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INDUSTRIAL ACCIDENT (SAFETY-) RISK MANAGEMENT

Guide to Concepts and Measures for The United Nations Industrial Development Organization

Report*

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*This document has not been edited.

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FOREWORD

The primary mandate of the United Nations Industrial Development Organization (UNIDO) is the promotion and acceleration of industrial development in developing countries. In this, the organization deals with more than forty different industrial sub-sectors ranging from engineering, metallurgy, leather, and food to various types of chemical industries.

In any industrial activity where raw materials are converted to intermediate and final products there is always an element of risk involved. This is more evident in industries dealing with toxic and hazardous chemicals in their process or carry out hazardous operations.

Lessons learned from major accidents clearly indicate that risk assessment, risk avoidance and proper management of acceptable risks should start from the very planning stage of any industrial activity and should also be included in any process modification in existing industries. While no industry can be one hundred percent safe, all efforts should be made to move closer to this safety level. This is only possible by increasing safety awareness at all stages and more so at the management and workers level.

UNIDO being responsible for promotion of industrialization in developing countries has a commitment to promote industrial safety related to operational, occupational and environmental aspects. The safety standards have always been a moving target and are becoming more and more stringent with time and based on lessons learned from accidents. Therefore it is vital that UNIDO staff members involved in programming, project formulation and implementation of projects are kept abreast of the latest developments, methodologies and guidance is given to incorporate all relevant safety requirements in their technical assistance projects in developing countries.

Based on this aim, this document will play an important role not only as a tool for UNIDO staff, but also for developing country governments and industries interesting in addressing the issue of industrial safety.

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INTRODUCTION

With the growing importance of the prevention of environmental damage due to industrial activities (and to human activities in general), interest is also increasing in the assessment of the possibility of damage or harm, that is the assessment of risk. There are various types of risk, but this document focuses on major safety-risks: the risks of a serious number of fatalities as the result of an industrial accident. Safety-risks are related to, but are not to be equated with, occupational-health risks or ecological risks.

The objective of this document is to provide UNIDO technical staff and developing country counterparts with a common understanding of the nature of such safety-risks, and how they could be reduced. Such an understanding will help communication with competent authorities in developing countries as well as with management in industry on how to allocate available resources most effectively in order to improve plant safety.

Complete safety is an important goal for planners, managers and workers in industry. However, it is virtually impossible to prevent accidents altogether. Therefore, a realistic target is to reduce the possibility of accidents to a level which is as low as reasonably practicable, that is not entailing excessive costs. This should take account of two desires of society:

1. the desire to spend its resources on risk-reduction measures most effectively and, at the same time,

2. the desire to invest in a financially viable industry generating benefits to all.

The process of reducing risk to a realistic minimum is called risk management. This guide is divided into the following sections.

First, a conceptual framework for distinguishing the various types of risks (for example, health, safety, ecological and property risks) will be offered. Next, an overview is presented of where in industry safety-risks exist and of what nature they are.

In chapter 2, the structure of risk-management is discussed. Emphasis is placed on the importance of various levels of control. Four methodological stages of safety-risk management are described:

1. hazard assessment;
2. risk analysis;
3. choosing tolerable levels of risk; and
4. risk reduction.

In chapter 3, this methodical approach is elaborated in more detail. The various methods and techniques are presented that have been developed specifically to detect and/or to reduce safety-risks. Here, attention is paid as much as possible to the particular situation of developing countries. The techniques used by the chemical industry appear most appropriate for the wide range of industries in developing countries. As many of the techniques are intended for the chemical process industries, and as the interest in this report originated from within the agro-chemical sector of UNIDO, in this guide the pesticide and fertiliser industries is highlighted as an example.

In chapter 4, safety-risk management is discussed for each of five different stages of industry-development:

1. Design;
2. Construction/Operation;
3. Transports to and from the premises;
4. Aging/Shut-down; and
5. Altering Surroundings.

For each of these five, a number of typical measures are highlighted that should be taken to establish safety.

In Annex 1, references are given to sources of more detailed information, that is major international governmental programmes. Of particular importance in this respect is the "Procedural Guide" of the Inter-Agency Programme (UNEP, WHO, IAEA, UNIDO) on the Assessment and Management of Health and Environmental Risks from Energy and Other Complex Industrial Systems. This guide offers a sophisticated tool to the rapid ranking of a wide range of safety-risks at the local level. As such, it provides the decision maker (authority or industry) with a first but comprehensive criterium for the assignment of risk-reduction priorities.

1. CHARACTERISING RISKS AND SAFETY-RISKS

There exist numerous definitions of risk ranging from highly qualitative to highly quantitative terms. It is commonly agreed that no single measure can capture all aspects of people's concern: risk is "a multi-attribute phenomenon". Furthermore, the specific meaning of risk is often dependent upon culture. For example, in U.S.-based literature "risk" is often conceived of as probability, which is implicit in phrases like "high hazard-low risk installations". In this report, risks are defined globally as the possibility of harm or damage, with harm/damage being any adverse effect to man and/or his environment. Hazards are defined as any physical situation that has the potential to cause harm to man or his environment (in the broadest sense). Safety is defined as the presence of negligible risks, irrespective of the nature of the risks (see below).

It is useful to analyze hazardous situations as single events determined by, and leading to, a series of other events: the so-called hazard chain (see Figure 1). The actual availability of mechanisms to "break" the links of the chain determines whether a hazard will be realised or not. Risks exist because of the probabilistic nature of such availability. Table 1 presents concrete examples of these abstract labels for the specific case of the pesticide industry.

With the help of the causal hazard chain, industrial risks can be distinguished in a number of ways. This is important as, to some extent, different types of risks demand different treatment. A first distinction is in terms of the types of harmful consequences. It can be damage to human health (somatic and/or psychic illness), loss of life (fatalities), or degradation of the physical and biological environment (ecological harm). Also, as a consequence of accidents there is usually damage to (cultural) property and investments by interruption of production and disruption of business. This leads to the breakdown of risks into health, safety, ecological and property risks[1].

[1]In the somewhat tautological notion of "safety-risk" the term safety has a restricted application, that is referring to the risk of lethal effects only.

TABLE 1: EXAMPLE USE OF TERMS ON HAZARDS AND RISKS

PESTICIDE INDUSTRY	
Activities	Pesticide formulation Storage in a warehouse Transport
Hazards	Leak of pesticide Involvement in a fire A road accident involving a vehicle carrying pesticide
Accidents	A fork-lift truck punctures a drum and spills pesticide A fire causes a plume of toxic smoke affecting a residential area
Harm	Workers die from pesticide poisoning Health of nearby residents affected Rivers contaminated and wildlife killed
Risk	A 1 in a million chance per year of a member of the public being killed by a pesticide release One worker being killed every 10 million hours worked
Risk Management	Use of hazard assessment to improve understanding of the risks A decision to introduce a safety training scheme for workers A decision that a computerised model of possible pesticide releases is not cost-effective

A second distinction is in terms of the size of the harmful consequences: minor and major. Some industries have the potential for major accidents which may cause harm beyond the immediate vicinity of the workplace, affecting many people or large areas of the environment[2].

[2]The distinction between minor and major harm should not be equated with the distinction between individual and societal risks. Typically, the latter distinction is made when referring to major hazards (see also Section 3.3.). Thus, it is possible to speak of individual risks with the potential of a major hazard.

Minor, personal accidents, affecting only one or two individuals at the same time (most often workers), occur relatively frequently. Major accidents are very infrequent but when they do occur affect many people, workers as well as members of the public[3].

Third, risks can be distinguished in terms of causation. They can originate as a direct result of 'normal' operations, that is routine releases, or arise from disturbed operations, that is of a sudden nature. This leads to the breakdown of risks into continuous and accidental (sudden) risks. Thus, for example, the disposal of hazardous waste is posing a continuous risk.

Fourth, risks can be distinguished in terms of the spread of releases. It can be restricted to those on-site (for example, employees: occupational health) or be extended to those off-site (public). This leads to the breakdown of risks into internal (occupational) and external risks[4].

A final distinction in use is between acute and chronic risks, the contrast typically being defined in dose and duration of exposure. Chronic risks, then, refer to the field of health effects, arising from long term exposure and usually to low concentrations of hazardous materials or working conditions.

A few additional observations regarding the above distinctions may be made. First of all, any particular risk can be characterised along the various dimensions described. Still other related dimensions exist, like immediate vs. delayed in effect. With respect to the distinction between health, safety and ecological risks, it should be noted that relatively few materials form major hazards to both humans and the ecology. Usually one hazard dominates. Apart from that, it has become common to speak of health, safety and environmental (HSE) risks instead of health, safety and ecological risks. Although the HSE-characterisation is not entirely consistent[5], it has become so widespread that this report will adopt this terminology, too.

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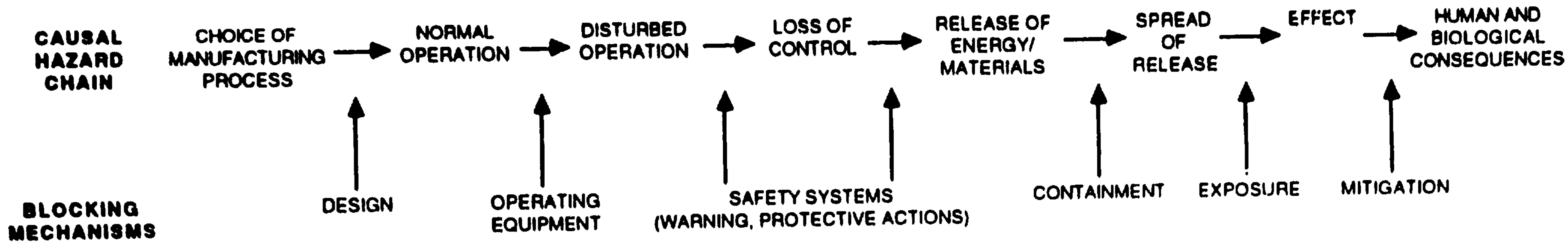
[3]As a cause of death in hazardous industries, major and minor accidents are roughly of equal significance. For example, the UK chemical industry found that about half of its fatalities came from minor, personal accidents and half from major accidents. However, in terms of adverse publicity and public concern, there is no doubt that with equal total number of fatalities major accidents dominate.

[4]The subject of internal as opposed to external health and safety is covered in guidelines as the World Bank Occupational Health and Safety Guidelines (1988). These give brief but specific recommendations in a wide range of industrial activities.

[5]The term "environment" usually covers not only 'Consequences' (that is, ecological harm) but 'Effects' as well (cf. Figure 1). Examples of the latter category are effects on water supply, recreational amenities, etc.

FIGURE 1: STRUCTURE OF THE CAUSAL HAZARD CHAIN AND ITS SEVERAL BLOCKING MECHANISMS



In the following sections of this report the focus will be on major, accidental safety-risks as they originate from hazardous industrial activities. Where instructive, the particular case of the pesticide or fertiliser industry is taken to illustrate the general approach outlined. Thus, fatalities that result from long term exposure to mostly relatively low concentrations are beyond the immediate scope, although their incidence may be affected directly by measures taken to reduce major safety risks. Also, safety-risks resulting from exposure to natural hazard sources or social stressors (for example, urbanization) are not considered.

1.1. The occurrence of safety-risks.

Safety-risks are determined by the nature of the materials involved in the hazardous activity and by the way they are handled (storage, transportation and processing, sometimes at high temperatures).

