ESCIS

Expert Commission
for Safety in the Swiss Chemical Industry

Series

**Safety**

# Introduction to Risk Analysis

## Approaches and Methods

**Booklet 4 1998**
**3rd revised edition**

# FOREWORD

*Ensuring the necessary level of safety and environmental protection in chemical processing plants and in particular in chemical production requires systematic risk analyses involving the following tasks:*

- *Collection and procurement of information and data*
- *Analysis of processes and operating sequences as well as installations and systems*
- *Determination of the risks using scenarios*
- *Risk assessment according to impact and the probability of possible events*
- *Determination of the measures required to reduce the risks*
- *Assessment of the remaining (residual) risks once the measures have been introduced.*

*Risk analysis is therefore the assessment of a situation in the form of an evaluating survey of all available factors relevant to the defined task. It results in measures restricting the risks inherent to the processes and installations to an acceptable level and is therefore one of the most important elements in the safety precautions taken by a chemical company. However, risk analysis affects not only the safety of processes and installations investigated. It also influences other areas such as environmental protection, product quality, energy consumption and economic efficiency.*

*The third edition of this ESCIS publication "Introduction to Risk Analysis" has been completely revised and brought into line with developments which have occurred since 1981 when it was first published. However, the publication has remained a* **brief general guide,** *the primary intention of which is to clarify approaches which have proved reliable in specialised chemical production (mainly batch processing in multi-purpose installations) and to indicate the most common working methods. Application, as appropriate, to other fields such as storage, biotechnology, infrastructural facilities and environmental matters is, of course, possible. ESCIS will issue special publications on such applications as the need arises.*

*Basel, November 1998*

**ESCIS – Expert Commission for Safety in the Swiss Chemical Industry**

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# INTRODUCTION TO RISK ANALYSIS

## Approaches and methods

## 1. Introduction, objectives

Legal provisions, standards, directives and guidelines, in-house safety regulations, etc. are designed to obviate frequently recurring safety problems using tried and trusted methods. They are the result of *retrospective* considerations of risk: the causes of accidents, loss or damage are investigated and measures introduced in order to prevent a repetition of similar occurrences, or at least to keep their consequences within acceptable limits.

However, in the highly innovative chemical industry, it has long since no longer been sufficient simply to gather information on experience gained (not always good experience). Practically every chemical process represents a particular combination of materials, equipment and process conditions. The necessarily high level of safety and environmental protection requires *far-sighted,* systematic hazard identification and risk assessment – *prospective risk analysis.* Its aim is to gain information essential to safety even *before* technical processes are implemented or installations commissioned ("artificial experience") in order to be able to take appropriate, targeted action against identified risks right from the start.

This introduction to the subject highlights the principles of a systematic approach and some alternatives for implementing hazard identification in the field of *chemical production* and its associated infrastructural facilities. This approach, however, can also be applied, as appropriate, to other fields such as storage, biotechnology, quality, energy and transport.

The causes can be grouped into two categories:

a) *Disturbances*
Deviations of actual from desired value. Deviations from defined safe conditions or states, which can be traced to technical failure, human error or external influences.

b) *System faults*
Causes not detected from the start (e.g. defective design), insufficient measures to prevent causes or defects which have arisen or infiltrated the system gradually (e.g. in the process sequence or in human behaviour).

A *risk* is understood to be a hazard which is evaluated in relation to the probability of occurrence of the undesirable incident and the severity of the possible effects. In *risk assessment* the combination of the two risk components, probability and impact, are considered.


## 2. Basic principles

### 2.1 Terminology

The possibility of a harmful incident such as injury, material damage or environmental contamination occurring is referred to as a *hazard.* It presupposes the presence of a threat (or potential), for example due to chemical substances, reactions or energy sources, which can lead to an undesirable incident as the result of a *cause* triggered, for example, by technical failure, by human actions or negligence.

### 2.2 Timing and reasons for risk analysis, key factors

#### 2.2.1 New processes

In the case of new processes or installations, risk analysis should ideally begin at the research stage and should then be systematically extended to cover all subsequent stages – chemical development, piloting, project implementation, commissioning, continuous operation. The obligation to implement *risk analysis in parallel with the development of projects* must be rooted firmly in the company safety policy. Accordingly, responsibility for its implementation must be clearly allocated at every stage.

**Development stages – Examples of key factors**

Research

Establishing a synthesis strategy and a manner of working appropriate to the hazards posed by the chemicals and reactions, and in particular the possibility of new or as yet unknown substances being produced.

Chemical development and piloting

Inclusion of safety and environmental protection criteria in the selection of synthesis pathways, e.g.

- physical and chemical properties of starting materials, intermediate and end products, reaction masses and waste products
- Recyclability of wastes
- Toxicity, acute and chronic
- Ecotoxicity
- Synthesis pathway, process conditions; quantity of hazardous chemicals in use and in stock (generation in situ as required, continuous process)
- Investigation of possible secondary reactions
- Process risk analysis
- Scale up, process heat
- Equipment required
- Process control
- Health and safety at work

Investment proposal, project implementation, introduction of process

Selection of location, modes of transport
Equipment planning
Analysis of interactions
Measurement and control technology, control concept
Safety devices and systems
Maintenance concept
Instruction and training concept

Commissioning, regular operation

Regulations for start-up and shut-down
Testing of safety devices
Periodical verification of safety level
Emergency planning

### 2.2.2 Existing processes

In the case of existing processes and installations, risk analyses are carried out or repeated

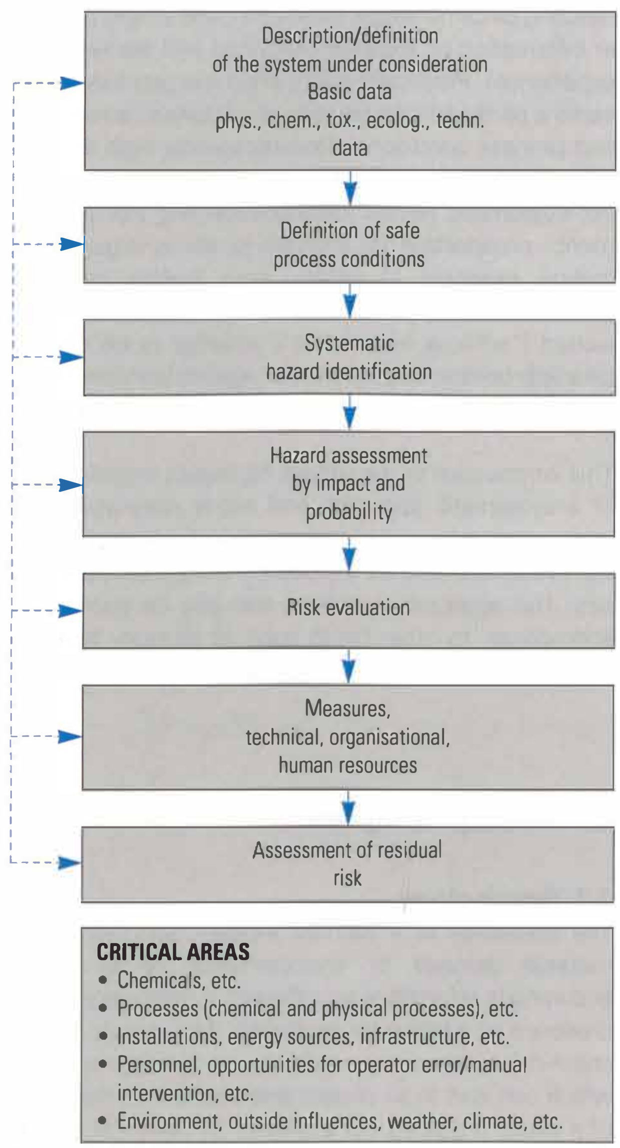
- if there is a possibility of new hazards, e.g. in the case of
  - changes to the procedure
  - changes or repairs to the installation
  - change of equipment
  - change in production location
  - change in raw materials (origin, form, specifications)
- in order to introduce new (internal or outside) experience
- in order to verify and improve the safety level periodically.

This is also a case where responsibility for implementation or further development of the risk analysis must be clearly allocated. As a rule the person in charge of production is responsible.

