CHECKLIST

Guide lines for safe design of process plants

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Account

This check-list serves mainly as a list of subjects related to safety which have to be taken into account when designing and constructing chemical plants.
The list has been arranged in such a way that it is possible to judge the various safety aspects of the subject according to their own merits - free from other considerations - during plant design.
It has been tried to compile this check-list so as to make it manageable by anyone, in his own special field, who is engaged in the development, design and construction of a process unit.
To obtain maximum reliability and hence availability of a plant the use of a check-list is a necessity for any specialist, thus incorporating safety in every development and design stage. A number of questions concerning safety have been formulated and put in line, while at the same time possible answers have been indicated.
Although the environment will often benefit indirectly from the safety measures, the committee does not consider itself competent to deal with questions pertaining to environment and nuisance. But they do want to draw attention to the fact that in the selection of a site for a new plant, environmental control and potential nuisance are also important aspects that have to be studied at an early stage and in consultation with the competent authorities.
Deliberately it has never been the aim to refer to relevant standards, regulations, directives etc. For the user of the check-list it is recommendable, however, to add these to the various subjects.
Undefined notions such as "ample", "safe", "sufficient" etc. should be used in accordance with existing safety regulations, or be compared with the views of such institutions as the various Inspectorates.
In this check-list an attempt has been made to indicate the subjects by catchwords; because not every subject lends itself to this systematization it has not been stringently pursued.

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I

1. CHOICE, SITUATION AND LAYOUT OF SITE

When considering the suitability of a site for establishing a chemical plant it must be investigated whether all the requisite safety conditions can be met on that particular site. If not then this may imply the necessity of looking for a more suitable site.

1.1 CHOICE AND SITUATION OF SITE

1.1.1 Dimensions of site

1.1.1.1 Size

The site should be large enough for a safe layout of the individual plants. There should be sufficient room for parking facilities, platforms for loading and unloading, service buildings, stores, storage tanks, purification installations and possible future extensions.

1.1.2 Nature of site; geophysical factors

1.1.2.1 Waterlevel

The site should be safeguarded against floods, high water table, strongly fluctuating water table and similar.

1.1.2.2 Nature of the soil

The soil should be sufficiently firm to prevent sagging and sliding. The following aspects are of importance in this respect.

Settling

Settling of the soil can be expected in areas where water is withdrawn, with backfilled soil and near former refuse-dumps, brooks and dikes.

Ground disturbances

Account should be taken of existing or expected geological disturbances and mine-disturbances.

Acidity

Investigation of the soil acidity is necessary to anticipate possible chemical attack of, foundations, cables, pipes, tanks etc.

1.1.2.3 Relief and slope

If a sloping site is selected it should be checked which precautions are necessary to prevent liquids, gases or fumes from reaching lower levels where they may constitute a hazard.

1.1.3 Climatological conditions

For a full evaluation of the safety measures to be taken at the site the climatological conditions are to be considered.

1.1.3.1 In connection with the dispersion of volatile and inflammable and/or harmful substances over the site and the windward positioning of ignition sources a study of the wind rose is necessary.

1.1.3.2 Calm conditions enhance the probability of increased concentrations of inflammable and/or poisonous fumes and gases at the site.
Owing to the presence of condensation nuclei (e.g. from cooling towers and very finely divided liquid or dust particles) the probability of fog formation may be enhanced.

1.1.3.3 Precipitation and temperature

The influence of climatological factors (such as precipitation and temperature) on the safety of a process are discussed in other chapters (civil-technical provisions, equipment, and general fire-fighting provisions).

1.1.4 Accessibility of the site

1.1.4.1 Road traffic

The supply and delivery routes of raw materials and final products should be safe with respect to the nature of the substances. Account should be taken of the ban on transporting certain dangerous substances through tunnels (see also 1.2.4). Further, facilities should be provided for the safe integration of cars, lorries, cyclists, pedestrians etc. from the site into the flow of traffic.

1.1.4.2 Railway

If rail transport is required it should be checked whether a safe connection with the existing railway system is possible.

1.1.4.3 Water

The possibilities for safe mooring, loading, unloading and manoeuvring of vessels have to be investigated.

1.1.4.4 External assistance

With a view to external assistance (fire brigade, medical service) the access roads should be free from obstacles such as level railway crossings, movable bridges, shunting-yards and the like.

1.1.5 General provisions

1.1.5.1 Fire fighting

An adequate supply of water should be available.

1.1.5.2 Drainage

Draining of rain water, fire water and process water should not only be technically possible but should also be considered in the light of environmental control.

1.1.5.3 Waste products

If waste products are produced then the methods of removal, temporary storage, processing and/or destruction are to be studied.

1.1.5.4 Energy

If energy is provided the reliability of generation and its supply should be investigated.

1.1.6 Situation of site with regard to effects by and on the environment.

1.1.6.1 Environmental control

Factors concerning environmental control and nuisance can be of decisive significance in the selection of the site and for its situation (see preface).
Some industries are very sensitive to certain types of air and/or water pollution. The presence of hydrocarbons in the intake of air separation equipment and air compressors etc. are examples of this.

1.1.6.2 Adjacency

It should be investigated what is present or in preparation at the adjacent sites, and what adverse interaction could ensue as a consequence. Not only the normal process conditions should be considered in this case, but in particular abnormal events, e.g. process interruptions. Pipeline tracks may constitute a source of danger or be endangered by traffic or incidents in nearly industries.

1.1.6.3 Ignition sources

Internal and external ignition sources may mutually and adversely affect the safety of the various industries involved. External ignition sources may include adjacent public roads, railways, overhead high tension cables, and open fire on neighbouring sites.

1.1.6.4 Vibration

It should be checked whether nearby industries cause vibrations that are unacceptable for sensitive instruments or equipment.
Further it should be investigated how far personnel are exposed or are going to be exposed to sound nuisance.

1.1.6.5 Stacks and other high structures

If the site is situated in the neighbourhood of an airfield it is to be investigated whether stacks and other high structures will constitue a hazard to aviation.

1.2 LAYOUT OF SITE

1.2.1 Administration buildings, service buildings and parking facilities.

1.2.1.1 Concentrations of people

Offices, laboratories, canteens and workshops where concentrations of people occur should be adequately segregated from hazardous locations so that under normal operational conditions as well as during interruptions they will be protected from hazards.

1.2.1.2 Internal traffic

In order to limit traffic, buildings that are not directly involved in the production process (including general stores, water preparation plants and similar) should be located at the periphery of the site.

1.2.1.3 Parking lots

Parking lots for passenger cars, lorries, road tankers and buses should be planned on the outside of the site or entirely outside the fenced area. A smooth dissolution of traffic during rush-hours, and safe entries and exits of parking lots and factory grounds merit special attention.

1.2.2 Private roads and internal railroads

1.2.2.1 Limitation road traffic

The rail and road plan should be such that road traffic in the operating area is minimised.

1.2.2.2 Accessibility

The roads should ensure adequate, multiple access to factory buildings, installations and stores (for service and fire fighting). To this end in large production units the plant sections can be separated by roads. The roadplan at and near the loading and unloading bays should provide the possibility for the vehicles to manoeuvre, wait and turn in a safe way.

1.2.2.3 Railway lines

Railway lines should be planned at ample distance from hazardous process units. In large production complexes a railway line traversing a production zone should be avoided wherever possible.
The place to load, unload and shunt railway wagons should be chosen such as to exclude prolonged and/or frequent blocking of road traffic.

1.2.3 Factories, process units, and auxiliary installations.

1.2.3.1 Situation

Vulnerable- and potentially hazardous units should be situated such that in the event of serious disruptions and incidents the consequences are localized to those particular units.

1.2.3.2 In order to attain adequate multiple accessibility large installations should be built in an elongated manner (which is often to the detriment of effective factory management), or they should be devided into logical units separated by compound roads.

1.2.3.3 What is said in 1.2.3.2 arises from the requirement that in order to fight a fire effectively it is essential that fire water, foam and the like can be applied from several directions. Further the water should be drained in such a way that any inflammable liquids floating on the water are prevented from spreading over other areas.
The site roads also serve as fire lanes to check the fire.

1.2.3.4 When positioning the equipment and the associated pipelines attention should also be given to necessary future maintenance, so that this can take place simply (and hence also safely). Included herein should be routine internal and external inspections, the removal and reinstallation of relief valves and similar.

1.2.3.5 The advantages of installing equipment whithin a building (protection of personnel and equipment against wind, rain and frost) are to be balanced against the disadvantages (impediment in fire fighting, poorer dispersion of escaped substances in most cases and hence higher concentrations with inherent toxicity and explosion hazards).

1.2.3.6 Pipe tracts

The installation should preferably be limited by a pipebridge at one side only.
High vehicles, cranes etc. may damage pipes if these are mounted above roads; these overhead crossings should be limited. If feasible use is to be made instead of troughs or channels. The equipment should be placed in such a way that there is the smallest possible chance of damage.

1.2.3.7 Installation with large quantities of inflammable substances

Installations handling large quantities of inflammable liquids or pressurized gases, where there is a hazard of large escapes, should be kept at such a safe distance from open fires as the local situation demands, taking into account the prevailing direction of the wind. These installations include storage facilities of inflammable liquids and gases.