These materials may be hazardous because of being[6]:

* Flammable (Note: Flammable means the same as inflammable. The opposite is non-flammable !)
* Explosive (unstable or reactive materials; including dust explosions)
* Toxic (that is, poisonous)
* Corrosive
* Stored under high pressure

The 1991 OECD publication "The State of the Environment" contains a list of major industrial accidents involving hazardous substances defined by one of the following criteria[7]:

a) 25 or more deaths;
b) 125 or more injuries;
c) 10,000 or more persons evacuated or deprived of potable water; d) $10 million or more damage to third parties (in $ 1980).

[6]There are many different classifications of hazardous materials. The most important is the UN Dangerous Goods Classification. See UN (1991); IMO (1986).

[7]These criteria were selected in order to include all accidents that were significant and to be confident that at least 80% of all accidents that satisfied the criteria would be covered. Oil spills from maritime transport, mining accidents, voluntary destruction of transportation means as well as accidents caused by defective products were not considered. Data bases used are likely to be more incomplete with respect to non-OECD countries.

When comparing the recorded incidence of injuries and multiple fatalities (in this case over 25 deaths at one accident) it appears that storing, transporting and processing of chlorine and ammonia poses health hazards (=b) more than safety hazards (=a).

Table 2 gives a breakdown of accidents with 25 deaths or more by geographic region. It is seen that non-OECD countries had a growing number of major accidents, especially Asia. Many more major accidents are happening outside OECD countries than in OECD countries. Table 3 shows the number of accidents by substance involved. The number of explosions with explosives and similar substances outside OECD is very high. The same is observed with ammonia. The higher incidence of major accidents in the category 'gasoline, oil, kerosine and petrochemicals' may indicate particularly unsafe handling and transportation of these hazardous materials (see also chapter 4).

1.2. Safety-risks and regulatory responses.

There is a close link between major accidents and the development of risk management techniques and procedures. As Table 4 shows, the shock of major accidents has often led company management and regulatory authorities to develop more strict methods to control the risks. A breakdown of accidents (period 1970-1989) within OECD countries by type of installation, region and date shows that major accidents with multiple deaths in fixed installations or transport activities have nearly disappeared in the 80's. This result may well be due to the accident prevention programmes and policies developed after the Flixborough and Seveso accidents.

TABLE 2: GEOGRAPHIC DISTRIBUTION OF ACCIDENTS INVOLVING 25 DEATHS OR MORE (EXCLUDING ACCIDENTS ON HIGH SEAS)

		1970/74	1975/79	1980/84	1985/89	TOTAL
OECD	Europe	1	4	4	1	10
	North America	2	2	0	0	4
	Pacific	1	0	0	0	1
OECD		4	6	4	1	15
Non-OECD	Europe	2	2	1	3	8
	Asia & Africa	4	3	7	11	25
	Latin America	1	3	5		10
Non-OECD		7	8	13	15	43
World		11	14	17	16	58

TABLE 3: HAZARDOUS SUBSTANCES MOST OFTEN INVOLVED IN SELECTED MAJOR ACCIDENTS

SUBSTANCE	NUMBER OF ACCIDENTS	
	OECD	NON-OECD
Explosives, Gunpowder, Dynamite, Ammunition	1	10
Fireworks	0	5
Butane, Propane, LPG, Butadiene, Propylene	17	10
Gasoline, Oil, Kerosene, Petrochemicals	9	18
Chlorine	13	3
Ammonia	2	9
SUB-TOTAL	42	50
Other (e.g. pesticide, fertiliser, acid, etc)	54	23
TOTAL Number of Recorded Accidents	96	73

TABLE 4: <u>EXAMPLES OF STANDARD SETTING-RESPONSES TO ACCIDENTS</u>

EVENT		POLICY MEASURE
1974	Explosion at chemical plant Flixborough/UK	Widespread use of Quantified Risk Assessment (QRA) in the UK.
1977	Release of toxic dust from factory, Seveso/Italy	EC-Directive (82/501) which required control of major hazards throughout the European community.
1984	Explosion at LPG-storage Mexico-City	Development of Codes of Conduct by multinational chemical companies applied to operations worldwide (Community Awareness and Emergency Response-CAER; Responsible Care-Program; Standardising QRA-approaches).
1984	Release of toxic gas from factory, Bhopal/India	Wide encouragement for accident prevention and emergency planning in India.
1987	Sinking of British passenger ferry at Zeebrugge/Belgium	First application of risk assessment to these ships; the adoption of international regulations based on risk analysis.
1988	Explosion and fire on British offshore production platform	Adoption of advanced safety regime based on QRA for offshore production.

One of the first states to make specific legislation on major hazards was the Health and Safety Inspectorate of Great Britain with the Control of Industrial Major Hazards Regulations (CIMAH, 1985). Guidelines of many other institutions have been based closely upon these regulations. for example, the World Bank guidelines for Identifying and Controlling Major Hazard Installations in Developing Countries. The CIMAH Regulations require a Safety Case to be written, part of which may be a risk analysis. The World Bank Guidelines specify a hazard analysis as the basis for risk management, because of these simpler techniques are more appropriate for developing countries. The Seveso Directive of the European Community requires a risk analysis of the plant as a basis for accident prevention, emergency planning and informing the public. The US Congress in 1990 amended the Clean Air Act, requiring that each facility conduct a hazard assessment, develop a risk management plan for review by EPA and take necessary corrective measures to improve facility safety and prevent accidental releases. The importance of these amendments is evidenced by the inclusion of far-reaching provisions authorizing EPA to enforce and penalise, and to seek criminal prosecution of company management posing "imminent or substantial endangerment" to public health or the environment.

2. CHARACTERISING RISK MANAGEMENT

Risks arise from the absence of appropriate action or, in terms of Figure 1, are due to improperly operating blocking mechanisms. Thus, it is the management of action that matters. In fact, accident analysis continues to reveal the predominance of organisational deficiencies over equipment defects. If there is good quality management, it will usually improve not only the level of health risks but will have a positive effect on the other types of risks as well. Risk management in the context of this report is defined as the process of making optimal use of available resources to minimise industrial (safety-) risks[8].

Risk management requires decisions to be made about issues like:

[8] In the overall science of industrial business, risk management is commonly viewed as the making of appropriate provisions to secure the company from financial risks, e.g., protection against liabilities. This often includes insurance costs regarding accidents. However, the insurance market has tended to insure on the basis of "maximum expected loss" relying on historical frequencies; hence, it has not adopted the risk assessment techniques described in this guidance, that is techniques relying on historical and estimated frequencies, to any significant degree. Also, it fears the nearly unlimited claims if it were to provide coverage for continuous and chronic risks. For these reasons, the technical and financial approaches of risk assessment often take place in parallel with only minimal overlap. However, for a number of reasons harmonisation and integration of approaches is commencing now in some industrialised countries by some of the larger hazardous industries.

* Whether the activity should be permitted at all ? (In the case of UNIDO: should the activity be supported at all?)
* Whether measures are necessary to reduce its risk ?
* How extensive the risk reduction measure need be ?
* What other land use should be permitted nearby ?
* Which of various options or alternative routes should be chosen, and what would be its immediate and future costs?
* And even: what level of risk management is appropriate ?

2.1. The importance of control.

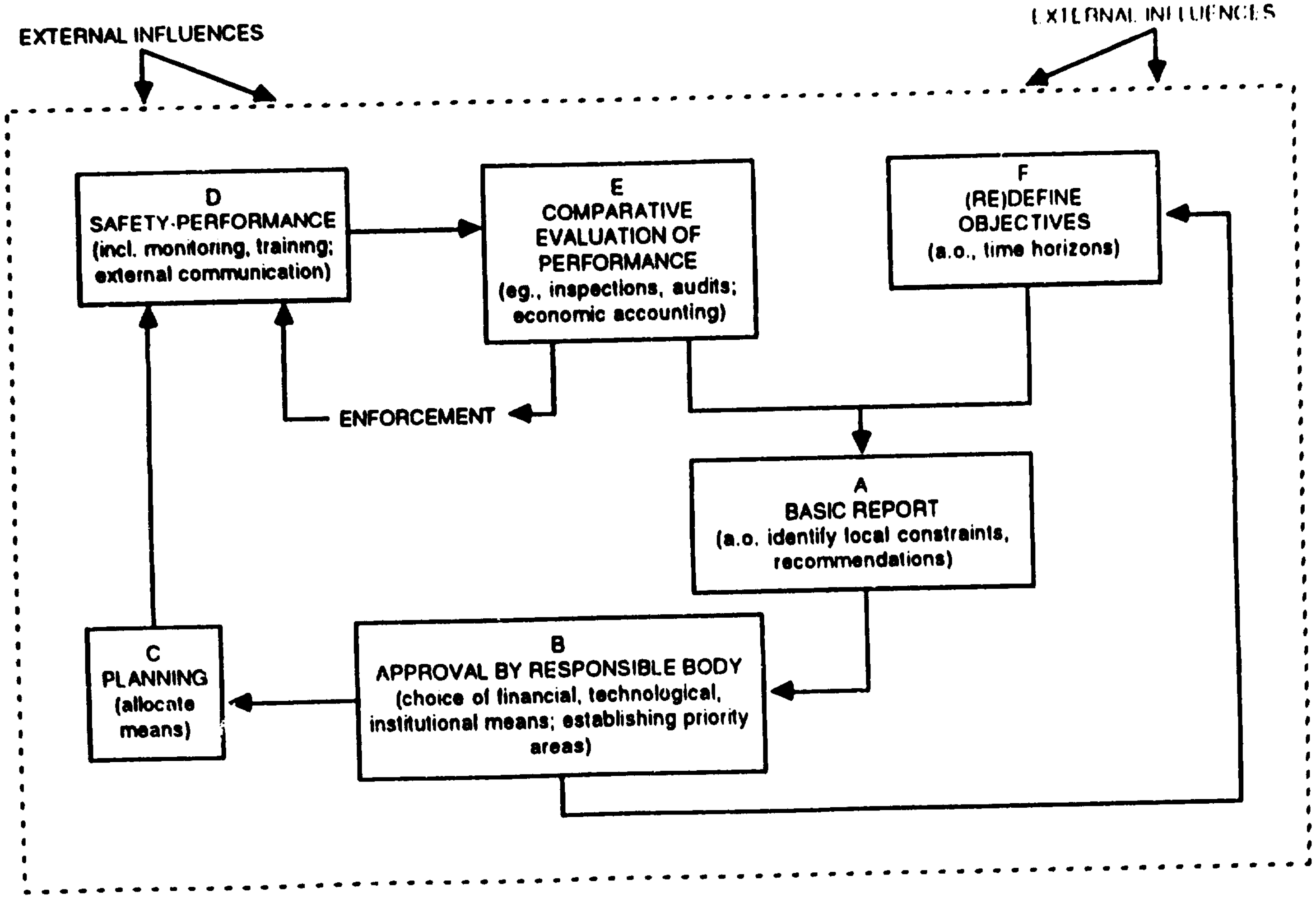
The risks of hazardous industrial activities per se are but one of the factors that influence the answers to the above questions. Operational, economic, social and political factors are as important. Safety is a variable to be actively controlled during the entire life-cycle of a plant or installation. All parties involved in this control, that is organisations involved in design, operation, legislation etc., should be elements of one integrated control function. Thus, optimal or cost-effective risk management requires the cooperation of professionals with different expertise at all stages of the "safety-management cycle", in-house as well out-side. This is expressed by *Figure 2*.