## 2.3 Systematics of risk analysis

Risk analysis must include the analytical stages indicated in the chart below for useful results to be achieved. It covers the entire system to be analysed (including all interfaces) and its purpose is to identify *all* imaginable occasions where the system under consideration might be unable to fulfil its intended function. In so doing, it is expedient to distinguish between critical areas such as

- Chemicals, etc.
- Processes (chemical and physical processes), etc.
- Installations, energy sources, infrastructure, etc.
- Personnel, opportunities for operator error, manual intervention, etc.
- Surroundings, outside influences, weather, climate, etc.




*Stages of analysis*

## 2.4 Teamwork

Risk analyses should be carried out by a team of *at least* two people. Only the combined skills of experienced specialists in a team can ensure that

- the risk analysis benefits from the experiences of individuals,
- hazards are sought and evaluated from different viewpoints,
- possible disadvantages of proposed measures can be recognised in good time,
- in the assessment of the risk, discretionary decisions have a broader support.

Depending on the key factors in the task, the following people must be involved:

- the consignor (process assigner)
- the (future) operating manager
- the designing engineer/engineer providing technical support
- specialists in the technical disciplines concerned
- if appropriate, a moderator not involved in the project who has knowledge of risk analysis methods (e.g. safety officer).

One prerequisite for efficient teamwork is the availability of all the necessary basic data and information relevant to safety. The basic data which are already known (see section 3.1) should therefore be compiled beforehand by the process assigner.

# 3. The individual stages of risk analysis

## 3.1 Collecting/establishing basic data, description/definition of the system under consideration

Hazards result from departures from safe process conditions. Therefore, in the first stage all basic data which are required to define the safe conditions must be compiled.

The process or process stage to be investigated, the raw materials and auxiliary materials, the chemical reactions and their products, the equipment or installation to be used with all its interfaces or points of contact with other technical equipment, with the indoor atmosphere and environmental climate and the members of staff in its vicinity must be defined. Some important factors are listed below:

- Specifications and properties of the raw materials and auxiliary materials (physical data, chemical properties, fire hazard, toxicity, ecological considerations, etc.)
- Process or process stage (chemical, physical): process conditions (temperature, pressure, concentration, feed rates, etc.), reaction characteristics, desired final condition of the processed substances
- Thermal stability under specified as well as extreme conditions
- Possible reactions of chemicals with one another as well as with materials of construction and auxiliary materials under specified as well as under extreme conditions and in the event of a mix-up
- System/equipment: size, agitation, materials (including seals and gaskets, packings, sealing liquids, etc.), resistance to pressure and vacuum
- Heating and cooling capacities; reaction chamber (live steam), double jacket, external heat exchanger/condenser
- Measuring and control equipment or process control system
- Opportunities for manual intervention
- Existing interfaces to other technical installations, for example feed and discharging devices, connections (valves) to chemical supply, disposal and energy systems
- Possible influences of the surroundings such as heat, cold, solar radiation, precipitation and depending on local circumstances also manipulations by unauthorised persons.

The basic data represent the foundations for the entire risk analysis. Such data must be compiled in the course of process development by drawing on available knowledge from practice and literature or, if necessary, by testing including trials under extreme conditions.

The decision which data and specifications are actually of importance to the safety of the system under consideration and must therefore be acquired or determined must be reached by those involved in the risk analysis on the basis of their specialised knowledge and experience.

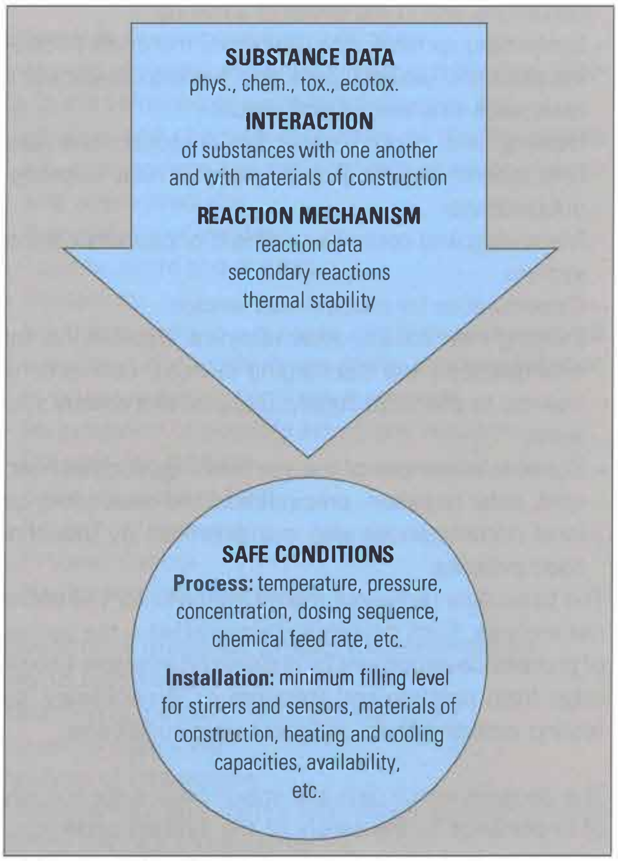
## 3.2 Definition of safe process conditions

Taking into account basic data, laboratory findings and equipment limitations, the conditions and limits are set out which have to be complied with for safe implementation of the individual process stages. These conditions and restrictions (with appropriate tolerances) form the essential foundation for the subsequent risk analysis stage in which possible deviations from the defined safe conditions are formulated and described.

The list of safe process conditions represents, for example in the case of system engineering, an important means of communication between chemists and engineers. Wherever possible therefore, in addition to verbal descriptions precise numerical values should also be specified for critical boundary conditions and substantiating evidence provided.

The following stages of risk analysis
- systematic hazard identification
- risk evaluation
- planning of measures
- assessment of the residual risk

build on the safe process conditions determined in this way as well as the boundary conditions to be complied with.




*Evaluation of basic data*

## 3.3 Systematic hazard identification

During this demanding stage of risk analysis, the process under consideration is studied in the context of its associated installations, staff, operating sequences and surroundings for situations, processes and possibilities which could lead to deviations from the defined safe conditions. In addition to the basic data, the basis for such investigations is formed by working and operating procedures, detailed and fully updated installation plans and thorough familiarity with the actual local circumstances and facts which are not indicated in the procedures and plans[1]. *That is why plant tours and inspections are a vital part of hazard identification.*

Complex projects must be divided into sections for risk analysis; however, their mutual dependence and any influences exerted by associated systems or from outside should also be assessed (interface analysis).
Hazard identification covers the following critical areas:
- Chemicals
- Processes (reactions and physical processes)
- Installations
- Energy sources
- Opportunities for operator/manual intervention
- Surroundings, outside influences, weather, climate.

Possible deviations from defined safe conditions are compiled specifying causes and effects in the form of a list of scenarios (hazard list), initially without evaluation.

A very wide range of methods exists for systematic hazard identification. However, the procedures[2] in bold type in the following summary are those which are usually applied in the chemical industry:

| Hazard identification methods | |
|---|---|
| Method | Example |
| **Intuitive**<br>**Inductive**<br>"What might happen?"<br>("What if ...?") | • **Brainstorming**<br>• Reference points, ***checklists***<br>• Failure mode and effect analysis (FMEA) (DIN 25 488)<br>• **Event tree analysis** (DIN 25 419)<br>• Decision table techniques (DIN 66 241)<br>• **Hazard and operability study** (HAZOP method) |
| **Deductive**<br><br><br><br>"How might it happen?" | • **Analysis of potential problems** (APP, e.g. the Kepner-Tregoe method)<br>• **Operating error analysis**<br>• **Fault tree method** (DIN 25 424) |

*Checklists*, in which experience gained over decades is summarised, have proven invaluable in hazard identification in process sequences of the speciality chemicals industry. Good checklists enable a multitude of potential safety problems to be detected at low cost. Depending on the critical area on which the risk analysis is focused, additional methods of specific hazard identification can then be included, appropriate to the defined task.

The procedure described above relates mainly to installations for chemical production and synthesis. By contrast, in the case of *infrastructural facilities* (such as stores, power stations, pipe bridges) the "chemical" hazards are not so strongly emphasised although the characteristics of the substances being handled and their undesirable reactions must be known. Here, risk analysis is intended to ensure the safe implementation of mainly physical operations or the generation or con-

[1] In the case of existing installations, for example: leakages, temporary installations, incorrect assembly, power or control cables subjected to mechanical or chemical damage, incrustation of heat-exchanger surfaces, influences of neighbouring installations and utility networks.