1.2.3.8 Potential ignition sources

When locating potential ignition sources such as flares, boiler-houses and switching stations with respect to installations where inflammable gases and liquids are present then the information gained from studying the wind rose should be used.

1.2.3.9 Segregating high risk equipment

Equipment presenting a relatively greater risk should to a certain extent be kept separated from other equipment.
Stations where extremely reactive substances are mixed, or where very toxic and corrosive substances are processed, and where pyrophoric substances are collected, should be separated from areas where fire hazard, toxicity, corrosivity or reactivity may cause damage.

1.2.3.10 Cooling towers

Cooling towers may cause mist and slipperiness in and outside the fence. Cooling towers should be placed in such a way as to cause the least possible hazard by mist, precipitated mist and frozen patches. The use of aircollers may be contemplated.

1.2.4 Fire fighting and rescue operations

1.2.4.1 Multiple access to the site

For effective rescue operations in the event of calamities adequate, multiple access to the site from several directions is desirable.

1.2.4.2 Location of mobile fire-fighting material and ambulances

Mobile equipment for fire-fighting and rescue operations should be stationed in a safe place, but in such a way that it can readily be moved to anywhere in the site.

1.2.5 Location of storage and loading facilities

1.2.5.1 Loading facilities, weigh-bridges

Warehouse for the storage of products, loading facilities and weigh-bridges should be positioned in such a way that traffic in the operating area is minimised and can take place over wide roads outside this area.

1.2.5.2 Storage

Storage of raw material, intermediate products and final products in carefully evaluated quantities should be such that - dependent on the vulnerability of the packing and the stability, inflammability and toxicity of the product - ample distance is observed within the storage area as well as with respect to production units and buildings.
A combination of substances stored in one storage area should not constitute a greater hazard than each individual substance stored.

1.2.5.3 Large tanks

Large tanks containing inflammable and/or toxic or corrosive substances should be placed in not more than two rows with a view to the accessibility in the event of fire fighting, rescue operations and maintenance.

2. PROCESS MATERIALS

In order to be able to design a safe plant one should be well informed about the properties of the materials that will be processed or produced. This comprises both single and multicomponent systems.
The same is true for ancillaries such as catalysts, media for the transfer of energy, and for products that may come about under abnormal process conditions (e.g. on decomposition). For elementary concepts concerning explosion reference is made to annex 1. In particular the following properties of substances are of interest in this respect.

2.1 PHYSICAL PROPERTIES

2.1.1 Physical properties of solids

Solids

These properties are:
- the temperature at which the solid phase changes into the liquid phase. It is desirable to draw up phase diagrams where necessary;
- the particle size distribution, the moisture content, the minimum explosive concentration and other factors in connection with the possibility of a dust explosion;
- the appearance (flakes, crystals, prills etc.) in connection with the possibility of caking;
- the expansion coefficient (in connection with rupture of the equipment);
- the solubility in the relevant liquid medium in connection with plugging;
- the possibility of static charging.

2.1.2 Physical properties of liquids, including liquefied gases.

Liquids, including liquefied gases

These properties are:
- the temperatures at which solidification and boiling phenomena occur, the possibility of under-cooling, and the vapour pressure to temperature relation.
  It is desirable to draw up phase diagrams where necessary;
- the solubility or miscibility with other substances; in particular with water (fire fighting);
- the viscosity (overheating);
- the density;
- the surface tension;
- the expansion coefficient;
- the possibility of static charging (see publication "Hazards of static electricity in the process industry").

2.1.3 Physical properties of gases

These properties are:
- the expansion coefficient;
- the density with respect to air (ventilation, concentration);
- the solubility in water;
- the Joule-Thomson effect;
- the critical temperature and pressure;
- the possibility of static charging (see publication "Hazards of static electricity in the process industry").

2.2 CHEMICAL PROPERTIES

2.2.1 Direct fire-risk

The following properties are greatly depending on, for instance, the process conditions, the appearance (a.o. particle size), the way and the time in which the energy is supplied. The question which should be asked time and again therefore is whether the available information is applicable as such. Special attention should be paid to:
- the explosion limits and the effect on them by other substances (e.g. by inert gas, oxygen etc.);
- the flashpoint;
- the ignition temperature and energy;
- the possibility of fermentative heating and auto-ignition (i.a. pyrophoric properties).

2.2.2 Reactivity

Special attention should be paid to the behaviour with respect to oxidizing and reducing agents, water including fire water, air, steam, oxygen and materials of construction. This should be studied also at temperatures that might be reached in the process under abnormal conditions. The possibility of hydrate formation should not be overlooked.

2.2.3 Instability

Special consideration should be given to:
- the possibility of formation and the presence of instable compounds such as peroxides, and the possibility of inflammable and/or toxic decomposition products being formed;
- the possibility of auto-ignition or polymerization with strongly exothermal effects under abnormal conditions;
- the causes that may initiate the foregoing processes, such as the sensitivity to temperature, friction and/or shock, the catalytic effect of contaminants, the acidity (pH) and the moisture content.

2.3 TOXICOLOGICAL PROPERTIES

2.3.1 General

Substances can cause poisoning in different ways. After entering the human body irritating-burning effects on the mucous membranes of the respiratory tract and/or digestive tracts may occur, but a change in biological processes of the human body is also possible. With many substances the occurrence of acute poisoning is very much in the limelight in practice. Other substances lead to predominantly chronic poisoning. Some substances have carcinogenic properties.
The place where cancer will occur may be dependent on the entrance route of the substance or the place of contact. The extent of toxicity is expressed in concepts as LD 50, and LC 50.
Acceptable concentrations are expressed as TLV and EPEL.
Consideration should be given to the fact that great differences in individual sensitivity may occur, while also the effect of some substances may be enhanced by the presence of other substances.

2.3.2 Assimilation

Toxic substances may be assimilated via the respiratory tract the skin, wounds or by swallowing. Assimilation through the skin via contaminated clothing is possible for many substances.
With some substances the poisoning that has been contracted via the skin does not come to light until later (phenol, hydrogen fluoride).

2.3.3 Solids

Apart from skin contact poisoning can also occur by inhaling fine dust particles. Some substances cause an affection of the lungs (pneumoconiosis); this can be incurable.

2.3.4 Liquids

Liquid absorption can also take place by inhaling droplets.
Acids and bases have a burning effect on the skin; solvents will often defatten the skin.

2.3.5 Gases, vapours

Many gases and vapours have an irritating effect on the eyes, causing the secretion of tears. Vapours of solvents often have a narcotic effect.

2.3.6 Radioactivity

When dealing with radioactive substances the type of radiation, the half-life time, the biological half-life time, the intensity of the radiation, and the exposed part of the body are of interest in connection with radiotoxicity.

2.3.7 Explanation of a few concepts

LD 50 (Lethal Dose 50)
Lethal dose 50 is that dose whereby 50 percent of the experimental animals die within a give time after administering of the material.
The lethal dose is mostly expressed in mg/kg bodyweight; the route of dosing and the experimental animal must be stated.

LC 50 (Lethal Concentration 50)
Lethal concentration 50 is that concentration whereby half the number of exposed animals die after a given time; concentration in mg/m^3 or ppm; the experimental animal must be stated.

TLV (Treshold Limit Value)
Treshold limit value is the maximum permissible concentration to which workers may be exposed for 8 hours a day and 5 days a week.

EPEL (Emergence Population Exposure Limit)
Emergence public exposure limit is that concentration which can be borne for a given period of time by workers in emergencies for a certain time without inflicting lasting damage to health, but possibly causing temporary nuisance or irritation or intoxication phenomena.

Remark
It should be noted that in this connection that the level of the odor threshold with respect to TLV and EPEL is of great significance.

3. REACTIONS, PROCESS CONDITIONS AND DISTURBANCE ANALYSIS

In order to assess whether a production unit complies with all the safety requirements made upon the process industry a disturbance analysis of each unit is to be made. Hereby a step-by-step check is made of what hazards may be encountered in the reactions under the process conditions, and especially under abnormal conditions.
The result of such a disturbance analysis is that quite often a number of problems can be discerned that originate from the process design. In order to solve these problems alterations in process and design may prove to be necessary. Implementation of these alterations can take much time unless a disturbance analysis is carried out at a very early stage.
Since the selection of the process and the raw materials greatly affect the possibility of developing a safe undertaking, the technical staff of the laboratory and the pilot plant should discern the hazards already at an early stage. Before giving shape to the plans to arrive at a production unit (pilot plant, test- or commercialinstallation) these plans will have to be submitted for discussion to those who afterwards will be charged with the project development, production, maintenance, instrumentation, safety, fire prevention and environmental control.
Apart from improving the safety aspects the performance of a disturbance analysis usually has also additional advantages such as:
- a more reliable process;
- an increased knowledge of the process;
- a better insight into the dependability of the process.

A well-documented disturbance analysis is also of great value for:
- discussions with Government agencies or insurance companies;
- drawing up directions for service and maintenance, and the training of executive staff and operators.

If in connection with the results of a disturbance analysis a process has undergone several alterations it is to be recommended to carry out another, limited disturbance analysis in order to check whether these alterations are acceptable when implemented into the whole constellation.
The following items go further into performing a tentative and a final disturbance analysis.

