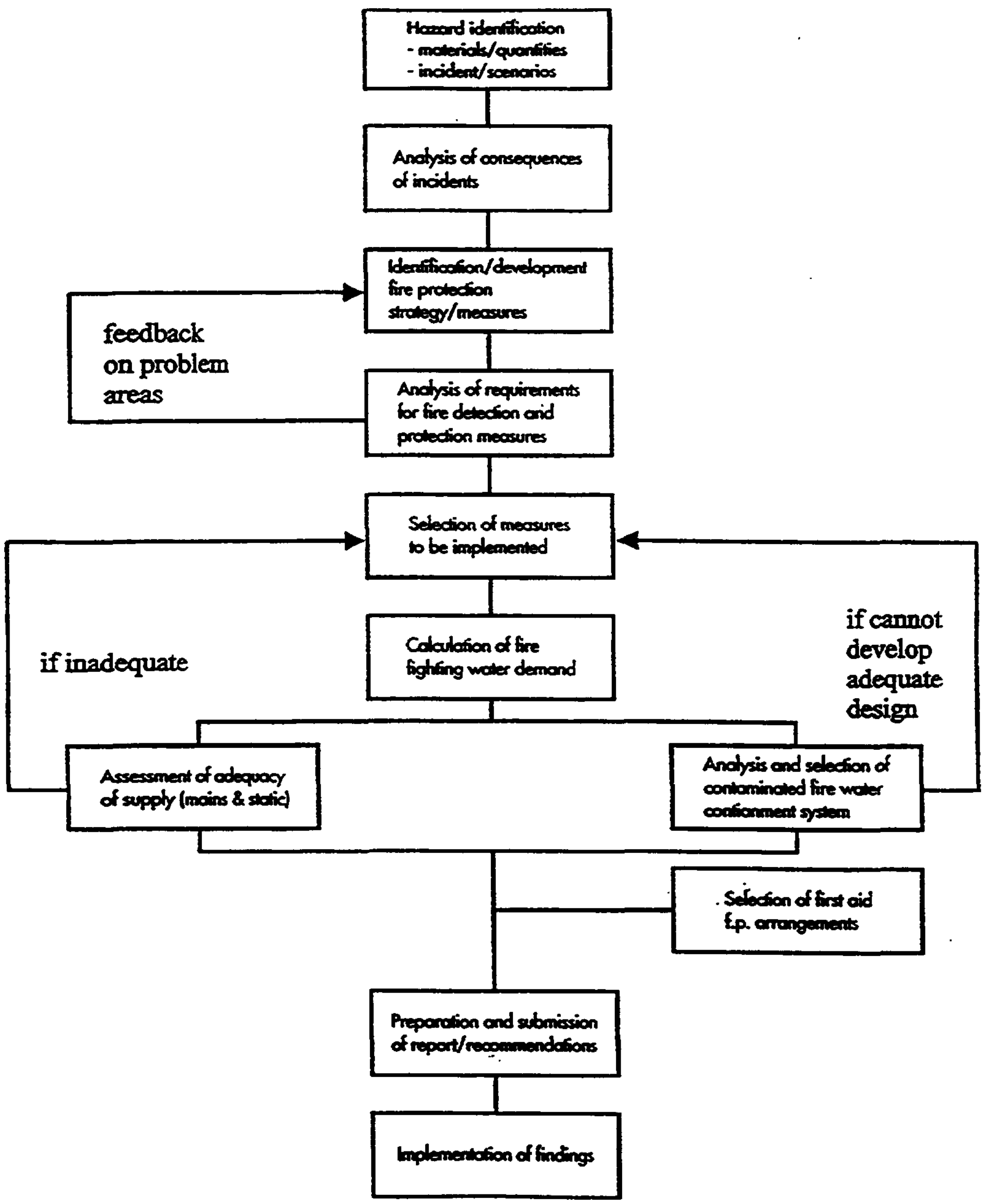

FIG. III-1. Flow diagram for a fire safety study

III-3. 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 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. (see Table III-1)

III-4. 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 and assumptions 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.

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 largely drawn from that study.

III-5. 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.

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.).