Putting this control into practice is the major condition enabling a satisfactory management of industrial risks. Rapid technological changes and the trend toward very large installations for centralised services have emphasised the core value of a control philosophy. In a series of World Bank workshops on safety control and risk management (Rasmussen and Batstone, 1991) it was concluded that, in general, an effective safety-strategy includes the use of two control principles: both traditional feedback control (reactive) and advanced feedforward control (pro-active). The latter requires a predictive model of possible disturbances and, consequently, a model of the internal processes. It is needed e.g. when measurement of performance quality takes time considerably longer than the propagation of disturbances through the system, or when the response of the system to control actions is subject to excessive delays.

In many cases insufficient provision is made for the feedback and feedforward of information. This criticism applies equally to the exercise of control by public/regulatory bodies as by the plant management[9].

[9]Typically underestimated is the relationship between stage E and C: did the planned activities lead to the desired performance/effects ? In fact, are concrete evaluations performed in order to provide the responsible body with an assessment of the performance of business ?

FIGURE 2: SCHEMATIC REPRESENTATION OF THE SAFETY MANAGEMENT CYCLE



2.2. Stages of (safety-)risk management.

As major accident risks are often not apparent in statistics for many years, and as our ability to cause such accidents has arisen very recently (in evolutionary terms), our only reliable means to control such risks is scientific risk management. Risk analysis and other instruments of risk management are still changing very rapidly. Most techniques have been developed within three industries which have the potential to cause major accidents:

* The nuclear power industry
* The on-shore chemical industry
* The off-shore oil and gas industry

Unfortunately, terminology for the different stages of risk management is not very well standardised. One of the reasons is that some programmes are not focusing on concrete hazardous industrial activities but concentrate on chemical substances (for example, the WHO-initiated programmes; see Annex 1). However, most approaches agree that sound risk management requires judgments to be made at each of four consecutive stages *(see Figure 3)*, while at the same time admitting that no clear-cut borderlines can be drawn between them.

I. Hazard Assessment[10]

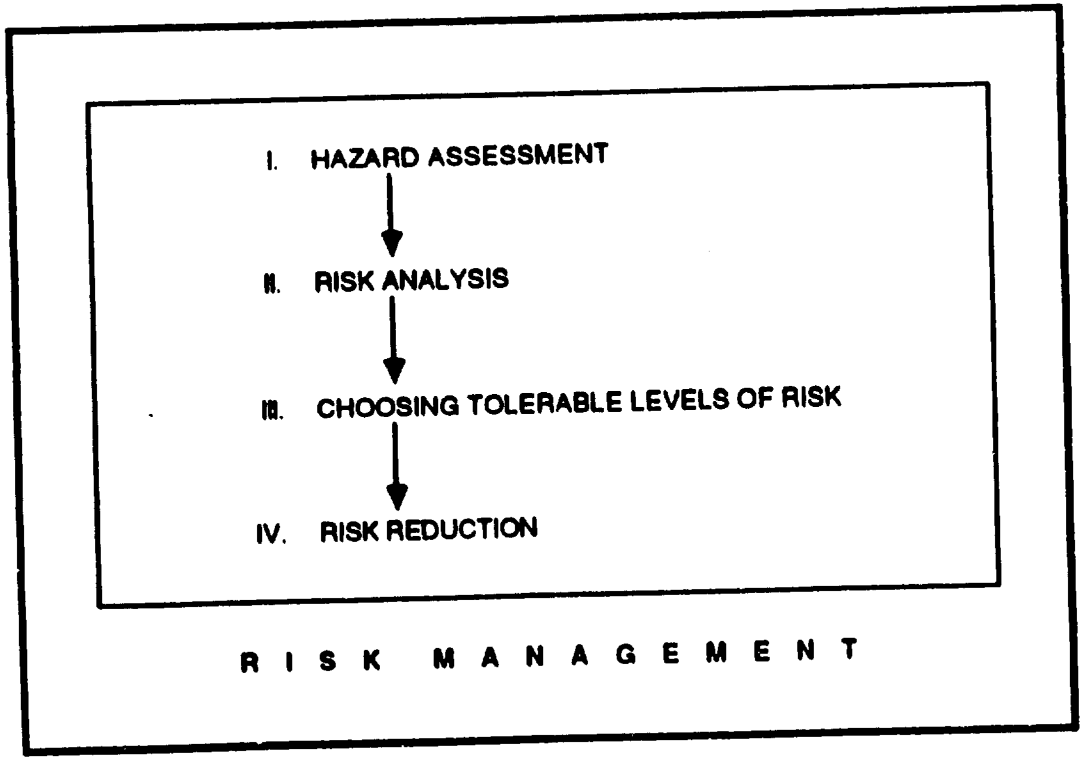
Hazard assessment consists of a range of relatively simple techniques to scope, analyze and evaluate hazards, involving mainly subjective and qualitative assessments of means to minimise them (also called Hazard Analysis; cf. OECD, 1991). The various techniques are not intended to quantify by detailed analysis the likelihood of events.

II. Risk Analysis

Risk analysis consists of more detailed and usually quantitative techniques to calculate/estimate the likelihood and potential consequences of possible major

[10]As will be discussed in the next Section, it is not always necessary for making sound decisions on risk reduction to enter the next stage of risk analysis. However, when the results of a hazard assessment indicate that a more detailed assessment of the risk is needed (entering the stage of risk analysis), the first stage of hazard assessment is also called hazard identification.

FIGURE 3: GRADUAL ENLARGEMENT OF FIELDS OF RISK MANAGEMENT



accidents, thereby providing a quantitative basis for selection of risk reduction measures[11].

In developing countries most safety problems can be resolved already considerably by applying the relatively simple techniques of hazard assessment. The main use of scientific risk analysis in developing countries has been by multinational oil and chemical companies that have one single safety policy for all their operations.

III. Choosing Tolerable Levels of Risk

Choosing tolerable levels of risk is the next stage. It consists of the selection and weighing of criteria upon which to base the decisions about how acceptable or, better, tolerable the proposed action at the estimated level of risk is[12]. Evidently, this implies social and economic judgments: do the benefits from having the industry (for example, in the form of jobs, tax revenues, petroleum products, fertilisers etc.) outweigh the risks? If not, at which level of risk would they? It requires answers to political questions as well.

In developing countries the incremental benefits of industrial activity may be very large. Thus, on the one hand, the safety-risks it may impose on workers and nearby residents, with a background of relatively high risks in daily life, may be considered less significant than in a developed country. On the other hand, accident records have revealed a trend for safety levels of aging plants to decline much faster in developing countries (notably as a result of encroaching population). Therefore, one might argue in favour of using the risk criteria of developed countries, in order to allow a safety margin for anticipated deterioration during plant life.

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[11]The process is also often referred to as Quantified Risk Assessment (QRA) when the distinction from the qualitative hazard assessment needs to be emphasised. The term 'assessment' already signals that there can be no sharp distinction with the next third stage. As a consequence, the label "Risk Assessment" is often used when referring to all first three stages and, thus, to cases that require application of the more sophisticated methods of stage 2.

[12]The terms 'acceptable', 'tolerable' or 'justifiable' all are often used interchangeably. The definition used in this report is that an activity as a whole, comprising a package of risks and benefits, may be regarded as "acceptable" to the operator, to UNIDO, or to the regulatory agency on behalf of the public. Its risks alone, which are borne with some reluctance, would then be regarded as "tolerable".

IV. Risk Reduction

Risk reduction refers to the selection and implementation of concrete measures to achieve the chosen level of safety considered tolerable. These could be measures affecting early and/or later links of the causal hazard chain. Although in general it is preferred to make in-process changes (source-oriented), in some situations add-on technologies (effect-oriented) or measures directed at the tail-end of the hazard chain, like improved emergency provisions, are the most reasonable contribution to risk reduction.

With the above distinctions in mind, it is possible to further qualify the terms risk assessment and risk management as Risk Assessment applying to the first three stages and Risk Management to include all four. However, as the distinction between the two terms essentially concerns the stage of implementation, it may not be surprising to find the two often used interchangeably.

Whereas the various types of risk can be distinguished conceptually in terms of the various links of the hazard chain, as indicated in Chapter 1, with a more in-depth perspective of the hazard chain there appears to be a considerable overlap. Human error (and also human violation of rules) play a role in the operation of all blocking mechanisms and thus are at the heart of risk management (cf. CMA, 1990). In fact, it is the same organisational functions that affect the various links. This is illustrated by *Figure 4.* A major topic then becomes how tight (or loose) the various organisational functions should be coupled in order to maintain the required flexibility of response to changing local conditions or disturbances.

There appear to be major cultural differences in approaches to this subject. In particular, it is by no means clear that operation of complex high-hazard systems in developing countries is less safe than in the western world[13].

Therefore, it is the quality of the management that, in the end, rules the health, safety and environmental risks . Measures to affect one particular type of risks usually have beneficial spin-offs to other types of risk as well. Also, it has been argued that good and bad organisations have the same kind of accidents but their frequency changes (cf. Rasmussen and Batstone, 1991). It is important to have managers not only interested in major accidents but in small accidents as well as, to a great extent, they both have the same origin. A high frequency of minor events may signal general lack of concern and, consequently, increased likelihood of major accidents. On the other hand, from a low frequency in itself one may not infer good protection against major accidents.

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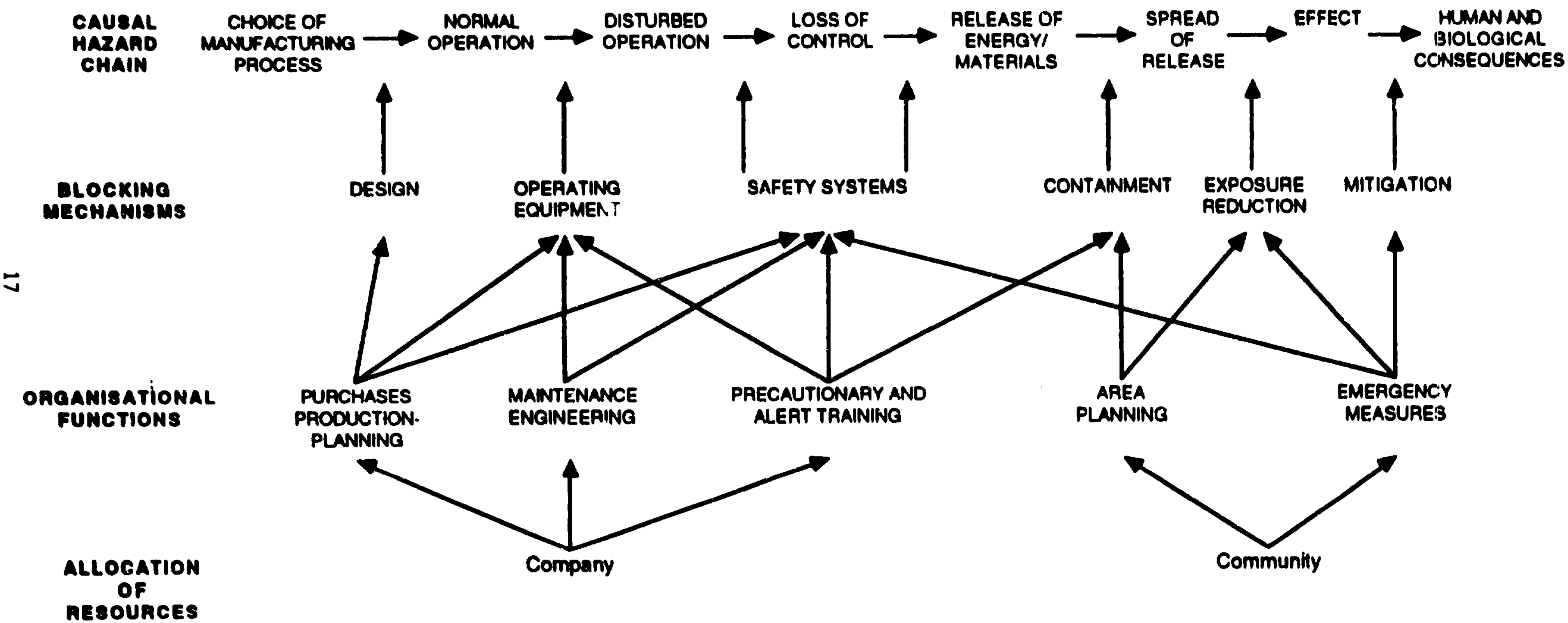
[13] A positive influence in developing countries may be: the pride and concern of the operating staff; the selection mechanisms applied; the particular career patterns promoting technical staff with in depth operational experience to management levels in contrast to the usual western tradition of hiring lawyers or business school graduates for management levels (Rasmussen and Batstone, 1991).