3.1 REACTIONS

To be able to perform a disturbance analysis for those parts of the installation within which the chemical reactions take place, sufficient data will have to be known with respect to the chemistry and thermodynamics of these reactions. Very important data are:

- the heat development as a result of the desired reactions;
- the mutual dependence of reaction rate and process variables;
- the limits within which the various process variables are to be kept so as to prevent undesirable reactions;
- the chemical and hence thermodynamic consequences of faulty dosage in quantity and/or order of the reactants or ancillaries;
- what thermodynamic effects may be encountered as a result of the occurrence of undesirable reactions which could be initiated by for instance a mechanical failure (pumps, stirring devices etc.), contamination of the raw materials and materials used, and a runaway of process variables beyond the limits necessary for the desired reactions.

3.2 PROCESS CONDITIONS

3.2.1 Normal process conditions prevail when the various values in the process are in agreement with predetermined values for optimal and safe procedures, or do not deviate more from these than by predetermined maximum differences.

3.2.2 Abnormal process conditions prevail when the relevant values get beyond the predetermined limits for optimal and safe procedures.

3.2.3 Process conditions can be static or dynamic. The first group (static) comprises temperature, pressure and composition.
The second group (dynamic) comprises temperature course, pressure course, degree of conversion, heat input and output, stirring rate, gravity acceleration (γ factor), pumping rate, flow rate etc.

3.2.4 Normal process conditions can also be determined for situations other than routine production, e.g. for starting and stopping the installation.

3.2.5 Whereas process conditions frequently have constant values in continuous processes, normal process conditions in batch processes may be coupled to a predetermined course of the several values (for instance, on the basis of periods of time).
In continuous reaction systems the predetermined values may in some cases be a function of production capacity. Some "normal" process conditions are also dependent on atmospheric conditions.

3.3 DISTURBANCE ANALYSIS

3.3.1 Tentative disturbance analysis

3.3.1.1 General

To analyse the consequences of all the situations that might present themselves a tentative disturbance analysis is made of each process unit with the aid of block diagrams. In this analysis it is examined which causes, as mentioned in 3.4 may lead to abnormal conditions (see 3.5), that could initiate critical situations such as fire or explosion (see 3.6).
On the basis of this examination safety measures are laid down, such as instrumental safety systems (see appendix chapter 3), alarm systems, relief systems and inter locking devices, to prevent abnormal conditions and critical situations.
It should be realized that everything associated with process control - hence also the protective systems throughout the design - will have to be considered as a coordinated system.

3.3.1.2 Block diagrams

In the block diagrams the reactions, process conditions, quantities of raw and ancillary materials, catalysts, intermediate and byproducts, waste materials (gaseous, solid or liquid) are mentioned wherever possible.
In the tentative disturbance analysis one finds out which data on the substances (see chapter 2) and process conditions additional information is needed to enable assessment of the hazards.
With the aid of the results obtained one arrives at the design of the installation that is subject again to disturbance analysis.

3.3.2 Final disturbance analysis

For the final disturbance analysis the following information should be available:

a. A list of process materials with relevant data (see chapter 2).
b. A description of the process with material and heat balances and a process flow-sheet.
c. A floor-plan with the location of the various units (see chapter 1) and/or maquettes.
d. Piping schemes and/or maquettes.
e. A drawing with the hazard classification in terms of possible ignition sources subdivided into:
  - electrical ignition sources;
  - all other ignition sources (furnaces, steampipes etc.);
f. Data concerning the energy supply and its reliability.
g. The process and instrumentation diagrams.

The following data should be supplied with these schemes:

- the quantities, pressures and temperatures of the media present under normal process conditions;
- the piping including the accessories and tracing with diameter, material, pressure classes and temperature classes;
- the safety devices, type (spring, weight, balanced, bursting disc etc.), set-pressure, capacity, the temperature up- and downstream the device, the way and location of discharge;
- the mechanical protection systems, for instance in the shape of interlocked valves;
- the pieces of equipment with the design pressure and design temperature, the maximum working pressure to be expected, the construction material, the working temperature, the dimensions, the corrosion and erosion allowance of the material, the insulation and the finish (see chapter 4);
- the pumps, the compressors and suchlike with the design pressure and maximum working pressure to be expected, the construction material, the design temperature and maximum working temperature to be expected, the pumping head, capacity, type of sealing, type of drive (turbine, electric motor etc.) and type of pump;
- the remaining pieces of equipment with moving parts in connection with among other things the effect of the moving parts on the medium: the type, drive, material and the way of sealing (see chapter 4);
- the measuring and control equipment, impulse lines, control characteristic, capacity, alarm system and the actions on impulse failure.

3.4 CAUSES OF ABNORMAL CONDITIONS

Abnormal conditions can result from many factors, such as:

- disturbances in the supply, discharge and circulation of process materials/flows;
- disturbances in the energy supply such as electric power, water, steam, air, fuel etc.;
- disturbance in the measuring and control equipment and the computer;
- the starting-up or shut-down of a process;
- maintenance activities;
- faulty actions, e.g. blocking in;
- fouling, corrosion and erosion;
- fire in the neighbourhood;
- meteorological effects such as lightning, gale, frost, etc.;
- fermentative heating;
- static electricity;
- failing equipment, accessories, packings etc.;
- animals (a beetle in an alarm device, short-circuiting in high tension installation by rats).

3.5 ABNORMAL CONDITIONS

The following conditions are examples of what may be considered abnormal:

- leakages, whereby substances escape or leak from the outside to the inside, as well as internal leakages from one compartment to another, for instance leaking pipes in an apparatus;
- a change in the proportion of reactants;
- interruption of the mixing or separation process by a failing mixer or a blocked separator;
- a change in temperature and/or pressure (a small change may initiate big effects);
- contamination of the reacting substances or flows (small amounts of air or other substances may have a catalytic effect);
- undesirable reactions such as polymerization and decomposition;
- overfilling;
- blockage;
- undesirable backflow;
- loss of communication.

3.6 CRITICAL SITUATIONS

It should be investigated whether abnormal conditions could lead to critical situations. A critical situation may be present when there is an acute risk of rupture of equipment or piping, leakage etc.
This may result in, for instance:

a. Fire and/or explosion or implosion.
b. Escapes of hazardous substances present or formed during the escape.
c. Escapes of hot or very cold substances.
d. Development of noise, smoke, mist etc.
e. Escalation of the points mentioned in a. through d.

4. EQUIPMENT (including piping and accessories)

4.1 INTRODUCTION

The hazards associated with the use of equipment can be twofold. Failing construction material of the equipment can give rise to a hazardous situation, but also the function and design of certain equipment may involve danger for the immediate surroundings.
In order to gain a better insight into the possibilities which may lead to the failing of equipment it is necessary to carry out disturbance analyses as described in chapter 3.
The hazards associated with equipment can often be warded off by fitting safety devices, by correct design and proper use. In order to avoid unsafe situations all equipment should be checked on which requirements should apply with respect to design, choice of material, construction, installation and special provisions.
As for the prevention of explosion hazards reference is made to annex "Explosion Prevention".

4.2 DESIGN

4.2.1 Explosion

If explosive conditions cannot be avoided in the equipment it deserves consideration to choose the design such that the explosion pressure can be withstood. In many cases explosionproof design is preferable, primarily for the protection of the surroundings.
If for technical or economic reasons this cannot be realized another solution can be found by applying bursting panels, explosion doors, or weak seams.
If one of these alternative solutions is applied the restriction holds that in the design and the location of the equipment the hazards resulting from the operation of these safety are taken into account.
These hazards may be, for instance, ejection of an explosion door or ejection of a flame, or of undesirable substances.

4.2.2 Ignition sources

Attention should be paid to avoiding as much as possible the application of moving parts which by friction or impact may give cause to the development of sufficient ignition energy in an explosive/inflammable atmosphere, both inside or outside the equipment. Catching foreign material that is capable of spark formation is a necessity in this connection.
Ignition resulting from discharge of static electricity should also be prevented.
It should also be borne in mind that spark formation may occur in electric equipment.
Contact between hot surfaces and substances having a low ignition temperature should be avoided as much as possible.

4.2.3 Pressure differences

Attention should be paid to the hazard that may occur when a high pressure system is connected with a system of lower pressure via a control valve, a reducing valve or a by-pass (e.g. round a reducing valve, control valve, a unit etc.).
In the aforementioned cases the low pressure system should be able to stand up against the same pressure as the high pressure system, or should be protected by a safety device.
In this connexion attention is drawn to the hazards of complicated combined blow off systems that can be closed, and to the hazards of those systems, whereby safety valves blow off into a system of lower pressure (so-called "silent blow off").
Heed should also be given to the possibility of thermal expansion as a result of the heat of the sun, steamtracing, and possible consequences of this, for instance, when blocking in a cooling liquid in a heat exchanger or when blocking in pipe sections.

4.2.4 Leakages

If there is a reasonable chance that a separating wall will fail then attention should be paid to the possibility of a excessive pressure rise on the low pressure side due to the large pressure difference with the high pressure space, in case of leakage.
When processing dangerous substances special attention should be paid to the sealing of rotating parts such as pumps, stirrers etc., in particular when high pressures are involved. Double mechanical seals may then be imperative.
The seal may be purged from outside by an inert substance under a pressure than the interval pressure.
In case of leakage if to atmosfere no hazard is created.