[2] Cf. Appendix 3 (page 23) for supplementary reading.

version of required forms of energy. Consequently, in this case the search for hazards focuses rather on the analysis of technical faults.

For risk analysis in *biological production installations,* the procedure must be adapted to the particular circumstances. For installations which work with micro-organisms or cell cultures in closed systems, however, a general risk analysis as for production or infrastructural facilities must also be carried out in every case. In addition, questions concerning the effects of the organisms or cultures on people (health and safety at work and, in the event of a major accident, for local residents too) and the effects on the environment as a consequence of an unintentional release should be worked out in detail. Hazard identification together with an investigation of the reliability or the possibility of failure of the various containment measures (physical, biological), of sterilisation/disinfection/deactivation and the behaviour of the released organisms/cells will thus play a pivotal role.

There is no one procedure which is equally suitable for all types of installation. Basically, the procedure for infrastructural facilities and for biological production installations corresponds to that for chemical processes, i.e. the stages of analysis listed in section 2.3 must be implemented in all critical areas. Analysis of the basic data may be less complex and the determination of safe conditions often seems more simple. However, it should be borne in mind that infrastructural facilities themselves can embody significant potential hazards. The content and emphasis of risk analysis on infrastructural facilities are therefore mainly oriented towards mastering such hazards.

In order to make the problem more accessible, it is often expedient to redefine precisely the purpose of the installation and then to inquire into possible deviations and their causes. It is also helpful – for example by brainstorming – to devise possible worst case scenarios and then to analyse the effectiveness or possibility of failure of the safety measures planned. In this connection the analysis of potential problems (APP) as put forward by Kepner and Tregoe[1] has proved effective.

The suitable method must be selected in each individual case according to the nature of the problem and the level of detail it requires so that expenditure of effort and results are in reasonable relation to one another.

The following stages in the course of the risk analysis are useful only after previous systematic hazard identification to trace the basic shortcomings, accident scenarios and fault sequences which could lead to incidents.

### 3.4 Hazard assessment, risk

By considering the causes and effects of the identified hazards, their *probability* and *impact* can be evaluated as *risk.* Such a risk evaluation is however not an end in itself, but is primarily an aid to decision-making regarding the scope of the measures to be taken. The focal point of such an evaluation is clearly the possible impact.

The examples of impact and probability assessment given in the following tables are by no means intended to be comprehensive or compulsory, but should at most be considered as typical.

Both tables are open to downward interpretation: all serious incidents are classed under "high" impact here (no differentiation between "high", "very high" and "catastrophic"). In the same way the probability of rare, very rare and extremely improbable incidents is initially assessed as "low".

[1] Kepner Ch. H., Tregoe B. B., *Entscheidungen vorbereiten und richtig treffen,* published by Verlag Moderne Industrie, Landsberg am Lech, 6th edition, 1992.

| **Impact** | **Effects on** | | |
|---|---|---|---|
| | **People** | **Environment** | **Property** |
| **Low** | Minor injury | Short-term offensive noise | Minor damage to machinery, loss of a batch |
| **Medium** | Injuries without permanent effects | Discoloration of surface water, unpleasant smell | Installation damage without prolonged interruption of operation |
| **High** | Injuries with permanent effects | Death of fish, defoliation, contamination of waste-water treatment plant | Loss of an installation, a building |

*Examples of the assessment of impact*

Appraisal of the impact, i.e. the damage and its after-effects which may be caused by an undesirable event, forms a basis for the subsequent implementation of suitable safety measures. Experience shows that the impact categories characterised in the table by some typical examples are usually more practical than abstract quantification.

Probability is in practice significantly more difficult to evaluate because, among other things, unquantifiable influences such as maintenance, training, management and motivation are also of significance. In the following table, some typical cases are summarised. As the assessment of probability is not free of subjective influences, it is practical to rely on

- experience
- comparison with similar situations
- statistical evidence
- in special cases, quantitative evaluation of fault trees.

In the case of both probability and impact, other assessment models, for example four-stage models, are possible and justified. One example of this is found in Appendix 2 (risk assessment practice in the canton of Aargau).

The "Zürich" insurance assessment model uses four impact grades, I catastrophic, II critical, III minor, IV insignificant and six probability grades, A frequent, B often, C occasional, D rare, E improbable, F impossible. This is a "relative quantification"method, i.e. an assessment of risks by comparative observation.

The main task in risk assessment at this stage is to create a rational basis for the implementation of measures. Quantification calculated in more detail is therefore often unnecessary; at the most it may be useful in estimating residual risks in critical processes.

### 3.5 Planning of measures

The "risk diagram"(see p. 11) illustrates qualitatively a relationship between risk, impact and the probability of an occurrence. Three risk categories[1] have been arbitrarily selected. Measures can be taken to reduce the risk.

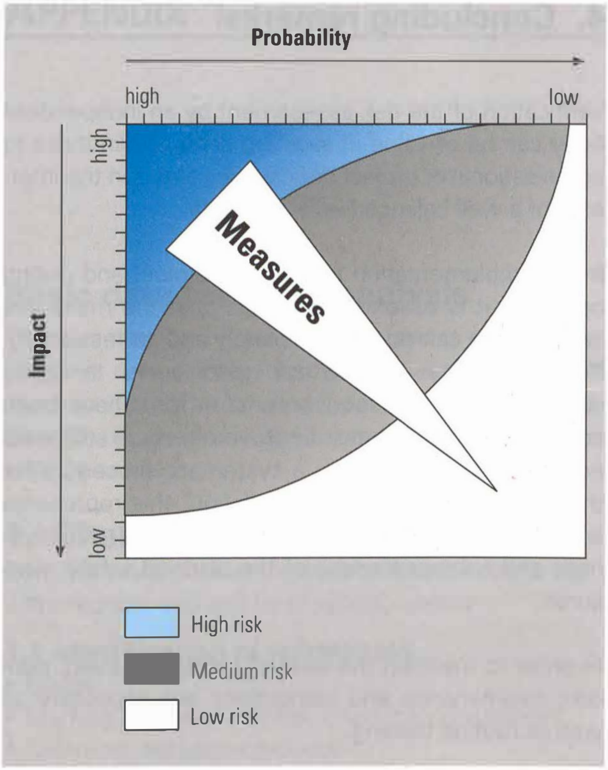
The safety measures to be taken are intended to reduce the risk to an acceptable level. The main thrust involves reduction of the impact. In chemical processes this is often achievable only by process development methods. The vital importance of risk analysis, even in the early stages of process development, is clearly apparent. Impact can also be reduced by technical means: fire alarm and sprinkler installations in stores, explosion suppression or explosion pressure relief in spray dryers, erection of a second barrier against undesirable release of substances, etc. However, it should be borne in mind that when resorting to measuring and control technology (from an additional measuring sensor to a process control system) in most cases it is only the probability of occurrence that will be drastically reduced, but not the impact.

Safety measures should therefore be planned according to the following priorities:
- Select process with the lowest risk (inherently safe process)
- Reduce risks by use of technical means

| Probability | Technical failure | Human error | Outside influences |
|---|---|---|---|
| **High** | Failure of<br>– analytical equipment (pH, redox or $O_2$ probes)<br>Leakage of improvised hose connection | Mixup of products in similar packaging<br>Misinterpretation of verbal instruction | Frost, rain |
| **Medium** | Failure of<br>– on-line measurement of data (p, T, L sensors)<br>– solenoid and regulating valves<br>Leakage at flange connection with flat gasket | Confusion of products delivered in drums/bags<br>Misinterpretation of written working instructions | Prolonged power cut, transport accident |
| **Low** | Failure of<br>– redundant elements<br>– fail-safe elements<br>Leakage at flange with groove and tongue joint | Confusion of products supplied through pipelines<br>Misinterpretation of written working instructions subject to double checking | Aeroplane crash onto chemical plant |

*Examples of probability assessment*

[1] See Appendix 2 (page 15) for examples of other risk categories applied in practice.




*Risk diagram*

- Install warning systems
- Take organisational and personnel measures
- Prepare emergency measures.

The following matrix chart shows the basic options for measures and their areas of application:

- Increased reliability (reduction of the probability of an incident), e.g. by automation of routine actions, preventive maintenance, warning and control systems, etc.

**Measures to limit the impact**
Prevention, suppression or reduction of the effects of an incident which has occurred using technical/organisational precautions such as alarm installations, fixed fire extinguishing installations, explosion suppression/explosion pressure relief or organisational/personnel measures such as emergency services and action programs for foreseeable incidents.