TABLE III-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 Petrochemical tanks(cool fire)	Corrosion tank base/floor Pipeline/pump leakage/rupture Tank overfilled Adjacent tank fire or bund fire heating tank contents to decomposition	Leakage of tank contents into bund. If ignited may result in pool or bund fire Emission or toxic products or vapours. Downwind effects depend on toxicant released and wind/stability conditions	Tanks cleaned, inspected, integrity tested annually Adequate foam stocks on site High level alarms to be provided on all storage tanks Foam/monitors to be provided in and around bund compound Tanks placed in separate bund Cooling system on all tanks

TABLE III-1. (cont)

Facility/Event	Cause/Comments	Possible Results Consequences	Prevention/Detection/ Protection Required
LPG Road Tanker Facility			
Flexible hose failure	Road tanker drives away whilst still connected	Gas disperses. If ignited may result in flash fire. Impact local	Fixed deluge system at road tanker bay
	Third party damage or excessive wear		Scully system on tanker loading
Pipe failure	Mechanical impact		Area drained
	Corrosion		Gas detectors around perimeter of LPG area
Pump seal failure	Pump not maintained		Pump shut off at two locations, local and remote
	Pump run dry		Isolation systems on main liquid lines
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			

TABLE III-1. (cont)

Facility/Event	Cause/Comments	Possible Results Consequences	Prevention/Detection/ Protection Required
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

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.

III-6. 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 of vapor spaces with inert gases.

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, 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, valves, switch or control actuators (local or remote).

Road and rail vehicles 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 have to be used.

The use of halons for proposed as 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.

III-7. 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 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 town 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.

III-8. 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, testing, treatment and disposal arrangements. The possibility of soil and groundwater contamination should be considered in the analysis.

III-9. 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.

III-10. 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 an area 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 area, 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 fire fighting media such as foam, dry powder, emergency equipment, etc. The facility location should be optimized in terms of accessibility to the different joint users.
- The formation of a mutual aid group to co-ordinate 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 area under consideration.

ABBREVIATIONS

AADT	Annual average daily traffic
ACDS	Advisory Committee on Dangerous Substances
ACMH	Advisory Committee on Major Hazards
AIChE	American Institute of Chemical Engineers
AIHA	American Industrial Hygiene Association
APELL	Awareness and Preparedness for Emergencies at Local Level
BLEVE	Boiling Liquid Expanding Vapour Explosion
BOD	Biochemical Oxygen Demand
Btu	British thermal unit
CAS	Chemical Abstracts Number
C.E.	Coal Equivalent
CEC	Commission of the European Communities
CFC	Chlorofluorocarbons
CFR	Code of Federal Regulations (USA)
CIMAH	Control of Industrial Major Accidents Hazards Regulations
DOE	Department of Energy (USA)
DOT	Department of Transportation (USA)
DWT	Deadweight
EEGL	Emergency Exposure Guidance Level
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency (USA)
ERDS	Event Recording Data System
ERPG	Emergency Response Planning Guidelines
FMEA	Failure Mode and Effects Analysis
FTA	Fault Tree Analysis
HASAWA	Health and Safety at Work etc. Act (UK)
HAZOP	Hazard and Operability Study
HSC	Health and Safety Commission (UK)
HSE	Health and Safety Executive (UK)
IARC	International Agency for Research on Cancer
IDLH	Immediately Dangerous to Life or Health
IHI	Initial Hazard Identification
ILO	International Labour Organisation
ISO	International Organization for Standardization
LC	Lethal Concentration
LD	Lethal Dose
LNG	Liquified Natural Gas
LPG	Liquified Petroleum Gas
MF	Management Factor
MHAU	Major Hazards Assment Unit
MHIDAS	SRD/HSE Major Hazards Incidents Data Source
MOR	Modification of Risk
NGO	Non-Governmental Organization
NIHHS	Notification of Installations Handling Hazardous Substances
NIOSH	National Institute for Occupational Safety and Health
NOAEL	No Observed Adverse Effect Level
NRC	Nuclear Regulatory Commission
NTP	National Toxicity Program
OECD	Organization of Economic Co-operation and Development
PCB	Polychlorinated Biphenyls
PCU	Passenger Car Unit
PHI	Potential Hazard Index

PM	Particulate Matter
PSC	Probabilistic Safety Criteria
QHA	Quantified Hazard Analysis
QRA	Quantified Risk Analysis
S.I.	Severity Index
SMS	Safety Management System
SPEGL	Short-Term Public Emergency Guidance Level
SRD	Safety and Reliability Directorate (UK)
SRS	Systems Reliability Service
STEL	Short-Term Exposure Limit
TDS	Total Dissolved Solids
TLV	Threshold Limit Values
TNO	The Netherlands Organization of Applied Scientific Research
TNT	Trinitrotaluene
TOC	Total Organic Carbon
TP	Thoracic Particles
TPD	Ton per day
TSP	Total Suspended Particulates
TTO	Total Toxic Organics
UKAEA	United Kingdom Atomic Energy Authority
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
US NOAA	National Oceanic and Atmospheric Administration
UVCE	Unconfined Vapour Cloud Explosion
VCE	Vapour Cloud Explosion
VOC	Volatile Organic Carbon
VROM	Ministry van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer (Netherlands)
WHO	World Health Organization

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