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TECHNICAL REPORT N°12

# **HAZARD IDENTIFICATION AND EVALUATION IN A LOCAL COMMUNITY**

This is the twelfth publication in a Technical Report Series that regroups the Guidelines, Overviews, Technical Reviews, and Workshop Proceedings previously published by UNEP IE/PAC. The regrouping into a single series will ensure a greater cohesion among future publications, and allows a single document to include the various elements of IE/PAC work that had earlier been presented separately.

As before, the Technical Report Series aims to meet the needs of a wide range of government officials, industry managers and environment protection associations, by providing information on the issues and methods of environmental management relevant to various industrial sectors.

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Work on both Swedish and English versions has been co-ordinated by Tommy Rosenberg, Rescue Director, Swedish National Rescue Services Board. UNEP would like to express its gratitude to him and to the Swedish National Rescue Services Board and the Swedish government for making his expertise available to APELL users worldwide.

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# FOREWORD

Awareness and Preparedness for Emergencies at Local Level (APELL) is a programme aimed at increasing prevention of technological accidents and improving emergency preparedness. It offers assistance to decision-makers in government, local authorities and industry, through providing relevant information and documents, training activities and technical support.

The APELL programme was launched in 1988 by the United Nations Environment Programme's Industry and Environment Programme Activity Centre (UNEP IE/PAC), in co-operation with governments and the chemical industry. This initiative followed various major technological accidents, in both industrialized and industrializing countries. As a first step the APELL Handbook was published. This describes a ten-stage process to guide local communities in strengthening their accident prevention and emergency response capability. APELL calls for leaders of industry, government and the community to co-operate, with the objective of identifying and evaluating hazards in the locality and of initiating plans to respond to the emergencies which could result from them.

This Technical Report on "Hazard Identification and Evaluation in a Local Community", prepared with the support of the Swedish Government and its National Rescue Services Board, will help all those concerned with the identification and evaluation of hazards in the community: particularly local government; police, fire and rescue services; and industry. The report consists of three parts. The introduction provides a general background to the handbook and gives some definitions. The second part describes the hazard analysis method and gives concrete examples of how to implement it. The third part consists of a series of Annexes, which provide more information to enable local communities to identify and evaluate hazards.

The UN Conference on Environment and Development's Agenda 21 calls for further implementation of and support for APELL. UNEP IE/PAC hopes that governments, communities and industries around the world which are putting APELL into practice will find the Guide useful and a source of continuing help.

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# 1

# INTRODUCTION

## 1.1

## The Scope of the Handbook

This Handbook is part of UNEP's Awareness and Preparedness for Emergencies at Local Level (APELL) programme .

**APELL deals with technical and industrial accidents.**

**The programme is designed to promote local co-operative action in order to create and/or increase community awareness of hazards that are potential threats to people, property and the environment; and to create and/or improve emergency preparedness.**

In the APELL-Handbook you will find on Pp.33-41 a ten-step approach to the process of planning for emergency preparedness at local level.

**This Handbook deals with and expands STEP 2 of the APELL process:**

**" Evaluate the risks and hazards which may result in emergency situations in the community".**

It deals with hazard identification, evaluation and ranking of risk objects, in relation to potential technical and industrial accidents in a local community. It provides a method for carrying out this work.

**The aims are to show how risk objects can be identified, evaluated and ranked by a basic "rough-analysis" method and to encourage an increased risk-consciousness and environmental awareness as development takes place in the community.**

Accordingly, the accidents considered here are events such as : large fires, explosions, leakages of substances which are poisonous or harmful to the environment, and natural disasters which could cause industrial accidents, such as landslides or floods.

This Handbook does not go into the risks associated with long-term climatic conditions or with the various leakages of hazardous substances from "normal" production in industry ( otherwise known as "normal operational emissions").

Its scope also excludes nuclear accidents and those of a strictly military nature.

Although the Handbook is concerned with industrial accidents and accidents with industry-related activities, the method presented can also be used for other types of accidents.

The Handbook is not intended to give examples of every kind of accident that could possibly occur.

It does not give detailed information on various substances and their possible accident risks and effects on-site or off-site. This type of information can be obtained from computerised databases, other handbooks (see references), etc.

**What the Handbook does do is to give you a "toolbox" with which to get started on the work of analysing potential hazards to get an overview of the most serious threats to people, property and the environment in the area, in order to improve safety measures, allocate resources, etc.**

It gives you the basics for hazard analysis. Various "tools" can be selected which are suitable for specific local conditions. They can be replaced or complemented by better ones when these become available, as a result of future studies or of increased hazard analysis know-how within the local community.

Some other risk analysis methods used by industry and other bodies are presented in Annex 3.7. They are outside the scope of this Handbook. However they could be of interest if and when you would like to go more deeply into Hazard Analysis.

**The Handbook is intended for people from industry, the fire and rescue services, environmental protection and health authorities and others, who have only limited experience of working in risk-related areas.**

"The heart of this process is a Co-ordinating Group of local authorities, community leaders, industry managers, and other interested persons."  
(APELL Handbook, Introduction, P.11.)

This Handbook has been designed to help these people answer the following questions:

- Where are the risk objects and hazards in our community?
- How do we define the hazards?
- How do we evaluate the hazards and the risk zones, as against the threatened objects?
- How do we rank the risk objects?
- How could the result of the analysis be presented to serve as a basis for the next steps of the APELL process?

Later steps in the APELL procedure involve incorporating the results of hazard analysis into the overall emergency planning process. Emergency planning includes: developing appropriate warning systems; providing for personal protection (in-place protection or evacuation); developing procedures for fire-fighters and other responders; being familiar with the health effects of chemicals; and providing for safe control and cleaning of the release or spill. (Detailed information about emergency planning is to be found in the US National Response Team's "Hazardous Materials Emergency Planning Guide" - see Annex 3.8.)

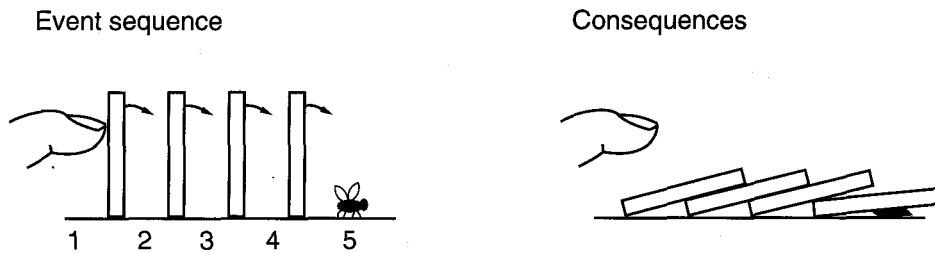
## 1.2 Some definitions

This section outlines certain terms used in the Handbook which are of importance for hazard identification and evaluation.

**Accident** - an unintended and unexpected event, occurring suddenly and causing damage to people, property or the environment.



**Accident event sequence** - a series of interdependent events leading to an accident.



**Consequences** - the results of an accident, expressed in quantitative or qualitative terms.

**Dimensioned damage estimate** - an estimate of the level of damage which can be expected from a hazard in a certain kind of accident. The worst case event is often considered so improbable that a smaller and more probable event is chosen as the basis for hazard evaluation and decisions on safety measures. For example, large storage tanks are designed so that it is very unlikely that all the contents would escape in the event of an accident. A leak from a pipe or valve is considered a more likely event and this is therefore chosen as the dimensioned damage estimate, for classification of the risk object, preparation of response plans, etc.

**Disaster** - is here taken from a local viewpoint to mean several deaths and tens of severely injured survivors, damage to property to a value of several million US dollars or long-term damage to the environment.

**External events** - e.g. lightning, extremely unusual weather conditions, earthquake, flooding, landslide.

**Good practice** - means following all the laws and regulations, as well as applying the standards, methods and routines which, over the years, have been shown to be the best.

**Hazard** - a threat which could cause an accident (alternatively, risk source).

**Incident** - the result of a chain of events which could have led to an accident if it had not been halted (a "near miss").

**Initiating event** - the first step in a chain of events leading to an accident.

**Knock-on effect** - a consequence resulting inevitably but indirectly from another event or circumstance.

**Malfunction** - a deviation from the expected functioning of a system.

**Maloperation** - a deviation from the expected behaviour of an operating system. This can be caused by a lack of understanding, stress, badly designed systems, misinterpretation of information or negligence.

**Probability** - expected scale of events (accidents) within a certain period of time.

**Risk** - is here taken to mean the probability of an accident occurring within a certain time, together with the consequences for people, property and the environment.

**Risk analysis** - is the systematic identification and evaluation of risk objects and hazards.

**Risk management** - covers all work related to risk, i.e. administration, insurance, inventories, valuations, inspections, etc.

**Risk object** - an industry, warehouse, railway yard, etc., containing a hazard or risk source. N.B. There may be various risk sources within any one risk object.

**Risk source** - see "Hazard"

**Risk zone** - the area surrounding a risk object which could be affected by an accident there.

**Safety survey** - a detailed investigation and risk analysis of a system. Various courses of events are studied to show the effects of efforts to reduce risk levels by taking different preventive measures.

**Safety zone** - an estimate of the distance required between a risk object and surrounding threatened objects.

**Threatened object** - people, environmental objects or property which are at risk from an accident due to a risk object in the vicinity.

**Worst case** - the possible event with the worst consequences. There are three types of "worst case":

1. the consequences are so limited that the risk is unimportant, whatever the probability of the event;

2. the consequences are so serious that the probability of the event must be very small if there is to be a tolerable level of risk. In extreme cases the lack of effective safety measures makes the risk intolerable;

3. the worst possible consequences are irrelevant since the probability is so low that the risk is negligible. However, when this kind of judgement is being made, the effects of sabotage and terrorism should be considered. This may mean that type 2 is chosen.

## 1.3

# Dealing with Risks

From a historical perspective, people have always been involved in risk management. If we go back in time, we can find a quotation from Pindaros, the Greek poet (518-442 BC), which is just as applicable today:

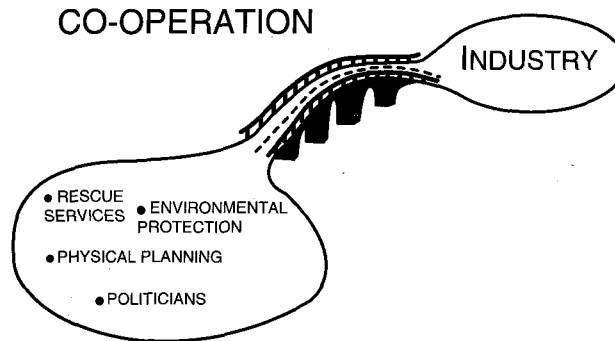
**"Blind are the thoughts we cast to the future. Against all the odds, innumerable things will happen"**

There is no such thing as zero risk. Nothing can be made 100% safe - whether we mean packaging, equipment, routines, vehicles or installations. In addition, terrorism or sabotage could lead to an accident which would be unexpected, such as a dam collapse, multiple fires or simultaneous explosions. Society is becoming ever more vulnerable. We can no longer use trial and error methods to direct the shape society takes in the future.

The authorities responsible for environmental protection, health and town planning should know more about the hazards present in the area and the circumstances which could lead to a disaster.

Industry must know its products and the hazards associated with them which could lead to accidents. It should freely communicate adequate information to fire and rescue services, the public and others.

In many places both community and industry are aware of the need to predict and prevent accidents. Unfortunately, all too often they work independently of each other! Often their individual efforts could be enhanced by co-operation.



It is necessary for maximum benefits and effectiveness to cooperate, agreeing on what threats are present and what the relevant responses should be. An earthquake does not respect political or administrative boundaries; a barbed wire fence round a chemical plant cannot contain a cloud of toxic gas.

Resources, including trained people, should be organised and deployed where they will have the greatest effect.

Co-operation at the local level is very essential and should lead to co-ordinated, effective and economically practical risk management, influencing both existing hazards and the shape society takes in the future.

Systematic work to identify, evaluate and rank various risk objects will make the threats more visible. It will therefore assist in making judgements ( as shown in steps 3-10 of the APELL process) on what preventive measures etc. will be most effective to protect people, property and the environment according to their vulnerability.

**There are two aspects of the term "risk" here:**

- **the probability of an accident occurring within a certain time;**
- **the consequences for people, property and the environment.**

Hazard analysis is an attempt to weigh the consequences of an accident against the probability of the accident occurring. The probability and consequences can rarely be calculated with mathematical precision. However, they can often be estimated with sufficient accuracy to provide the basis for practical measures to counter the risks.

The probability of an accident occurring and causing damage is reduced if the danger is recognized by all those affected and the cause and effects of the event are understood. Studies of consequences of combined effects are also very important (eg. fires causing poisonous gas, explosions causing leakages of poisonous substances, etc).

Developments in society are resulting in factories and housing areas being located nearer to each other. At the same time the transport of inflammable, explosive and environmentally hazardous chemicals is increasing. The demands for improved efficiency and increased capacity often lead to more sophisticated equipment and more dangerous processes being used in industry. This implies that the need for an effective way of handling risks is growing within both industry itself and society in general.

The people responsible for making decisions in industries where the greatest risks of major accidents exist must recognize the need for effective handling of these risks.

There are several reasons for this. For example:

- the health and safety of employees and those living near the factory;
- the avoidance of damage to property and the environment;
- industry's need for good relations with the authorities and the general public, if it is to develop in a positive way;
- the need for uninterrupted production, in order to maintain reliable delivery and good customer relations,
- the cost of damage to its own factory, as well as those located nearby, which could jeopardize the survival of the company.

An accident can also affect the general public's attitude towards industry. The pressure of public opinion can force a company to close down. It is not enough for a company to rely on insurance payments as its only way to cope with hazards!

The management of these hazards to prevent accidents is therefore needed within industry, with the involvement of local authorities. This work should cover both practical and administrative matters, as well as management routines.

Efforts to prevent accidents demand full commitment and substantial resources, especially in "high risk" industries. Smaller companies, suppliers etc. may need to draw on assistance from larger companies. All the same, accidents can never be eliminated completely, however great the efforts to prevent them. A well trained and equipped rescue service, on-site and off-site, will always be required.

In working with hazard analysis, as well as communicating the results of the analysis, we must realise that people feel very anxious about a variety of threats to life, health, property and the environment. This anxiety is rarely based objectively on the risks involved. As far as probability and consequences are concerned, some of the most serious sources of risk are travelling by car, smoking and drinking alcohol. However these risks do not cause much anxiety. This could be due to the fact that an individual has the ability to take in the significance of these risks, and experiences them in everyday life. In addition, the way a particular risk is judged is often affected by the opportunity an individual has to avoid exposing himself to it.



*Car accident on the Boulevard Périphérique, Paris, April 1989.  
Photo : Direction de la Sécurité et de la Circulation Routière.*

It is vital that people are aware of the hazards to which they are exposed. They must know where the hazards are that could injure them and what the situation is really like there, if they are to know how to protect themselves. Newspaper headlines concentrate on the sensational aspects of a story, giving less space to objective descriptions of an accident.

In the back of most people's minds there is a misplaced optimism that "an accident cannot happen to me". This is particularly obvious in relation to road accidents. The statistics are shocking. In the last 30 years 5 1/2 million people have been killed in the Western world (including Japan). 230 million have been injured, a quarter of them seriously. Why aren't day-to-day road accidents regarded with the same degree of interest as (for example) chemical accidents? This is perhaps partly due to the fact that we are used to hearing about road accidents and we choose to expose ourselves to the risk.

The risks which people expose themselves by choice, in connection with activities such as rock-climbing, skiing, sailing, driving a car and cycling, are many times higher than the risks associated with nuclear accidents, large chemical leakages, fires and the like. (As far as the individual himself is concerned, the consequences of either kind of risk could be disastrous). The latter kind of accident is however viewed with much greater anxiety by the majority of people; an anxiety which is often based on a very imprecise knowledge of the probabilities, causes and effects of these accidents. It is therefore most important to achieve a more accurate perception of actual threats.

When considering accident risk and ranking risk objects it is necessary to make comparisons in the knowledge that risk analysis is dealing with uncertainties. The greatest difficulty is in evaluating and comparing very small probabilities. Statistics can be useful when ranking risk-objects but the collective experience of the Co-ordinating Group is most important.

The problem with statistics is that they show what has happened, not when the next accident will take place. Conditions vary greatly from case to case. An estimate of probability is, by definition, not the same thing as a firm prediction.

But we can use statistics to make comparisons, show trends and estimate the effects of preventive measures. The statistics must be up to date and consistent. It is important that every country and local authority keeps its own collection of statistics, in order to be able to follow developments and gain understanding of these matters.

**Both probability and consequences must be considered when drawing conclusions from comparisons. It is common to concentrate on the risks with the greatest consequences. When attempting to reduce risk levels systematically, however, it may be necessary to weigh an event with low probability but serious consequences against one which is more likely but causes less damage.**

## 1.4

# Benefits of Hazard Identification and Evaluation

Dialogue and co-operation between different authorities in a community, together with industry, is very important when evaluating threats, looking at the possibilities of reducing them and allocating responsibilities and resources.

The analysis should also be followed up by preventive measures of various kinds. These will always be required, together with an effective emergency response system, since society can never be made completely risk-free. The knowledge and experience that communities gain from the analysis should be taken into account in work on:

- emergency planning
- choice of routes for the transport of dangerous goods
- information and warning systems
- civil defence
- physical planning
- environmental protection, etc

The Handbook contains several examples of accidents arising from planning decisions that were questionable from the risk standpoint. For example, residential areas have been built or extended around dangerous industrial plants, airports etc. Planning permission has been given for houses or factories on land liable to landslide or flooding. New hospitals have been located beside dangerous industries. New houses have been built near large petrochemical stores, etc.

Chances of achieving a greater degree of risk-consciousness as society develops are improved by increased co-operation between the local authority's planning and executive bodies.