Finally, in the planning of measures one should always bear in mind the following factors:

**Safety measures can themselves present new risks...**
It is possible for a safety measure to have the required effect on the problem in question, but to create new risks elsewhere; for example: safety valve on containers for toxic substances (while it prevents the container from bursting, employees or the environment are put at risk if the device is triggered), a rupture disk on equipment with combustible dust (discharge of hazardous flames can be expected). *Safety measures, in particular those of a technical nature, must therefore be carefully examined to ensure that they do not themselves entail new risks.*

| Area of application | Type of measures<br>Eliminative measures | <br>Preventive measures | <br>Measures to limit impact |
|---|---|---|---|
| **Technical** | Other methods of synthesis | Technical process control,<br>alarm systems | Explosion pressure relief,<br>sprinklers |
| **Organisational** | | Process surveillance by personnel,<br>training and instruction | Emergency services |
| **Personnel** | No employees<br>in the hazard area | on behaviour in the event<br>of process deviations | Instructions for emergencies |

*Matrix chart of measures*

## Eliminative measures
Elimination of potential hazards, e.g. by the selection of an alternative synthesis path or alternative technical solution and, in extreme cases, giving up a process altogether.

## Preventive measures
Reduction of existing risks by
- Minimising the impact, e.g. by reducing the potential hazard (reduction of stocks, continuous processing instead of batch processing), etc.
- Reducing exposure, e.g. by selecting a suitable location, remote control of hazardous operating sequences, etc.

## Simple error should never be ruled out...
People, even the best, most reliable workers, do make mistakes (incorrect action, negligence). The same applies to the managers responsible for their supervision.

The following principle thus holds: *Safety measures should be designed to ensure that a simple human error cannot lead to an incident with a major impact.*

## 3.6 Assessment of residual risk
This final stage of risk analysis takes into account the risk remaining despite all the measures which have been planned. There are no universal criteria which can be applied to judge the acceptability of its impact. In

addition to purely technical factors, economic, company, specific environmental and sociopolitical aspects also have an effect. If the residual risk is classed as too uncertain or too high, the risk analysis must be pursued in greater depth from the appropriate stage onwards (planning of measures, hazard identification or, if necessary, basic data).

Particularly before putting a process into production, renewed verification of the risk analysis is a valuable control instrument. In the event of process changes or modifications to an installation, appropriate control measures should be used to ensure that the safety aspects of such changes are thoroughly examined.

To sum up, in general a process or an installation will satisfy current safety requirements if
- a thorough risk analysis has been carried out
- the available knowledge and scientific tools have been put to optimum use
- the safety measures comply with the legal requirements, the state of the art, the findings of the risk analysis carried out and the relevant safety regulations and guidelines.

As measures only cover those risks which have been identified and correctly assessed, the residual risk is composed of
- risks which are consciously accepted
- risks which are identified but are incorrectly assessed,
- hazards which are not identified.

} residual risk

*Every available opportunity must be used to reduce the unknown components of the residual risk.*

# 4. Concluding remarks

Verification of the risk assessment by an independent body can be of value in avoiding habitual blindness to organisational or project deficiencies and is in the interests of a well balanced level of safety.

In the implementation phase of a project and during operation it is essential to ensure that the measures selected are carried out completely and professionally. Periodic safety reviews can also serve to verify whether the safety requirements in force have been complied with or whether improvements are still needed. One important step is a systematic procedure for the commissioning of an installation: this represents another good opportunity to check overall effectiveness and appropriateness of the planned safety measures.

In order to maintain the level of safety achieved, periodic maintenance and inspections are necessary as well as routine training.

Risk analyses are also the basis of safety assessment by the authorities, for example under the Swiss Ordinance on Protection against Major Accidents (the StFV). The methodology of risk analysis is beneficial both for summary reports and for risk determinations compiled in compliance with the StFV (cf. ESCIS publication No. 10 "Risikoanalyse im Zusammenhang mit der Störfallverordnung [StFV]"). Therefore, subsequent accessibility or traceability of documents must be ensured so that proof of the means used to reduce recognised risks to an acceptable level can be furnished at all times. From the point of view of the authorities, residual risks, the effects of which may exceed the works perimeters, are the real risks to the public at large. As only impacts classed as «high» – and normally associated with correspondingly low probabilities of occurrence – are of relevance here, it may be necessary for these assessments to be broken down more distinctly and even quantified in particular cases.

Experience of incidents is the most valuable information for the verification, correction and supplementation of risk analyses. Incidents and even near-misses must therefore be carefully evaluated and documented.

The benefits of risk analysis stand or fall by the appropriateness of the measures selected, the care and conscientiousness applied in their implementation and the efforts made to maintain the level of safety achieved in the long term.

## Basic data for a risk analysis

This summary is in "menu" form and is not comprehensive; new findings and technical developments must constantly be taken into account. The risk analysis team decides from case to case what information is actually needed.

## 1. Chemicals

(raw materials, auxiliary materials, reaction mixtures, intermediate, end and by-products, waste)

### 1.1 Identification of substances

- Origin
- Marking (common names, chemical designation)
- Sampling, acceptance check
- Identification, analyses
- Risk of mixup

### 1.2 General data on substances

- State of aggregation
- Density
- Vapour pressure
- Boiling point
- Melting point
- Specific heat
- Concentration
- Purity, impurities
- Compatibility with materials of construction

### 1.3 Safety data

- Flash point
- Explosion limits
- Ignition temperature
- Sensitivity to impact and friction
- Dust explosion hazards
- Susceptibility to detonation
- Electrostatic properties
- Reaction to heat, water, air (e.g. pyrophoric materials), light

### 1.4 Toxicity data

- TLV value
- IDLH value
- Oral toxicity
- Effect on eyes, mucous membranes, respiratory tract, skin
- Effect after acute and repeated exposure (e.g. allergies)
- Effect of long-term exposure (damage to organs, carcinogenicity)
- Warning symptoms (odour threshold, irritant action)

### 1.5 Ecotoxicity data

- Water pollution class (D, CH)
- Biodegradability
- Toxicity to fish
- Toxicity to daphnia
- Toxicity to bacteria
- Malodorous/intensive smell

## 2. Processes

(chemical and physical processes)

### 2.1 Thermal effects, kinetics

- Heat of reaction and decomposition
- Reaction and decomposition rates, temperature ranges
- Gas development
- Delay of reaction and accumulation of reactants
- Type, quantity and characteristics of decomposition products

### 2.2 Influences on the progress of reaction

- Deviations from normal reaction conditions (e.g. temperature, pressure, concentration)
- Catalytic effects

### 2.3 Undesirable reactions

- Polymerisation
- Reactions with water, heating/cooling media, air, reaction products
- Reactions with other substances used in the process; possibility of mixup
- Reactions in sewers or ventilation ducts
- Reaction with materials of construction, contamination

### 2.4 Opportunities for the safe interruption of the reaction

- Process stage
- Monitoring after interruption
- Permissible duration of interruption

### 2.5 Physical processes

- Retardation of boiling
- Thermal shock by crystallisation
- Foaming, frothing
- Crust formation/heat dissipation
- Change in viscosity
- Electrostatic charges
- Softening/smudging (mill)
- Melting
- Evaporation/sublimation

## 3. Installation

### 3.1 Equipment
- Type, size/capacity
- Materials of construction including seals, packings, liquid seals
- Connections/interfaces to other installation parts/areas
- Mechanical stability (pressure/vacuum)
- Catalytic effects on substances
- Heating and cooling capacities
- Minimum level for stirrers, sensors, agitator baffles
- Ventilation of equipment (power, disposal of exhaust air)
- Pressure relief/containment
- Accessibility for maintenance, cleaning

### 3.2 Measurement and control equipment, alarms
- Reliability, failure probability
- Redundancy
- Fail-safe characteristics
- Hierarchy of alarms
- Opportunities for manual intervention

### 3.3 Particularly critical events, defects
- Pitting/corrosive penetration of reactor wall/leakages
- Stirrer stoppage/breakdown
- Ingress of air
- Power cut
- Mechanical defects of auxiliary units (pumps, etc.)
- Disturbance/failure of process control system
- Incorrect operation/negligence

### 3.4 Sources of energy/fuels
- Fire/ignition hazard
- Danger of suffocation
- Danger of poisoning
- Danger of confusion/mixup
- Contamination
- Availability/failure probability