FIGURE 4: DEFENCE-IN-DEPTH REPRESENTATION OF BLOCKING MECHANISMS TO CAUSAL HAZARD CHAIN



3.1. SPECIAL MEASURES AND TECHNIQUES OF HAZARD ASSESSMENT

Hazard assessment is intended to prompt consideration of hazards which might otherwise be overlooked in a project design, so that the risks can be minimised before they are locked into a completed design. The results of a hazard assessment may show that a more detailed assessment of the risks is justified.

The main techniques of hazard assessment are:

* Hazard Survey (or Preliminary Hazard Analysis);
* Hazard and Operability Study (HAZOP);
* Failure Modes, Effects and Criticality Analysis (FMECA);
* Hazard Indices (or Hazard Ranking).

Hazard Assessment may involve quantitative calculations (for example, consequence analysis; see below), but it is primarily qualitative. Because it is relatively simple, it is particularly suitable for use in projects in developing countries. For this reason, special measures and techniques of hazard assessment will be presented in this guidance with more detail.

3.1.1. Hazard Survey.

A hazard survey (or preliminary hazard analysis, PLA) is a review of an activity to identify the hazards and gain a qualitative understanding of their significance. As a mainly intuitive exercise, it gathers information from sources such as:

Surveys of previous accidents.

Has the activity suffered accidents in the past? This is one of the easiest (and most frequently overlooked) ways of identifying hazards. It provides a simple intuitive warning of the types of accidents which may occur, although it cannot be comprehensive, especially for new or unusual materials and technologies. Nevertheless, this is a very important first step and ensures that the lessons from previous accidents are not overlooked.

Previous experience.

Has the activity suffered any near-misses or operating problems? For an existing activity, operating staff are likely to have ideas on potential accidents based on their own experience. This may be structured in a HAZOP or FMECA (see below). However, they may tend to concentrate on relatively frequent "nuisance" problems and overlook less likely major accidents.

Hazardous materials data.

Does the activity involve intrinsically hazardous materials ? Most hazardous chemicals are now included in standard classifications which indicate their primary hazard, for example, flammable, toxic, explosive etc. Many of the more common chemicals are covered by data sheets which indicate their properties in more detail. Sources of such data sheets include:

* Environmental Canada Technical Information for Problem Spills (ENVIROTIPS), a series of detailed reports on 35 common material.
* US Coast Guard Chemical Hazards Response Information System (CHRIS), a manual containing two pages of data for each of about 300 materials.
* US National Institute for Occupational Safety and Health (NIOSH) Pocket Guide to Chemical Hazards, with brief data on about 400 materials.
* Sax & Lewis (1989) Dangerous Properties of Industrial Materials, a reference book with brief data on about 20,000 materials.

Several organizations maintain computerised data bases. A guide to them was produced by OECD (1991).

Guidelines and codes of conduct.

Does the activity conform to good engineering practice? Codes of practice for design and operation exist for almost every major type of hazardous industry. They usually take account of previous accident experience. However, because they are written as guides for design or operation, they usually do not specify the hazards which each measure is intended to control, and therefore are difficult to use for the identification of specific hazards. Detailed guidelines and codes of practice exist on virtually every aspect of the storage and handling of hazardous materials[14].

They typically provide:

* A general identification of the hazards in the activity;
* Advice on location of buildings and other hardware design issues;
* Reviews of safety management aspects relevant to the activity;
* Guidance on fire protection and emergency planning;
* Check lists for a preliminary hazard review.

Guidelines are published by standards bodies (for example, American National Standards Institute), industry associations (for example, American Petroleum Institute), large chemical manufacturers (for example, ICI), national regulatory bodies (for example, UK HS-Executive) and international organizations (for example, ILO).

Major hazard threshold quantities.

Does the activity involve quantities of hazardous materials which would bring the installation under major hazard legislation ? Threshold quantities in these regulations provide a

[14]However, blank spots exist. For example, UNIDO is initiating a project to develop integrated safety guidelines for pesticide formulation in developing countries.

very simple indication of relative hazards, although they are not necessarily reliable in every case. For example, the EC Seveso Directive specifies threshold quantities for process and storage of 180 materials, including many pesticides, above which the provisions of the regulation applies. Table 5 specifies a number of them. These EC values, too, were not developed rigorously and should not be used as the only assessment method.

Hazard checklists.

These may range from a simple list of hazards identified by other means in previous risk assessments, to a detailed questionnaire designed to prompt consideration of all possible accident causes. They can only really be drawn up with a specific activity in mind.

3.1.2. Hazard and Operability Studies (HAZOP).

A hazard and operability study is a systematic review of a process-plant design, considering each subsystem of the process in turn and subjectively evaluating the consequences of deviations from normal operating conditions. It is normally used to generate recommendations to improve the safety and operability of a design, but has also been applied to other operations, for example, hydrocarbon well-drilling. A guide to the technique is included in ILO (1988).

3.1.3. Failure Modes, Effects and Criticality Analysis (FMECA).

A failure modes, effects and criticality analysis (or its earlier form, FMEA) is a systematic review of a mechanical system, considering each component in turn, and subjectively evaluating the effects and criticality (that is importance) of a failure there. It may be used to check that nothing has been overlooked in the design, or to identify hazards for a risk or reliability analysis.

The analysis is based on a form which begins with a systematic list of all components. For each component the form requests: component name; function of component; possible failure modes; causes of failure; how failures are detected; effects of failure on primary system function; effects of failure on other components; necessary preventive/repair action. In addition, it requires a rating of frequency of failure and a rating of the severity (that is consequence) of failure. Failures are rated as critical if they have high frequency and/or severity ratings. In these cases, special protection measures may be considered.

FMECA has been applied to mechanical systems such as aircraft, hydrofoil vessels, oil production wells etc. It is not normally used for chemical plants, since HAZOP is preferred.

TABLE 5: EXAMPLE THRESHOLD QUANTITIES IN SEVESO DIRECTIVE

MATERIAL	THRESHOLD QUANTITY (tonnes)
General flammable substances	
Flammable gases	200
Highly flammable liquids	50000
Specific flammable substances	
Hydrogen	50
Ethylene oxide	50
Specific explosives	
Ammonium nitrate fertiliser	*5000
Nitroglycerine	10
Trinitrotoluene	50
Specific toxic substances	
Acrylonitrile	200
Ammonia	500
Chlorine	25
Sulphur dioxide	250
Hydrogen sulphide	50
Hydrogen cyanide	20
Carbon disulphide	200
Hydrogen fluoride	50
Hydrogen chloride	250
Sulphur trioxide	75
Specific very toxic substances	
Methyl isocyonate	*0.15
Phosgene	0.75

* As amended in 1987

3.1.4. Hazard Indices.

The DOW Index and its development, the DOW/MOND-Index, provides an easy method of ranking the relative risks between process plants. These methods assign debits and credits to various plant features: debits are assigned to safety features which might contribute to an incident and credits to safety features which might mitigate its effects or frequency. The debits and credits are combined into an index which is the relative hazard ranking of the plant. A simplified version is given in ILO (1988).

These hazard index methods are useful at the conceptual stage for obtaining a rough assessment of the risk likely to be associated with a plant and for indicating where additional emphasis on safety might be placed. However, they do not necessarily encompass all the hazards associated with a novel process, and they are relatively superficial. They are not particularly helpful for identifying specific hazards, yet they are widely used for insurance purposes.

The above indices apply to the relative risks between plants, that is risks to one individual (employee, resident) exposed. They are primarily tools for industry management. From the point of view of the local authorities there is often a need, too, to compare the various industrial sources of major hazard in terms of the risks they pose to the community as a whole.

Recently, a comprehensive method has been proposed to achieve an initial ranking of such collective or 'societal risks' for areas that accommodate a large number of varying major hazard sources (for the concept of societal risk, see section 3.2.3.). For a large number of substances, used either in fixed installations or in transportation, the off-site consequences (C, the number of people killed at one accident) are estimated quantitatively, taking into account specific area conditions like emergency preparation. As the next step, for each of the estimated major consequences the probability of occurring (P) is estimated, again taking into account a number of source characteristics like average weather conditions and plant safety management. The combination of estimates C and P provides the indices that enable the setting of priorities for further detailed analysis of the different sources of group risk. The method is described in detail in the Inter-Agency Project (1992).

3.2. SPECIAL MEASURES AND TECHNIQUES OF RISK ANALYSIS.

Risk Analysis, conceived of as the second stage of risk management, is performed only for highly hazardous activities where the more qualitative hazard assessment approach and even prudent safety management cannot be considered sufficient. Usually it must be performed by specialist consultants, making it a relatively expensive exercise.

Risk Analysis starts with defining the "system", that is by identifying a comprehensive list of possible accidental events. Once the hazards have been defined, the next step is to evaluate the potential consequences if accidents occur. It requires exposure assessment and dose-response assessments (cf. Figure 1). This often involves some computer modelling, for example, calculating the dispersion pattern of a pesticide in the prevailing wind if a drum happens to leak, and the number of injuries or fatalities which could result. In parallel with considering the consequences, a risk analysis must consider how likely it is for the accident to occur. The likelihood is normally expressed as frequency per year. Combination of the two elements -likelihood and consequences- of each hazard allows the risk to be calculated; they may be presented in different forms.

3.2.1. Consequence Modelling.

In the context of safety risks, consequences are measured in terms such as the size of zone affected by the accident and the number of people in the zone who may be killed or injured. These consequences cannot be predicted deterministically, because they depend on many unknown variables such as the amount of hazardous material released, the time of the day, the warning received etc. Therefore, they can only be predicted for particular circumstances known as failure cases, or probabilistically on the basis of:

* analysis of previous accidents;
* theoretical modelling of consequence zones, population distributions, failure case probabilities and impacts.