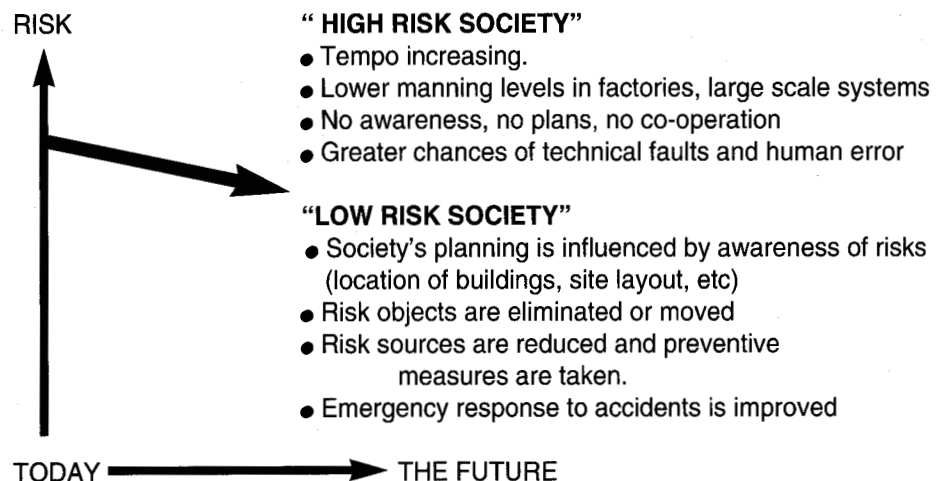
Co-operation is required not only within the community (industries included) but also between communities; so that each may produce its own co-ordinated picture of risks, and thereby improve risk-consciousness, in order to develop or to review its emergency plans etc. Several communities can share the same risk object - the effects of an accident there can reach across boundaries.

The community should judge which hazards can be reduced, or risk objects made safer, by moving people or industry to another location, and should decide whether this can be done in the short or long term. It is very expensive to move an industrial site once it has been built. It is therefore desirable that a risk object should be built in as safe a location as possible. When this has been done, a hospital, school or residential area should not be built next to it.

When considering hazards in society it is also wise to look at industrial and technological developments expected in the future.

"Progress" and "the future" are often considered only as an extension of what has happened in the past. Prediction of other possible scenarios and making plans for these are just as important for effective risk management. All forecasts soon become out-of-date. They must be reviewed regularly if they are to serve their purpose.

The experience, information and results obtained from hazard identification and evaluation can influence the shape society will take in the future.



# 1.5 How to Use the Handbook

## APELL Step 1:

"Identify participants in the Co-ordinating group and establish communications".

## APELL Step 2:

"Evaluate the risks and hazards which may result in emergency situations in the community"

In what follows, you will find an overview of the second step of the APELL process and a guide to this Handbook.

### HAZARD IDENTIFICATION, EVALUATION AND RANKING: STAGES

**WHERE** are the risk objects and the hazards?

(Examples, see chapter 2, figure 2:2 )

The risk objects and hazards can be found in

- industry
- terminals
- supplies
- transport lines
- public facilities (e.g. schools and hospitals), etc.

The local authorities and industries are the responsible actors here. Interaction between them and sharing the same perception of the risk objects and hazards are very important.

**DEFINE** the hazards. (Examples, see chapter 2, figures 2.1-2.4 and annexes 3.1-3.6)

Figure 2.1

COMMUNITY.....  
OBJECT/AREA.....

L = Life                      S = Speed  
E = Environment        Pb = Probability  
P = Property             Pr = Priority

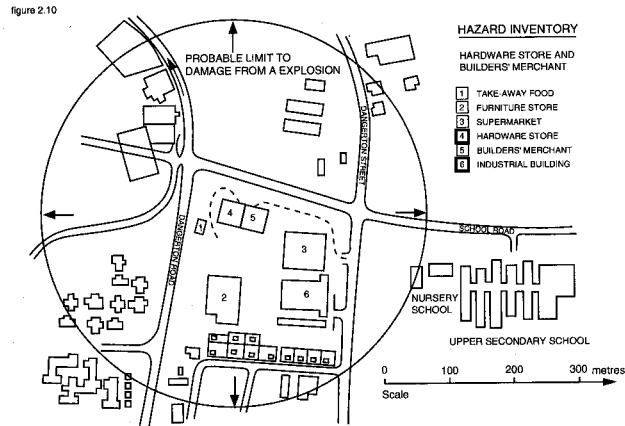
① Object	② Operation	③ Hazard (quantity)	④ Risk-type	⑤ Threat-ened object	⑥ Conse-quences	7-10 Seriousness				⑪ Pb	⑫ Pr	⑬ Comments	
						L	E	P	S				

The types of hazard present must be defined. These could be toxic, flammable, reactive, explosive, natural or a combination of several hazards.

It is also important to know the quantities of the products. (See also information in the references, e.g. "Guide to hazardous industrial activities", Netherlands, 1988.)

INDUSTRY should know its products and give information about them freely to the community.

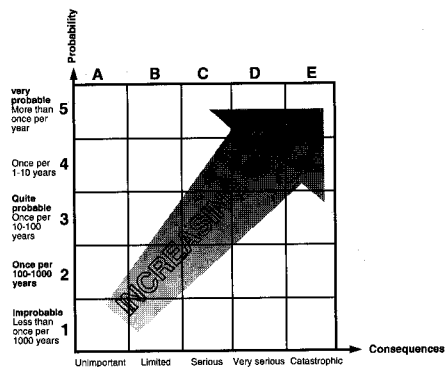
**EVALUATE** the hazards and risk zones ( on-site and off-site) in relation to the threatened objects. Information stored in computer programs or in other Handbooks (see references) may be needed here.  
 ( Examples, see section 2, figures 2:1 -2.5 plus the examples in figures 2.9-2.15 and annexes 3.1-3.5)



The interaction between INDUSTRY and the COMMUNITY is also very important here. At a later stage experts and computer codes could be useful.

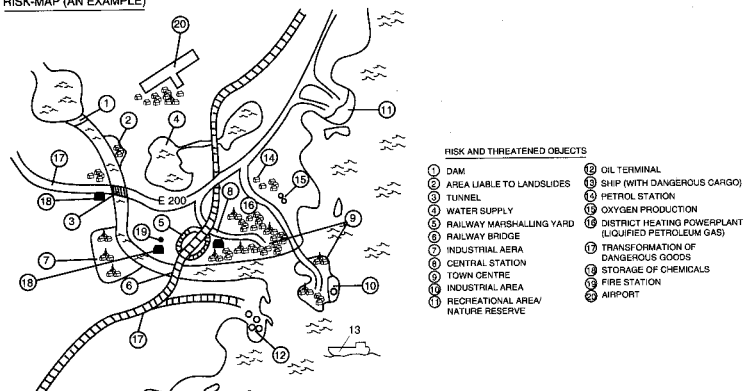
**RANK** the risk objects  
 ( Examples, see risk matrix in figure 2.6 and the comments.)

**RISK MATRIX**



The Co-ordinating group should rank the risk objects, for purposes of resource allocation and of reviewing and/or developing rescue plans, tactics, etc. The presentation of the results could be done using a map as shown in figure 2.8.

RISK-MAP (AN EXAMPLE)



**COMMUNICATE** the results of the analysis and the ranking, both within industry and in the community.



# 2 HAZARD ANALYSIS METHOD WITH EXAMPLES

Hazard identification and evaluation in a community should map where threats exist that could give rise to accidents and in what circumstances these hazards become dangerous. The survey report should contain an inventory of risk objects, hazards and threatened objects.

The probability of an accident associated with these hazards should be evaluated and its consequences for people, the environment and property estimated.

The result of the analysis is a valuable aid to the work of the local authority. It provides a planning base for the fire and rescue services. In cooperation with industry and others, it can be used for environmental planning, building planning, etc.

The analysis is intended to give an overview of the hazards that exist and to show :

- where serious accidents can occur ( risk objects)
- what the threats may be ( hazards)
- which types of accident can occur ( risk types)
- who and what could be affected and where ( threatened objects)
- in what way and on what scale damage could be caused ( consequences)
- the ( very approximate) probability of the accident
- which factors increase the risk.
- a way to present the results of the analysis.

In the next steps of the APELL process the need for various preventive and damage-reducing measures, review of emergency plans, etc., can be assessed.

## 2.1 Analysis and Organisation

Even though the process of hazard analysis described here is fairly general, without technical detail, a broad range of experience is still required to investigate the often complicated circumstances that give rise to accidents.

The analysis work therefore demands:

- an understanding of what is meant by the terms risk object, hazard, risk type, threatened object and consequences, etc, ( see definitions in chapter 1.2);
- good organisation and planning,( step 1 in the APELL process);
- willingness to commit both money and time;
- reliable information which provides a reasonable basis for the analysis (interaction between industry and the authorities in the community is necessary for this);
- good contacts between people in local authorities and companies in industry, commerce and transport;
- the support of the political and administrative bodies within the community.

During the analysis it must be decided:

- which risk objects and hazards should be included- should any be left out?
- whether any particular hazard/threatened object should receive special treatment?
- which geographical area should be covered? (Remember that a risk object can be located outside the community, e.g. upstream or upwind, or outside the country.)
- what criteria are to be used for assessing when a potential accident must be considered to be a major accident, either because the consequences would be serious for the community or because the local authority does not possess the resources to deal with it?
- when and how should the analysis be finished and reported?

An appropriate way to organise the work is to form a Co-ordinating Group, as suggested in the APELL Handbook. This should have a fairly small number of members, representing for example fire and rescue services, hospital and health services, civil defence, industry, environmental authorities and building authorities.

## 2.2

# Basis and Background for the Analysis.

The experience of members of the Co-ordinating Group and their knowledge of local conditions are very important resources for the analysis work. Other people from local authorities and industry can also contribute a great deal.

Information for the work can be obtained from:

- this Handbook
- other literature (see references in Annex 3.8 and in the APELL Handbook).
- maps showing (and information about)
  - the road network, railways and air fields
  - buildings
  - shops, supermarkets, depots and petrol stations
  - industrial areas
  - docks
  - power lines
  - district heating, water supply and sewage networks
  - water catchment areas
  - natural gas pipelines
  - mines
  - reservoirs
  - plans for land-use and building
  - shelters
  - areas at risk from flooding, landslides, winds etc.
  - valuable/vulnerable areas calling for special protection, etc
- the list of companies operating in the area
- the inventory of large quantities of hazardous materials
- any records arising from regulation of the transport of dangerous goods.

- results from traffic and other surveys (road, rail and air)
- up-to-date emergency plans
- statistics and information on accidents and incidents
- information on the number of local inhabitants and workers at industrial sites.
- computer programs, etc. (N.B. Annex 3.7 to this Manual includes a description of "Technical Guidance for Hazards Analysis" and the computer programme CAMEO, which has been demonstrated in APELL Seminar/Workshops. These will help planners to perform a somewhat more detailed hazard analysis than is described in this Manual. )

**Use figure 2:1 on Page 26 for the work.**

**Work your way from left to right for each hazard!**

An overview of the procedure is shown below.

Figure 2.1

COMMUNITY.....  
OBJECT/AREA.....

① Object	② Operation	③ Hazard (quantity)	④ Risk-type	⑤ Threatened object	⑥ Consequences
----------	-------------	---------------------	-------------	---------------------	----------------

IDENTIFICATION \_\_\_\_\_ EVALUATION  
 1 2 3 \*a 4 5 \*b 6  
 Object Operation Hazard Risk type Threatened Consequences  
 objects

L = Life S = Speed  
 E = Environment Pb = Probability  
 P = Property Pr = Priority

7-10 Seriousness				⑪	⑫	⑬
L	E	P	S	Pb	Pr	Comments

CLASSIFICATION \_\_\_\_\_ RANKING \_\_\_\_\_  
 7 8 9 10 11 12 13  
 Life The en- Property Speed Probability Priority Comments  
 vironment

\*a End here if the hazards are negligible.  
 \*b End here if there are no relevant threatened objects.

1. What particular risk object(s) is/are being analysed?
2. What kind of operations are being undertaken?
3. What hazards (quantity, toxic, flammable, etc.) are involved in these operations?
4. What risk types can be caused by the hazards, in combination with other hazards?
5. Where are the threatened objects? How vulnerable are they?
6. How can they be affected? What are the consequences? What are the risk zones on-site and off-site (very approximately, unless detailed computer models are available) ?

7. How seriously can people on-site or off-site be affected?
8. What could the impact on the environment be? For how long?
9. What could be the costs of an accident, in terms of deaths and hospitalisation of people, environmental clean-up, loss of and damage to property, etc?
10. How fast could the accident develop? For how long could it go on?
11. What are the probabilities of the events? How often do they happen?

What does past experience show?

12. What is the priority of the risk object(s) ? How severe could the consequences be for people and/or the environment and/or property ? What are the resources needed to cope with the accident? Would the results of an accident happening there be affordable?

The results of the judgements from 11 and 12 put together gives the ranking of the risk object. (See also Matrix 2:6.)

13. Comments on "Worst-case" and "Dimensioned damage estimate". (See definitions in 1.2 above.)

Various hazards and the types of threat associated with them are described in Annexes 3.1-3.5. Generally speaking, it can be said that accidents are caused when energy is released in an uncontrolled manner.

**Potential energy** is released when a dam or a pressure vessel ruptures, when an avalanche or landslide takes place or when a building collapses.

**Kinetic energy** causes injury in eg. road accidents, strong winds or tidal waves.

**Thermal energy** causes injury when hot water or molten metal escape.

**Radiant energy** takes the form of heat and light in fires, or radiation from radioactive sources.

**Chemical potential energy** is liberated in fires, explosions and uncontrolled chemical reactions.

Chemicals can affect the environment, either suddenly or over a long period of time. They can be toxic or cause a lack of oxygen when broken down biologically. They can also change pH- values or accumulate in the upper end of the food chain. Substances with a bad taste or smell can damage water catchment areas or wilderness areas important for hunting, fishing and recreation.

Combination accidents occur when energy in one form is released in an uncontrolled manner, leading to the liberation of another form of energy.



*Fire in a storage depot, Melbourne, 1985.  
Photo : F. BALKAU*

**The Probability** should take account of all the sources of risk for a hazard. Statistics and information from accidents and incidents can form a basis for the estimates. However the probability is affected by many things and can vary greatly for similar installations and risk objects in different locations. Some factors affecting the risk are given in figure 2.4.

For example, the probability of a road accident is linked to the type of user, the traffic intensity and the nature of the road (width, road surface, junctions, visibility, speed limits etc.).

Loading and unloading dangerous goods is a particularly risk-filled process in the chemical industry. In an industrial process, the risk increases in proportion to the number of manual operations.

The probability of having a large fire and the speed of a fire's development are related to the quantity of combustible materials in the building and the ease with which they can be ignited. Fire separation (installation of fire doors, etc.) and ventilation also affect the probability of a fire leading to large scale damage.

The Co-ordinating group's own estimates of probability are usually sufficient for the initial rough calculations. Representatives of the companies in question should help to make a more detailed study of industrial sites. When necessary, the mechanisms causing or compounding an accident could be analysed by methods outlined in annex 3.7. In complicated cases the risk object can be divided up into separate parts and the probabilities for each part calculated.

**The consequences** are estimated by taking into account the character of the hazard and the objects in the locality which would be affected. Typical questions at this stage are:

- Are very toxic chemicals present?
- Is there such a large quantity of poisonous gas that it could escape in concentrations dangerous to those in the vicinity?
- Could hazardous chemicals react with other chemicals nearby or with water or with the atmosphere, to create another chemical(s) hazardous to the community?
- Are fertilizers, pesticides and herbicides stored in such quantities that a fire would produce gases harmful to those in the vicinity? Would a fire lead to polluted water escaping as a result of attempts to extinguish the fire?
- Does a store of combustible material constitute a serious fire risk to those in the vicinity? Could it produce harmful smoke?
- Is there a serious risk of explosion or fire from the handling of inflammable gases in liquid form?
- Could the design of a building cause problems with evacuation in an emergency or hinder access for the rescue services?

In other words it is important to remember:

- the potential of the hazard, ie. the quantities and toxicity of dangerous chemicals or stored energy, and the kind of accident caused,

- the location of the hazard, the vulnerability of threatened objects nearby, the prospects for response by the rescue services and others and decontamination once the acute phase is over,

- the effects on the local economy,
- the risk that the threatened object will cause the accident to worsen.

The factors given in figure 2.4 affect both the probability of an accident occurring and its consequences.

The task of hazard analysis includes an overall classification of individual hazards according to probability, consequences and warning times. This work can be simplified with the use of a "risk matrix" as shown in figure 2.6 and examples 2.9-2.15. The analysis will assist local authorities and industry in setting priorities for future planning.

The probability that a hazard will cause an accident can be placed in one of five classes by estimating how often it can be expected to occur.

<b>Class</b>	<b>Frequency</b>
1 Improbable	less than once every 1000 years
2	once every 100-1000 years
3	once every 10-100 years
4	once every 1-10 years
5 Very probable	more than once per year

The estimate is based to a large extent on the expertise of the members of the Co-ordinating group, together with statistics and information from accidents or incidents.

If the hazard poses a serious threat, a more careful study of the accident frequency may be called for, with use of the appropriate statistics and computer models. A technical safety survey may be necessary, if human responses or technical systems play an important part in preventing the potential accidents.

A number of detailed methods of risk analysis are given in annex 3.7. The general application of such complicated methods is beyond the scope of a community hazard analysis and simpler methods are sufficient as a basis for local planning. However industry must know its own hazards and, if necessary, use detailed methods of risk analysis to assess them.

A rough estimate of the speed at which an accident could develop and its consequences for people, property and the environment can be arrived at in a similar manner. Five classes can again be used, with 1 standing for the least serious consequences and 5 for the most serious. This is illustrated in figure 2.5.

The hazard is described by a variety of numbers, for

- probability
- consequences
- speed of development.

A combined risk evaluation including all these factors is necessary, giving the likely risk class.

## 2.3

# Procedure

### 2.3.1 Basis

The group should begin by deciding on the objectives for the analysis and the level of detail required. An "analysis map" (see figure 2:8) covering the geographical area in question is needed. Only those objects of relevance to the analysis should be included. Use figure 2:1 for the work and to summarize the results.

### 2.3.2 Inventory

A list should be made of the objects to be included in the analysis (examples of risk objects and hazards are given in figure 2.2). The analysis map provides a starting point. A visit to the location of the risk object should always be made, especially for the objects that are predicted to be major threats.

### 2.3.3 Identification

Begin with the form for hazard analysis in figure 2.1. **To start, choose an object and area with which all the members of the Co-ordinating group are familiar.** The other hazardous installations and risk objects in the municipality can be studied subsequently.

The parts of an installation or risk object which contain hazards should be listed in **column 1.**

The operation taking place at that part of the installation should be shown in **column 2,** for example:

- manufacturing, purification, mixing, packing
- storing, loading
- transport
- selling
- energy production, energy distribution, transformer equipment
- maintenance, repairs
- market gardening, meat production
- hospitals, schools, entertainment facilities, sports amenities

List the substance or energy forms which create the accident risk in **column 3.** Show the quantities of hazardous chemicals, together with other relevant information, e.g. degree of toxicity, which affects the potential scale of an accident.