### 3.5 Storage (piece goods, silos), tank farms, transit
- Stored goods/goods in transit, transloading
- Quantities
- Fire and explosion hazards
- Warning systems
- Fire protection/fire fighting
- Retention capacity for extinguishing water and leaks

### 3.6 Structures, buildings and their safety features
- Structural divisions (open-air facilities, hall construction, multistorey building, bunkers)
- Resistance to pressure (relief?), fire (fire compartments?), corrosive gases and vapours (including combustion gases)
- Retention basins for extinguishing water and leaked fluids
- Fixed fire extinguishing systems
- Gas detectors
- Room ventilation
- Drainage systems, sewer (disposal)

### 3.7 Opportunities for operator/manual intervention
Functions
- Manual work (filling, emptying, transportation, cleaning)
- Operation/monitoring (at the equipment, in the control room)
- Information processing in control rooms, computer-controlled installations

Level of knowledge (instruction/training)
- Equipment
- Safety devices and systems
- Unit operations (distilling, filtration, drying, etc.)
- Products (origin, delivered form, specifications)
- Hazards (product-specific, process-specific)
- Control concept/process control system
- Task-oriented training, process-specific and general
- Handling of respiratory equipment, fire extinguishing gear, lifesaving equipment
- Conduct in the event of an emergency
- Monitoring and further development of skills

Conditions in the work area
- Day duty/shift
- Presence of supervisors
- Heat, dampness, cold, noise, stress
- Exposure, protective measures, personal protective equipment, monitoring

### 3.8 Immediate surroundings/neighbourhood, weather/climate, forces of nature
- Incidents in neighbouring plants, in the works, in the neighbourhood
- Traffic problems (shift staff cannot get to work in time)
- Day/night
- Temperature (frost, solar radiation)
- Precipitation, wind, dust
- Unrest, strike, sabotage
- Earthquake[1], flood, cyclone

[1] See ESCIS booklet No. 11 *Behelf zur Ermittlung der Erdbebensicherheit von Bauten und Anlagen der chemischen Industrie (Guide to the determination of safety of constructions and facilities in the event of earthquakes in the chemical industry*, only available in German).

# Appendix 2

## Risk categories applied in practice

### *Examples of risk assessment in the chemical industry, the insurance industry and from the cantons of Aargau, Basel-Landschaft and Zürich, Switzerland*

In Switzerland, the cantons enforce the Ordinance on Protection Against Major Accidents where implementation is not assigned to Federal Government. For this enforcement function, which also includes risk assessment, there is, within the limits defined by the Ordinance and the relevant *BUWAL* (Federal Office of Environment, Forests and Landscape) handbook, a certain degree of freedom of action and judgement, which is interpreted and applied differently by the various cantonal authorities. The cantonal offices contacted in the course of the preparatory work for this appendix have not yet firmly established their procedures for risk assessment.

A presentation used previously in the canton of *Aargau* has already been included in ESCIS booklet No. 10 *Risikoanalyse im Zusammenhang mit der Störfallverordnung (StFV) (Risk analysis under the Ordinance on Protection Against Major Accidents,* only available in German); the same graph is reproduced in this appendix, supplemented by a more detailed system of four categories of consequences (impact) concerning possible effects on man, the eco-sphere and infrastructure.

In the canton of *Zürich,* risks are assessed using safety objectives, indicators and safety criteria and the result appears as a cumulative curve in the probability/impact diagram. Depending on the result, i.e. whether the cumulative curve exceeds the acceptable range despite the measures taken, the acceptability of the risk must be assessed by the commission for accident prevention or, ultimately, by the government of the canton. Assessment of the acceptability of risks is carried out in a similar fashion, as described in Handbook I to the Ordinance on Protection Against Major Accidents (Appendix G). Certain indicators have been adopted unchanged (number of victims killed, discounted costs). For the assessment of damage to the environment, indicators which are as easy to measure and assess as possible are sought and these should lead as many administrative bodies as possible to a uniform view of environmental damage. This is still under discussion at the time of going to press[1].

It is evident that in the case of risk assessment by the cantonal authorities, it is not just *analytical factors,* i.e. aspects which can be established more or less scientifically that may be decisive, but also *political* factors which are of consequence; *social acceptance* of the risks is by no means unimportant. The illustrations reproduced on the following pages show methods of risk assessment in the cantons of Aargau, Basel-Landschaft and Zürich. They should be regarded only as highly simplified illustrations of assessment practice.

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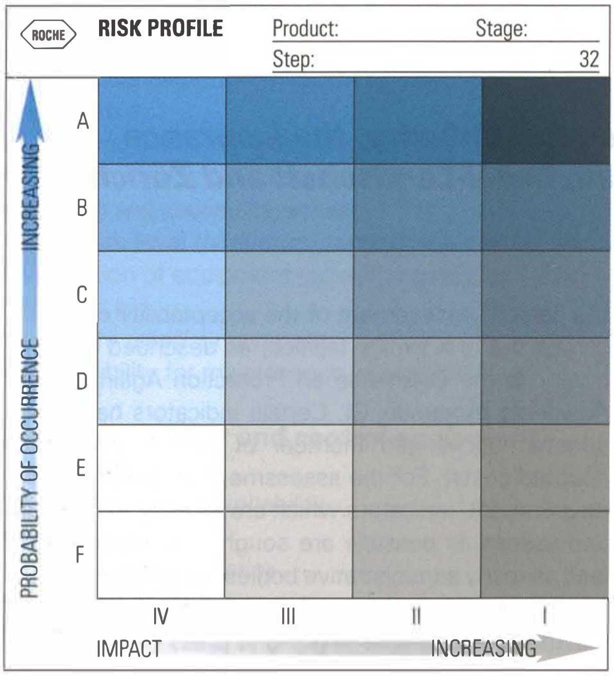
[1] The «Assessment Criteria» working party of the Swiss Federal Commission for AC protection prepared the following guidelines: *Beurteilungskriterien I zur Störfallverordnung StFV.* Beurteilung der Schwere von Schädigungen/Beurteilung der Tragbarkeit des Risikos, Richtlinien für Betriebe mit Stoffen, Erzeugnissen oder Sonderabfällen. *Assessment criteria I under the StFV (Ordinance on Protection Against Major Accidents).* Assessment of the severity of damage/acceptability of risk, guidelines for operations with substances, products or hazardous waste, only available in German and French, BUWAL, Bern, 1996.

# APPENDIX 2

## Risk categories applied in practice

### *Example from the chemical industry*




| I = Impact | P = Probability of occurrence | |
|---|---|---|
| I catastrophic | A frequent | D rare |
| II critical | B often | E improbable |
| III minor | C occasional | F practically impossible |
| IV insignificant | | |

*Graph 1: Example of risk assessment. (Source: F. Hoffmann-La Roche AG)*

| Impact class | Description | |
|---|---|---|
| I | People<br>Environment<br>Property | Deaths, evacuations outside the premises<br>Long-term damage beyond the confines of the premises<br>> 10 million SFr., outage time of the installation: > 1 year |
| II | People<br>Environment<br>Property | Injuries, irritant effects outside the premises<br>Reversible damage in the neighbourhood<br>< 10 million SFr., outage time of the installation: months |
| III | People<br>Environment<br>Property | Injuries confined to the premises, nuisance to neighbourhood<br>Premises, at the most the waste-water purification facility is affected<br>< 2 million SFr., outage time of the installation: weeks |
| IV | People<br>Environment<br>Property | Minor injuries on the premises only<br>Area affected ranges from installation to premises<br>< 1 million SFr., outage time of the installation: days |

*Table 1: Example of a semi-quantitative impact assessment. (Source: F. Hoffmann-La Roche AG)*

| Probability | Description | |
|---|---|---|
| A | frequent | more than once a year |
| B | often | once a year |
| C | occasional | once in 5 years |
| D | rare | once in 30 years |
| E | improbable | once in 100 years |
| F | practically impossible | once in 1000 years |

*Table 2: Example of a semi-quantitative process-level assessment of probability. (Source: F. Hoffmann-La Roche AG)*