Techniques for consequence modelling are described in detail in CCPS(1989). This textbook contains a chapter on consequence analysis with a review of available models and full presentation of relatively simple models, including worked examples. Another major source is the World Bank Guidelines for Major Hazard Control in Developing Countries (1988). As a complement to this document a manual has been developed of relatively simple techniques for analyzing the consequences of the releases of toxic, flammable or explosive materials, usually used in the form of a computer programme (see Technica, 1988).

3.2.2. Frequency Estimation

The key aspect which distinguishes risk analysis from hazard analysis is the quantified estimation of how likely it is that the accidents will occur. The main approaches to estimating accident frequencies are the following.

Historical Accident Frequency Data.

This uses previous experience of major accidents without analyzing the initiating causes.It is a simple approach, relatively easy to understand, but it is only applicable to existing technology with significant experience of accidents.

Fault Tree Analysis.

This involves breaking down an accident into its component causes, including human error, and estimating the frequency of each component from a combination of generic historical data and informed judgment. It is a relatively complex technique, and requires a more sophisticated approach to component probabilities and system reliability.

Theoretical Modelling.

The frequencies of some types of accidents can be predicted using theoretical models of the accident situation. An example of this is ship collision, where the ship movements can be represented by a theoretical model and the frequency of collisions determined by simulation or analytical solution.

Event Tree Analysis.

This is a means showing the way an accident may develop from an initiating event through several branches to one of several possible effects/consequences (cf. Figure 1). The technique is usually used to develop the initiating event frequency estimated by one of the above three means into a failure case frequency suitable for combining with the consequence models of section 3.2.1.

3.2.3. Risk Composition and Presentation.

When the frequencies and consequences of each hazard in the activity have been estimated, they can be combined to form measures of its overall risk. The exercise of combining the consequence zones from numerous failure cases and weighting them by their frequencies is a complex task for which special computer programmes exist.

Risks of major hazards, calculated in the above way, are often expressed in two complementary forms:

* Individual risk: the risk of lethal harm to one individual person, worker or member of the public (see Section 3.3.1)
* Collective or societal risk: the risk of lethal harm to a whole group of persons exposed to the hazard (see Section 3.3.2.).

3.3. SPECIAL MEASURES AND TECHNIQUES OF CHOOSING TOLERABLE LEVELS OF RISK.

The numerical risk estimates which result from the risk-analysis process have to be translated into qualitative terms, as decision makers must balance risks against other relevant factors. Risk criteria are the (chosen!) standards that determine whether the calculated numerical risk estimates (for example, 10^{-7} per year) are above, equal to or below threshold values ("intolerable", "negligible" or in between, that is the "grey area"). These judgments are presented to the public to justify the decision to continue, to modify or to terminate a given hazardous activity.

It should be emphasised that the adoption of any particular risk criterium entails a societal trade-off, however implicit, of economic costs of alternative ways to allocate tax money. Thus, it implies a particular valuation of the value of human and biological life. Because of the nature of these value judgments (for example, varying between individuals and economic regimes, altering with time, accident experience, etc.) it is impossible to prescribe universally applicable criteria that determine whether or not risks are tolerable. In the following Section 3.3, numerical risk criteria are discussed. Other approaches are discussed in Section 3.4.

3.3.1. Numerical Individual Risk Thresholds.

Individual risk criteria ensure that individuals living or working near to the transport route do not bear an intolerable risk. They may also be used for land-use planning, or to help protect hospitals etc., which are difficult to evacuate in an emergency. Individual risk criteria are normally applied to members of the public without taking account of the benefits of the activity, that is, assuming that people nearby receive no more benefit from the chlorine transportation than average. Consequently, individual risk criteria are largely independent of the activity to which they apply. Once a risk has been defined which members of the public are expected to tolerate from hazardous activities over which they have no control, it should not matter whether this risk comes from, for example, chlorine or LPG, road/rail or sea transport, or a fixed installation.

A number of government authorities are basing their value judgments, for example, licensing policy, directly on numerical estimates of individual risk (reviewed and compared by Technica, 1990). Criteria which these governments use for individual risk regarding the public are summarised in Table 6. The first HSE criteria in the UK originated as guidelines for nuclear power stations, but have been proposed for the transport of dangerous substances as well. The HSE criteria for new housing developments near existing installations are somewhat different, and refer to a "dangerous dose" rather than risk of death. They are roughly equivalent to risk of death a factor of 3 lower.

Workers involved in a hazardous activity are normally expected to tolerate higher risks than members of the public. The HSE has suggested a criterion for maximum tolerable risk of 10^{-3} per year. Other criteria for workers are often expressed in the form of Fatal Accident Rate (FAR), which is defined as:

$$FAR = \frac{\text{Fatalities x } 10^{8} / \text{ year}}{\text{Person-hour exposed / year}}$$

The UK chemical industry has used its historical FAR of 3.5 prior to the Flixborough accident as a target value. ICI discovered that about half of its FAR was due to minor accidents (for example, dropped objects, falls) and so adopted a FAR of 2 for major hazard accidents (for example, chlorine releases).

3.3.2. Numerical Societal Risk Thresholds.

Societal risk criteria ensure that the risk to society as a whole or to individual communities from the activity are not disproportionate to the benefits it brings. Societal risks include the risk to every exposed person, even if they are only exposed on a brief occasion. They are usually the dominant consideration for transport activities which spread their risks over a constantly changing population along the routes. Societal risk criteria are often expressed as lines on a F-N curve, showing the frequency (F) of accidents involving N or more fatalities.

This allows them to control not only the average number of fatalities or injuries from all sizes of accident, but also the risks of catastrophic accidents killing many people at once. It should ensure that the public fear of a major accident is balanced by the benefits received from the hazardous activity.

Societal criteria have not been as widely used as individual risk criteria because the concepts and calculations involved are much more difficult. However, their value is beginning to be recognised, especially for transport activities, but also as complementary to individual risk criteria in general (cf. Smets, 1991, for recent developments at OECD-level).

TABLE 6: OFFICIAL INDIVIDUAL RISK CRITERIA FOR THE PUBLIC

AUTHORITY	MAXIMUM TOLERABLE RISK (per year)	NEGLIGIBLE RISK (per year)
Ministry of Housing, Physical Planning and Environment (VROM), The Netherlands. **New plants**	10^{-6}	10^{-8}
Ministry of Housing, Physical Planning and Environment (VROM), The Netherlands. **Existing plants/Combined with new plants**	10^{-5}	10^{-6}
Health and Safety Executive (HSE) of the United Kingdom. **Nuclear power stations**	10^{-4}	10^{-6}
Health and Safety Executive (HSE) of the United Kingdom. **New housing near existing plants**	10^{-5}	10^{-6}
Interdepartmental Co-ordinating Committee for Potentially Hazardous Installations of Hong Kong.	10^{-5}	not used
Department of Planning (DP) of New South Wales, Australia **New plants and Housing**	10^{-6}	not used
Environment Protection Agency (EPA), Western Australia. **New plants**	10^{-5}	10^{-6}

Two governments have published interim numerical societal risk levels. The Netherlands (VROM) criteria for off-site risk from new chemical plants indicates the maximum tolerable risk of accidents involving 100 or more fatalities as 10-7 per year for a single plant. Hong Kong interim guidelines for off-site risks from potentially hazardous installations show the maximum tolerable risk of accidents involving 100 or more fatalities to be 10^{-5} per year per single plant (*see Figure 5*).

3.4. SPECIAL MEASURES AND TECHNIQUES OF RISK REDUCTION

Risk reduction is the process of selecting the practical means to achieve the lower level of risk as indicated by the outcomes of the risk assessment, whether this assessment was conducted largely in a formal way (as at the stage of risk analysis) or whether it relied primarily on professional judgment (as with many hazard assessment techniques). Several possible approaches exist to the selection of risk reduction measures. In addition, one would like the selection to lead to enduring improvements. The most important means to ensure such improvement are audits.

3.4.1. Different approaches

Although various typologies have been suggested, in general three basic approaches could be distinguished:

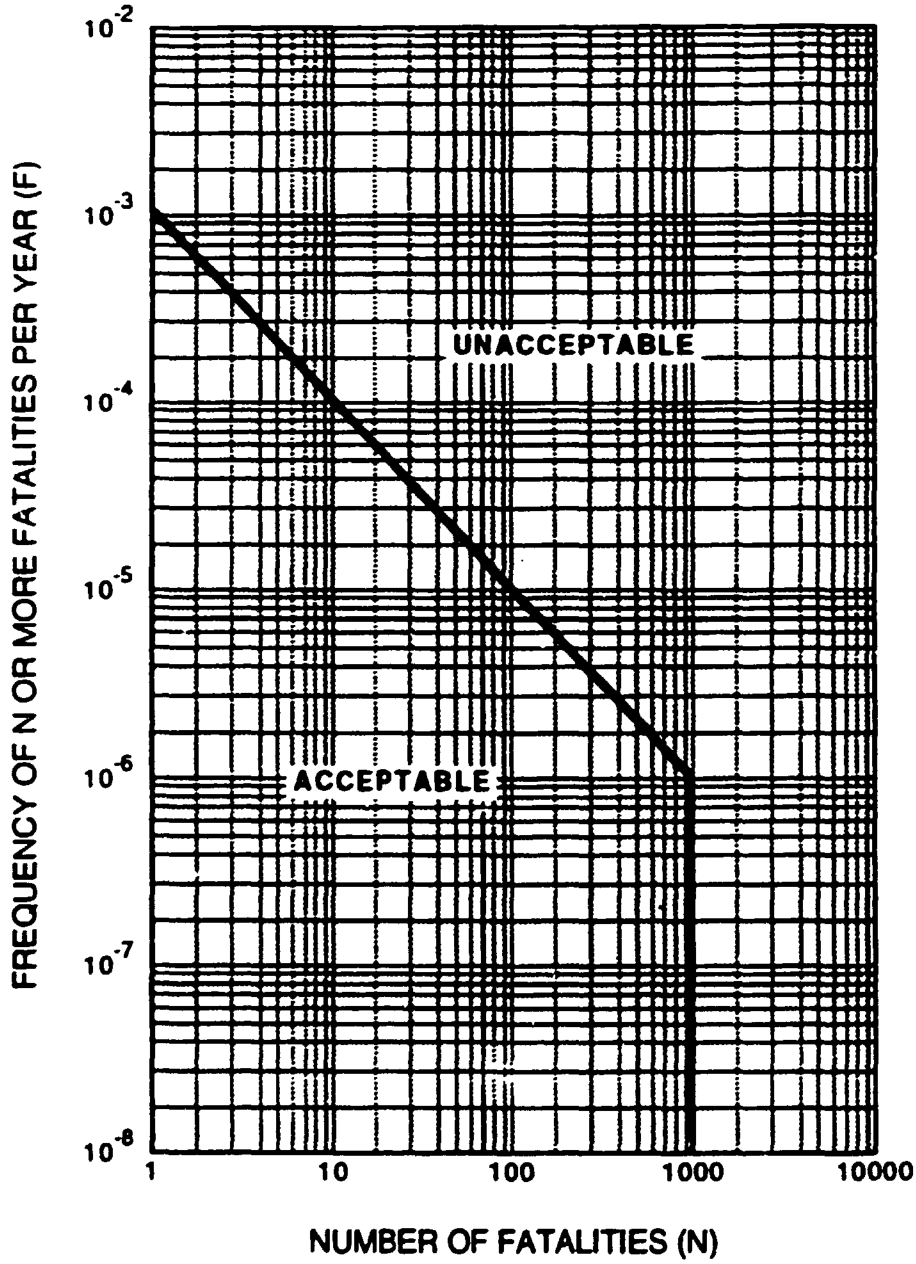
* Ambient- or Effect-oriented.
* Technology- or Source-oriented.
* Cost/Benefit-oriented.