The types of accident that could be caused by each hazard should be shown in **column 4.** These could include: landslide, building collapse, flooding, release of a dangerous chemical, fire, explosion, collision or something similar. List also the combination accidents that could be caused.

Threatened objects are shown in **column 5**. If the hazards present are not serious threats to people, the environment or to property, then the risk object(s) under consideration can be omitted from the rest of the exercise.

#### 2.3.4 Evaluation

In many cases it is sufficient to estimate the scale of the consequences. These should be shown in **column 6**. It is important to see whether consequences are likely. It is not always necessary to estimate in great detail. Risk zones on-site and off-site should be considered.

It may be necessary to seek expert advice when the consequences are hard to predict. Models for estimating the spread of gases and their effects are available for use on personal computers.(see annex 3.7).

#### 2.3.5 Classification

Start with the outlines for classification in figure 2.5

Class the estimated consequences from 1 to 5 for:

life (fatalities/injured) -	<b>in column 7, "L"</b>
environmental objects -	<b>in column 8, "E"</b>
property -	<b>in column 9, "P"</b>
speed of development, amount of warning -	<b>in column 10, "S"</b>

#### 2.3.6 Ranking

Estimate the probability from 1 to 5 and write this in **column 11, "Pb"**

Weigh up the various consequence classes, arriving at a classification of each hazard. Show the priority of each of them from A to E in **column 12, "Pr"**.

It is very important to know about the "worst-case scenario" but it is not necessarily the decisive factor in emergency planning. The priority for the work should be to find risk objects and hazards and to classify the threats in the following order:

- people
- environment
- property

Give the risk object an overall class based on the matrix in Figure 2.6 (1C, 2D, etc.); according to your judgement of the probability of an accident arising from the hazard(s) and the seriousness of its consequences (the "dimensioned damage estimate" and the "worst case"). SEE GUIDANCE IN FIGURE 2.7.

See some examples in figures 2.9 -2.15

The risk objects have now been ranked.

You may want to go back and change your ranking for some objects when you have learned more.

The use (if any) of a dimensioned damage estimate, any other facts worth noting and any recommendations, e.g. for safety zones or emergency plans, should be written in **column 13, "Comments"**.

#### 2.3.7 Presenting the Results of the Analysis

The exercise will produce a number of forms containing the information shown above. These forms will in themselves be of great value to various local authorities. However it



is difficult to get an overall picture of the risk objects if the information is presented only on a large number of forms. It is therefore advisable to show the most important information on an overall "risk map" (see figure 2.8). Risk objects can be marked by symbols showing their ranking, together with associated threatened objects of various kinds. It is also important to have a detailed map for the location of each important risk object. This should also show the predicted zones in which the hazard could cause deaths, injuries and damage. See figures 2.9-2.15 for examples.

Now you know where the most potential risk objects and hazards are in the community. You have defined the hazards, evaluated their potential to harm or kill people, to damage the environment and to destroy or damage property. Last but not least you have ranked the risk objects and documented your findings.

Now it is time to communicate your results and to take the next step (3) in the APELL-process: "Develop or review emergency plans and identify weaknesses" ; together with actions to prevent accidents.



**Figure 2.2**

**Examples of risk objects**

**Common hazards**

**Docks**

Large and variable quantities of many types of dangerous substance (flammable, explosive, poisonous etc). Cranes, vehicles.

**Depots, terminals, stores**

See docks

**Ships**

Dangerous goods, oil

**Railway marshalling yards**

Dangerous goods, oil

**Canals**

Dangerous goods

**Airports**

Fuel, dangerous goods

**Aircraft**

Fuel, dangerous goods

**Processing industry**

Refineries, petrochemical, inorganic chemical, pharmaceutical, paint, steel/metal, cellulose/paper textile, etc

Pressure vessels, tanks, stores, containers, processing equipment with hazardous substances in the form of raw materials, catalysts, products, byproducts, waste and high voltage electricity.

**Other industry**

Plastics, rubber, engineering, saw mills and other wood production industry etc

Pressure vessels, stores, storage tanks with poisonous/flammable substances, etc

**Hydro-electric power stations**

Dammed water, high voltage electricity

**Thermal power stations**

Inflammable substances, pressure vessels, high pressure steam, hot water, high voltage electricity.

**Nuclear power stations**

Radioactive and poisonous reactor materials, pressure vessels, high pressure steam, hot water, high voltage electricity.

**Natural gas pipelines**

Inflammable gas, pressurized pipelines.

**Other pipelines**

Inflammable, poisonous and environmentally hazardous substances, pressurized pipelines.

**Petrol stations**

**Oil depots**

Inflammable, poisonous and environmentally hazardous substances

**Department stores**

Combustible and poisonous substances, aerosol sprays.

**Builders merchants**

Large quantities of wood.

**Hardware stores**

Explosive and combustible substances.

**Saw mills**

Combustible substances, wood.

**Municipal facilities** such as water purification plant, sewage treatment plant, swimming pools.

Hazardous substances.

**Hospitals**

Hazardous chemicals.

**Schools**

Hazardous chemicals.

**Hotels**

Tall buildings.

**Silos**

Combustible dust.

**Quarries** and other large mountain/underground sites

Unstable rock/soil, gases, drainage water, vehicles.

**Areas liable to flooding** landslide and building collapse

Geological conditions

**Aerial ropeways/cableways**

Heights

**Tunnels**

Risk of collapse, difficult situation for rescue work

**Roads**

Vehicles, dangerous goods.

.....

.....

.....

**Figure 2.3**

**Threatened object**

**Consequences**

**People**

Personnel  
Visitors  
People living nearby  
Fire and rescue service and  
civil defence personnel  
Children, elderly people

Anything from anxiety, through  
injury, to many deaths

.....  
.....  
.....

**Environment**

Sea, lakes, rivers, canals

Boat, ferry and plane crashes, drowning,  
leakages of hazardous substances  
(water supply, nature reserves)  
Pollution, bad taste, sabotage damage

Water supply

Recreational area

Nature reserve

Agricultural land

Forest

.....  
.....

Leakage of hazardous substances, fire

Leakage of hazardous substances

Leakage of dangerous and environmentally  
hazardous substances

Fire

.....  
.....

**Property**

Airport terminal

Railway station

Underground railway

Docks

Hospital  
Care centre  
Nursery school  
Hotel  
Theatre  
Sports arena

Any thing from minor damage to complete  
destruction.

As above, plus collisions

As above, plus smoke damage

As above, plus leakage of dangerous  
substances

Anything from minor damage  
to complete destruction



Cinema

Water supply

Pollution, bad taste, sabotage damage

Water purification plant

As for water supply

Industry

See Figure 2.2

(N.B. the possibility of combination accidents, e.g. a landslide which then causes a chemical leakage, etc)

.....

.....

.....

.....

#### Figure 2.4

#### Factors affecting hazards and risks

The following factors should be considered when assessing risk objects, hazards and, when applicable, threatened objects:

- the presence of hazards (type, quantity and potential)
- extreme conditions, for example when dealing with dangerous substances
- the effects of storing various substances together
- the fact that containers of chemicals might be poorly marked or completely unmarked
- the distance to critical threatened objects and the safe distance to limit knock on effects
- the importance of people acting in a correct manner so that:
  - the risk of damage is avoided
  - the rescue services and threatened objects are warned and kept well-informed
  - rescue work is effective
- the importance of safety equipment and other support services functioning properly
- the effects of natural forces such as rain, snow, wind, avalanche, waves etc
- the likely or possible damage and estimated number of casualties
- the possibility of detecting a dangerous event while it is still in its initial stages
- the probability and possible effects of sabotage

## Figure 2.5

Classification ( see Matrix in Fig. 2.6) of the consequences of a potential accident, the speed at which the accident would develop and the probability of it occurring - for use in the analysis of threatened objects and/or separate hazards.

### Consequences for life and health

Class	Characteristics
1. Unimportant	temporary slight discomfort
2. Limited	a few injuries, long-lasting discomfort
3. Serious	a few serious injuries, serious discomfort
4. Very serious	a few (more than 5) deaths, several (20) serious injuries, up to 500 evacuated
5. Catastrophic	several deaths,(more than 20), hundreds of serious injuries, more than 500 evacuated.

### Consequences for the environment

Class	Characteristics
1. Unimportant	no contamination, localised effects
2. Limited	simple contamination, localised effects
3. Serious	simple contamination, widespread effects
4. Very Serious	heavy contamination, localised effects
5. Catastrophic	very heavy contamination, widespread effects

### Consequences for property

Class	Total cost of damage (M USD, pounds, etc)
1. Unimportant	< 0,5
2. Limited	0,5 - 1
3. Serious	1 - 5
4. Very Serious	5 - 20
5. Catastrophic	> 20

**Speed of development****Class**

1. Early and clear warning
- 2.
3. Medium
- 4.
5. No warning

**Characteristics**

- localised effects/no damage
- some spreading/small damage
- hidden until the effects are fully developed/immediate effects (explosion)

**Probability****Class**

1. Improbable
- 2.
3. Quite probable
- 4.
5. Very probable

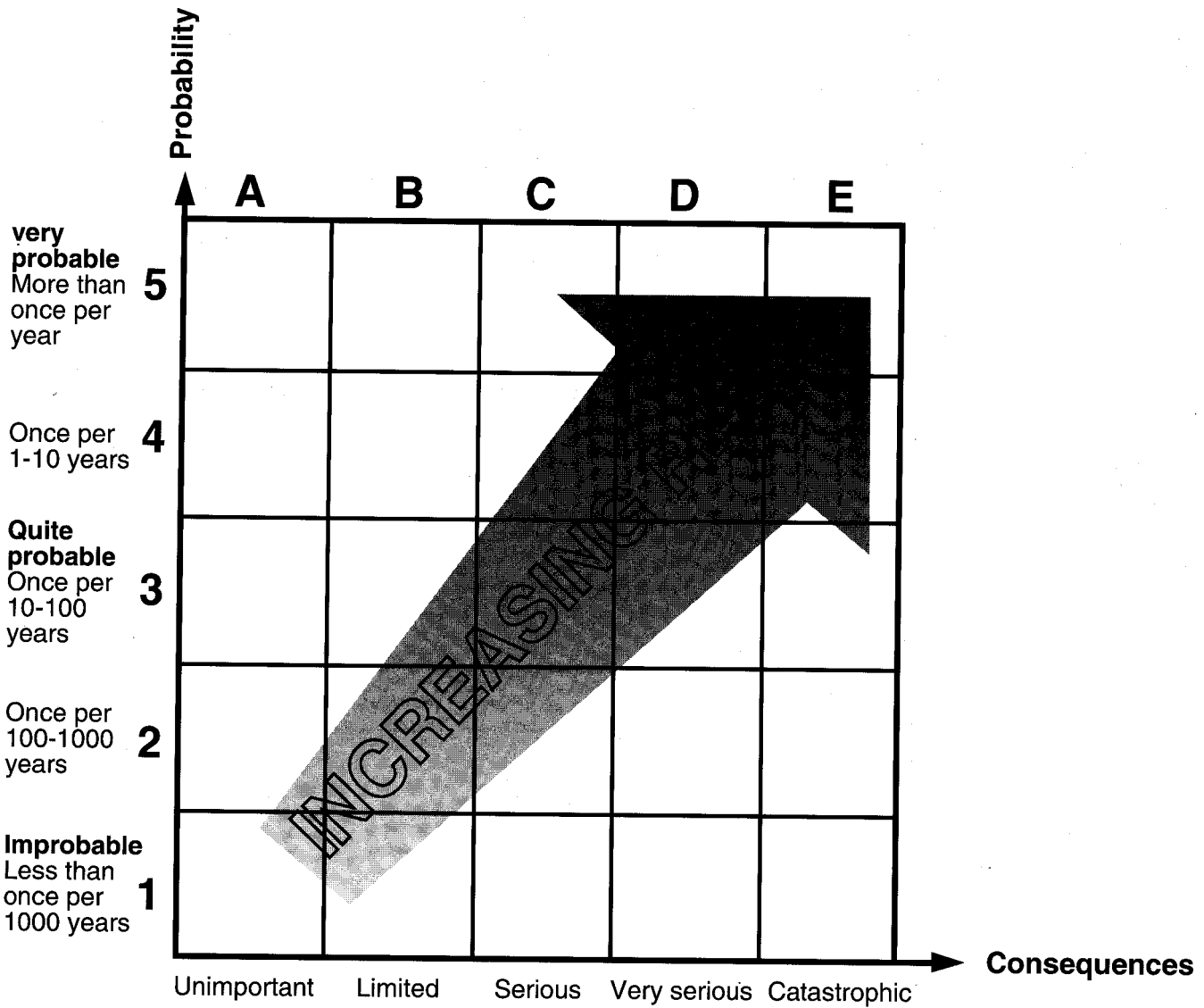
**Rough estimate of frequency**

- less than once per 1,000 years
- once per 100-1,000 years
- once per 10-100 years
- once per 1-10 years
- more than once per year



Figure 2:6

# RISK MATRIX



**Figure 2:7**  
**Ranking of Risk Objects and Hazards from a Local Viewpoint.**  
**(Comments on the Risk-Matrix in Figure 2.6.)**

It is necessary to rank the risk objects in order to allocate resources, to decide where preventive measures should be taken first, to develop emergency plans, etc.

When attempting to rank risk objects systematically it is also necessary to weigh up different kinds of hazards within the risk object. This will be a matter of judgement for the Co-ordinating Group. Both probability and consequences must be considered. It is common to concentrate on the risks with the greatest consequences. When attempting to reduce risk levels systematically, however, it may be necessary to weigh an event with low probability but serious consequences against one which is more likely but causes less damage.

The results of the ranking should influence the development of a concrete programme of action necessary to protect and save lives, the environment and property on-site and off-site.

Examples of actions that could be necessary:

**Column**

- E Risk objects and operations where the consequences of an accident could be CATASTROPHIC for life, the environment or property should be shown in Column E. Situations where the rescue efforts would be too difficult or extensive for the local authority concerned to carry out by itself should also be shown in Column E. Reinforcements would be needed from neighbouring authorities and industries, etc.

**Actions:**

The hazard(s) should be reduced in scale or if possible eliminated.  
Preventive measures should be taken.

Personal protection planning (on-site and/or evacuation) should be undertaken.

The hazard(s) should be included in rescue service planning - special equipment and specially trained personnel may be needed by health care services, ambulances, police etc

- D Risk objects and operations where the consequences could be VERY SERIOUS should be placed in Column D. The rescue efforts would be difficult but it would be possible to deal with the accident using the local authority's rescue /fire brigade and the personnel/resources of the industry in question, etc

**Actions:**

Much the same as for Column E.

- C Risk objects and operations where the consequences could be SERIOUS should be shown in Column C. The rescue (fire) brigade / industry has the resources to cover the rescue efforts.

**Actions:**

Preventive measures  
Emergency planning

**B** Risk objects and operations where the possible consequences for life, property or the environment are LIMITED should be given in Column B

**Actions:**

Preventive measures  
Emergency planning

**A** Risk objects and operations where an accident would have more or less UNIMPORTANT consequences should be shown in Column A.

The risk objects containing hazards with a low probability and limited consequences (1-2/A-B) can be discarded at an early stage of the analysis. However it is important that this selection is done carefully.

It is always useful to know the potential "worst-case" of a hazard. But the "worst-case" event is often considered so improbable that a smaller and more probable event, the "dimensioned damage estimate", is chosen as the basis for safety measures, ranking of the risk object, etc.

It is useful to be able to assign one class to a particular risk object, often based on the "dimensioned damage estimate", taking into account all the different hazards present. This can be done by considering the probability (1-5) and the consequences (A-E) for all hazards.

**Examples of ranking risk objects:**

**5 A** High probability but more or less unimportant consequences.

Example - An oil depot with minor leakages because of a defective shut-off valve.

**4 B** Limited consequences but happens every three years.

Example - An industry with a potential for fires. A worker once got his hands and face burned. The area had to be cleaned and repainted.

**3 C** Serious consequences but quite probable.

Example - A factory with potential for explosions. Ten years ago the factory had an accident with one person killed and three seriously injured. Property damage was assessed at three million USD.

**2 D** Not so often but with very serious consequences.

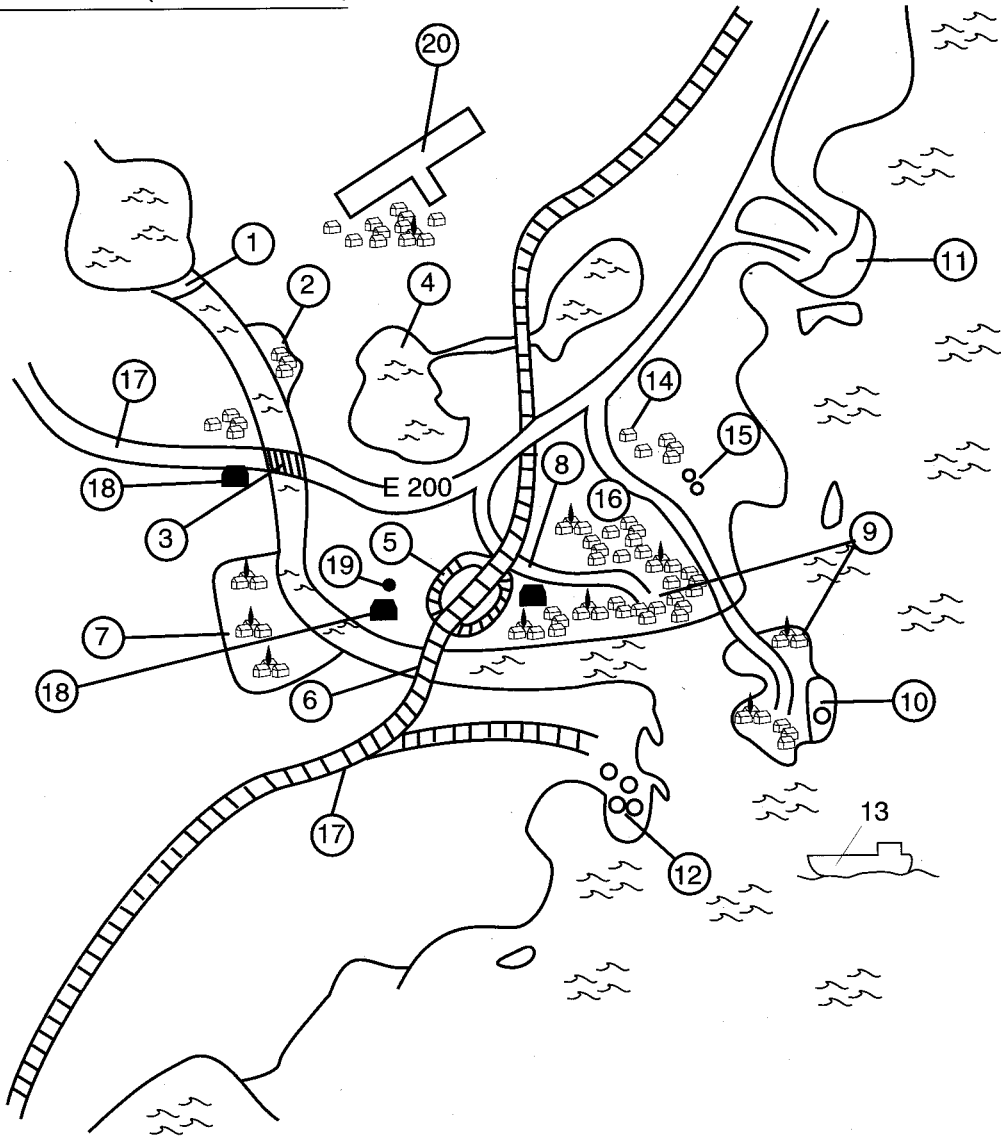
Example - The accident in an industry in Seveso, Italy, July 1976. Release of dioxin in an area of 4-5 sq.km. 250 people injured and 600 evacuated. International help was needed for diagnoses and treatment of injuries as well as chemical analysis and decontamination measures.