4.2.5 Plugging

It is also possible that plugging of the equipment takes place due to the nature or constitution of the medium being processed, which may result in a too high pressure.
The shape of certain parts of the equipment may play an important role in this respect.

4.2.6 Pump capacity and breathing

When designing breathing and venting systems the maximum pump capacity and possible weather effects should be taken into account.

4.2.7 Vacuum

When designing equipment attention should

also be paid to the possible occurence of vacuum as a result of:
- condensing steam in a closed space
- an insufficiently vented space
- the sucking action of a pump or a compressor etc.

Designing various types of equipment for complete vacuum is to be recommended in many cases.

4.3 CHOICE OF MATERIAL

When selecting the material for the equipment consideration should be given to the following.

4.3.1 Corrosion and erosion

When selecting the material consideration should be given to the possibility of corrosion by the substances present, the possibility of erosion by solid and liquid particles, and a possible combination of these two.
Besides attack and weakening of the material on the spot itself corrosion can also cause difficulties at a distance, for instance by blocking tubes and equipment owing to the accumulation of corrosion products. Also other forms of corrosion, such as stress corrosion, hydrogen corrosion, intercrystalline and transcrystalline corrosion etc. should be considered, as well as corrosion from the outside (especially underneath the insulation) and corrosion by wandering currents in the case of underground piping.
In this connection the possibility of cathodic protection is pointed out.

4.3.2 Chemical effects

When selecting the material of construction the possible occurrence of catalytic effects of the material on the medium and vice versa should be investigated.

4.3.3 Resistance

When selecting the material consideration should be given to the resistance of the material (including synthetic- and packing materials) with respect to the medium (attack, solution, hardening, swelling, deformation etc.), vibrations, anticipated wear, and process conditions.

4.3.4 Temperature and temperature fluctuations

When selecting the material consideration should be given to the normal process temperatures as well as to the maximum and minimum possible temperatures occurring as a result of disturbances or under the influence of weather conditions.
One should not forget the possible changes in the structure of the material resulting from large en frequent temperature fluctuations.

4.3.5 Pressure and pressure fluctuations

When selecting the material attention should be paid to the working pressure as well as to the maximum possible pressures occurring as a result of disturbances.
One should also keep one's mind open to the occurrence of frequent pressure fluctuations, vibrations, and the low cycle fatique of steel types with high yield stress.

4.3.6 Spark formation

When selecting the material consideration should be given to spark formation owing to friction or impact, especially when applying materials of different hardness. If necessary, sparkless materials should be applied for e.g. rotating parts, hose couplings etc.

4.3.7 Static electricity

When selecting the material for V-belts, hoses, filter bags etc. consideration should be given to the desirability of applying materials of sufficient electric conductivity.

4.3.8 Insulation

If insulating material is filled in loosely one should keep one's mind open to the possibility of this material getting into the equipment.
When selecting the insulating material consideration should be given to the propagation of fire via the insulating material, its absorption of inflammable liquids, and the development of a so-called "cold bridge".

4.4 CONSTRUCTION

The following should be taken into account when constructing the equipment.

4.4.1 Meteo-effects

During construction of the equipment consideration should be given to the critical wind velocity in respect of ressonnance, snow and wind load, lightning etc.

4.4.2 Grounding and bridging

Attention must be paid to the possible occurrence of static electricity. To prevent energetic discharges in an explosive/combustible medium, equipment, parts and pipes should be electrically earthed or bonded.

4.4.3 Vibrations

The possibility of vibrations which may cause fracture should be checked.
Mechanical vibrations mainly occur in and near equipment with moving parts (e.g. pumps, compressors, stirrers etc.).

Vibrations can also be caused by appreciable velocity variations that may result from the operation of safety valves, control valves etc. The own frequencies of equipment, pipework and buildings may amplify these vibrations. For high-frequency vibrations see 4.4.5.

4.4.4 Stresses

Possible stresses resulting from expansion, contraction or the weight of the pipeline and the product (expansion bends, expansion bellows, flexible couplings and stayings) need careful study.
These stresses often become manifest near flange connections and brauch connections on equipment and may result in fracture.
Also stresses resulting from reaction forces may lead to fracture, for instance when blowing off via safety valves that have not been adequately mounted or supported.

4.4.5 Noise

Production and propagation of noise should be prevented if they do damage to the auditory organs, interfere with communication, or deteriorate the physical and psychical conditions.
For the prevention of noise the construction and design of potential sources are of importance (e.g. gear-boxes, compressors, ventilators, shaping of pipes, and the presence of reducing devices). Total or acoustic enclosure should be considered (see also 4.5.6).

4.4.6 Sealing

Generally speaking, the number of seals should be minimized.
The construction of the seals should fit in with the system.
In this connection the following deserves attention:

- seals should be effectively contained;
- temperature and pressure fluctuations should be met efficiently;
- the use of, for instance, mechanical seals may sometimes be an adequate solution. In case of rotating parts mechanical seals have the drawback that skilful fitting is necessary, and that a leak may increase rapidly;
- stuffing-box packings for non-rotating parts are satisfactory in general, because in case of leakage this will be insignificant initially, and maintenance is easy;
- if cooling is applied the coolant should be chemically inert with respect to the medium;
- if hazardous substances are used the application of a seal liquid may be considered;
- with gas compressors constant supply of seal liquid should be ensured; also an alarm in case of interruption of the supply could be considered;
- the use of immersion pumps.

4.4.7 Hoisting facilities

The necessity/desirability should be studied to provide the possibility of safe dismantling and transport by fitting special provisions such as e.g. hoisting lugs, by installing fixed hoisting equipment in appropriate places etc.

4.5 LOCATION OF EQUIPMENT

When the location of equipment is determined. following points need attention:

4.5.1 Detonation and decomposition

If it is not possible to prevent a rapid decomposition, a homogeneous explosion and/or a detonation at all times, and this possibility cannot be circumvented in the design then erection in suitable bunkers should be considered.

4.5.2 Consequences of fire and explosion

Equipment constituting an increased risk should be set-up in such a place as to cause the least possible secundary damage in case of an incident.

4.5.3 Leakage and spillage

The construction of trays, sumps, bunds etc. to collect and remove the substances should be considered.
Inflammable and hazardous substances in those places where they can regularly be drained off (e.g. when draining, sampling etc.) should be collected in a closed system in such a way that they cannot spread over floors or in the atmosphere.
In special cases such as for instance when using chlorine and phosgene a safe removal of the gases to a disposal system should be provided.

4.5.4 Accessibility

Good accessibility that operations, is essential to ensure that inspection, maintenance, repairs and fire-fighting can be carried out unimpeded. Also adequate facilities for entering equipment should be present, such as platforms, stairs, manholes etc.

4.5.5 Protection of personal

The occurrence of injuries as a consequence of touching hot pipes, falling and bumping should be minimized. Fitting bare pipes that will be heated within reach, and placing valves, piping and other parts of equipment at head level or inside the gangways are to be avoided; if this is not possible then adequate padding should be applied.

4.5.6 Noise

Bothersome and offensive sound that can propagate and be amplified via pipework, buildings or construction parts, even if the source is acoustically enclosed, is to be prevented.
The following measures may serve to abate noise:

- installation of noise sources on resilient mounting systems;
- complete insulation and acoustic enclosure of energetic sound sources by isolated installation outside buildings, and fitting flexible pipe-sections between noise sources and connected piping;
- no or absorbing contact between pipes, walls, floors etc.

4.5.7 Stresses

Care should be taken that no undesirable stresses will occur when pipework is mounted. Ample facilities should be provided for expansion or contraction when the temperature increases or decreases.
The pipes should be well alligned so as to prevent forcing them when they are being connected since this might give rise to stresses.

4.6 SPECIAL PROVISIONS

In addition to the necessary protection of equipment against overheating, overpressurizing, overfilling etc. (see annex chapter 3), attention should be paid to the following.

4.6.1 Energy interruption

In most cases it is undesirable if electrically driven equipment is automatically set in operation as soon as power supply is resumed.
When power supply is interrupted there must be a possibility to switch over to another energy supply for vital parts of the equipment.
Where necessary delay systems should be incorporated to prevent unnecessary shut-downs in case of very short interruptions.

4.6.2 Explosion prevention

Explosive reactions can sometimes be prevented by:

- additional cooling
- adding inert gases
- adding catalyst poison
- eliminating ignition sources.

At an early stage these reactions can sometimes be stopped by a suppression system.

4.6.3 Detection equipment

It deserves consideration to investigate where and to what extent the application of detection equipment to signalize inflammable or explosive mixtures and the presence of toxic substances is useful or necessary.
The same goes for the detection of overheating of equipment by e.g. infrared, colour changing paint, etc.

4.6.4 Flame arrestors

In places where flashback may occur flame arresting devices are to be used.

4.6.5 Spark arrestors

Spark arrestors are to be used in those places where sparks may constitute a hazard (e.g. on exhausts of internal combustion engines).