Ambient-oriented

Ambient-oriented approaches specify the level of human health and welfare that is to be considered safe (or clean) without consideration of costs or technological feasibility. Often the required levels of protection are set close to the background exposure levels.

The Risk Criteria approach (see Section 3.3.) is a particular case of this general category of approaches. The numerical risk thresholds chosen have been determined as a very small deviation of the total risk for someone to die taking all sources of exposure into account. If the risks are rated intolerable, risk reduction measures must be adopted regardless of costs. If the risks are negligible no further measures are needed. This approach has the advantage of giving clear guidance about major hazards, and it may show that many industries have negligible major hazards. However, it requires a risk assessment to be performed and stringent numerical risk thresholds to be set, and so may not yet be appropriate for many situations in developing countries.

FIGURE 5: HONG KONG GOVERNMENT SOCIETAL RISK THRESHOLDS (INTERIM)



Technology-oriented.

Here, the best available technology (BAT) is selected, regardless of the risk reduction it achieves, and sometimes regardless of costs. This has the advantage of not requiring a risk assessment and of being easy to justify to the public, and so tends to be selected when there is heavy political pressure in decision making. It has the disadvantages that the best technology can be unproven and difficult to obtain, and this approach is often an extremely expensive way of reducing risks. This makes it inappropriate for developing countries as it may lead to industry becoming uneconomic. A great number of alternatives to BAT have been developed which, to some extent, should take account of these objections. Well known examples are "best practicable technology" and "best available technology not entailing excessive costs"[15].

Cost/Benefit-oriented

Within this category of approaches measures are selected if they have a favourable ratio of benefit (that is, risk reduction) to cost (that is, capital expenditure and operating costs). It involves a trade-off between safety and economy, which is sometimes difficult to justify to those who do not directly bear the costs. *Figure 6* shows that not all money spent on safety is wisely spent.

Particularly regarding decisions between alternative risks, that is decisions between options aimed at the same benefit, the cost/benefit approach is a very powerful approach. In environmental legislation, it has been shown to be the most efficient way of achieving risk reductions (cf. Luken, 1991). Cost/benefit trade-offs can be made in a number of ways ranging, in theory, from highly personal and subjective to highly formalised and objectified. When made subjectively, decision makers, whether in government or industry, consider the range of possible actions and select those which they believe are appropriate for the industry and society. This has the advantage of being very flexible and of automatically taking account of immediate economic and local constraints. It may be appropriate for low-hazard industries in developing countries. However, its disadvantages are its potential for inconsistency and abuse.

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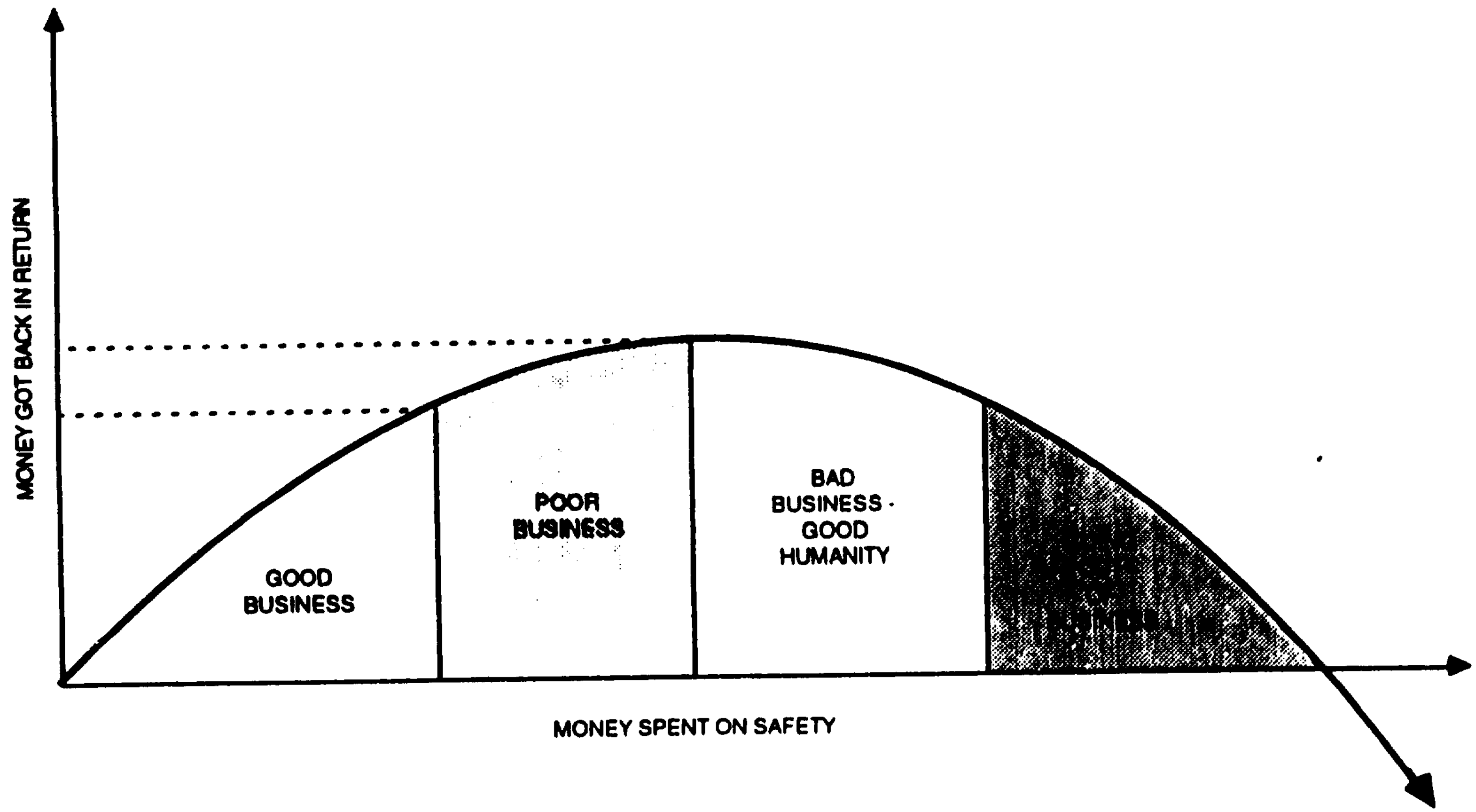
[15]This approach has been carried to considerable lengths under the US Clean Air Act (1970), which incorporates a variety of different technology standards, including:

- Best Available Control Technology (BACT)
- Best Available Retrofit Technology (BART)
- Lowest Achievable Emission Rate (LAER)
- New Source Performance Standards (NSPS)
- Reasonably Achievable Control Technology (RACT)
- Maximum Achievable Control Technology (MACT)
- Generally Achievable Control Technology (GACT)

Quoted from UNIDO (1991), Policy Advice on Integrated Industrial and Environmental planning and Management in the Yugoslavian Republic of Montenegro, Vienna.

FIGURE 6: EFFECTS OF INCREASING EXPENDITURES ON SAFETY (SOURCE: KLETZ, 1985)



Less subjective is to rely upon the experiential history of the craft or profession itself. Indeed, it is the professional himself who has learned best to balance costs and benefits in the interest of his own business. Within such a code-based approach, measures are selected which conform to good engineering practice according to relevant industry guidelines and/or codes of practice. This has the advantage of giving objective guidance and taking account of practical constraints. However, guidelines based upon codes of conduct often do not specifically address major hazards, and most are based on experience in industrialised countries, so compliance may be uneconomic for developing countries.

Calculating costs and benefits in a formal way is the most explicit approach. Its openness is both its strength and its weakness, as in matters of risk assessment one is often facing large uncertainties.

The above listed approaches to risk reduction are not as mutually exclusive as they might appear. Hybrid approaches exist also. For example, cost/benefit considerations can be included in the risk criteria approach and applied to the grey area where risks are neither negligible nor intolerable. Because of the importance of cost/benefit considerations in risk reduction, the most explicit and formal of the cost/benefit approaches will be presented in more detail below.

3.4.2. Cost/Benefit Analysis of safety-risk reduction.

Cost/benefit analysis is a technique for evaluating the risk and economic implications of a remedial measure by calculating and comparing

a) the cost of implementing the measure with
b) the benefits of the measure, in terms of the risk-factored cost of the accidents it would avert. Usually, not only the value of lives saved is taken into account but also the economic 'savings' by not incurring costs caused by other types of harm/damage.

Costs of safety-risk reduction.

The total annual cost of risk reduction measures includes one or more of the following:

* Costs of capital investment (for example, on safety hardware, land purchase, relocation costs) written-off over an assumed working lifetime of the measure at an appropriate interest rate.
* Operating expenditures (for example, on annual safety training, extra staff). Extra operating costs from safer workplace practices are normally not included as they are assumed to be balanced by cost savings from the generally more efficient operation.
* Lost profits (before tax) if the measure involves withdrawing from an activity altogether.

Table 7 presents an example of some of the above costs for safety improvement in a pesticide warehouse.

TABLE 7: <u>EXAMPLE COSTS FOR IMPROVEMENT OF WAREHOUSE SAFETY</u>

RELOCATION COST £1 M	
Working lifetime Payback period Rate of discount	25 years 10 years 8% pa
Annual Cost £60,000 per year (£1 M x $(1.08)^{10/2}$/25)	
TRAINING COST for 10 staff, duration 1 week per year	
Salary Employment cost factor	£15,000 pa 2.0
Annual Cost £6,000 per year (£15,000 x 1/52 x 10 x 2.0)	

<u>Value of damage-costs averted.</u>

The costs of accidents averted by the (safety-)risk reduction measures includes the following.

A. The value of (statistical) fatalities averted. A typical value of £ 2 million (or FF 20 million: see Smets, 1991) has been used in recent analysis in some developed countries. Explicit valuation of human life has been recognised to provide an efficient and objective means of risk management in industrialised societies. The main approaches to valuation of lifes are:

- Human capital approaches. These estimate the value of life in terms of the future economic output which is lost when a person is killed.This may be in terms of gross output (in effect, the lifetime salary) or net output (in effect, the lifetime tax payments). This narrow economic approach is now largely discredited since it is recognised that people value life for its own sake rather than for its capacity to maintain economic output.

- Willingness-to-pay approaches. These estimate the amount that people in society would be prepared to pay to avoid a statistical fatality, using their observed behaviour in the past or their expressed opinions on hypothetical situations in questionnaires. This is generally considered to be the most credible approach, although estimates are very variable.

- Implicit value of life or revealed preference approach. The costs and benefits of legislation which public authorities have adopted on safety measures can sometimes be analyzed to show the implicit values of life. However, these show wide variations[16], and the approach assumes that the previous decisions were correct.

* Court awards. Sums awarded to dependants for accidental death show the differing values of life in many countries, but are not an ideal measure. For example, in the UK damages to dependants for wrongful death reflect only their share of the income the victim would have earned, that is a net output approach. In the US, awards may include a large component for subjective loss to dependants, and are partly seen as penalising the perpetrator.