**1 E** Very low probability but with catastrophic consequences.

Examples - Bhopal (poisonous gas), India, December 1984.

- San Juanico ( gas cloud explosion), Mexico, 1984

RISK-MAP (AN EXAMPLE)

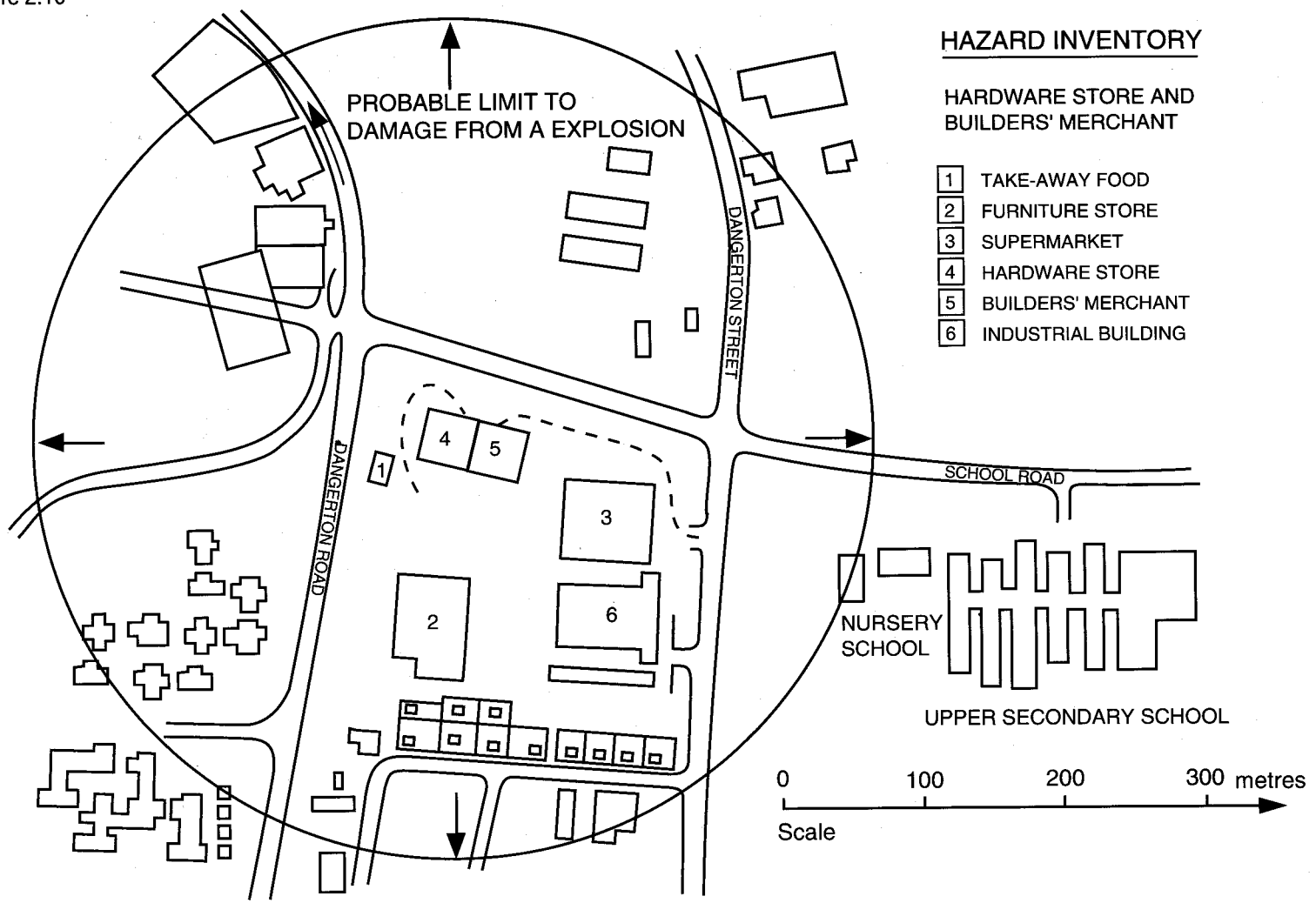


RISK AND THREATENED OBJECTS

- |                                     |   |
|-------------------------------------|---|
| ① DAM                               | ⑫ OIL TERMINAL  |
| ② AREA LIABLE TO LANDSLIDES         | ⑬ SHIP (WITH DANGEROUS CARGO)                           |
| ③ TUNNEL                            | ⑭ PETROL STATION  |
| ④ WATER SUPPLY                      | ⑮ OXYGEN PRODUCTION                                     |
| ⑤ RAILWAY MARSHALLING YARD          | ⑯ DISTRICT HEATING POWERPLANT (LIQUIFIED PETROLEUM GAS) |
| ⑥ RAILWAY BRIDGE                    | ⑰ TRANSFORMATION OF DANGEROUS GOODS                     |
| ⑦ INDUSTRIAL AREA                   | ⑱ STORAGE OF CHEMICALS                                  |
| ⑧ CENTRAL STATION                   | ⑲ FIRE STATION  |
| ⑨ TOWN CENTRE                       | ⑳ AIRPORT   |
| ⑩ INDUSTRIAL AREA                   |   |
| ⑪ RECREATIONAL AREA/ NATURE RESERVE |   |



figure 2.10



## Notes on figures 2.9 and 2.10

**For your first hazard analysis, use the information in figures 2.9-2.15 but start your own work with a smaller object that the Co-ordinating Group members are familiar with.**

The following information may be of use when considering the example of the hardware store and the builders' merchant.

The two companies have different owners but share the same building, which is part of a shopping centre.

As illustrated in figure 2.10, the shopping centre also has a kiosk with take-away food, a furniture store and a supermarket as well as an industrial building. It is planned to extend the industrial building towards the supermarket. A petrol station is going to be built between the furniture store and Dangerton Road. A new residential development is planned for the land on the other side of Dangerton Road.

The owners estimate the likely number of personnel and customers at the time of an accident to be:

1 Take-away food kiosk	25 - 50
2 Furniture store	20 - 80
3 Supermarket	150 - 500
4 Hardware store	40 - 120
5 Builders' merchant	20 - 50
6 Industrial buildings	0 - 165

The shopping centre is bounded on three sides by busy roads with the following average number of vehicles per day:

Dangerton Road	7000
School Road	4500
Dangerton Street	5500

There is a residential area next to the shopping centre. Blocks of flats house about 500 people. There is also a number of older detached houses.

A secondary school with 1250 pupils and teachers is situated at a distance from the shopping centre.

The shopping centre has parking places for 375 cars. There are two main entrance and exit roads.

Deliveries to the back of the hardware store pass between the take-away food kiosk and the store. Deliveries to the builders' merchant arrive at the back of the store via a roadway to the rear of the supermarket.

The hardware store was built at the beginning of the 70s. It has a corrugated iron facade on a steel framework. On the ground floor there is a large hall, as in a supermarket. On the upper floor there is a smaller selling area with offices round the outside. Fire alarms and smoke vents have been installed. The builders' merchant's premises consists of a large hall. The dividing wall between the two stores is not sufficiently fire-proof.

Liquified petroleum gas cylinders are stored in the middle of the hardware store (300 x 1kg). Paints and solvents are also stocked in the store. The smaller containers are kept along the outer wall opposite the take-away food kiosk. Larger containers for professional decorators are kept beside the wall dividing the two stores, that is to say in the middle of the building as a whole. There are 1000 l solvents, 3000 l inflammable paints and 6000 l water-based paints, giving a combined total of 10 000 l. The actual size of the stock varies during the year, being topped up at the beginning of every summer.

The builders' merchant has a large stock of wood - on average about 300 cubic metres, including impregnated wood. This is stored both indoors and outdoors. There are stocks of roofing felt and cellular plastic. There is also a depot for LPG (about 300 cylinders of 6-11 kg) and gas for welding (about 500 cylinders of 20-40 l).

There is a drain in the floor of the hardware store leading to a sewer. The builders' merchant has two drains in the floor. These are connected to the normal drains which flow out in a nearby river. The ground at the shopping centre was covered with asphalt when the supermarket and furniture store were built. Drains from this surface also lead to the river, but flow into it at a different point to those from within the builders' merchant's premises. Water used to extinguish a fire in these two stores would therefore enter the river at two other points, as well as via the sewers.

Because of the possibility of explosions and because many people are at risk, the risk object is given the classification 3C.



Figure 2.1

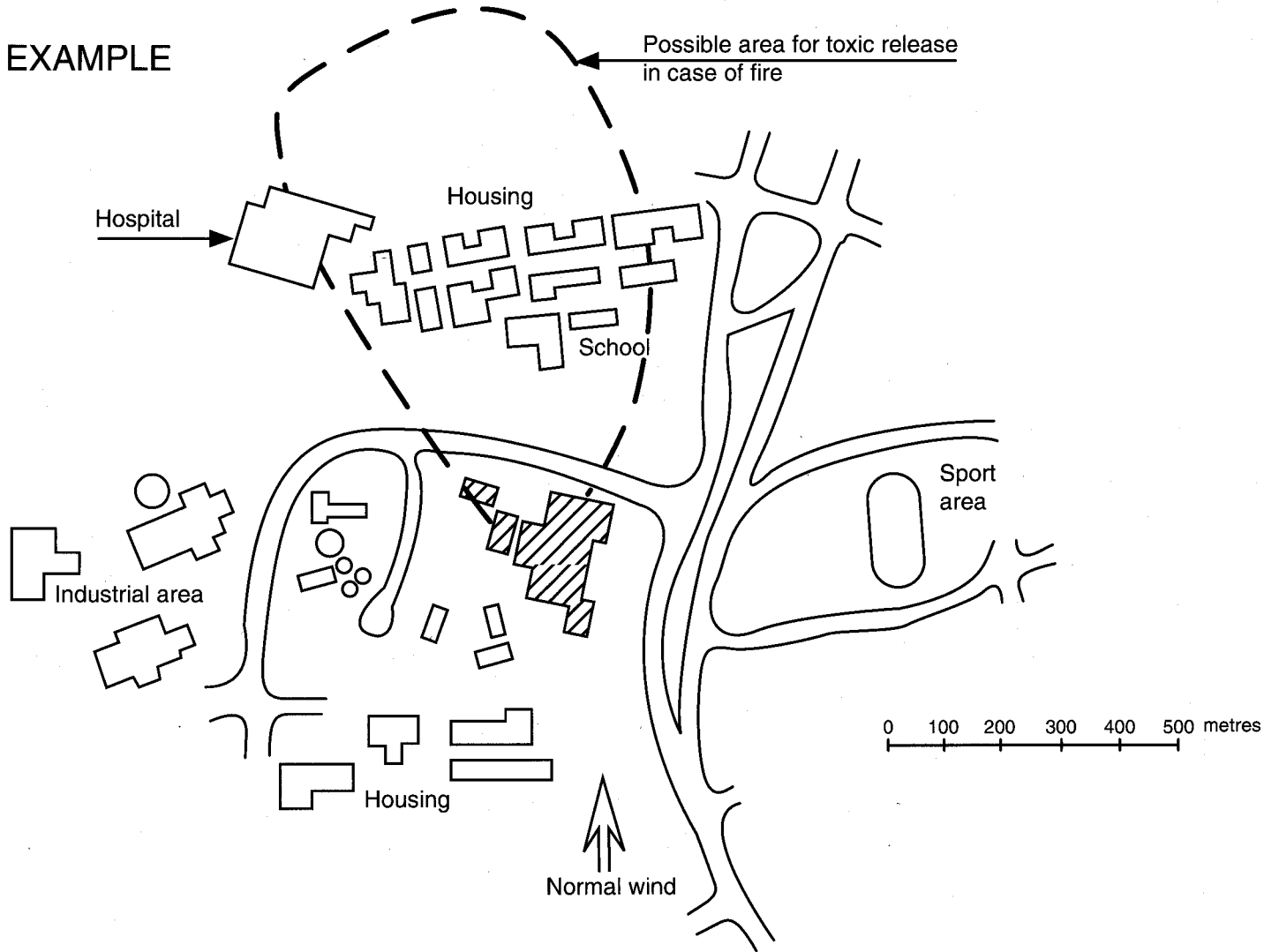
COMMUNITY.....  
 OBJECT/AREA..... **Plastics Factory**.....

L = Life  
 E = Environment  
 P = Property  
 S = Speed  
 Pb = Probability  
 Pr = Priority

① Object	② Operation	③ Hazard (quantity)	④ Risk-type	⑤ Threatened object	⑥ Consequences	7-10 Seriousness				⑪ Pb	⑫ Pr	⑬ Comments
						L	E	P	S			
Foam Area	Foam Production	TDI 50 tons Polyol 100 tons Amines 2 tons	Leakage " Fire Hydrogen Cyanide Nitrous gases	Personnel " Personnel People living near factory	Poisoning (inhalation) Poisoning Burns	2	2	1	4	3	B	
						2	2	1	4	3	B	
						3	1	3	2	2	C	
Area for Hardening	Hardening	Polyurethane 100 tons	Self ignition	"	Poisoning (inhalation)	2	1	4	4	4	C	
Area for Cutting	Cutting	Polyurethane 100 tons	Fire giving off TDI and Hydrogen Cyanide	Personnel People living near factory Rescue-personnel	Poisoning Breathing difficulties Pneumonia	4	1	5	4	3	D	Dimensioned damage estimate
Area - Roads	Transport	TDI 25 tons Polyol 25 tons Amines 1 ton	Leakage loading/unloading collision	Drivers Personnel Rescue - personnel	Poisoning Breathing difficulties	2	2	1	4	2	B	
						2	2	1	4	2	B	
						3	1	3	4	2	C	

Figure 2.12 Plastics Factory Map

figure 2.12



### **Notes on Figures 2.11 and 2.12.**

In this example, a Plastics Factory, you will find various chemicals (hazards), which are threats to workers, local inhabitants, etc.; either by giving off toxic gas in case of fire or by being poisonous themselves.

As you can see in figure 2.11 the risk object consists of different areas.

The area considered most hazardous is the one where the plastics are cut. People as well as property are in danger here. This information is important for safety measures and allocation of resources as well as for rescue tactics.

In working with this "rough analysis" method, it is important to remember that the main thing at this stage is not to produce a mathematically exact value for all the hazards or all their possible risk zones. This is anyway most unlikely to be possible. It is much more important to get an overall view of the problems, rank the risk objects and do something about the threats to people, property or the environment.

In case of fire in the factory, people living near by are at risk from toxic gas, as you can see in Figure 2.12. This type of problem is quite common in developed as well as developing countries.

Risk-consciousness is important in physical planning (industry and housing, hospitals, etc., should not be located too close together) and in considering the social impacts of economic development.

It is also important to communicate the risks to people living near the industrial area, in this case in order to protect them from the effects of a toxic release.

Because of the possibility of toxic gas emission in case of fire and the potential effects on the people living nearby, the risk object is given the overall ranking 3D.

Here, as in most cases, it is not possible give an exact value for the probability. But since there have been several fires giving off toxic gas in recent years, an accident of the type shown in this example is quite probable.

Figure 2.13 Map of Oil Depot

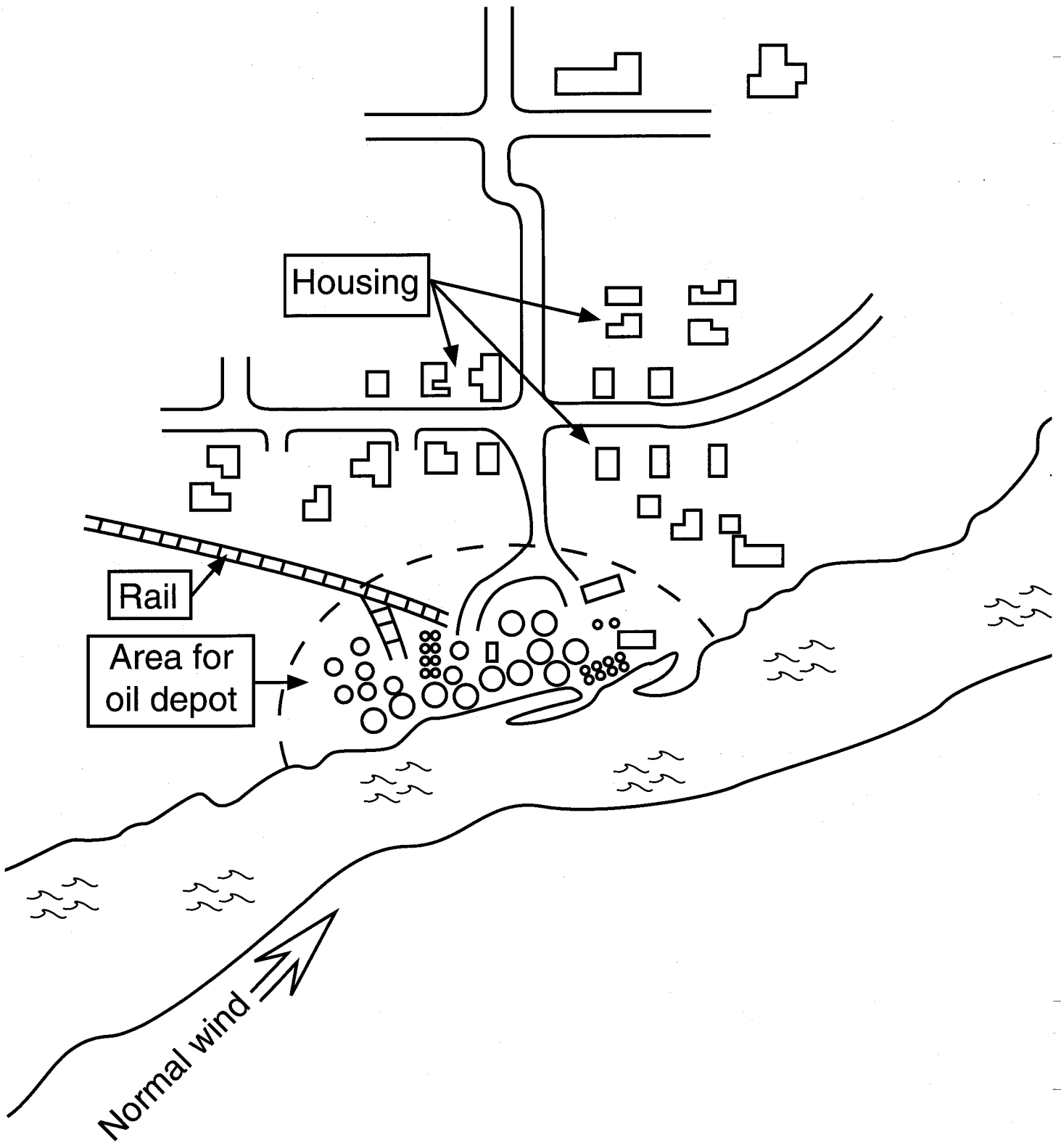


Figure 2.1

COMMUNITY.....  
 OBJECT/AREA..... **Depot of oil and oil products (overall view)**.....