4.6.6 Freezing and solidifying hazards

Measures should be taken to prevent undesirable solidifications and freezing.

4.6.7 Codes.

Identification of piping, valves etc., and the use of safety symbols in appropriate places is strongly recommended.

5. THE STORAGE AND HANDLING OF DANGEROUS SUBSTANCES

5.1 THE STORAGE OF DANGEROUS SUBSTANCES

The conditions laid down with respect to the safe storage of dangerous substances take into account the nature and quantities of the substances. Dangerous substances may be stored in drums, cylinders or tanks. A number of fundamental aspects of storage, however, mean that there are certain subjects to which attention must be devoted in the storage of dangerous substances irrespective of their nature and the way in which they are stored. The kind of measures which such considerations will call for, however, will depend entirely upon the actual type of storage in question and will differ accordingly. This section will attempt as far as possible to give the essential points only.

5.1.1 The danger

5.1.1.1 Nature of the danger

One of the first points which one must establish is the nature of the danger. This may be:
- flammability
- explosiveness
- reactivity
- radioactivity
- stability
- toxicity
- possible fire-promoting properties (see also Section 2).

5.1.1.2 Size of storage unit

The nature of the danger and the scale of storage together determine the size of the theoretical danger. The first question therefore must be what is the total maximum permissible amount that may be stored. This applies equally well to a tank farm for liquids, consignments of drums, and the storage of cylinders, for example, of gas. This principle even applies to the bulk storage of solids; the sort of point to consider in such cases is the size of the bays and/or sheds. The size of the danger is also dependent on the distance from centres of population, public roads etc. Generally speaking centralization of the storage of dangerous substances is a help when it comes to providing the necessary facilities, but consideration must be given, in connection with what has just been said, to the establishment of limits for the maximum total amount to be stored in any one area.

5.1.1.3 Distances

The size of the danger will determine the effect on the immediate environment in the event of an incident. On this in turn will depend the appropriate selection of distances, relevant considerations being:
- distances between the storage units themselves
- distances from storage units to parts of the plant
- distances from storage units to loading points
- distances from storage units to site roads and railways
- distances from storage units to site limits
- distances from storage units to office buildings
- distances from storage units to centres of population and public roads.

5.1.2 Storage possibilities

5.1.2.1 Form of storage

In certain situations it is possible to make a choice from various different forms of storage each having its attendant risks. Liquified gases for example may be stored under pressure or at low temperature under atmospheric pressure; flammable liquids in ground-level tanks, underground tanks or in tanks on mounds.

5.1.2.2 Choice of storage

The form of storage selected will depend on the potential danger, the distances listed under 5.1.1.2 and the risk of an incident.

5.1.3 Precautions

5.1.3.1 General precautions

In order in the first place to prevent incidents and, secondly, in the event of an incident to be able to act swiftly, attention must be devoted to a number of general precautions e.g.;
- more than one point of access to the storage areas, rooms or sheds
- roads and gangways between the tank pits, tanks, piles, pallets, piles of sacks etc. of adequate width
- good accessibility to the storage units, e.g. not more than two rows of tanks in a tank pit
- adequate lighting of storage sites, in sheds and stores etc.
- good communications with other locations on site (telephone, alarm system)
- good ventilation of storage sheds; in the case of storage of flammable substances, forced draught is sometimes necessary (on account of vapour densities)
- avoidance of storage of substances that react with each other in adjacent tanks

or other storage units.

5.1.3.2 Special precautions

Depending on the nature of the substances stored special precautions are sometimes necessary. Consideration should be given to:
- the effect of temperature on reactive substances (protective measures against directly radiated heat)
- the effect of the presence of air in contact with highly flammable or reactive substances may necessitate the use of an inert atmosphere (a blanket of nitrogen or carbon dioxide)
- where flammable substances are stored in spherical tanks or saddle tanks, consideration must be given to whether or not it is necessary to make the ground slope and provide a system for trapping any liquid that leaks
- where liquefied toxic gases are stored, measures to enable swift action to be taken in the event of major leakages in order to minimize evaporation (collection systems, foam systems)
- where dangerous liquids or gases are stored, the discharge capacity of safety valves should be such that the vapours resulting from the heat flux of a nearly fire can be relieved
- the location of the vent to atmosphere of safety valves and locations where the liquids or gases can be destroyed if necessary. The more so in the case of toxic liquids and gases.
- precautions in the case of storage of dangerous liquids or gases to prevent overfilling of containers
- the use of flame-arrestors in the storage of flammable liquids or gases. (Flame-arrestors are often removed in winter)

The installation of permanent firefighting equipment should also be considered (sprinkler systems, foam or halogen firefighting systems). In the case of larger tanks, the use of a floating roof or some system of reducing evaporation must be considered. Where flammable substances are concerned, the sizing of the drainage system of the area round the storage site (e.g. the tank pit) must also be based on the capacity of the available firefighting and/or cooling system.

5.2 THE HANDLING OF DANGEROUS SUBSTANCES

At points where lines and hoses have to be coupled to transportable tanks, which during loading and discharge are often open to atmosphere, the risk of leakage of dangerous liquids, vapours and gases is present to a more serious extent. The location of the installation, the installation itself, safety precautions and operating procedures must take into account the greater hazard.

5.2.1 Selection of the loading site

5.2.1.1 Surroundings

Under normal handling procedures, and even in the event of a serious leakage, any substances released may not form an inadmissable hazard for the surroundings. On the other hand the surroundings (furnaces, rail and road traffic in the vicinity) may not form an unacceptable hazard for the loading operations.

5.2.1.2 Distance

The distance between the loading site and the storage site must at least comply with the pertaining guidelines and regulations.

5.2.2 Roads and railways (see also Section 1)

5.2.2.1 Access roads

The loading site access roads must be so routed that they avoid the other danger zones of the plant.

5.2.2.2 Trafic density

The traffic density in the vicinity of the loading site must be kept to a minimum.

5.2.2.3 Level location

Roads and railways must be perfectly level where vehicles and rolling-stock await loading, to avoid the risk that cars start moving in advertently.

5.2.2.4 Obstruction

Ample facilities for manoeuvring, shunting and parking must be provided. Railway loading sites must be so arranged that roads are never blocked as a result of shunting or waiting.

5.2.2.5 Siting near buildings

Weighbridges, administrative sections (dispatch offices), queueing and parking facilities must be so laid out as to promote swift and safe completion of the loading procedures.

5.2.3 Methods of loading and unloading

The selection of the product-handling system depends on the properties of the substance. The following factors should be taken into account:
- the properties of the substances to be loaded (see section 2, process substances)
- the risk of the formation of explosive mixtures of vapour and/or dust and air, and ways of preventing this
- the degree to which the escape of liquids, gases and vapours must be prevented (use of closed systems)
-

- the extent to which it is necessary to directly interrupt the product delivery (emergency stop).

5.2.4 The design of the loading site

5.2.4.1 Accessibility

Good accessibility to rail- and road tank-cars, and ships by way of, loading stages, ramps and docks with suitable escape routes is a must. In the case of ships, two points of access should always be provided.

5.2.4.2 Leakages

Facilities must be provided for catching and safely draining away leaking liquids and/or rendering them harmless.

5.2.4.3 Discharge

Provisions must be made for discharging the cargo of a transport tank both in part and in whole (e.g. in the case of overfilling or a returned off-specification product).

5.2.4.4 Equipment

Lines pumps and other equipment must be located such that the risk of damage from collisions is excluded, or alternatively, other measures must be taken to prevent such accidents.

5.2.4.5 Loading bays

Loading bays must be claerly marked and wheel chocks and brake drags must be available.

5.2.4.6 Earthing

Adequate equipment must be available for earthing transport units and other equipment.

5.2.4.7 Communications

Provisions must be made for adequate communication between the operating personnel.

5.2.4.8 Lighting

Adequate lighting (including emergency lighting) must be provided.

5.2.4.9 Protective clothing etc. and fire-fighting equipment

Suitable personal protective clothing and equipment, emergency showers and firefighting equipment must be provided in sufficient quantities and at strategic points, so arranged that they can be reached at all times irrespective of the direction of the wind.

5.2.5 Pumps, lines and ancillary equipment

5.2.5.1 Flow rate

For the establishment of pump capacities and line diameters and also in the use of filters and other ancillary equipment, the most important factor is the safe flow rate to prevent dangerous levels of electrostatic charging when handling low electro-conductinity liquids.

5.2.5.2 Safe distance

Pumps and ancillary equipment should preferably be fitted in rigidly mounted pipe sections and at a safe distance from the loading point, but at the same time be easily accessible. It is also desirable to fit an emergency cut-off valve that can be operated from a safe distance, and also to fit an emergency stop system on the pumps.

5.2.5.3 Lines

Solid lines are preferred. Where the use of hoses is essential these should be:
- inspected and approved
- capable of withstanding the highest possible operating pressure
- suitable for the substance to be handled.

Regular replacement of the hoses should be considered. Provisions must be made to prevent hoses and couplings from being dragged along the ground in view of the risk of sparks and to avoid damage and contamination.

5.2.5.4 Couplings

An adequate stock of adaptors and couplings must be available so that a safe connections can always be made.