B. Costs of hospital treatment, lost production and injury payments. Except in releases or accidents with no fatality potential, these costs are usually a negligible addition to the total.

C. Property damage costs, both for the plant and the surrounding area. These can be estimated as fractions of fatality costs from historical data.

D. Business interruption costs. These are very difficult to estimate and are often omitted for this reason.

E. Ecological damage costs. These are also difficult to estimate and value; sometimes they are assumed equal to clean-up costs.

Some of these costs may be covered by insurance, but insurance in effect only spreads the cost from firms which have suffered accidents onto those which have not. Companies therefore usually include all costs in a cost/benefit analysis, whether insured or not.

As many people find decisions about safety-risk reduction on the basis of the value of lifes difficult to accept, remedial measures should generally be adopted unless their cost is grossly disproportionate to the costs of accidents averted. As a guideline, a factor of 10 could be used, which is well within the range of values for the valuation of life. Thus, a remedial measure whose cost is less than 10 times the risk-factored cost of accidents averted is not grossly

[16]For example, costs range from $200,000 for initiating the trihalomathane drinking water standards to $92 billion for the atrazine/alachlor drinking water standard. Analysis of 18 EPA regulations reveals a mean value of $66.9 billion per premature death averted. Eight OSHA standards imply a mean value of premature worker death of $9.8 million. The National Highway Traffic Safety Administration appeared to maintain the highest cost/benefit ratio with a mean cost of $1 million. Source: Office of Management and Budget, Reforming Regulation and Managing Risk-Reduction Sensibly, 1992-Budget Document, sent to Congress Jan. 1991 (IX,C,Part Two). All values are in 1990 dollars.

disproportionate and hence should be adopted in order to make the risk "As Low As Reasonably Achievable" (ALARA). Table 8 shows this calculation for the example presented earlier[17].

3.4.3. Safety Management Guidelines

The above described cost-benefit analyses and the 'grossly disproportiate'-rule can be considered as a guideline for risk managers on how to allocate resources for risk reduction. A number of more general guidelines exist on what a good safety management system should contain (see also Annex 1). Specific guidelines for the chemical process industry are:

* American Petroleum Institute Recommended Practice on Management of Process Hazards (API, 1990).
* Occupational Safety and Health Administration proposed rule on process safety management of highly hazardous chemicals (OSHA, 1990). This is similar to the API code but will be a legal requirement for highly hazardous chemical plants in the USA.
* Centre for Chemical Process Safety Guidelines for Technical Management of Chemical Process Safety (CCPS, 1989). This is more detailed but broadly similar to the API and OSHA rules.

Of particular interest is the set of Codes of Conduct developed by the US-Chemical Manufacturers Association (CMA) over the past years. Its development was motivated especially by the need to broaden the dialogue and interaction between plant and its several audiences. The set necessarily covers a broader range than safety-risks only.

The separate codes are:

* The Process Safety code;
* The Pollution Prevention code;
* The Employee Health and Safety code;
* The Distribution code [focusing on conducts in transportation];
* The Product Stewardship code.

[17]Note: The factor of 10 is not included as in this case a value of life from the upper end of the range has been used.

TABLE 8: EXAMPLE COST-BENEFIT ANALYSIS OF RISK REDUCTION MEASURES

Basic Risk (fatalities per year)	1×10^{-2}	
Risk reduction measure	RELOCATION	SAFETY TRAINING
Reduction in risk (%)	90	20
Reduction in risk (fatalities per year)	9×10^{-3}	2×10^{-3}
Value of life	£2m	
Total accident cost per fatality	£4m	
Value of risk reduction (£ per year)	36000	8000
Cost of measure (£ per year)	60000	6000
Conclusion	Reject	Adopt

3.4.4. Audit Techniques

There are several techniques for reviewing, auditing and assessing safety management systems, which also give useful guidance on how an existing system might best be improved. They range from evaluations by external auditors to assessments conducted by in-house professionals, from audits lasting several days to checks of much shorter duration. Each type of audit has its own characteristic advantages and disadvantages, thus is dependent upon the particular hazard situation which one is chosen.

Examples of techniques that are relatively easy to administer are:

* The International Safety Rating System (ISRS) or "5-Star System" (Bond, 1989). This consists of an extensive question set and points-scoring system, after which an appropriate star rating may be awarded. Its advantages are that it provides an objective evaluation of safety management, and provides clear goals for improvement of performance. It is relatively well established and is applicable in many different activities (from chemical plants to underground railways). Its disadvantages are its comprehensive bureaucratic approach, the lack of a theoretical basis to the questions and scoring, its focus on occupational safety and health issues, and its focus on measurement and control rather than the complete management systems approach advocated in the CCPS guidelines, for example.

* The MANAGER technique (Pitblado et al., 1990). This consists of a question set and points-scoring system, intended to audit safety management and produce a "management factor" which allows the results to be linked to a quantitative risk assessment. This, together with a relatively clear theoretical basis, is its main advantage. Its disadvantages are its focus on the chemical industry and the need for judgment of performance relative to US/West European chemical industry norms.

4. SAFETY-RISKS MANAGEMENT UNDER VARYING STAGES OF INDUSTRY DEVELOPMENT

Safety-risks are determined by the manner in which hazardous substances are handled, now and in the future. This distinction in terms of time frame is trivial. Yet it is of particular relevance when addressing situations where comprehensive regulatory regimes have not yet been crystallised. This is the case, by definition, in many developing countries.

As discussed earlier and illustrated by Figure 4, unexpected changes can occur at all links of the causal hazard chain. They can be endogenous or can arise from external impacts. The complexity of major hazard industries requires a general systems approach to management, with a central role of feedback and feedforward (planning) mechanisms. Profitable system operation will then depend on continuous adaptation to change, based upon a general framework that enables managers at lower levels to develop their own detailed rules of conduct (cf. Rasmussen and Batstone, 1991). In this sense, disciplined control of changes is the key to effective risk management.

With this perspective of change or development in mind, here five levels or stages of industrial development could be distinguished. To a certain extent, these conditions succeed each other when developing industrial activities. Below, for each of these stages a number of risk-control measures are highlighted. Although many measures to identify, to assess and to reduce safety-risks are relevant at all stages of industrial development, some are particularly suitable at one particular stage. This is expressed in a clear way by Table 9 (Inter-Agency Project, 1992) for the various techniques of hazard assessment.

Typically, most attention is being devoted to the stages of design and operation. However, some of the most serious industrial accidents were catastrophical because of the insufficient attention paid both by public authorities and industries to the other stages of industrial safety.

TABLE 9: **RANGE OF APPLICATIONS OF HAZARD/RISK ASSESSMENT TECHNIQUES IN PROCESS INDUSTRIES (SOURCE: INTER-AGENCY PROJECT, 1992)**

	SITE SELECTION/ EARLY DESIGN STAGE	DESIGN STAGE OF NEW PLANTS	OPERATIONAL STAGE OF NEW AND EXISTING PLANTS	MODIFICATION TO EXISTING PLANTS
Process System Check List	B	B	A	B
Safety Audit/Review	C	C	A	C
Dow and Mond Hazard Indices	C	B	A	C
Preliminary Hazard Analysis	A	C	C	A
Hazard Operability Studies	C	A	B	A
"What If" Analysis	A	C	B	A
Failure Mode and Effect Analysis	C	A	A	B
Fault Tree Analysis	C	A	A	B
Event Tree Analysis	C	A	A	B
Cause-Consequence Analysis	C	B	A	B
Human Reliability Analysis	C	A	A	B

A = Best suited B = Could be used C = Least suited

4.1. Design

It is a common understanding that, by and large, risks are determined by the level of attention paid to the various risk-factors during the design process. However valid this belief in itself is, it only holds in practice if, in fact, the design allows the management to operate the plant with the necessary flexibility to respond to both on-site and off-site changes. Therefore, when designing a given level of industrial safety, both technical (engineering) and organisational measures should be considered.

Illustrative measures [18]:

a. Apply the appropriate standard techniques for assessing the major hazards.
b. Check layout preferences against requirements to separate adequately inherent reactive functions or items of equipment. Include zoning requirements in project proposals if necessary.
c. Identify those operational tasks that, because of their relationship to the prevention of accidents, should be subject to specific management controls.
d. Compare designed operation with existing public (legal) and private (corporate) standards and anticipate significant future changes towards stricter norms.
e. Evaluate demands from other areas, in particular ecology, and assess their simultaneous impact on the cost-effectiveness of technologies that reduce safety-risks (principle of integrated environmental planning).
f. Against the background of the expected lifetime of the plant, consider the various alternatives of in-process vs. end-of-pipe solutions to reduce safety (and environmental) risks.
g. Communicate with financial institutions which (ought to) take into account the amount of resources needed to comply with public safety requirements as well as corporate safety policy.
h. Submit the application for a license according to national and corporate requirements. To facilitate understanding and increased commitment, distinguish as much as possible between basic information (simplified reporting) and technical detail (appendices).

In addition, anticipate measures of Section 4.2.

4.2. Construction, start-up and operation

A great number of measures must be taken to assess whether the proposed industrial facility can be operated at the required levels of safety. They range from the testing of components to the idle operation and, finally, to the operation of the entire plant under full load. Although at this stage technical measures are paramount, organisational provisions have to be made as well in order to establish the proper foundation for continuing safe performance.

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[18]The measures listed do not represent any preferred order of application.

Illustrative Measures:

a. Purchase certified equipment when critical to the safety of the plant.
b. During construction, conduct tests of all components, controls and safety devices considered crucial to achieve safe operation.
c. Develop explicit operating procedures, including how to behave with respect to foreseeable emergencies (for example, shut-down).
d. Establish internal quality assurance system, extending from product quality to the quality control of the manufacturing processes. Identify possible trade-offs between workers' safety and consumer/customer product demands.
e. Draw up an emergency plan and establish the necessary personal links with relevant institutions (police, fire, medical, transport, nearby hazardous installations, media etc.)
f. Develop a financial policy (for example, insurance) to account for any claims following major accidents.
e. Implement 'workers right to know' and 'workers need to know' programmes. A special safety officer or safety committee should be assigned with the proper responsibility (for example, the power to block proposed operations for safety reasons), and be protected against prejudice.
g. Incorporate safe behaviour into all employees' performance reviews.

In addition, anticipate measures of Section 4.3.

4.3. Transports to and from the premises

No single plant or operation stands on its own. Each is linked to its surroundings, and each of these off-site links may contribute to the on-site safety behaviour. Not only the transportation of materials and equipment to and from the plant (as in the case of hazardous waste removal) establish such links, but there is often a steady flux of (sub)contractors who are commissioned to work at the plant. A number of measures exist which should reduce and limit the risks originating from these links with 'outside' sources.

Illustrative Measures:

a. Select only (sub)contractors with good performance records and who adhere to prescribed safety requirements.
b. Communicate precautionary and preparedness measures on a standard basis to (sub)contractors and visitors who may come near hazardous processes.
c. Establish a clear-cut liability between company and (sub)contractor/supplier for damage in case an accident occurs.
d. Develop a system of product stewardship stimulating the transfer of safety information throughout the chain of suppliers/customers.

In addition, anticipate measures of Section 4.4.