L = Life  
 E = Environment  
 P = Property

S = Speed  
 Pb = Probability  
 Pr = Priority

① Object	② Operation	③ Hazard (quantity)	④ Risk-type	⑤ Threat- ned object	⑥ Conse- quences	7-10 Seriousness				⑪ Pb	⑫ Pr	⑬ Comments
						L	E	P	S			
<b>Storage Tanks</b> - crude oil - gasoline - liquid petro- leum gas (LPG) - NO2 fuel oil (furnace, diesel stove) - NO4 Fuel oil (plant heating) <b>Storage of                      LPG-bottles</b> <b>Filling station</b> <b>Oil/LPG</b> -pipeline - rail - trucks - ships  <b>Roads</b> <b>Railways</b> <b>Harbour</b>	Refinery Storage Loading unloading Transport	<b>Crude oil</b> 100.000 m3 Flammable	Fire/leakage	Depot as a whole <b>Life</b>	Depot as a whole <b>Life</b>						<b>D</b>  Risk object that has to be studied in depth	
		<b>Gasoline</b> 500.000 m3 Flammable	Fire/leakage	- workers - drivers - crews - fire and rescue serv. - the public	- anything from a few burns to many deaths							
	<b>LPG</b> 10.000 m3 Explosive	Fire/explosion	- shores - water - air	<b>Environment</b> Contamination in water and on shores, severe burns of woodland								
	<b>NO2 and NO4</b> 600.000 m3 Flammable	Storage Transport	Fire/leakage	- tanks - vehicles - oil products - houses - ships - equipment	<b>Property</b> - smoke damage - building collapses, fire damage, destruction of oil products							
	Storage Transport Loading unloading	<b>Stored LPG</b> 20.000 m3 Explosive Flammable	Fire/explosion									
	Transport Transport Transport Loading unloading	Vehicles Ships Trains etc	Collisions									

Figure 2.1

COMMUNITY.....  
 OBJECT/AREA... **Depot of oil and oil products (in depth)**.....

L = Life  
 E = Environment  
 P = Property

S = Speed  
 Pb = Probability  
 Pr = Priority

① Object	② Operation	③ Hazard (quantity)	④ Risk-type	⑤ Threatened object	⑥ Consequences	7-10 Seriousness				⑪ Pb	⑫ Pr	⑬ Comments		
						L	E	P	S					
<b>Area Storage Tanks</b> - LPG - gasoline  - crude oil - fuel oils  <b>Storage of LPG bottles</b>  etc.	Refinery Storage Loading Unloading Transport  Storage Transport  etc.	LPG 10.000 m3	<u>Explosion</u> (Primary)	<u>Life</u> Workers Drivers Crews Fire and Rescue serv Public <u>Environment</u> Air Land Water	<u>Life</u> Deaths/injuries " / " " / " " / " " / " " / " <u>Environment</u> Contamination and destruction of air, land	4-						Dimensioned damage estimate		
						5	-	-	5	2	D			
						4	-	-	5	2	D			
						4	-	-	5	2	D			
						3	-	-	5	2	D			
						2	-	-	5	2	C			
						-								
						-	3-4	-	5	3	D		To consider	
<b>Filling station oil/LFG</b>  - trucks - ships - rail - pipelines, etc	Storage  Transport Loading unloading etc.			<u>Property</u>  Tanks Vehicles Houses Oil products	<u>Property</u>  Destruction " Collapses Destruction	-	-	3	5	2	D	To consider		
						-	-	4	5	2	C			
						-	-	4	5	2	D			
						-	-	5	5	2	D			
<b>Roads</b> etc	Transport etc		Boiling Liquid Exp. Vapour Exp. (BLEVE) (Secondary) <b>Fire</b> <b>Leakage</b> etc			5	5	5	5	1	E	"Worst-case"		
<b>Railway HARBOUR</b> etc	Transport Loading unloading etc	Gasoline 500.000 m3 etc												

## Notes on Figures 2.13-2.15

In figure 2.13 you see a map of a fictitious oil depot and its surroundings. It is not uncommon for housing, oil depots, industries, etc., to be situated too close together. As also shown in figure 2.13, consideration is not usually given to meteorological conditions when the siting of industries, oil depots and houses is being planned.

In this fictitious case the prevailing wind comes from the sea. If there is a fire in the depot, the smoke (or a gas cloud) is probably going to affect the people living in the nearby housing.

Figure 2.14-2.15 shows how to use the rough analysis method step by step.

**Of course you have to study all the hazards present in order to get to know the risk object and its potential for accidents. (This is not done in this example.)**

To start with, it would be of interest to get an overall view of the risk object, especially if it is as big as shown in figure 2.13. Such a view is shown in Figure 2.14. It is clear from this that there are several different kinds of hazards and possible risk types in this risk object. It is not possible here to give examples of every kind of accident that might occur. Some accidents are obvious, e.g fires giving off huge plumes of black smoke or leakages of oil damaging the environment. Other possible accidents and threats are less overt. The Co-ordinating Group and the owner(s) of the oil depot should therefore do the analysis work together.

With the results of the analysis in hand, it is possible to review or to develop emergency plans and to start work on preventive measures and on the allocation of resources on-site and off-site. (For a more "in-depth" study the risk analysis methods shown in annex 3.6 are normally used, together with information stored in computerised databases and other tools)

As you can see in figure 2.15, the storage tanks area, especially the LPG store, is probably where the "worst-case" scenario could happen - a BLEVE ( Boiling Liquid Expanding Vapour Explosion). As a dimensioned damage estimate you might choose another event, like a fire or a leakage of oil or a minor explosion. The risk object is given an overall ranking of 2D, with 1E possible.

# 3 ANNEXES

In Annexes 3.1-3.6 you will find information to support your work on hazard analysis.

In Annex 3.1 you will find information on natural forces that must be considered by industry and the community in preventive and rescue work.

Annex 3.2 will give you some guidance on fire hazards.

In Annex 3.3 you will find some explanations on explosions as a result of physical processes and as a result of chemical reactions.

How dangerous are chemicals? In Annex 3.4 you will find some explanation of where and how chemicals can be dangerous.

Many deaths are caused by a combination of events. Annex 3.5 will give you a brief outline of these problems, together with some examples.

In Annex 3.6 are some selected examples of accidents in various countries. It is very important to collect information from your own community on near-misses and accidents.

In Annex 3.7 you will find examples of risk analysis methods used in industry and elsewhere.

References and some other useful information are to be found in Annex 3.8



## 3.1

# Natural disasters

In global terms the most frequent kinds of natural disasters are flooding, earthquakes, cyclones and drought. Volcanic eruptions, tornados and landslides are less frequent.

It is estimated that, on average, natural disasters claim 25,000 lives and cause damage valued in excess of \$3000 million per year. There are great geographical variations in the risk that an individual is exposed to. About 95% of all natural disasters occur in developing countries. Natural disasters rarely cause many deaths in industrialised countries.

Factors affecting the risk are:

- population density
- building structures
- how long the event lasts
- how sudden and unexpected the event is
- how often such events occur and the number of incidents which preceded it.

Examples of hazards in connection with natural disasters are dams, seismically active areas, river banks and mountainous areas.

The extent to which people can minimise the effects of a natural disaster depends on how well informed they are about the likelihood of a disaster and the damage that could be caused. People's perception of risk plays an important role in this. For example, certain areas beside rivers in Sweden are liable to landslides. Some residential areas are thought to be unstable and houses could end up in the river if a landslide took place. However the desire to remain where you live, perhaps where you have lived for all your life, is stronger than the perceived risk. People living in built-up areas are more worried about daily threats, such as traffic, crime and pollution, than about the relatively slight risk of a land-slide. This means that politicians and those responsible in local authorities must show awareness of environmental risk at a very early stage in the planning process. A landslide at, for example, a chemical plant could have disastrous consequences.



*"Rescuers search for survivors after the earthquake in Leninakan, Armenia, 1988".  
Photo : Stig Dahler, Swedish National Rescue Services Board.*

Every year there are about one million registerable seismic or microseismic tremors around the world. About 100,000 of these are felt by people, and 10 or 20 cause damage.

#### Examples of Earthquakes

Year	Place	Deaths
1906	San Fransisco, USA	452
1927	Nanshan, China	200.000
1963	Skopje, Yugoslavia	1.000
1976	Tangshan, China	243.000
1989	San Francisco, USA	63

One reason that so many people have died in earthquakes is that multi-storey buildings and houses were constructed of brick without reinforcement. Building collapse is the principle cause of deaths and injuries in earthquakes. In 1989 an earthquake in San Fransisco caused wide-spread fires and the collapse of some multi-storey road sections. An earthquake in an area with chemical industries, LPG plants etc. could have catastrophic consequences for people, property and the environment.

Earth tremors can trigger **landslides**. Landslides in areas with hazardous industries, depots etc. could also be disastrous.

Sometimes giant **tidal waves** can accompany an earthquake. These are called "Tsu-namis" and can reach a height of 50 metres, travelling at a speed of up to 700 km/hr in deep water. The Tsu-namis after the eruption of Krakatoa in 1883 reached a height of 40 metres and drowned 36,000 people.

**Typhoons and hurricanes** have rarely killed more than a few hundred people in the USA in recent times. A hurricane in 1982 caused 155 deaths and damage to property worth about \$23,000 million. The same hurricane killed nearly 10,000 in the Caribbean. In 1970 a hurricane in the Indian Ocean resulted in a catastrophe in Bangladesh, with a death toll of 300,000 and material damage too widespread to estimate. A hurricane in 1988 killed about 100 people and made 10% of Nicaragua's population homeless. At nearly the same time a typhoon in the Philippines killed 3-4,000 and made more than 110,000 homeless.

**Flooding** is not unusual, both in industrialised and in developing countries. However such events often have more serious consequences in developing countries. A flood in China in 1938 washed away a whole city and one million people died.

Depending on local conditions, the following natural forces must be considered by industry and others in their land-use planning, their installation design, their processes, management, emergency plans etc:

- earthquake
- landslide
- flooding
- wind ( typhoons, hurricanes)
- waves (tsu-namis)
- extreme frost, extreme drought, extreme sun.

The effects of a natural disasater can be reduced by having early warning systems, safer building methods, reliable transport systems and contingency plans.

## 3.2 Fires

A fire is a chemical oxidation process giving off energy, mostly in the form of heat. The generation of smoke and toxic gases is an important risk factor in a fire. Additional risks are caused by combination effects such as explosions or the leakage of contaminated water when extinguishing the fire.

The speed of the development of a fire varies greatly, depending on the material's combustibility and energy content, its physical form (solid, liquid or gas) and the availability of oxygen.

Fire hazards are caused by collections of substances which can be ignited when they are heated or come into contact with other substances. Some strong oxidizing agents or self-igniting substances also constitute fire hazards.

Firemen are repeatedly exposed to smoke containing a variety of harmful gases. When various different chemicals are present in smoke, they can interact to produce a smoke which is much more dangerous than the sum of the individual parts (synergy).

Carbon monoxide is usually the most dangerous gas produced by a fire. Hydrogen cyanide is an extremely toxic gas which is produced when material containing nitrogen burns. Chemical analysis has shown that varying quantities of hydrogen cyanide are present in smoke from synthetic products such as polyurethane, melamine and nylon. The proportion of hydrogen cyanide increases as the temperature of the fire rises. Products containing fluoride give off hydrogen fluoride at high temperatures. Many fluoride compounds are extremely poisonous, even in low concentrations. Products containing sulphur, eg rubber, give off sulphur dioxide when warmed. Care must be taken at fires involving pesticides or herbicides. These often contain arsenic and chrome. Some can even give off gases similar to nerve gas.

Gases from fires involving large concentrations of dangerous substances can spread over great distances. It is therefore vital to carry out a careful analysis of this kind of hazard. It is also important that there are instruments to detect the harmful substances most commonly produced in fires.



Consequences of fire in a factory, Melbourne, 1985.  
Photo : F. BALKAU

### 3.2.1 Fire - Risk Objects and Threatened Objects:

Public buildings -

eg discotheque  
department store  
restaurant  
sports arena  
cinema  
theatre  
hotel  
hostel  
schools

Hospitals and other care homes

Industrial plants

eg saw mill  
petroleum refinery/storage depot  
chemical plant  
plastic, rubber and paint factory  
engineering plant  
steel mill  
cellulose production unit  
explosives factory/storage depot  
any plant handling liquified petroleum gas  
papermill, paper store, tank farms, etc.

Nuclear power stations

Docks

eg oil terminals  
ships with inflammable cargoes  
warehouses with a high turnover of a variety of goods

Railway marshalling yards - wagons with inflammable loads

Natural gas facilities

Underground installations

eg mines  
underground railways  
military stores

The use of liquified petroleum gas (LPG) and natural gas is increasing. They are transported by pipeline or in lorries, ships and trains. There is always the risk of a leakage leading to an explosion or fire when these gases are handled.

A crash involving a petrol tanker could have disastrous consequences in a built up area.

Large quantities of inflammable chemicals are handled in railway marshalling yards. These are often located in the middle of towns, which means that an accident could have serious consequences.

Large quantities of aviation fuel are handled at airports.

The loads of two lorries involved in a collision can come into contact with each other, leading to a very dangerous situation.



*Fire in an LPG storage tank*

### **3.2.2 Factors Raising the Risk Level:**

- the increasing use of inflammable chemicals and dangerous industrial processes
- lightning
- electrical faults
- negligence and complacency when handling hazardous chemicals
- poorly marked or unmarked containers of hazardous chemicals
- arsonists, drug addicts and alcoholics who behave in a dangerous and unpredictable way
- sabotage
- large and complex installations with unknown contents, which make the work of firemen increasingly dangerous.

### **3.2.3 Factors Reducing the Risk Level:**

- automatic systems to extinguish fires are becoming more reliable and effective
- automatic fire alarms are becoming more reliable and effective and fire alarms are being installed in homes
- smoke vents are becoming more reliable and effective - normal ventilation systems can spread harmful smoke in a building
- safer building techniques

- the location of fire stations near to risk objects
- pre-planning and regular exercises
- faster fire engines with effective equipment
- good access for fire engines
- strict regulations for fittings in public buildings
- good training and information for personnel in the rescue services
- less smoking
- information to the general public on television, radio and in newspapers
- information to schools and companies

**risk level increases**

- large/high buildings
- complexity
- combustible material
- combustible fittings
- sabotage, terrorism

**can be countered by**

dividing into sections, sprinklers  
 smaller units, good overview  
 product development, information and education  
 inspection, technical improvements  
 fire prevention to minimise the consequences

**threat**

- fire
- smoke
- emergency exits
- number of floors in building
- building construction
- building material
- building's fire load
- operation
- number of occupants
- handicapped/sick occupants
- extinguishing systems
- fire alarm
- rescue service's ability to save life and property

**factors to consider**

intensity, speed at which fire spreads  
 thickness, toxicity  
 number, accessibility  
 evacuation of the building  
 - especially if under ground  
 strength, air-tightness, fire-resistance  
 combustibility, toxicity in a fire  
 time for evacuation  
 fire risk, fire load, preventive measures  
 possibility of evacuation  
 possibility of evacuation  
 saving life and property  
 possibility of evacuation, saving life and property  
 response time, manpower and equipment

There are examples from the second world war of large scale fires developing into fire storms. These intensive fires consume a large amount of oxygen. The suction from the fire can pull people and animals into the flames.

Sabotage and arson attacks can lead to serious fires and explosions.

The need for methods to evaluate various risks has increased as industry and society

have developed. Complex calculations are required to estimate the probability and consequences of a fire with some precision. There is no general method to estimate fire risk for any building and all operations. Several different methods are available. Some of them can be used to show the effect of various preventive measures on the level of risk. Fire risk investigations are particularly important for industrial sites, depots, hospitals, schools, hotels and public buildings.

The method for evaluating fire risk which is used most frequently in Europe was developed in Switzerland by M. Gretener in the 1960s. It is intended for industrial establishments but can also be applied to department stores, hotels, exhibition centres, blocks of flats and hospitals.

Gretener's method takes account of the architecture, construction and contents of the building in order to evaluate fire risk. Combustibility, fire load, smoke production and the corrosive effects of smoke are considered. (With a limited supply of oxygen, a fire in oil, plastic or rubber can produce large quantities of smoke although the intensity of the fire is low. Fires can also produce corrosive or toxic gases)

Around 1980 a new method for risk analysis was developed in the USA, providing a new approach to the problem. It attempts to take account of the effect of people's actions as well as that of automatic equipment. Various categories of people are considered - for example the old, sick and handicapped. The method is based upon balancing protective measures against the risks that different groups are exposed to. Protective measures are taken to include people's responses to the situation and their possibility of escape, as well as the physical features of the building.

### **3.2.4 Examples of Serious Fires:**

#### **The Sherwin - Williams Warehouse Fire**

On 27th May 1987 an estimated 40 litres of inflammable liquid were accidentally spilled in a car paint distribution centre in Dayton, Ohio, USA.