5.2.5.5 Uncoupling

Provisions must be made for depressurizing delivery lines and hoses and letting them drain before they are uncoupled.

5.2.6 Safety devices and interlocks

5.2.6.1 Overfilling

In cases where filling to above the maximum allowable level could give rise to critical situations, two independant filling control systems must be provided. One of these being a continuous measurement made by a calibrated method. The prime purpose of measurements made during filling is to prevent overfilling (in certain cases measurement by means of weighing may be appropriate). Linking the measuring device to an automatic cut-off mechanism will reduce the chance of overfilling.

5.2.6.2 Leakages

It must be possible to swiftly interrupt the delivery of liquid in the event of serious leakage (emergency stop for the pump, non-return valves, remote-controlled, quick shut-off valves and flow limiters can all be employed as precautions in case of line failure).

5.2.6.3 Interlocking

Consideration should be given to the necessity of interlocking rail points, barriers etc. and pumps. In certain cases it is advisable to consider an interlock system between the earthing circuit and the pump.

6. HANDLING AND REMOVAL OF HAZARDOUS WASTE PRODUCTS

6.1 INTRODUCTION

For loading and unloading of dangerous goods reference is made to 1.2.5 and 5.2.
The transport of dangerous goods via roads and inland waterways should comply with the Dangerous Goods Act and the Transport Regulations for Dangerous Goods based on this Act, with the annexes ADR (roads) and ADNR (inland waterways).
For the transport of dangerous goods by rail the RID annex 1 of the General Transport Regulations and of the Tramway Regulations holds in the Netherlands.
For the disposal of waste products into the air, the disposal via sewers, or for tipping these on refuse-dumps numerous acts apply such as the nuisance Act, the act concerning air pollution, the act concerning pollution of surface waters, and Provincial and Municipal Regulations. In preparation is a bill concerning the disposal of wastes: the chemical wastes act.

6.2 ASPECTS OF DISPOSAL

When the release of waste products is anticipated consideration should be given to among other things:

- the way of disposal: continuous or discontinuous in the air (height, diameter and location), via soil, sewer or means of transportation (road, rail or water);
- the composition and quantity of waste product per point of disposal and per unit of time, the disposal rate and temperature both under normal and abnormal conditions;
- the hazard aspects and properties of the substance per point of disposal (see section 2);
- the fire prevention (see section 9);
- the existing or expected conditions for disposal;
- the control and supervision of the points of disposal such as flares and other destruction plants (see section 3), in particular in case of discontinuous disposal.

6.3 REDUCTION OF DISPOSAL

Improvements per point of disposal can possibly be attained by:

- burning the substance to be disposed of, taking into account the products that may be released;
- conversion of the substance to be disposed of to one which is more acceptable to the environment:
- returning the substance to be disposed of to the process;
- process alterations reducing the quantity of waste products, or rendering them more suitable to processing;

- using the waste product as raw material.

Remark

In this item the protection of the environment is most pronounced; the improvements should not be implemented, however, at the cost of safety.

7. CIVIL ENGINEERING ASPECTS

In the design, building and maintenance of plant installations attention must be devoted from the point of view of safety to the following civil engineering aspects (see also section 1).

7.1 THE GROUND

7.1.1 Soil structure

It is common knowledge that different types of soil have different properties. Alternating stress patterns, compressive strength, sloughing, permeability and vibrations can all affect the bearing capacity of the soil.

7.1.2 Soil conditions

Well before the design of a plant installation, thorough soil tests must be made to establish the character of the ground and its mechanical properties and hence its bearing capacity.

7.1.3 Acidity

A test must be made to establish the acidity of the soil in view of the possibility of attack of the foundations, cables pipes and underground tanks etc.

7.1.4 Ground movements

In addition to natural settlement, regular or irregular settlement resulting from water extraction, infill, old rubbish dumps, old creeks and dikes etc. must be taken into account. Attention must also be devoted to existing or expected subsidence caused by mining, natural gas production, salt extraction and the geological structure.

7.1.5 The ground surface

At points where leakage can be expected the ground must be duly treated if necessary.

7.1.6 The water table

Variations in the water table, including long-term variations, must also be taken into account.

7.2 FOUNDATIONS

7.2.1 Soil tests

The results of the soil tests along with the static and dynamic loads to be expected must be taken into account in the design of the foundations. Inadequate foundations can result in the fracture of lines and uneven settling of equipment, installations and tanks.

7.2.2 Natural frequencies

In the case of the foundation of machines, care must be taken to ensure that the natural frequency of the spring mass system of the piles does not coincide with that of the machine.

7.2.3 Flow side

Allowance must be made for the increased settlement of the foundations as a result of vibrations (flow slide).

7.2.4 Viscosity changes

Allowance must be made for the increased settlement of friction piling as a result of viscosity changes in the ground caused by vibrations.

7.2.5 Unwanted vibrations

The foundations and mountings of machines giving rise to vibrations must be so designed as to transmit the least possible vibration. Unwanted vibrations caused by pile-driving activities in the vicinity of installations must be avoided and there are a number of special methods that can be employed in such cases.

7.2.6 Tank foundations

The bearing capacity of the sub-soil in the case of tank foundations must be consistent beneath the whole foundation in order to prevent uneven settlement. The composition of a tank foundation must be such as to prevent attack and weakening of the base. The sloping face of the foundation to the surrounding area must be given a waterproof revetment so that rainwater dripping off the tanks cannot weaken the foundations. A certain amount of even settlement of a tank is tolerable provided that this is taken into account in the design of the pipe work.

7.3 DRAINAGE SYSTEMS

Depending on the substances to be removed, drainage systems are potential sources of danger because of the possibility of the formation and distribution of explosive gas and air mixtures. Dangerous substances can also be transported via sewers to parts of the site at which the necessary safety precautions relating to dangerous substances are not taken. The general drainage scheme and the detail design of the civil engineering aspects thereof must therefore not only take account of the capacity and construction materials etc. of the system but also of the possibility of the formation of explosive gas and air mixtures.

A distinction can be drawn between sewers according to function; whether they are for the removal of:

- rainwater and other meteoric water
- coolingwater
- chemically polluted water
- oil-polluted water
- domestic waste water.

The function in turn will determine the choice of design;

- open drains
- half-full drains
- flooded drains.

7.3.1 Junctions

At the junction between two different drains, suitable precautions must be taken to ensure that there can be no movement from the section of sewer carrying the most dangerous medium to the less hazardous section. Adequate precautions must also be taken at such junctions to deal with the possibility of liberation of dangerous vapours.
Where different sorts of waste water come into contact care must be taken to ensure that no undesired reactions can take place.

7.3.2 Capacity

The capacity of the sewer must be matched to the maximum rainfall rate (in the Netherlands 25 mm/hour) or, the maximum volume of fire water, which ever is the greater. The maximum volume of fire water being the water from permanent firefighting and cooling systems plus water from mobile units. Allowance must also be made for blockage of drains by pieces of insulation and other materials that could get carried inti the drainage system as a result of firefighting operations.

7.3.3 Materials

The construction material of sewer pipes must be appropriate for the properties and condition of the media to be removed.

7.3.4 Flexible connections

Connections from process plant on a firm base to unsupported drainage systems must be flexible enough to prevent fractures.

7.3.5 Mechanical loading

Where drains are subject to mechanical load (under roads), adequate measures must be taken to protect them.

7.4 ROADS

7.4.1 Roads system

See Section 1 for details of the road system. The road system should be laid out with a view to ensuring ready access by fire appliances, ambulances etc. to the scene of an accident.

7.4.2 Materials

In the selection of surfacing materials for the loading site possible reactions of spilled substances (liquid oxygen) with the road surface must be taken into account. Allowance must also be made for other forms of attack.

7.4.3 Road construction

The roads must be designed for a maximum permissible load that is high enough for all normal trafic including fire appliances etc. The maximum permissible loads on bridged, syphon crossings and jetties must be clearly indicated; vulnerable spots must be protected (guard rails etc.).

7.5 BUILDINGS (see also Section 9)

7.5.1 Internal arrangements

The internal arrangements of a building must take into account the hazards of fire and explosions and the possible presence of asphyxiating or toxic substances.
This is particularly applicable to modifications of production facilities especially in the case of existing areas that were not originally designed for such purposes
Factories and work places are often subject to various acts and the buildings must therefore comply with these.
In many countries the plans must be submitted to various government bodies for approval.

7.5.2 Materials

The materials used must be both chemically and physically as resistent as possible to weathering and any substances released into the atmosphere, or must be adequately protected. The harmful effects of the products of chemical compounds released from the building materials used or other substances present as a result of fire, must also be taken into account.

7.5.3 Construction

The method of attachment of cladding, windows and the like requires special attention in view of the high wind loads that can be expected. Processes involving an explosion hazard should generally be carried out in a safe place in the open air or in bunkers. Where, under normal circumstances, there is a risk of explosion outside pieces of equipment but within a building, the building must be suitably designed to reduce the violence of such an explosion (e.g. collapsible walls and a light roof structure). Where the explosion force can be expected from outside, the appropriate design features must also be incorperated. The vacuum that occurs after an explosion sometimes does more damage than the initial pressure wave.