# Appendix 2

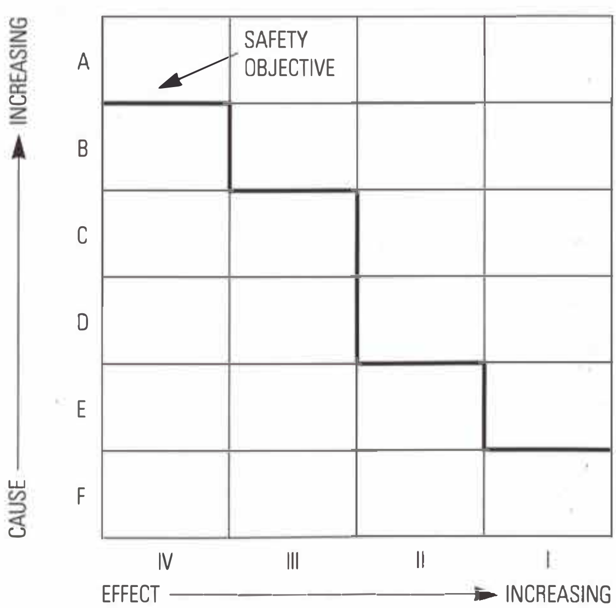
## Risk categories applied in practice

### *Examples from the insurance industry*

The "Zürich" insurance group bases its calculations on a two-component risk definition using the following categories:

| **Probability (cause)** | | **Impact (effect)** |
|---|---|---|
| A frequent | D rare | I catastrophic |
| B often | E improbable | II critical |
| C occasional | F impossible | III minor |
| | | IV insignificant |

A risk-profile grid is drawn up in which the safety objective, i.e. the acceptable risk to be established by the analysis team in accordance with certain rules and considerations and upon agreement with its management (or in line with the expected safety level) can be illustrated by a stepped line.



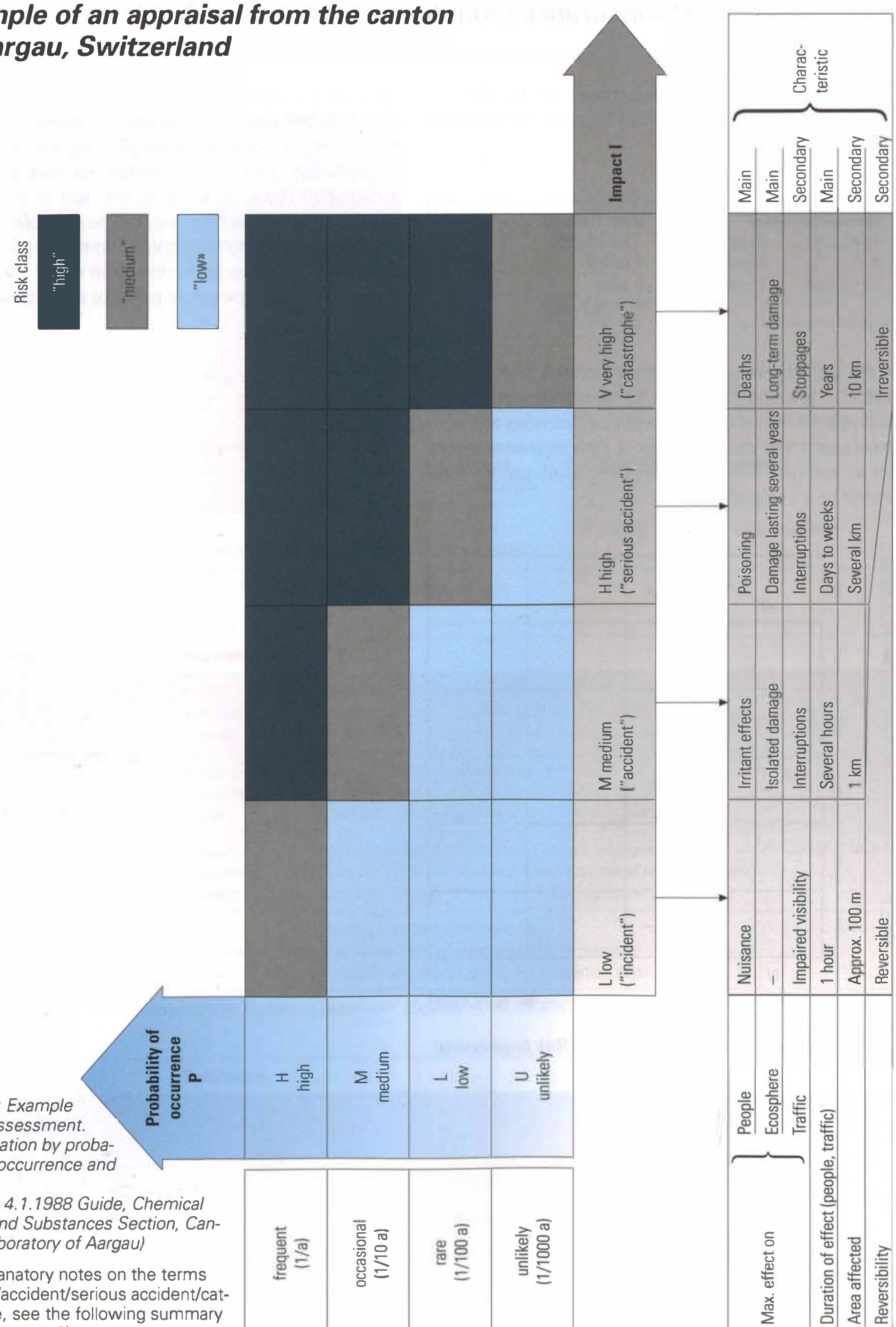

*Graph 2: Example of a risk-profile grid.*
*(Source: Zürich Insurance Group Risk Engineering)*

After careful verification, the risks below or to the left of the safety-objective line are no longer taken into account in damage limitation as they are within the safety-target area and therefore considered to be acceptable. Those above or to the right of the safety-objective line, however, are not acceptable and are treated according to their priority so that they can possibly be moved also below or to the left of the safety-objective line and therefore become acceptable.

# APPENDIX 2

## Risk categories applied in practice

### *Example of an appraisal from the canton of Aargau, Switzerland*




*Graph 3: Example of risk assessment. Classification by probability of occurrence and impact. (Source: 4.1.1988 Guide, Chemical Safety and Substances Section, Cantonal Laboratory of Aargau)*

For explanatory notes on the terms incident/accident/serious accident/catastrophe, see the following summary (Table 3, page 19).