Sparks from an electric fork-lift truck ignited the spilled liquid and the resulting fire destroyed the entire warehouse, consuming 5 million litres of inflammable liquids. The warehouse was situated in an area supplying drinking water. The fire fighters opted for a controlled burn-out because no adequate water retention devices were available. The fire lasted for six days but thanks to the burn-out decision major contamination to the ground-water was avoided.

#### **Sandoz Warehouse Fire**

During the night of the 31st October 1986 a fire broke out in a warehouse belonging to Sandoz at Schweitzerhalle, near Basel in Switzerland.

The fire spread rapidly. Drums exploded and were thrown through the air, damaging nearby buildings where some 1000 tons of highly inflammable liquids were stored. To avoid a catastrophe the fire chief decided to extinguish the fire. Water used to extinguish the fire became contaminated. It flowed into the river Rhine (from which water was being pumped to fight the fire). This contaminated water contained pesticides and other toxic chemicals, which killed fish and other forms of life in the river. Drinking water supplies further downstream had to be shut off.

#### **Chemical Factory, Tours**

In June 1988 there was a fire in a chemical factory near Tours, France.

The fire spread very quickly because inflammable products were stocked close to each

other. About 600 tons of chemicals were destroyed, being dispersed into the atmosphere and a river flowing past the factory. A dense black cloud drifted towards the city of Tours. The drinking water for about 12,000 people had to be cut off for several days.

There are many examples of fires in public buildings, such as hotels and discotheques, which have claimed many lives. Fires, together with road accidents, are the most frequent events the rescue services have to deal with.



*Fire resulting from chemical processes, Pemex, Mexico .*



## 3.3 Explosions

### 3.3.1 Definitions

The word explosion is used to cover all processes characterized by a sudden flow of material (usually consisting mostly of hot gases) out from one point.

There are two main types of explosion, depending on how the sudden flow has been caused:

#### Explosions as a result of physical processes

- stored energy in the form of pressure x volume is suddenly liberated,
- external energy is suddenly supplied to a solid or liquid substance, transforming it into gas.
- energy is suddenly supplied to a gas, which increases its pressure,

Examples of explosions caused by physical processes: pressure vessel explosions, steam explosions.

#### Explosions as a result of chemical reactions

These are caused when reactions that give out heat provide the energy for the flow of material. There are three ways for this to take place. In each case the substances concerned must be present in the right proportions and well mixed.

##### - Heat explosion

The reaction mixture has roughly the same temperature throughout. The liberation of energy takes place at the same time throughout the mixture. Example: rapid uncontrollable chemical processes.

##### - Deflagration

The liberation of energy takes place in a thin layer which has a high temperature, the rest of the volume having the same temperature as the surroundings. The next layer to react is warmed up by the conduction of heat through the mixture. The speed of deflagration is low - mm/s for solids and liquids, m/s for gases. The speed of deflagration depends on pressure (increasing with increased pressure). The deflagration is started by a localized pulse of heat.

##### - Detonation

The liberation of energy takes place in a thin layer which has a high temperature, the rest of the volume having the same temperature as the surroundings. The next layer to react is hit by a shock wave and warmed up by compression heat in gases or deformation heat in solids. The speed of detonation depends on the movement of the shockwave through the reactants and is therefore high - km/s for all materials. The speed of detonation does not depend on the surrounding pressure. The detonation is started by a localised shock.

In certain circumstances a deflagration can turn into a detonation (eg in the cases of large quantities, porous solids or obstacles creating turbulence in the flame front in a gas).



*Fire resulting from explosion on board an oil tanker, Genova, 1991.*

### **3.3.2 Hazards**

#### **3.3.2.1 Explosions Caused by Physical Processes**

**Pressure vessels** and processing equipments for compressed gases are latent bombs. Faults in materials, corrosion or being struck by another object can cause the wall of a vessel to rupture, with a consequent explosion. The force of the explosion is determined by the energy stored - that is  $P \times V / (k-1)$ , where  $P$  is pressure (Pa),  $V$  is volume (m<sup>3</sup>) and  $k$  is the  $c_p/c_v$  for the gas.

Pressure vessel explosions cause damage as a result of the pressure wave and flying debris.

Liquids at a temperature exceeding 100°C can cause steam explosions. If water (or any other liquid with the same or lower boiling point) finds its way into the hot liquid there will be an explosive production of steam. The steam produced has a far greater volume than the original water (several thousand times the volume!). Steam explosions can occur at foundries and in cellulose production (soda vessels). The force of the explosion is determined by the temperature of the hot liquid and its heat capacity as well as the volume of the liquid that boils.

Steam explosions cause damage as a result of the pressure wave as well as fire and burns caused by the escape of the hot liquid.

**Explosions caused by external energy** (usually electrical) can take place in a solid, liquid or gas. If sufficient energy is supplied, it will cause a solid substance already in gas form greatly to increase its pressure. There is always the risk of this kind of explosion when there is a short circuit in a large oil or gas-cooled transformer. Damage is caused by the pressure wave and flying debris.

#### **3.3.2.2. Explosions Caused by Chemical Reactions**

It is possible to cause explosions with any kind of heat-producing (exothermic) chemical reaction.

## **Exothermal processes in industry**

There is always the risk of an explosion when an exothermal process is being used in the chemical industry. All it needs is a fault in the regulation of quantities in the process or in the cooling system.

The easiest way to recognise equipment for exothermal processes is that it includes a cooling system of some kind, usually water cooling, which is meant to keep the temperature within certain limits.

The force of an explosion is determined by the total amount of energy liberated, which is given by the quantity of the reaction. The damage is mostly due to the pressure wave and flying debris.

## **Unintentional mixtures of air and fuel**

Explosive mixtures are created when:

1. inflammable gases are mixed with air
2. inflammable liquids with a low boiling point evaporate in air
3. inflammable liquids at a high temperature escape into air
4. inflammable liquids at high pressure are ejected into air
5. combustible solids in a powder form whirl round in air

1-3 give gas mixtures, 4-5 aerosols.

The mixtures are only explosive within a certain interval of the fuel/air ratio, depending on the substance in question.

The energy content of the mixture is greatest when there is exactly enough oxygen present in the air to burn the fuel completely. This is usually called the stoichiometric concentration and lies about halfway between the limits of the explosive mixture. The stoichiometric concentration for combustible aerosols is about 100 g/m<sup>3</sup>, the lower boundary being about 1/3 of that.

Deflagration of a fuel/air mixture in a closed space produces a pressure of about 7 bars ( 1 bar = 1.033 atmospheres at stoichiometric concentration and atmospheric pressure). Detonation in similar conditions produces about 20 bars.

Deflagration in an open space does not produce such a high pressure (as long as the fuel/air cloud is not very large). However detonation in the open produces the same pressure as in a closed space.

Damage is caused by the effects of heat and pressure, but flying debris can also cause damage ( eg. glass from broken windows).

**Latent hazards**, in the same order as the five types of mixtures given above:

1. Compressed or condensed inflammable gases (eg. LPG, natural gas, acetylene, hydrogen, ammonia, ethylene).
2. Inflammable liquids with boiling points under 100°C in tanks and processing equipment (eg. ether, alcohol, acetone, petrol).

3. Inflammable liquids in processes where the temperature is at or above the boiling point of the liquid at atmospheric pressure.

4. Inflammable liquids in processes at high pressure.

5. All finely divided combustible solids that can be caught up in the air when handling (loading/unloading, regulating quantity) - eg. flour, sugar, starch, aluminium powder.

The greatest risks are for powders in large quantities, as in silos, and with certain energy-rich substances such as aluminium.

The hazards in 1-4 above arise from: the inadvertent release of fuel caused by faults in components; corrosion; equipment being struck by another object; or human error.

### **Substances that can break down and give out energy**

There is a number of chemical compounds which, on being given initial energy (from heat, friction or being struck), can break down explosively. Many are classed as explosives - but not all! Special permission is needed to produce or obtain substances designated as explosives. However, many commonly used substances can cause explosions but are not classified as explosives. These include: peroxides (hydrogen peroxide and organic peroxides); aluminium salts with an oxygen carrying group such as a nitrate, chlorate, perchlorate, chromate, dichromate, etc; and metal complexes of the form metal-amine-nitrate (or chlorate, perchlorate, chromate, dichromate, etc). Of these, hydrogen peroxide, ammonium nitrate and ammonium perchlorate are handled in the largest quantities.

An explosion causes damage as a result of heat and pressure effects and fires often occur.

### **Mixture of an oxidizing agent and combustible material**

An explosion can be caused when a solid or liquid oxidizing agent is mixed with fuel. The greatest energy is released if there is a stoichiometric mixture. It is easy to get an energy content of 5- 10 MJ/kg, i.e.as much as conventional explosives!

Common solid oxidizing agents are peroxides, nitrates, chlorates, perchlorates, chromates and dichromates.

Common liquid oxidizing agents are perchloric acid, nitric acid, hydrogen peroxide, tetranitromethane.

The fuel can be more or less any combustible organic substance, metal, alloy, sulphur or sulphur compound.

The most common hazard is a combination of a liquid oxidizing agent and solid combustible material, or vice versa, which are handled or stored near each other.

The hazard leads to an explosion if an inadvertent release leads to the two materials coming into contact. This could be the result of a fault in equipment, corrosion, equipment being struck by another object or human error.

The damage from this kind of explosion is the same as that caused by conventional explosives.

### 3.3.3 Consequences

People are injured in explosions due to the effect of pressure, flying debris and heat.

**The parts of the body most sensitive to pressure** are the ear drums, lungs and stomach/intestines. The ear drum is damaged at an excess pressure of 35 kPa. Lungs are damaged at about 70 kPa, 300 kPa putting life in danger. The severity of injuries to the lungs and stomach/intestines also depends on the length of exposure and rate of increase in pressure.

If the pressure is sufficiently high and long-lasting a person can be knocked over. Serious injuries (eg fractured skull) come with an impulse density of about 380 Pa x s (380 Ns/m<sup>2</sup>)

**Injuries from flying glass** are also common. Pieces of glass weighing between 0.2 and 2 g penetrate skin if they have a speed of 65-80 m/s, and penetrate the stomach wall at 70-155 m/s.

Explosions caused by chemical reactions also cause **injuries from the heat radiation generated**. About half of the energy liberated takes the form of heat.

Burns to the hands and face are caused by the following amounts of energy:

first degree burns	50- 80 kJ/m <sup>2</sup>
second degree burns	120-200 kJ/m <sup>2</sup>
third degree burns	200-350 kJ/m <sup>2</sup>

(The lower value is for short, intensive exposure - of about 1 s - the higher for longer exposure - about 10 s )

Due to their large surface areas buildings can stand exposure only to relatively low pressures if they are to be left undamaged. Windows are damaged at as little as 1 kPa. Limited damage to windows, doors and external surfaces occurs if the pressure exceeds 5 kPa and impulse density is greater than 100 Pa x s. Serious damage (i.e. only a quarter of the building left standing) occurs at 40 kPa and 400 Pa x s.

Explosions that take place indoors nearly always lead to serious damage for this reason. Note that people cope much better with exposure to pressure than buildings do!

When heat is generated there is the risk of easily combustible materials, such as paper, curtains etc, being set on fire. This takes place if the energy level is at 200-350 kJ/m<sup>2</sup>, the level producing third degree burns.

Establishments for communications and the supply of electricity, water, etc, are specially attractive targets for sabotage.

In wartime the likelihood of explosions increases greatly. Most weapons cause a great deal of damage where they land, as well as throwing out shrapnel, which can penetrate steel at a distance of several hundred metres.

Pressure vessel explosions and fuel/air explosions would often occur when an industrial area is attacked.

After an attack there would still be a high risk of explosions, for example from delayed action or unexploded bombs. Bomb disposal must be done by trained experts.

### 3.3.4 Examples of Serious Explosions

A bomb explosion in the railway station at Bologna, Italy, caused the roof to collapse, killing 85 people. It is the worst explosion of modern times, though there have been many other accidents with explosives. Here are some other examples:

#### **Longview, Texas, USA, 1971**

On February 1971 a preasure ethylene gas pipe broke in a plant near Longview, Texas and the vapour cloud found a source of ignition and exploded. The explosion broke numerous other pipes and caused the release of many thousands of pounds of ethylene. The larger vapour cloud which resulted ignited and exploded violently. Four people were killed and 60 were treated in hospital.

#### **Bantry Bay, Eire, 1979**

On 8 July 1979 a small explosion took place at the oil terminal at Bantry Bay. An oil tanker was unloading oil. Later there was a large explosion accompanied by a fireball. Missiles from the explosion travelled up to six miles. All 42 members of the crew were killed, together with 8 other people, mostly terminal operators.

#### **Henderson, USA, 1988**

An explosion, caused by a fire, devastated a rocket fuel factory in Henderson near Las Vegas, USA, 1988. Ammonia, ammonia perchlorate and hydrochloric acid were being handled in the factory.

In addition to the two deaths, about 350 workers and Henderson residents were hurt. The main injuries were cuts and abrasions, from flying glass and debris, and bruises and sprains from being knocked down by the shock waves.

The blast damaged more than 50 % of the buildings in Henderson, forcing shops, offices and schools to close. The damage was initially estimated at more than \$70 million, \$ 23 million of which was uninsured.

### 3.3.5 Hazard Analysis Methods

It is necessary to know the amount of energy released and the distance from the object in question. Approximate values for the danger area for the most common kinds of explosions are given below. Only the effects of pressure are considered and it is assumed that the explosion takes place outdoors.

For more precise estimates a computer program is needed, which takes account of geometry, the strength of the object in question, shrapnel, heat effects etc.

#### **Pressure vessel explosions**

Estimated energy released  $E = P \times V / (k-1)$

where: P is gas pressure (Pa)

V is volume in m<sup>3</sup>

k is cp/cv for the gas

Examples of values for k:

air	1.40
ammonia	1.32
argon	1.67
nitrogen	1.40

oxygen	1.40
carbon dioxide	1.31
hydrogen	1.41

Estimate the corresponding amount of explosives in kg by dividing E by 5 000 000 (  $5 \times 10^6$  ). Then estimate for the radius of the danger area for people and buildings (see diagram 3.3.1).

### **Explosions of solid or liquid substances or mixtures of an oxidizing agent and fuel**

Go directly to the diagram in 3.3.1, using the quantity in kg of substance or mixture in question.

The diagram is for explosives with an energy content of 5 MJ/kg. If the actual energy content of the substance is known, multiply the quantity in kg by the factor (actual energy /5).

### **Fuel/air explosions**

Calculate the amount of explosives in kg corresponding to the explosive effect of the mixture

$$\text{kg} = 0.02 \times M \times Q$$

where: M = kg inflammable substance released in air

Q = heat from combustion of the substance in MJ/kg (if this is unknown, use the value 50 MJ/kg)

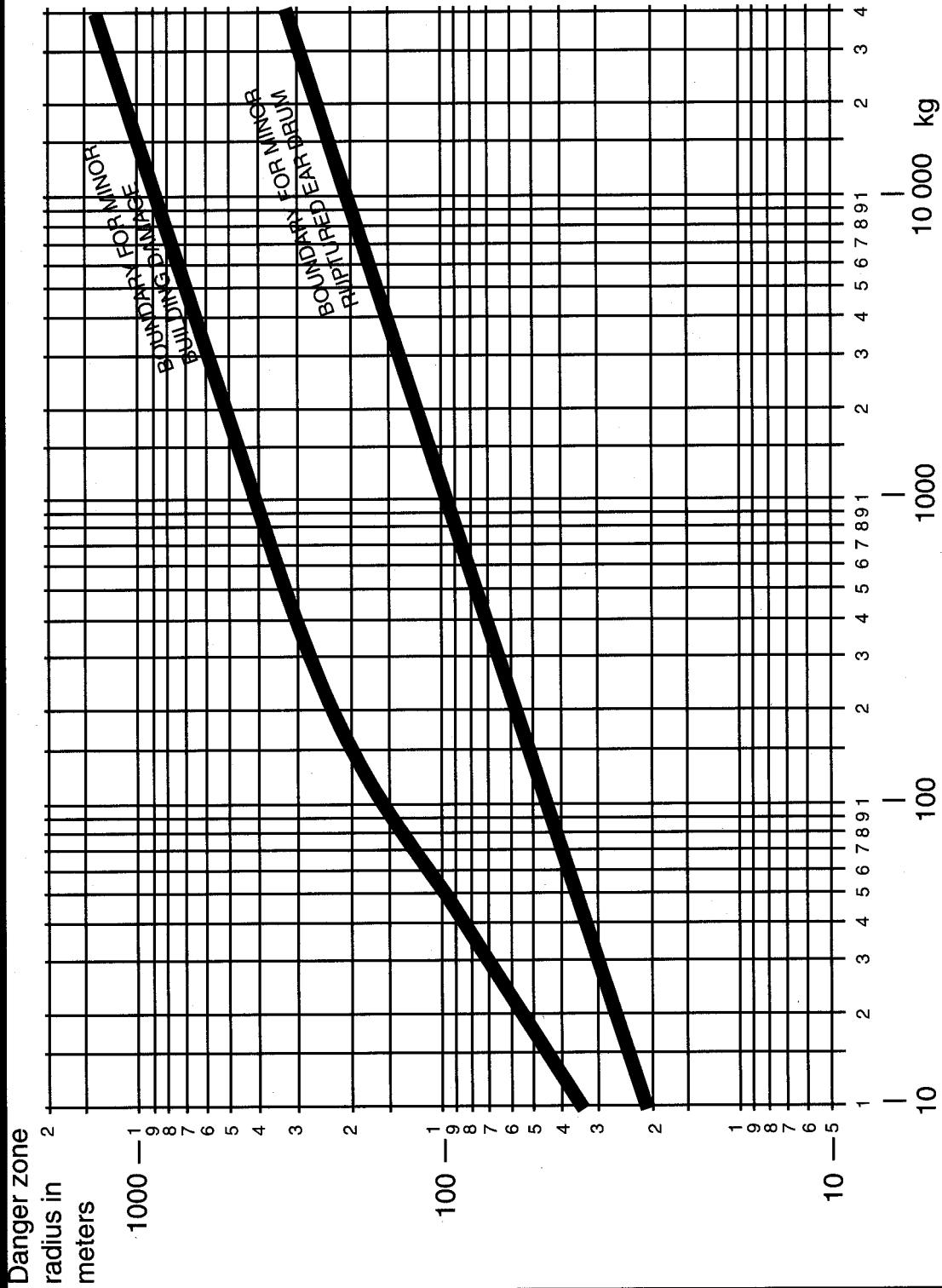
The estimated amount of kg should be doubled for hydrogen, ethylene, acetylene.