7.5.4 Ventilation

Where ventilation is provided by drawing in outside air a system should be provided for stopping the draught in the case of, for example, a gas alarm outside the building. Where gas detection equipment is provided it can be linked automatically to the ventilation system cut-off. Other measures may be necessary where special filters are fitted in the air inlet. Where there is a risk of an explosive mixture in an extraction system any source of ignition in the system must be avoided. The capacity of a ventilation system must be such that the formation of explosive mixtures or concentrations harmful to health is prevented, or that if such situations do arise, they are quickly corrected.

7.6 ADDITIONAL POINTS RELATING TO INSTALLATIONS

7.6.1 Design

In addition to the strenght requirements of the structure to meet static loads, allowance must also be made for the effects of dynamic loads like vibrations, expansion and contraction due to temperature changes, and possible explosions. In the case of very large dimension like large tanks, checks must be made to establish whether the foundations will take the extra forces due to low pressure on the leeward side in strong winds. The static load to be used for design purposes must where necessary be based on equipment filled with liquid if for inspection purposes for example such equipment is in fact filled with liquid although under normal operating conditions it contains gas.

7.6.2 Floors platforms and stairways

The ways up to operating platforms and work floors must be safe to use, viz. verticle ladders, for example, should be caged-in and their length should be kept to a minimum. Floors, platforms and treads of stairs must be anti-slip. Where there is considerable danger of fire or agressive substances, it may be advisable locally to use closed floors. Catwalks between distillation columns and the like may not be so stiff that they affect the stability of the installations.

8. DIVISION OF SITES IN AREAS

8.1 Although a plant should be so designed as render it impossible for inflammable substances to escape from the equipment into the open air, this possibility can never be completely ruled out.
In order to reduce the chance of a fire or explosion in such cases the possibility of ignition of an inflammable gas/air mixture should be minimized; the location of ignition sources plays an important part in this respect.
In areas where an inflammable gas/air mixture may be encountered a great deal of attention should be paid to the design of electrical installations.

8.2 To enable the optimal assessment of the necessary special provisions for electric installations - respectively to enable the right choice of electric equipment suitable for this application - hazardous areas for gases and vapours are divided in zones that are closely related to the degree of probability to which an explosive gas mixture may be present.

8.3 In sequence of decreasing propability of an explosive mixture in hazardous areas the following zones are distinguisted.

Zone 0

An area within which an explosive gas mixture is present permanently or for prolonged periods.

Zone 1

An area within which the probability of an explosive gas mixture is high under normal operating conditions.

Zone 2

An area (only under abnormal operating conditions) in which the probability of an explosive gas mixture is low, and in which such a mixture, if present, will only exist for a short time.

Unclassified zone

An area not covered by the foregoing zones.

8.4 In view of the significance of a justifiable division into areas with regard to electric equipment reference is made to the various national and international codes.

9. FIRE PROTECTION

9.1 INTRODUCTION

Fire protection consists, on the one hand, of measures to prevent the occurrence and limit the spread of fire and, on the other hand, of measures to effectively fight the fire once it has started.
Fire prevention measures include specially designed features in buildings and plants, efficient detection and alarm systems and thorough training of staff, etc. Control measures include fire brigades, firefighting equipment, automatic and non-automatic extinguisher systems, etc. Before implementing fire prevention measures it is advisable to become fully acquainted with the existing situation, the current standards and the possible consequences of fire in the area in question. In some cases a careful study can provide optimum security by simplifying or reducing the number of systems to be used and/or rationalizing the firefighting organization. The following measures may be mentioned in this context:
- interconnection of fire-water systems;
- the utilization of existing emergency power supplies;
- maintaining of a central store of extinguishing equipment.

A thorough knowledge of the local situation is equally essential for the drafting of action plans and a disaster contingency plan (see section 10).

9.2 FIRE PROTECTION OF BUILDINGS AND/OR PLANTS

9.2.1 Fire prevention

Attention should be given to the following points which are important for fire prevention:
- the flammability of the construction materials, taking into account the possible absorption of process materials;
- the materials to be used in places where the generation of sparks has to be avoided or is undesirable (for example, prohibition of the use of aluminium paint on steel, permanent electrical conductivity of floors);
- the design and location of ducts for smoke or combustion gases;
- the installation of heating systems;
- the installation and design of electrical systems;
- the locating of gas storage- and distribution systems;
- the provision of adequate ventilation, which may result in underpressure or overpressure;
- protection against lightning.

9.2.2 Personnel safety

In order to prevent or minimize personal

accidents in the event of fire, allowance should be made for:
- the number, location and dimensions of exits and emergency exits from rooms in the building and from the building itself, which should be adequate for the number of people involved.
  Allowance must be made for the fire risk of each room;
- the avoidance of dead-ends in corridors or galleries;
- the correct type, location and swing of doors;
- the non-slip qualities of floors and stairways and the strength of handrails;
- the clear indication of emergency escape routes and provision of emergency lighting;
- the materials used for emergency escape routes, as regards their flammability and/or their ability to generate smoke and toxic decomposition products.

9,2.3 Restricting the spread of fire

The spread of fire can be reduced by:
- division into compartments, both horizontal and vertical, making due allowance for the routing of pipework, air and ventilation ducts, transport facilities, stairways, lifts, expansion joints, etc.

Partition walls should be designed to prevent penetration by fire;
- dividing long escape routes into sections by fitting fire doors, smoke traps, etc.
- fitting liquid-retaining sills or sumps which empty quickly and safely;
- fitting ventilation shafts with baffles which close automatically in the event of fire;
- providing for remote control of the ventilation system from a safe place;
- adopting measures to prevent the propagation of fire to other buildings or plants. Some ways in which this can be achieved are: fitting fire doors or sprinkler curtains at both ends of essential bridges, connecting tunnels, chutes, conveyor belts, pipe ducts, etc.; fitting wire-reinforced windows; fitting fireproof material or fire walls; protecting roofs against fire (sparks), etc.

In addition to these measures, fire damage can be minimized by:
- covering load-bearing members with fireproof, heat-insulating materials;
- internal water-cooling of hollow load-bearing structures;
- installing sprinkler systems, water screens, static firefighting systems, etc.;
- providing adequate facilities for draining fire water;
- minimizing smoke damage by fitting smoke vents in stairways, sheds, working areas, etc. The smoke vents must be fitted at the correct locations and it must be possible to open them in case of fire.

9.3 FIRE FIGHTING ORGANIZATION

The fire fighting organization must be adapted to suit the nature and extent of the risk. Effective co-operation between the own organization and the external auxiliary organizations is essential for effective fire fighting.

9.3.1 Task of the organization

The task of the own fire fighting organization is to fight the fire from start to finish, or at least during the time between the detection of the fire and the arrival of the external auxiliary services.

9.3.2 Manpower

Both the manpower and the stock of fire-fighting equipment available to the own fire service must be related to the nature of the risk and the firefighting equipment already provided in the area in question. A sufficient number of trained personnel should be present at all times, depending on the shift system worked at the plant.

9.3.3 Composition

The fire service personnel should be selected such that people with an expert knowledge of plant operations are available when fires occur.

9.3.4 System of command in the internal fire service

The internal fire service should preferably be commanded by people who are in a position to have a broad view of the nature and extent of the risk, even in a fire emergency situation.

9.3.5 Operational command

An agreement should be reached in advance between the internal fire service and any external auxiliary units concerning operational command.

9.3.6 Communication

It is recommended that communication systems within each area should be adapted to one work effectively in conjuction with another in order to avoid delay in calling for assistance and to prevent misunderstandings when internal and external services are working together.

9.3.7 Special work

Fire prevention measures and, if necessary, control measures must be adopted before carrying out work which is outside the normal production schedule.

9.4 FIRE DETECTION AND ALARM

The way in which the alarm is raised depends on whether the fire is detected automatically or otherwise. The staff should be given thorough training on what to do if they detect a fire and how to operate the manual alarm systems (telephone, manual fire alarms).
In the case of automatic fire alarm systems, care should be taken to ensure that the signal is transmitted and received reliably.

9.4.1 Automatic fire detection

If an automatic fire detection system is used, the method of detection (flame, smoke, temperature) should suit the location and nature of the possible types of fire.

9.4.2 System-generated false alarms

The alarm circuitry should be designed such that system-generated false alarms are minimized.

9.4.3 Environment-generated false alarms

Environment-generated false alarms resulting from incorrect methods of detection or incorrect alarm locations should be minimized.

9.4.4 Reception of alarm signal

The signal from automatic fire alarm systems, whether or not these are coupled to automatic extinguishing systems, should be transmitted to a control unit located in a safe and strategic place which is continuously manned.

9.4.5 Internal alarms

Alarms to order evacuation of the staff of a department should be chosen specifically for that department; they should be clearly audible at all times (in spite of background noise) and should be confined to the part of the plant in question. An external alarm may be given if necessary, to guide fire service personnel to the site of the fire.

9.4.6 Mobilization of industrial fire service

The signal mobilizing the fire service team(s) should be such that it does not cause panic or undue interest.

9.4.7 Calls for external assistence

It is preferable to have a direct telephone connection with the auxiliary services, in addition to the normal telephone line.

9.4.8 Design and maintenance of equipment

The construction, inspection, testing and maintenance of equipment should be carried out in accordance with the applicable regulations.