4.4. Aging and Shut-down

In general, the management of safety-risks during the aging stage of industrial activity boils down to the updating and/or repeating of the steps described in sections 4.1.-4.3. However, as aging often goes unnoticed, the implications of major changes in the plant design go unheeded and the attention to safety is likely to fade away. Such major changes are, for example, the extension of a facility with new units; the repair and/or modification of existing equipment; the operation of a plant at loads exceeding the designed capacity, e.g. during periods of high stress due to special production demands; and, not least important, major changes may occur in the organizational structure of the operations.

Illustrative Measures:

a. Keep good records of plant performance in general and of the handling of hazardous substances in particular.
b. Adopt strict incident reporting rules and guarantee that it is followed by proper investigations.
c. Allow regular inspections and testing of components, especially those that are critical to safety.
d. Carry out maintenance programmes.
e. Periodically review safety performance (auditing)
f. Cooperate with the licensing authorities when deciding about which modifications require notification or renewing of permits.
g. Provide adequate training and education to company personnel on safety and emergency matters. Cross-posting of line managers to HSE staff should be implemented to the extent possible.
h. Support the 'right-to-know' of surrounding communities; communicate on behaviour to adopt in case of an emergency and approach residents as true neighbours.
i. Contribute to the firm establishment of institutions, professionally or otherwise, that are devoted to the cause of safe operation.

In addition, anticipate measures of Section 4.5.

4.5. Altering surroundings

More often than not the physical surrounding will gain a completely different appearance during the lifetime of a plant. For example, housing may have encroached to the facility's boundary (which behaviour, for example, was at the root of the disasters in Mexico-City, 1984 and Bhopal, 1984). The direct consequence of such indirect off-site changes is that with no technical changes at the plant site (and often with not much company input in those off-site developments!) the safety-risks of the plant operation will have increased considerably.

Illustrative Measures:

a. Formulate a corporate zoning policy. Anticipate relocation if off-site developments appear to be beyond influence.
b. Stimulate the establishment of the necessary infrastructure and, to that end, share responsibilities with the public authorities.
c. Communicate actively with local authorities and media on the dangers of uncontrolled physical planning (that is the necessity of zoning distances).

d. Develop community awareness programmes and actively provide access to safety-information: Comprehensive, Correct, Clear, Credible and Consistent (the traditional 5 C's).

REFERENCES

A.P.I. (1991) Management of Process Hazards, Recommended practice 750.

Bond, J. (1988) The International Safety Rating System or the Five Star Audit System, London: U.K.-Institution of chemical Engineers.

C.C.P.S. (1989) Guidelines for Chemical Process Quantitative Risk Analysis, New York: American Institute of Chemical Engineers.

C.E.C. (1982) Council Directive 82/501/EEC("Seveso-Directive"), Brussels: Commission of the European Communities, as amended by Council Directive 87/216/EEC.

C.C.P.S. (1989) Guidelines for Technical Management of Chemical Process Safety, New York: American Institute of Chemical Engineers.

C.M.A. (1990) A Managers Guide to Reducing Human Error, Washington (D.C.)

D.P. (1990) Risk Criteria for Land Use Safety Planning, Sydney: Dept. of Planning (Hazardous Industry Advisory Planning Advisory Paper 4).

Dutch National Environmental Policy Plan (1989) Premises for Risk Management, The Hague: Tweede Kamer, 1988-1989, 21137, no.5.

E.P.A. (1987), Environmental Protection Authority Statement on the Evaluation of the Risks and Hazards of Industrial development in Western Australia, Environmental Protection Authority Bulletin 278 (Also included in EPA,1990).

E.P.A. (1990) Review of the Guidelines for Risk Assessment in Western Australia- Information to Assist Public Input to the EPA, Environmental Protection Authority.

Fernandes Russell, D.P. (1987) Societal Risk Estimates from Historical Data for UK and Worldwide Events, Norwich: University of East Anglia.

Gibson, S.B. (1976) Risk Criteria in Hazard Analysis, Chemical Engineering Progress, February.

GIFAMP (1988) Guidelines for Safe Warehousing of Pesticides, Brussels: Groupements International des Associations Nationales de Fabricants de Produits Agrochemiques.

H.S.C. (1988) Control of Substances Hazardous to Health-Approved Code of Practice, London: Health and Safety Commission HMSO

H.S.E. (1985) A Guide to the Control of Industrial Major Hazard Regulations 1984, London: Health and Safety Executive-Series, Booklet HS(R)21.

H.S.E. (1987) The Tolerability of Risk from Nuclear Power Stations, London: Health and Safety Executive.

H.S.E. (1988) COSHH-Assessments-A Step by Step Guide to Assessment and the Skills Needed for It, London: Health and Safety Executive

H.S.E. (1989) Risk Criteria for Land Use Planning in the Vicinity of Major Industrial Hazards, London: Health and Safety Executive

I.L.O. (1988) Major Hazards Control-A Practical Manual, Geneva: International Labour Office

I.L.O. (1991) Prevention of Major Industrial Accidents-An ILO Code of Practice, Geneva: International Labour Office

I.M.O. (1986) International Maritime Dangerous Goods Code, London: International Maritime Organisation

Inter-Agency Project (1992) Procedural Guide for Risk Management for Large Industrial Areas Involving Complex Energy Systems, Vienna: IAEA.

Kletz, T.A. (1985) Eliminating Potential Process Hazards, Chemical Engineering, April 1.

Luken, R.A. (1990) Efficiency in Environmental Regulation, Boston: Kluwer Academic Publishers

Marshall, V.C. (1987) Major Chemical Hazards, Chichester: Ellis Horwood.

Needleman, L. (1987) Monetary Evaluation of Damages and Other Costs Related to the Transport of Dangerous Goods, University of Waterloo (Canada)

O.E.C.D. (1991) Users Guide to Hazardous Substance Data Banks Available in OECD Member Countries. Paris: OECD, Environment Directorate

O.S.H.A. (1990) Process Safety Management of Highly Hazardous Chemicals- Notice of Rulemaking, 29 CFR Part 1910, Federal Register, Vol. 55 (137)

Pitblado, R.M., J. Williams and D.H. Slater (1990) Quantitative Assessment of Process Safety Programs, in: AICheme, Plant Operations Progress, Paper presented at CCPS-Conference on Technical Management of Process Safety, Toronto.

Rasmussen, J. and R. Batstone (1991) Towards Improved Safety Control. Findings from the World Bank workshops oct.'88/nov.'89.

Sax, N.I. and R.J. Lewis (1989) Dangerous Properties of Industrial Materials, New York: Van Nostrand Reinhold.

Smets, H. (1991) Social constraints on tolerable risks near a hazardous installation, University of Paris I (unpublished paper).

Technica (1989) Tsing Yi Island Risk Assessment Report, Hong Kong: Government Publisher (Report for the Electrical and Mechanical Services Department).

Technica (1990) Public Risk Criteria for the Kwinana Industrial Area. Western Australia (Report to the EPA)

U.N., (1991) Recommendations on the Transport of Dangerous Goods, New York: United Nations.

U.N.E.P., (1990) Storage of Hazardous Materials - A technical Guide for Safe Warehousing of Hazardous Materials, Paris: United Nations Environmental Programme

World Bank (1988a), Occupational Health and Safety Guidelines, Washington: World Bank, Environment Department

World Bank (1988b), Guidelines for Identifying, Analyzing and Controlling Major Hazard Installations in developing Countries, Washington: World Bank (contained in Technica, 1990)

ANNEX 1.

MAJOR INTERNATIONAL PROGRAMMES ON THE ASSESSMENT AND MANAGEMENT OF INDUSTRIAL RISK[19].

OECD: High Production Volume Chemicals Programme (in collaboration with the European Commission, UN International Programme on Chemicals Safety, UNEP and the International Register of Potentially Toxic Chemicals - IRPTC).

Objective: Assessing available information and, wherever necessary, conducting additional research to develop SIDS (Screening Information Data Sets) on potential hazards of about 1500 chemicals that are produced in high volumes (> 1000 tonnes/year globally or > 10 tonnes/year nationally).

This programme is based upon joint research by governments and industries in 24 OECD member countries.

Contact: OECD, Chemicals Division. 2 Rue André Pascal, 75775 PARIS Cedex 16. France.

OECD, Guiding Principles for Accident Prevention, Preparedness and Response (1992)

Objective: To provide a comprehensive description of the roles and responsibilities of parties concerned with the prevention of risks of major industrial accidents, that is government authorities, management of hazardous installations, workers at the installation and the potentially affected public.

These guidelines will be the basis of Recommended Actions to the 24 member states on the prevention of accidents etc., including special issues of investments and aid programmes related to hazardous installations in non-OECD countries.

Contact: OECD, Chemicals Division. 2 Rue André Pascal, 75775 PARIS Cedex 16. France.

UNEP: International Register of Potentially Toxic Chemicals
(IRPTC; established in 1976).

[19]For information on international programmes established by industry contact: For USA: Chemical Manufacturers Association (CMA), 2501 Str. NW, WASHINGTON (D.C.) 20037, USA. For Europe: Conseil Europeen des Federatioins des Industries Chimiques (CEFIC), Avenue E. van Nieuwenhuyse 4, 1160 BRUSSELS, Belgium.

Objective:	To provide easy access to carefully scanned information on effects of chemicals on man's health and his environment (a.o., pathways into the environment; eco-and zootoxicity; waste management; (inter)national recommendations and legal mechanisms for the control of chemicals).

IRPTC is covering data from well over 100 countries. A PC-version to access the register is in preparation.

Contact:	UNEP/IRPTC, Palais des Nations, 1211 GENEVA, Switzerland.

UNEP: Awareness and Preparedness for Emergencies at the Local Level (APELL, launched 1987).

Objective:	To provide a detailed and stepwise guidance at the community level to contingency planning and emergency response concerning industrial accidents.
Contact:	UNEP-Industry and Environment Office, Tour Mirabeau, 39-43 Quai André Citroën, 75739 PARIS Cedex 15, France.

ILO: Prevention of Major Industrial Accidents. An ILO Code of Practice (first published in 1991).

Objective:	To provide guidance in the setting up of an administrative, legal and technical system for the control of major hazard installations.

If this Code of Conduct is approved at the 1992-ILO convention, ratification by ILO member countries should follow. This ILO Code has been developed in parallel to the OECD Guiding Principles. They are similar in scope and consistent with each other. Only minor differences exist in the subjects covered. The ILO Code has as its clear focus the concrete major hazard control system at the works level: what are its components and what is needed to make it work? In turn, the OECD Principles pay greater attention to indirect conditions such as R&D, international investment and transfer of technology.

Contact:	International Labour Office, CH 1211 GENEVA, Switzerland.

WHO, ILO, UNEP: International Programme on Chemical Safety (IPCS)

Objective:	To strengthen the national capabilities for safer use of chemicals.

Contact: WHO (Attn. Mr. Mercier), Div. of Environmental Health, 20 Avenue Appia, 1211 GENEVA 27, Switzerland

UNEP, WHO, IAEA, UNIDO: Procedural Guide for Risk Management for Large Industrial Areas Involving Complex Energy Systems.

Objective: To provide a compilation of procedures and techniques with which to address both health, safety and environmental aspects in an integrating manner when developing industrial activities at regional scales. This Inter-Agency project offers a practical guide to regional planning bodies when setting priorities regarding the construction of facilities, waste disposal, transportation of hazardous waste etc.

Contact: IAEA. (Attn: Mr. S. Haddad) PO Box 100, 1400 VIENNA, Austria.