See diagram 3.3.1 for the radius of the danger area for people and buildings.

# FOA

## Explosion shock wave damage

Diagram  
3:3:1





## 3.4 Chemical Leakages

### 3.4.1 Chemical Accidents

Chemical accidents are the result of an uncontrolled release of a substance that is poisonous or harmful to property or the environment. The risks depend on the characteristics of the substance in question, the quantities being handled and the processes used, as well as the vulnerability of the surroundings and the emergency measures taken to minimize the consequences of the accident.

### 3.4.2 How Dangerous are Chemicals?

Chemical substances are either elements or compounds. There are between 100 and 200 different kinds of atoms and elements are made up of just one of those kinds. Compounds are made up of a variety of elements such as methane (carbon and hydrogen), water (hydrogen and oxygen) and salt (sodium and chlorine). Preparations are made up of mixtures of chemical substances, for example paint which consists of a pigment, a resin and a solvent.

A substance can be dangerous in many ways. It can be toxic, reactive, explosive, inflammable, radioactive or corrosive. Two important aspects are toxicity and reactivity.

#### Toxicity

Most substances that can give rise to serious injuries to people and animals are marked with T or a skull and crossbones.

There are several ways that a toxic substance can be taken in:

- inhalation of contaminated air
- absorption through the skin
- ingestion via the mouth

Some substances lead to a general poisoning of the whole body. Other substances only affect certain organs. Corrosive and irritating gases such as chlorine, sulphur dioxide and ammonia can seriously damage the lungs. The level at which a substance is toxic varies greatly depending on its effects. Dioxin, or 2,3,7,8-tetrachlorodibenzoparadioxin (TCDD), is an extremely toxic substance with a variety of harmful effects. Trials on guinea pigs have shown it to be fatal in a dose as low as a millionth of a gram per kilogram bodyweight.

Chemical releases in the environment can poison animals directly, but they can also have an indirect effect, for example in rivers or lakes when the biological breaking-down of a chemical uses up the oxygen in the water. The consequent severe oxygen shortage kills many kinds of plants and fish. Substances that are difficult to break down can find their way into the food chain, accumulating at the upper end and causing great damage to the whole eco-system.

#### Reactivity

Damage can occur when a reactive chemical reacts with another chemical in an uncontrolled way. Mistakes with raw materials or temperature and pressure can cause a reactor vessel to rupture and lead to the unintentional production of highly toxic substances. When a fire takes place it can convert a relatively harmless chemical into something dangerous which is then spread in the surroundings as the result of the fire itself or of the efforts to put the fire out.

Table 3.4.1, page 72, shows various types of hazardous chemicals and their harmful properties.

Containers and packaging for hazardous chemicals must have markings showing them to be dangerous when in transport, for sale or being used in industry. There should also be written information about hazards and precautions. This should give information on risk classification, composition and characteristics. In addition, potential injuries should be listed, together with details on combustibility and the risk of explosions, as well as advice on preventive measures and emergency routines. Special arrangements to convey such information, e.g. translation into other languages, may be necessary when chemicals are transported (by rail, highway or air) into other countries. For example, dangerous chemicals have been released during fires at airport warehouses.

In places where hazardous substances are handled there should be an up-to-date list covering the particular chemicals in question. This list, together with the written information about hazards and precautions, is an important reservoir of information when identifying risk sources. Information is also required on the properties of these chemicals when evaluating the probabilities and consequences of accidents in a risk analysis.

Under the heading **composition**, the written information about hazards and precautions should give details on what toxic substances are present and in what proportions. The physical properties of a substance are of significance for how it disperses in the environment. The following information on the product should therefore be given under the heading **physical/chemical properties**:

<ul style="list-style-type: none"><li>● form (solid, powder, granular liquid-viscosity, colour etc)</li><li>● boiling point</li></ul>		<b>properties affecting dispersal</b>
<ul style="list-style-type: none"><li>● melting point</li><li>● density</li></ul>		
<ul style="list-style-type: none"><li>● gas density relative to air</li></ul>		
<ul style="list-style-type: none"><li>● flash point</li><li>● ignition temperature</li><li>● flammability range</li></ul>		<b>flammability</b>
<ul style="list-style-type: none"><li>● pressure at 20oC</li></ul>		
<ul style="list-style-type: none"><li>● speed of evaporation relative to ether</li><li>● solubility in organic solvent</li></ul>		<b>dispersal and flammability</b>
<ul style="list-style-type: none"><li>● solubility in water at 20oC</li></ul>		
<ul style="list-style-type: none"><li>● pH when concentrated and in normal dilution</li></ul>		<b>corrosive and environmental effects</b>

Under **biological properties** the following information is given:

- fatal dose for a mouse, rat or rabbit, toxic effects on plants and animals
  - mutagenic and carcinogenic effects, allergic reactions
  - how the substance breaks down
  - chemical/biological need of oxygen
  - risk of bioaccumulation
- toxicity**
- environmental effects**

In some cases certain points are omitted. When something is not relevant for a particular product, this should be stated. A lack of information is then clearly due to insufficient knowledge or a mistake on the part of the manufacturer or importer.

Chemical information sheets have been produced for a great number of elements and compounds. They contain much the same information on physical, chemical and toxic properties as should appear in the written information about hazards and precautions.

Radioactive substances are an especially dangerous group. Certain radioactive substances such as plutonium are so poisonous that their toxicity can constitute a greater danger than their radioactivity.

Information on various substances, their properties and risks can be found in international "Dangerous Goods folders".

### 3.4.3 Hazards

Dangerous goods are a hazard at all times. However the risk they constitute depends on how likely it is that they will leak and what consequences that would have. The most dangerous class is gases condensed under pressure, such as LPG, chlorine, sulphur dioxide and ammonia. Large quantities of these gases are handled and an accident could have catastrophic consequences.

About 200 substances are given in the EC "Seveso directive". A limit is set for each substance. If that safe limit is exceeded, then the establishment must be described carefully. Details must be given on its location, surroundings, layout and equipment as well as on the risks present, methods of operation and systems of maintenance. The size of the workforce and its safety training must also be stated, together with a catastrophe plan and methods for informing those who live nearby.

Risks are involved when processing chemicals. In some cases the form or composition of a dangerous chemical can be altered to make a process safer.

It is through increased knowledge of risks and suitable methods of handling hazardous substances that the dangers can be kept at an tolerable level. In spite of all the risks, there have been relatively few very serious accidents; and with proper rescue efforts the damage caused by an accident can be minimized.

### The Risks of Handling Chemicals

An important factor is the quantity of the chemical being handled. Table 3.4.2 gives examples of the safe limits for a variety of chemicals, as given in the EC "Seveso

Directive". If these values are exceeded, then the operator has to supply information on risks and counter-measures. Of course accidents can still happen when a chemical is being handled in a quantity well below the safe limit.

Technical factors such as the pressure and temperature of a process also affect the hazard.

Gases condensed by cooling are less of a risk than gases condensed by pressure. Substances that are normally liquid can, when processed at a high pressure and temperature, leak out and evaporate in large quantities.

The level of risk also increases if two chemicals that react strongly are being processed or if there are many steps in the process. Loading and unloading material is a hazardous operation. The equipment also affects the risk associated with any given process.

To handle dangerous substances in a safe way, there must be administrative measures to maximize safety; such as operational routines and regular maintenance, waste disposal, training and risk analysis of the system and the installation as a whole.

A hazard analysis for a locality can rarely include a detailed inspection of equipment and methods in the chemicals industry. Competence and resources for this should exist within the company operating the installation. From the local authority perspective it is most important to find out:

- which dangerous substances are being handled in a quantity that could cause a serious accident
- what damage could be done and how widespread it could be
- if the technical conditions increase the hazard (pressure, temperature, process type, common storage)
- if there is an understanding about hazards and the need for safe equipment, safe methods, training, catastrophe plans, etc., at the company in question
- if the hazards demand a response from the local authorities

The greatest hazards would appear to exist in large-scale chemical plants. However knowledge about hazards and the need for the correct response to them has meant that so far there have been few very serious accidents in these plants.

### **The effects of the surroundings on risk**

The probability of an accident occurring is affected to some extent by the conditions around the chemical plant in question.

Hazards and risks associated with the road transport of chemicals depend on traffic intensity, speed limits and road conditions. So-called "external factors", such as land slides, flooding, extreme weather or power cuts, can lead to uncontrolled releases of dangerous substances from a chemical plant.

Factors such as temperature, extreme precipitation and winds can affect the amount of a chemical that is released and its dispersal, which has a bearing on the consequences.

Another factor which influences the consequences of an accident is the distance to buildings containing workers, as well as the distance to houses, hospitals, schools etc. As far as the environment is concerned water supplies, lakes, rivers, agricultural land and nature reserves are especially sensitive to chemical leakages.

Sabotage could lead to the large scale leakage of dangerous chemicals from tanks at a time when safety systems have been put out of action. This means that the theoretical "worst case" could occur - something for which the rescue service plans are not usually geared up. The handling of chemicals in new places could put a large number of people at risk. Damaged buildings and temporary accommodation offer less protection against gases than a normal, relatively air-tight building does. The emergency services will be hard pressed, leading to difficulties in limiting damage and taking care of the injured.

#### 3.4.4 Examples of Accidents Caused by Leakages of Chemicals.

In the accidents described below chemical leakages led to damage as the result of poisoning. About 40 such accidents occurring in the years 1914-1979 are given in F.R. Lees' book "Loss Prevention in the Process Industries", Vol 2. Many of these took place when dangerous goods were under transport. In addition about 130 accidents caused by fires or explosions are described in the book.

Accidents involving petroleum products may have serious consequences for life, property and the environment.

Here are some examples showing different types of accidents:

Year	Location	Event	Deaths	Injured
1959	California, USA	Explosion of LPG and fire	23	
1968	Pernis, the Netherlands	Explosion and oil slops	2	25
1976	Seveso, Italy	Leakage of dioxin	0	193
1977	Umm Said Qatar	Fire ( 1 sq mile) and explosion	7	many
1979	Bantry Bay, Eire	Explosion on oiltanker at terminal	50	
1984	San Juanico Mexico	Explosions and fire LPG	600	7,000
1984	Bhopal, India	Leakage of methyl isocyanate	>2,500	>10,000

Chlorine was both the first poison gas used in war and the first pressure-condensed gas to be handled on a large scale. At first, equipment, materials, knowhow and routines for liquid chlorine were not safe enough in relation to the dangers it posed. Until the 1950's, accidents with chlorine dominate the statistics. Since then the number of accidents with chlorine has decreased. At the same time other hazardous substances have been handled in ever increasing quantities, leading to new risks and, unfortunately, new accidents.

According to OECD statistics the probability of being killed in an accident involving dangerous substances which causes at least five fatalities is much the same as that of being struck by lightning. In addition, the frequency of accidents is diminishing slowly.

Oil fires and explosions are now the main cause of serious accidents. A number of accidents involving oil tankers, storage tanks and pipelines have resulted in the release

of large quantities of oil into the environment. Accidents of this type, together with growing use of and transportation of petroleum products throughout the world, have created an awareness of the risks associated with oil. For a long time to come, oil will still be the dominant fuel and a necessity of our industrial society.

Movement of petroleum products from oil fields to the consumer requires various types of transport, including tankers, pipelines, trains and trucks. Numbers of spills at the point of transfer from one type to another is high.

No two oil spills are exactly alike. The behaviour of oil on water or land is dependent on the type of product. Pre-emergency planning at local level is the most effective tool to deal with any oil spill. The risk of fire and explosion is a major concern for all concerned with handling, storage, transport or clean-up operations.

### **Transport**

Freight transport is an essential activity upon which many industries are dependent. Geographic and demographic conditions can make transport very important. According to OECD about 10 per cent of all tonnage transported consists of hazardous substances. Increasing quantities of dangerous goods are transported by road, with more and more diversified risks to road users, the general public and the environment. However, accidents with dangerous goods can also occur on the railways, at sea or in the air - that is to say, more or less anywhere at any time.

Transport of dangerous goods is to a large extent border-crossing traffic. This is of international concern and calls for co-operation, internationally agreed rules and sharing of information and experience.

Accidents with the transport of dangerous goods have received much publicity recently. There has been increased public concern since the 1978 road accident at Los Alfaques in Spain, when 200 people lost their lives because of a BLEVE (Boiling Liquid Expanding Vapour Explosion) of propylene.

It is therefore important to define precisely what is meant by a dangerous goods accident. A vehicle carrying dangerous goods may be involved in an accident without the load influencing what happens. A distinction should be made between this kind of accident and one where the dangerous goods affect the course of events. A part (however small) of the load must escape for the event to be considered a dangerous goods accident.

The probability of being killed in an accident involving dangerous goods is very small. The consequences of an accident with dangerous goods can be very serious, so it is important that the probability of such events remains low.

The risks can vary from substance to substance and also for a given substance under different conditions. Accidents can take several different forms. (N.B. Accidents with dangerous goods often occur when they are being loaded or unloaded.)

Here are some selected major road accidents involving hazardous goods and materials:

Year	Place	Substance	Deaths	Injured
1970	Ohio, USA	LPG	6	
1973	France, Saint Amand des Eaux	Propane	9	45
1976	Houston, USA	Ammonia	6	178
1987	Herborn, Germany	Petrol	4	



*Transport accident, Paris area.  
Photo : François Cepas, D.S.C.R.*

**Table  
3.4.1**

**Hazardous Chemicals**  
- types, characteristic properties, examples  
(Source: Riskhantering 3, Kemikontorets förlag AB)

Type	Criteria	Examples
Explosives	Classed as an explosive	ethyleneglycoldinitrate picric acid trinitrotoluene
Inflammable gas, compressed or condensed	gases that can burn in air at or below + 21oC	acetylene ethylene oxide LPG
Very inflammable liquid	liquids with flame point at or below + 21oC	acetone petrol carbon disulphide
Inflammable solid	solids than can easily be ignited and will then continue to burn*	red phosphorous
Self-igniting substance	substances that at normal temperatures ignite in air without an external source of energy*	raney-nickel trichlorosilane white phosphorous
Substance giving off inflammable gases on contact with water	substances that give off dangerous quantities of inflammable gases (1 litre of gas per kg per hour) on contact with water or damp air*	calcium carbide calcium sodium
Oxidizing agent or reactive substance	substances that react exothermically when in contact with other substances (for example by giving off oxygen) and therefore constitute a fire risk	sodium nitrate hydrogen peroxide
Poisonous gas, compressed or condensed	Gases with LC50<2000mg/m3 for rats exposed for 4 hours	formaldehyde hydrogen sulphide chlorine sulphur dioxide
Poisonous liquid or solid	substances with LD50<400 mg/kg dermal for rats or rabbits, or LD50<200 mg/kg oral for rats	calcium cyanide carbon disulphide tolvene diisocyanate



Corrosive  
liquid  
or solid

substances that  
cause ulceration  
of the skin on up  
to 4 hour's contact

phenol  
hydrofluoric acid  
sodium hydroxide  
nitric acid

Large quantities of gases with a low toxicity such as freons, carbon dioxide and nitrogen can also constitute a serious health risk in closed spaces.

\* See Official Journal of European Communities No L 257/15, 1983

#### Table

#### 3.4.2 Examples of chemicals and safe limits

From the EC council Directive 24th June 1982 (Revised 19th March 1987) on the major accident hazards of certain industrial activities ( the so-called "Seveso Directive").

Substance	Max. total quantity being handled (in tons)
Inflammable gases	200
Inflammable liquids, class 1	50 000
Acrylonitrile	200
Ammonia ( anhydrous )	500
Chlorine	25
Sulphur dioxide	250
Sulphur trioxide	75
Sodium nitrate ( as fertilizer )	5 000
Sodium chlorate	250
Acid ( liquid )	2 000

Releases amounting to a small percentage of the above limits can cause serious accidents. The consequences depend on the substance's properties and such factors as the speed of the release, conditions for dispersal and the vulnerability of the surroundings.

## 3.5

# Combination Accidents

In a combination accident one event leads to another, which itself can cause more damage.

It is not possible to list all the conceivable combinations. Even actions taken in response to an accident can have serious consequences. The fire in the Sandoz plant in Switzerland (1986) is an example of this - water used to extinguish the fire contaminated the whole Rhine. You must use your imagination to think of potential knock-on effects when doing hazard analysis, as well as in emergency response situations. Knowledge of local conditions and reports of incidents are necessary to the creation of an inventory of places in which hazards can cause combination accidents.

**Some selected examples of combination events from recent years are given below:**

### **Hearne, Texas, USA 1972**

On 14 May, 1972, crude oil sprayed out from a pipeline into the air, showering the surrounding countryside with oil. The oil flowed along a stream beneath a railway and a highway. The crude oil was ignited by an unknown source. The resulting explosion and fire killed one man and seriously burned two other people. An intense fire several hundred feet high and about 200 feet long burned on the surface of the oil, along the stream and on the railway, road and stock-pond, and scorched the whole area.

### **Beek, the Netherlands, 1975**

In the early morning of 7 November 1975 the startup was under way of Naphta Cracker II, on the 100.000 ton per annum ethylene plant at Beek.

An escape of vapour was observed near the depropanizer. Shortly after, the cloud ignited and there was a massive unconfined vapour cloud explosion. The explosion killed 14 people and injured 104 inside the factory and 3 outside it. It caused extensive damage and started numerous fires. It also caused fire to break out in the pipeline system and six tanks ranging in capacity from 1.500 to 6.000 m<sup>3</sup> within a common dike burnt out.

### **Baton Rouge, Louisiana, USA, 1976**

On 10 December 1976 some 100 tons of chlorine escaped from a storage tank at a chemical factory in Baton Rouge. The plant had been shut down for maintenance. During the start-up an explosion occurred. The force of the explosion was sufficient to dislodge the chlorine tank from its foundation. The tank fell and was punctured, allowing chlorine to escape. The explosion was attributed to the presence of natural gas in the inert gas purge system of the plant. The release continued for about 6 hours. The gas was carried about 1 kilometer by the wind. The local population was evacuated and there were no fatalities.

### **Westwego Louisiana, USA, 1977**

On December 1977 a series of explosions took place in the silos of a large grain elevator at Westwego, Louisiana. There were 45 silos involved, containing corn, wheat and soya beans. Thirty-five people were killed. Most of these were in an office building which was crushed when a 250-foot concrete tower fell on it. The value of the silos was estimated at the time to be 100 million USD.