# Risk categories applied in practice

## Example of an appraisal from the canton of Aargau, Switzerland

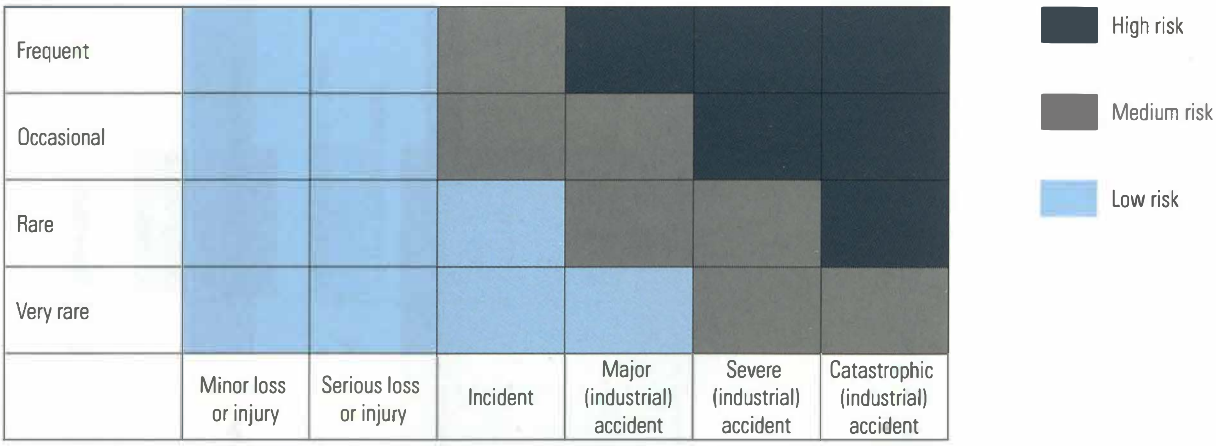
| Effect / Impact | L low | M medium | H high | V very high |
|---|---|---|---|---|
| **PEOPLE** | | | | |
| **Poisoning/chemical burns** | **Nuisance** | **Irritant effects** | **Poisoning** | **Long-term damage/deaths** |
| • Area affected | Immediate surroundings | Neighbourhood | Community | Region |
| • Duration of effects | < 1 day | < 1 day | < 1 week | > 1 week |
| • Number of persons with health damage | Isolated cases | > 10 | < 50 | > 50 |
| • Medical treatment | Out-patients | Hospitalisations | Hospitalisations | Hospitalisations |
| **Physical injuries (surgery)** | **Nuisance** | **Minor injuries** | **Severe injuries** | **Long-term damage/deaths** |
| • Area affected | Immediate surroundings | Neighbourhood | Community | Region |
| • Duration of effects | < 1 day | < 1 day | < 1 week | > 1 week |
| • Number of persons with health damage | Isolated cases | > 10 | < 50 | > 50 |
| • Medical treatment | Out-patients | Hospitalisations | Hospitalisations | Hospitalisations |
| **ECOSPHERE** | | | | |
| **Surface waters including sewers** | **Isolated damage** | **Damage over one year** | **Damage over several years** | **Long-term damage** |
| • Area affected | Local stream < 500 m | Local river < 5 km | Regional river < 50 km | River extending over regional borders > 50 km |
| • Duration of damage (sewage treatment plants) | Hours | Days | Weeks | Months |
| • Death of fish | | < 100 kg | < 1000 kg | > 1000 kg |
| • Duration of regeneration | A few weeks | Months | Within 1 year | Years |
| **Ground water including soil** | **Isolated damage** | **Damage over one year** | **Damage over several years** | **Long-term damage** |
| • Extent of pollution | < 50 m | < 500 m | < 5 km | > 5 km |
| • Duration of effects (drinking water) | None | <1 week (individual collecting chamber) | < 1 year (several collecting chambers) | >1 year (regional extent) |
| • Restoration: extent, duration | Simple operation < 1 week | Simple project < 1 month | Coordinated project < 1 year | Coordinated project > 1 year |
| **INFRASTRUCTURE** | | | | |
| **Supply/disposal** | **Interruptions** | **Isolated damage** | **Regional damage** | **Damage beyond regional borders** |
| • Area affected | Neighbourhood | Community | Region | Damage beyond regional borders |
| • Duration of damage | < 1 h | < 1 day | < 1 week | > 1 week |
| • Financial loss | < 1 million SFr. | < 10 million SFr. | < 100 million SFr. | > 100 million SFr. |
| **Traffic** | **Nuisance** | **Diversion** | **Interruptions** | **Stoppages** |
| • Area affected | Immediate surroundings | Neighbourhood | Community | Region |
| • Duration of effects | < 1 h | < 1 day | < 1 week | > 1 week |

*Table 3: Example of guidelines for the classification of impact according to types of effect. (Source: Guide to the Summary under the Ordinance on Protection Against Major Accidents (StFV), Chemical Safety and Substances section, Cantonal Laboratory, Aargau, only available in German).*

# Appendix 2

## Risk categories applied in practice

### *Example from the canton of Basel-Landschaft, Switzerland*




*Graph 4: Example of a risk graph. (Source: Building and Environmental Protection Directorate of the canton of Basel-Landschaft, Switzerland)*

For explanatory notes on the terms incident/accident/serious accident/catastrophe, see the following summary (Table 4, page 21).

# Appendix 2

## INCIDENT

We consider an **incident** to be an occurrence involving minor injury to individual humans and animals, which is limited in time and is reversible and/or minor and reversible damage with local impact on the environment, which is limited in time.

### EXAMPLES

**Humans/large animals** Out-patient treatment of a maximum of 10 persons not involved. Nuisance and hindrance through offensive odours for a maximum of 1 hour.
Impairment of the capacities of some animals is observed.

**Water** Some detriment with local impact; the occasional fish may die. No detectable deterioration in the quality of ground water and drinking water.
Local interruption of drinking water supply (hours).

**Soil** Isolated parts of agricultural land within local area is not cultivable for one growing season.
A harvest of less than 1 ha is completely or partially lost.

**Ecosystem** Reversible damage to flora and fauna.

**Public facilities** Utility supplies (electricity/water/gas), communication and traffic are disrupted or impaired for a short period (hours).
The effectiveness of sewage treatment plants is reduced. Pollutants enter surface waters and/or sewage sludge.
In sewage systems, pipelines may be damaged (leakages).

## ACCIDENT

We consider an **accident** to be an occurrence involving minor injury with reversible effects and limited in time to many humans and animals and/or minor reversible damage limited in time to the environment within a radius of a few kilometres.

### EXAMPLES

**Humans/large animals** Up to 100 persons not involved need outpatient treatment. Nuisance and hindrance by offensive odours occur for a maximum of 4 hours. Occasional evacuation of buildings for several hours.
A maximum of 10 animals perish or have to be slaughtered.

**Water** Some detriment with wider local impact; up to 1000 kg fish die. The ground water is contaminated above a ground-water protection zone.
Outage of isolated drinking water collecting chambers for less than one week. Drinking water is not available for days.

**Soil** A maximum of 1 ha of agricultural land is not cultivable for one growing season.
At least half the harvest on less than 10 ha is lost.

**Ecosystem** Reversible damage to flora and fauna on a maximum of 10 ha; fertility of the soil is impaired for a maximum of one growing season.

**Public facilities** Utility supplies (electricity/water/gas), communication and traffic are stopped or disrupted for days.
Waste-water treatment plants do not provide effective purification for a maximum of 1 day.
In sewage systems, waste-water removal is interrupted for a maximum of 1 day.

## SERIOUS ACCIDENT

We consider a **serious accident** to be an occurrence involving irreversible injury to individual humans and animals and/or irreversible damage to the environment in small areas, or reversible environmental damage to a large area.

### EXAMPLES

**Humans/large animals** More than 10 persons not involved need hospitalisation. Isolated deaths occur. Nuisance and hindrance through noxious odours last a maximum of 12 hours. The evacuation of many buildings is required for several hours.
11 to 100 animals die or must be slaughtered.

**Water** Detriment with wide local impact; huge numbers of fish die. Ground water just above a ground-water protection zone is contaminated. Outage of several drinking water collecting chambers in the region for up to one year. Drinking water is not available for weeks.

**Soil** A maximum of 1 ha of agricultural land can never be cultivated again or a maximum of 10 ha are not cultivable for 5 years.
A harvest of more than 10 ha is lost.

**Ecosystem** The fertility of the soil is permanently impaired on more than 1 ha.
Damage to more than 10 ha of nature reserve.

**Public facilities** Utility supplies (electricity/water/gas), communication and traffic are stopped or disrupted for weeks.
Sewage treatment plants do not provide effective purification for a maximum of 5 days. Removal of waste water is not possible for a maximum of 1 week.

## CATASTROPHIC ACCIDENT

We consider a **catastrophic accident** to be an occurrence involving irreversible injury to many humans and animals and/or temporary damage with regional extension or irreversible environmental damage to a large area.

### EXAMPLES

**Humans/large animals** Hospitalisation of more than 100 persons. Several deaths occur. Nuisance and hindrance through noxious odours last more than 12 hours. Evacuations lasting several days are required. More than 100 animals die or must be slaughtered.

**Water** Detriment with regional impact; huge numbers of fish die. Ground water within a ground-water protection zone is contaminated. Outage of regional drinking water supply for more than 1 year. Drinking water is unavailable for months.

**Soil** A maximum of 1 ha of agricultural land can never be cultivated again or more than 10 ha are not cultivable for a maximum of 5 years.
A harvest of more than 100 ha is lost.