### **Restaurant explosion, Stockholm, Sweden 1981**

A violent explosion caused great structural damage to a building housing a restaurant in central Stockholm. Fortunately no one was injured, since the restaurant was empty at the time, as was the road outside. A fire broke out on the fourth floor and spread to other parts of the building. Ruptured gas pipes increased the risk of the fire spreading.

### **Heavy rain, Italy, July 1987**

At least 25 people were killed in Italy as a result of landslides and flooding following torrential rain. In the same month 22 people died when they were buried in mud on a campsite in the village of Le Grand-Bornand in the French Alps.

### **Dangerous goods accident, Borås, Sweden 1987**

A railway tanker containing concentrated hydrochloric acid began to leak at a chemical factory. A large white cloud spread over a shopping centre and residential areas. About one thousand people had to be locked into the shopping centre. 6 - 8 cubic metres of acid escaped. It was the fourth accident at the factory. Each accident had been followed by criticism of the local authorities, which allowed the factory to be built as late as in 1979.

### **Fighter plane crash, West Germany, 1988**

A West German fighter plane was a matter of seconds from crashing into a nuclear power station.

### **Flooding, West Germany, 1988**

Flooding caused environmentally harmful waste to escape, contaminating ground water in the surrounding area.

## 3.6 Selected Examples of Accidents in Various Countries, 1970-1989

Sources: OECD statistics, Swiss Reinsurance Company.

Year	Place	Cause	Product	Deaths(d)/inj(i) /evacuated (e)
1970	Osaka, Japan	Explosion	Gas	92 d
1973	Fort Wayne, USA	Rail accident	Vinyl-chloride	0 d 0i 4.500e
	Market Tree, "	" "	LPG	0 d 0i 2.500e
	Greensburg, "	" "	Chlorine	0 d 0i 2.500e
1974	Flixborough, UK	Explosion	Cyclo-hexane	23 d 104i 3.000e
	Decatur, USA	Rail accident	Isobutane	7 d 152-
1975	Beek, Holland	Explosion	Ethylene	14 d 107i -
	Heimstetten, Germany	Warehouse	Nitrogen	0d 0i 10.000e
1976	Houston, USA	Silo explosion	Wheat	7 d 0i 10.000e
	Lapua, Finland	Explosion	Explosives	43 d - -
	Seveso, Italy	Leakage	Dioxin	0 d 193i 730e
1978	Los Alfaques, Spain	Road accident	Propylene	216 d 200i-
1979	Bremen, Germany	Mill explosion	Flour	14 d 27i
	Mississauga, Canada	Rail accident	Chlorine/ Butane	0 d 0i 200.000 e
1980	Mandir Asad, India	Industrial accident	Explosives	50 d - -
	Barking, USA	Industrial fire	Cyanide/Sodium	0 d 12i
1981	Tocaoa, Venezuela	Explosion	Oil	145 d 1.000i
1984	Sao Paulo, Brazil	Pipeline explosion	Petrol	508 d - -
	Bhopal, India	Leakage	MIC	>2.500 d 10.000 i > 300.000 e

	San Juanico, Mexico	Explosion BLEVE	LPG	600 d 7.000i
1986	Chernobyl, USSR	Nuclear accident		direct 31d 500 i >112.000 e
	Basel, Switz.	Warehouse fire		caused severe environmental damage to Rhine
1987	Harbin, P R of ChinA	Explosion in a flax factory		49 d
	Djakarta, Indonesia	Fire in textile factory		30 d
	Pampa, USA	Explosion in a chemical plant		31 d severe damage
	London, U K	Fire in underground station		30 d
1988	Paris, France	Train collision in a railway station		59 d
	North Sea	Piper-Alpha platform		166 d
1989	Near Ufa, USSR	Gas leaking out of pipe-line explode because of sparks from two trains		645d
	Pasadena, USA	Gas cloud explosion in a petrochemical plant		23 d - -
	Alaska, USA	EXXON Valdez lost about 40 million litres of crude oil		cost at least 2 bn. US \$

## 3.7 Other Risk Analysis Methods

This annex will give brief information about some of the risk analysis methods used by industry and others. It could be of interest to know about some of these methods, if and when you would like to go beyond the scope of this Handbook, to go more deeply into the problems and to do more detailed hazard analysis.

A number of methods for identifying and evaluating hazards are outlined below. The first methods give an overview and are suitable for a locality risk analysis. Those following are more analytical and systematic. They are more suitable for the detailed analysis of high risk installations carried out within industry. However it is useful for those involved in work at a local authority level to know about these methods. The information provided by industry on risks associated with technical systems may well be based on one of these more advanced methods.

The need for reliability in industrial processes means that equipment is often complicated. Hazard analysis is intended to create a better understanding of the interplay between various systems and how a complicated course of events with a high degree of human error can lead to a serious accident. The results of such a detailed analysis can be used when:

- deciding where to locate hazardous operations
- deciding on investments in equipment to prevent accidents or limit their consequences
- designing processing equipment and control systems
- dimensioning safety systems such as safety valves, sprinklers, containment walls etc
- creating operational and maintenance routines
- writing safety documents for an establishment

Analysis methods are much the same when identifying and characterizing risk sources, whether they involve fires and explosions or chemical leakages. Estimations of probability can also be made using the same methods. However, different methods must be used when considering consequences (see "Consequence Analysis" below).

### 3.7.1 Overview methods

#### 3.7.1.1 Checklists (comparative analysis)

Checklists are most often used in comparative analysis to identify known hazards and to check that recognized standards are being followed.

Large and complex systems require detailed checklists which are adapted to the type of process in question. Such checklists often include specific requirements for the technical make up of the equipment and for suitable operating procedures.

The result of the analysis is a list of notes on whether a number of specifications are being met.

There are more general checklists for an overview of the risks in a system as a whole. They contain questions on the characteristics of chemicals being handled, hazardous processes, the effects of external factors such as power and water supply failures,

together with the state of emergency equipment etc. This kind of checklist is often used in "Rough Analysis" and "What If? Analysis".

### **3.7.1.2 "Rough Analysis"**

Rough analysis or "preliminary risk analysis" is used to identify risk sources without going into technical detail. Often the aim is to get a rough picture of which systems are a serious risk. A more detailed method could then be used for the high-risk systems. A rough analysis is used at an early stage when planning a new industrial project.

The result of a rough analysis is a list of risk sources and a very approximate evaluation of the probability of an accident occurring, together with an estimation of the consequences.

The analysis requires information on the characteristics of chemicals being processed, the quantities, the type of equipment and routines being used, etc, together with details on the installation's location and surroundings.

The method is suitable for a community risk analysis.

### **3.7.1.3 "What If? analysis"**

This method is used to identify risk sources by asking what the effect would be of a number of unexpected events and finding out which of these would have serious consequences. The method is often used in industry to look into the risks associated with changes in equipment and operational routines.

The analysis results in a table of possible accidents and their consequences, together with proposals on measures to reduce risk if this is thought necessary.

"What If? analysis" requires a better knowledge of the processes and operational routines at an installation than a rough analysis does. It is therefore often carried out by interviewing those responsible for the operation and maintenance of an installation. Possible problems and mistakes are outlined in a questionnaire. A suitable technical description of the installation is required as a basis for the analysis (including plans and process/instrument diagrams where necessary).

The method is logical and gives valuable information without too much work, as long as there is a good descriptive basis and the aims are clearly defined. It is suitable as a more detailed follow-up to a rough analysis at specially hazardous installations. As such it can be a useful tool in a community risk analysis.

## **3.7.2 More detailed methods**

### **3.7.2.1 Relative ranking (Dow and Mond index)**

Index methods are used to identify risk sources and to classify different sections of installations for processing chemicals according to fire and explosion risk. Detailed manuals are used to work out various risk and bonus factors from information on what is processed, equipment, control and safety systems, etc. These numerical factors are then used to work out indices for fire and explosion risks as well as "total" risk. These judgements are based on comparison with data from previous accidents. The risk category shows whether preventive measures should be considered. By working out indices for various parts of an installation, an objective comparison of risks can be obtained.

The method is more demanding than those given above, the analysis techniques taking some effort to learn. There is a computer program for the method, developed by Dow and Mond.

### **3.7.2.2 Risk and reliability analysis (HazOp)**

This is a much more detailed and analytical method than those mentioned earlier. It is used to identify risk factors and potential operational problems, as well as working out the course of an accident or break in production. The analysis leads to a basic understanding of the importance of certain critical components and the effects of human error in operation and maintenance, as well as producing a list of hazards and points that could lead to breaks in production. A detailed technical background is needed for the analysis. The work is based on diagrams of process and instrument systems, a number of key words being used to focus attention on potential deviations from normal conditions.

Risk and reliability analysis is of use within industry. It is only justifiable as part of a community analysis of very complex systems where an accident would have serious consequences. Few municipal facilities would require such a detailed analysis.

### **3.7.3 Operator and competence analysis**

Faults in a system usually occur as a result of mistakes by operators or malfunctions of components. There are two similar analysis methods; one focusing on the consequences of human error, the other on technical malfunctions. Both methods are suitable for a limited analysis of particular systems or tasks. They are not relevant during the initial stages of a community risk analysis.

#### **3.7.3.1 Human reliability analysis**

The method is used for one particular aspect of operation or maintenance. The operator's responses to various situations are documented in a logical order. The effect of these responses being applied too late or not applied at all is considered in the discussion that follows. Mistakes with potentially serious consequences are noted.

A detailed knowledge of the system in question is required for this analysis, together with an understanding of routines and the decision making process. Experience shows that mistaken interpretations of dangerous situations and the failure to act in the best way are common causes of accidents. It is therefore important to see if equipment is set up and routines laid down so that human error can be avoided where possible and its consequences limited should it occur. The effects of human error should be considered in many more fields - at present most interest is shown by the chemical industry.

#### **3.7.3.2 Malfunction, effect and consequence analysis**

The method leads to a table of components, their functions, their potential malfunctions and the consequences of these malfunctions. The method concentrates on components but can also be used to predict the effects of human error. The work is based on a list of components, a description of the system and its function (P & I diagram) and experiences of malfunctions. The method is systematic and suitable for use in many technical systems. The method is not able to give much information when a system is so complicated that a certain malfunction can only cause an accident if a number of other mistakes or malfunctions occur. In these cases it is necessary to use a tree diagram.

### **3.7.4 Tree methods**

These methods are based on tree diagrams systematically displaying a number of events which are dependent on each other. Detailed descriptions of processes and equipment are required. The methods are very time consuming and the results are difficult to interpret. They are therefore limited to a particular part of a system (an



exception to this is risk analysis at nuclear power stations). Computer programs do exist to support the construction and interpretation of tree diagrams.

#### **3.7.4.1 Fault Tree analysis**

This is used to identify combinations of mistakes and mechanical faults that can lead to certain kinds of damage. The "top event" is the starting point for the analysis. The probability of the top event can be worked out from the conditions causing it to occur which are displayed in the level of the tree immediately below. Those events are in turn caused by events at a lower level. You follow the conditions back down the tree to arrive at the initial "base" event. The method produces a fault tree and a table which outlines the combination of base events which is necessary and sufficient for a top event to occur.

#### **3.7.4.2 Event Tree analysis**

This is used to identify and evaluate initial events which can lead to damage, by illustrating the connections that exist between various stages in an accident. Initial events could be malfunctions in components, human error or external factors such as landslides or lightning.

The analysis begins with a given event and then goes on to look at its consequences and the conditions that must prevail for the event to go further. (Fault tree analysis goes in the opposite direction, starting with a given top event and then looking at its causes).

#### **3.7.4.3 Cause and effect analysis**

This is a combination of the two methods described above. You begin with an intermediate event and look at what effects it could produce, then go back to consider what would be required to cause the intermediate event. The graph is similar to a tree with roots constituting potential initial events. The roots come together to form a trunk constituting the intermediate event. The trunk branches out into a number of possible final events, some of which may be undesirable.

#### **3.7.4.4 Consequence analysis**

The methods outlined above are attempts at identifying risk sources. They illustrate how various factors affect the probability of an accident by constituting an initial event or leading the process towards a dangerous conclusion. Consequence analysis looks at the damage that an accident would cause.

Consequence analysis of processes involving dangerous chemicals should show:

- how large could be the leakage as the result of certain kinds of damage to a particular system
- how a substance should disperse (concentrations and exposure times)
- what could be damaged in the area affected by a leakage
- the damage to be expected to life, property and the environment

The majority of leakages involve only a small part of the total amount of the chemical being handled. They occur from leaking pumps, pipe junctions etc. Breaks in pipelines can lead to larger leakages. If highly dangerous chemicals are being transported, it is usual to divide a pipeline into a number of sections and install pressure gauges and automatic valves, limiting the size of a potential release. It is rare to have a large leakage of chemicals even in transport accidents.

The physical properties of a chemical, together with its temperature and pressure, affect the size of a leakage. Condensed gases stored under pressure can cause sudden, large-scale leakages. By being mixed with air (flushing) the chemical can be provided with energy, speeding up evaporation. A leakage from below the surface of the liquid leads to a much greater release than if the leakage is located above the surface. High pressures and temperatures can cause a liquid with a high boiling point to escape with such power that it becomes finely divided and boils or evaporates to a great extent.

The dispersal of a chemical leakage depends on the form of the substance (gas, liquid, solid, powder) and the conditions at the site of the leakage. Gases, mists and powders will be spread by the wind. Diffusion and turbulence will cause the concentrations to decrease as the chemical disperses.

Deposits on buildings, vegetation and the ground will also reduce concentrations in the air. Solid particles and water soluble gases are also extracted from air by rain or water sprays.

Computer programs have been developed to enable dispersal predictions to be made, based on models taking into account the chemical's properties, meteorological condition and the surroundings. A release near ground level with low winds and temperature inversion leads to the highest concentration in air. Reactive substances can sometimes break down while airborne, affecting the dispersal.

Leakages on the ground are affected by its geological constitution and its affinity for certain chemicals. Liquids can pass through sand and marl, quickly reaching the water table. With clays it is a much slower process. Layers of soil that are acidic have a tendency to bind alkaline metal ions. Humus-rich layers can bind organic substances such as oils.

Lakes and rivers are affected directly by a leakage or contaminated indirectly via ground run-off or ground water. Dispersal in water depends on whether the substance floats, sinks or dissolves. The substance can disappear from the water system by dissolving, evaporating or breaking down. Many substances such as metal salts and highly chlorinated hydrocarbons are stable and insoluble. They can cause serious long-term problems by accumulating in the food chain.

Poisonous gases such as chlorine, sulphur dioxide, ammonia and vinyl chloride are transported in large quantities as compressed gases. It is above all in this form that large-scale leakages can occur, spreading very quickly and exposing plants and animals to dangerous doses of toxins. However the accidents in Seveso and Bhopal, together with the Sandoz fire at Basel show that, in unfortunate circumstances, other poisonous substances can be formed and lead to serious accidents.

There are some computer programs on the market which could be useful when evaluating hazards, e.g. CAMEO from the US, IRIS, SEA BELL from the Netherlands, RISKAT from the UK and RISK from Sweden. Some details about CAMEO (Computer-Aided Management of Emergency Operations) are given here, since it is regularly demonstrated in APELL Seminar/Workshops and the US Environmental Protection Agency is in the process of producing a version for use in other countries in the context of UNEP's APELL programme.

CAMEO is a software program which assists local planners in managing information about chemicals in the community and in conducting a hazards analysis. CAMEO uses the methodology described in "Technical Guidance for Hazards Analysis" (published in 1987 by the US EPA, FEMA and DOT). This methodology is in three parts: hazard analysis; vulnerability analysis (identifying the geographical area at risk); and risk analysis (estimating the likelihood of an accident and the severity of its consequences).

The method can be quickly applied to all known hazards in a community - using credible worst case assumptions about quantity stored, toxicity, weather conditions, topography and atmospheric stability - to identify which hazards pose the greatest risk to the community. Planners then gather more detailed information about the risk object and use more realistic assumptions to develop scenarios that can be used for planning, exercising the plan and training responders. The "Technical Guidance" includes tables and charts, so that it can be used by community planners without resort to the computer software.

CAMEO includes an extensive database for over 3,000 chemicals. It allows planners to store information about facilities and transportation routes as well as individual hazards (including facility and community maps) and to draw vulnerable zones which identify threatened objects around each hazard. The air modelling program in CAMEO allows planners to develop detailed scenarios, taking into account local weather, storage conditions of the chemical and various release scenarios.

## 3.8 References \* and Other Useful Information

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\* Swiss Reinsurance Company, Switzerland

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\* United Nations Environment Programme (UNEP)

"Industry and Environment Review"

UN Bookshop/Sales Unit, Palais de Nations, CH 1211 Geneva 10, Switzerland.

Here you will find some more useful references.

US National Response Team

Hazardous Materials Emergency Planning Guide

&

US EPA, FEMA, DOT

Technical Guidance for Hazards Analysis

Both Washington DC, USA, 1987 - contact Title III Hotline, (1- 800) 535 0202. Enquiries about the CAMEO program should be directed to, US EPA, CAMEO Program, 401 M. St. SW, Washington DC 20460, USA

# UNEP INDUSTRY AND ENVIRONMENT PROGRAMME ACTIVITY CENTRE

## About UNEP - IE/PAC

The Industry and Environment Programme Activity Centre (IE/PAC) (previously the Industry and Environment Office - IEO) was established by UNEP in 1975 to bring industry and government together to promote environmentally sound industrial development. The IE/PAC is located in Paris. Its goals are : (1) to encourage the incorporation of environmental criteria in industrial development plans, (2) to facilitate the implementation of procedures and principles for the protection of the environment, (3) to promote the use of safe and "clean" technologies and, (4) to stimulate the exchange of information and experience throughout the world. IE/PAC provides access to practical information and develops co-operative on-site action and information exchange backed by regular follow-up and assessment. To promote the transfer of information and the sharing of knowledge and experience, IE/PAC has developed three complementary tools: technical reviews and guidelines; "Industry and Environment" review; and a technical query-response service. In keeping with its emphasis on technical co-operation, IE/PAC facilitates technology transfer and the implementation of practices to safeguard the environment through:

- promoting awareness and interaction;
- training activities;
- and diagnostic studies.

## Some recent UNEP - IE/PAC publications

Industry and Environment Review (quarterly), ISSN 0378-9993. Issues deal with topics such as: hazardous waste management, technological accidents, environmental auditing, industry-specific problems, environmental news.

Guidelines for Assessing Industrial Environmental Impact and Environmental Criteria for the Siting of

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Environmental Aspects of Nickel Production - a technical review part I. Sulphide pyrometallurgy and nickel refining ISBN 92 807 1133 4, 127 p, 1988.

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