**Ecosystem** The fertility of the soil is permanently impaired on more than 10 ha.

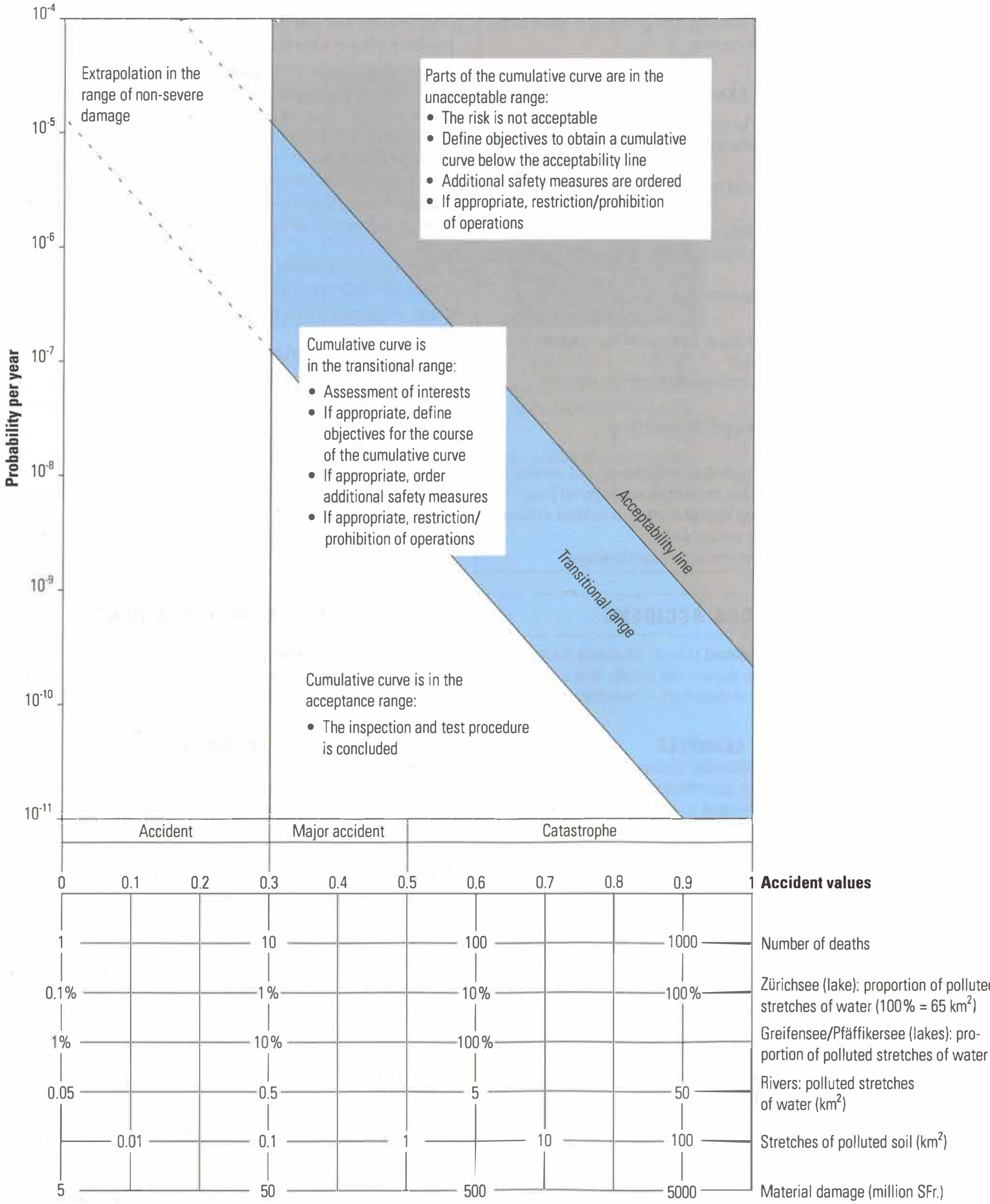
**Public facilities** Utility supplies (electricity/water/gas), communication and traffic are stopped or disrupted for months. Sewage treatment plants do not provide effective purification for weeks.
Removal of waste water is not possible for more than 1 week.

*Table 4: Example of guidelines on the assessment of the acceptability of risks. (Source: Building and Environmental Protection Directorate of the canton of Basel-Landschaft, Switzerland)*

# APPENDIX 2

## Risk categories applied in practice

### *Example from the canton of Zürich, Switzerland*




*Graph 5: Example of a probability/impact diagram with assessment criteria and allocation of accident values for the damage indicators used. Damage ≥ 0.3 is considered to be severe. This process applies to industries handling substances, products or hazardous waste. (Source: coordination unit for accident prevention of the canton of Zürich, Switzerland)*

# APPENDIX 3

## Supplementary reading

[1], [2], [3], [4], [5], [6], [7], [8], [9], [10] are recognised as being the most important methods of hazard identification concerning human error and technical faults.

### I Intuitive methods (brainstorming) [11]

### II Inductive methods
- Reference points, checklists [11]
- Failure mode and effect analysis (FMEA) [12], incident sequence analysis (incident tree analysis) [13], deviation analysis (failure mode and effect analysis) [9]
- Hazard and operability study [14], [15], [16], PAAG (HAZOP) method [17]
- Morphological method [18]

### III Deductive methods
- Fault tree analysis [19], [20]

### IV System analysis [21]
- MORT (Management Oversight and Risk Trees) [22]
- Safety audits [23]


[1] Lees F. P., Loss Prevention in the Process Industries, *Hazard Identification, Assessment and Control*, Butterworths, London, 1980.

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[3] Zogg H. A., *"Zurich" Hazard Analysis, A brief introduction to the "Zurich" method of Hazard Analysis*, Zurich Insurance Group Risk Engineering, "Zurich" Insurance Company, Zürich, 1987.

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[5] Schmalz F., *Sicherheit chemischer und verfahrenstechnischer Anlagen*, lecture script, ETH Zürich, 1995.

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[13] DIN 25419 (Deutsche Norm – German standard), *Ereignisablaufanalyse, Verfahren, graphische Symbole und Auswertung (event tree analysis, method, graphical symbols and evaluation)*. Beuth Verlag, Berlin 1985.

[14] Kletz T. A., *Hazop & Hazan, Notes on the Identification and Assessment of Hazards,* The Institution of Chemical Engineers, Rugby, 1983.

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Chemical Industry Safety and Health Council of Chemical Industries Association, *A Guide to Hazard and Operability Studies,* London, 1977.

[18] Zwicky F., *Entdecken, Erfinden, Forschen im Morphologischen Weltbild,* Verlag Baeschlin, Glarus, 1989.

[19] DIN 25424, Part 1 (Deutsche Norm – German standard), *Fehlerbaumanalyse, Methode und Bildzeichen (Fault tree analysis, method and graphical symbols),* Beuth Verlag, Berlin, 1981.
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Umsetzung der Norm SIA 160, Beurteilungskriterien, Schutzbedarf, 1994

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**Static Electricity Tutorial, Version 1.0, 1999**

## Special brochures in the ESCIS SAFETY series:

**Wegleitung für den Brandschutz und die Brandbekämpfung in Freilufttankanlagen im Innern von Fabrikarealen der chemischen Industrie, 1990**

**Wegleitung: Raumlüftung in Stückgutlagern für Chemikalien, 1991**

## Videos in the ESCIS SAFETY series:

**Explosionsschutz, 1998**

Video Teil 1 Risikoanalyse und sicherheitstechnische Kenngrössen

Video Teil 2 Vorbeugender Explosionsschutz

Video Teil 3 Konstruktiver Explosionsschutz

Video Teil 4 Risiken und Schutzmassnahmen, Kurzpräsentation der Videos 1–3

**Explosion Protection, 1998**

Video Part 1 Risk analysis and safety characteristics

Video Part 2 Preventive explosion protection

Video Part 3 Constructional explosion protection

Video Part 4 Risks and protective measures, brief presentation of videos 1–3

## Bulletins published to date in the ESCIS SAFETY series:

Nr. 1 **Der einfache Fehler, Februar 1994**
Nº 1 **La simple faute, février 1994**

Nr. 2 **Transportsicherheit, Juni 1995**
Nº 2 **Sécurité des transports, juin 1995**

Nr. 3 **Routine – eine Gefahr?, November 1996**
Nº 3 **La routine – un danger?, novembre 1996**

Nr. 4 **Schlauchleitungen/-verbindungen, August 1997**
Nº 4 **Conduites flexibles et leurs raccordements, septembre 1997**

Nr. 5 **Prozessleitsysteme und Ereignisse**
**Zur Sicherheit von computergesteuerten Anlagen, August 1998**
Nº 5 **Systèmes de conduite de procédé et événements**
**De la sécurité des installations conduites par ordinateur, août 1998**
Nº 5 **Process Computers and Incidents**
**Reflexions on the safety of computer controlled plant, August, 1998**

Copies of the above can be obtained at a nominal price from Dr. R. J. Ott, Bereich Chemie, Abteilung Arbeitssicherheit, Suva, Postfach, CH-6002 Luzern, Switzerland, Phone 041 419 53 39, Telefax 041 419 52 04, E-mail: chsvlvzi@ibmmail.com