9.5 CLASSIFICATION OF FIRES ACCORDING TO EUROPEAN STANDARD EN2 OF 1973

The ability to extinguish a fire depends on one or more of the following actions of the extinguishing media:
- the interruption in the supply of fuel (cover);
- the interruption in the supply of oxygen (cover);
- cooling of the fuel to below the ignition temperature;
- negative catalysis (= inhibition of the combustion process);
- change in the ratio of the flammable mixture (fuel/oxygen dilution).

The extinguishing media depending on their extinguishing action are therefore suited specifically to extinguish flammable materials in certain categories.

9.5.1 Fire water

9.5.1.1 Source of fire water

Fire water may be drawn from:
- open water;
- waterworks companies;
- streams;
- tanks;
- storage basins (incl. cooling tower basins);
- combinations of the above.

In view of the fact that the supply of fire water must be guaranteed at all times, allowance must be made in selecting a source of fire-extinguishing water for the possibility of freezing, drying out, pollution, etc.

9.5.1.2 Volume of fire water

The volume of fire water must be commensurate with the fire risk; factors to be taken into account are fire load, rate of combustion, spread of the fire, cooling of equipment and tanks, etc.
Depending on the type of system (e.g. as a part of the cooling water supply system), it must be possible to use the required amount of fire-extinguishing water without restricting the supply of cooling water to the plant and equipment connected to the system. Refer to 7.3.2 regarding the drainage of fire water.

9.5.1.3 Pressure

The supply pressure on the fire-extinguishing water must be adequate to meet the nature and extent of the fire risk (height of buildings or plants, safe distance for firefighting, etc.)
It should be borne in mind that a certain pressure is necessary for the proper operation of permanent extinguishing systems.

9.5.1.4 Water mains for firefighting

The underground main for fire water must be kept full at all times and maintained at a slight over-pressure. Care must be taken to ensure that the supply of sufficient fire-extinguishing water is not interrupted as a result of power failure or a mechanical defect in the pump and main system.

9.5.1.5 Location of water pumps

The location of the water pumps must be selected such that the proper working of the pumps is not affected in the event of fire. Careful maintenance and thorough testing to ensure correct operation is essential.

9.5.1.6 Pipework and ancillary equipment for fire water

The following points must be borne in mind when designing pipework and ancillary equipment for fire water:
- the water should be supplied from two points so that the supply is not interrupted when parts of the system are shut off;
- the pipework should preferably run underground below the frost line;
- construction materials, protection and design are dependent on the local terrain conditions;
- surface pipework must be protected against mechanical damage, frost, fire and explosions;
- surface and underground hydrants must be situated such that a sufficient number of hydrants can be brought into use at all times;
- the spacing between hydrant should preferably not exceed 60 metres;
- underground hydrants should be marked so that they can be located easily in all weathers;
- suitable provisions must be made to facilitate action by external auxiliary services (for example, couplings);
- the location of pipework, hydrants, etc. must be indicated on an accurate drawing which is available on site.

9.5.1.7 Permanent installation

In addition to the systems described above, sprinkler systems may also be fitted. If the systems are fed by the fire extinguishing water supply, the volume of water mentioned in 9.5.1.2 and the pipe work mentioned in 9.5.1.6 should be calculated accordingly. The design and installation of the systems is generally governed by installation regulations.

9.5.2 Foam

In view of the fact that water is an important constituent of fire fighting foam, foam systems must fulfil the same conditions (frost protection, location of pipework etc.) as mentioned in 9.5.1.

9.5.2.1 Type

The type of foam (heavy, medium or light) must be chosen to suit the nature and extent of the risk.

9.5.2.2 Stability

The foam must not be affected by the medium to be extinguished or by any other extinguishing media which may be used simultaneously.

9.5.2.3 Efficiency

The means of applying an effective foam layer depends on the medium to be extinguished, and suitable provisions should be made accordingly. The efficiency of the foam system should preferably be determined by testing.

9.5.2.4 Storage life

Foaming agents may in some cases have a limited life, especially in the ready-to-use condition. Regular checking for foam formation, sedimentation, contamination, etc., of the foaming agent is essential.

9.5.2.5 Viscosity

The foam system must be designed such that the viscosity of the foaming agent does not exceed the value indicated for this agent under any weather conditions.

9.5.2.6 Stock

The stock of foaming agent must be sufficient to cover at least twice the largest area for which foam extinguishing is required.

9.5.2.7 Capacity

In the case of heavy foam, the capacity of static foam systems should generally be such that a foam layer 25 cm thick can be applied to the whole of the area in question in 10 minutes.

9.5.2.8 Construction materials and design

At the design stage and when selecting construction materials, allowance must be made for the corrosive properties of water and foam.

9.5.2.9 Drainage

As regards the drainage of foam, it should be borne in mind that foam presents no risk to the proper operation of waste water purification plants, oil traps, etc.

9.5.3 Powder

9.5.3.1 Type

The type of powder must be selected in accordance with the category of the medium to be extinguished.
A distinction is made between the following categories of fire:

Category A

Fires involving solid materials of primarily organic origin which generally become incandescent.

Category B

Fires involving liquid materials or materials which liquefy.

Category C

Fires involving gases.

Category D

Fires involving metals.

9.5.3.2 Stoppages

Suitable precautions must be taken with static extinguishing systems to prevent plugging by excessively rapid build-up of gas pressure, condensation in the system, etc.

9.5.3.3 Capacity

The capacity of static and mobile fire-fighting units should be of the following order of magnitude, at least for fire categories B and C;

- in the case of surface fires, a capacity of at last 4 kg/m2/sec., based on sodium bicarbonate powder;
- in the case of space fires, a capacity of at least 0.6 kg/m3/sec, based on sodium bicarbonate powder.

9.5.3.4 Stock

The stock must be sufficient to maintain the supply rate stated in 9.5.3.3 for at least 10 seconds.

9.5.3.5 Output

The supply pipework must be designed to ensure that each spray nozzle gives the same output.

9.5.4 Gaseous extinguishing media

Gaseous extinguishing media may be divided into liquefied gases, cooled and compressed gases and gases under working pressure.

9.5.4.1 Applications

In general, gas extinguishing systems are primarily suitable for fighting fires in enclosed spaces, because gaseous extinguishing media work principally by reducing the oxygen content to below the peak value. The peak value depends on both the extinguishing gas and on the material to be extinguished. One of the factors affecting the choice of extinguishing gas is the possible occurrence of side-reactions which may, in their turn, produce dangerous situations, such as the generation of static electricity or the occurrence of undesired chemical reactions with the material to be extinguished.

9.5.4.2 Health hazard of gaseous extinguishing media

The use of gaseous extinguishing media brings with it the danger of asphyxiation. It is not only the gas itself which may be harmful to health - its decomposition products may have a similar effect.

9.5.4.3 Operating delay

In spaces in which people work and fire protection is provided by a gas extinguishing system, the functioning of the firefighting system must be proceeded by an alrm. The interval between the alarm and the operation of the system must be adequate to allow the personnel to evacuate the area safely.

9.5.4.4 Gas requirement

The required rate gas depends largely on the plant or object which the system protects, and the stock of gas is determined on this basis.

9.5.4.5 Construction materials and design

The construction materials and design of the firefighting system must make allowance for any corrosive properties of the extinguishing medium. Low temperatures may also present problems.

9.5.4.6 Correct operation

It is essential to ensure that the extinguishing system operates correctly at all times. Important factors affecting this are:
the location, the temperature and the pressure. Allowance should also bemade for the possibility of generation of static electricity.

9.5.5. Other extinguishing media

In addition to the above mentioned extinguishing media, which are of a fairly general nature and which may be taken to include

steam, there are other specific extinguishing media whose effect depends on one or more of the properties described above (water, foam, powder, gas).
Dangerous side-effects (for example static electricity, toxic vapours) or low efficiency of such extinguishing media will determine whether a specific extinguishing medium is necessary and which medium is most suitable.
It should be pointed out that water is the only effective medium in cases where explosive combustion processess can take place.

10. GENERAL EMERGENCY PLANNING

10.1 INTRODUCTION

If, despite all the measures that have been taken, an emergency does arise, it must be possible to fall back on established emergency facilities and procedures, because in an actual emergency situation there is no time to develop a plan of action to deal with all the possible consequences. Emergency precautions must undergo continuous revision in line with changing circumstances and all possible eventualities must be provided for (see Section 3). Suitable precautions are:
- measures in case of an operational emergency situation
- measures in case of escape of liquids and gases
- measures in case of fire and explosion
- personal protective clothing and equipment
- training and maintenace
- communication systems
- briefing and employee information.

10.2 OPERATIONAL EMERGENCY SITUATIONS

If serious operational anomalies cannot be corrected by automatic or manual action, an emergency situation may arise that demands special countermeasures - if possible according to a pre-determined plan. An example of this is the situation in which a plant may find itself in the event - despite all precautions - of failure of the cooling system for the low-temperature atmospheric storage of liquefied gas.

10.3 ESCAPE OF LIQUIDS AND GASES

Measures must be taken to counteract the consequences of a liquid or gas escape. The plant must have contingency plans for such emergency situations.
Examples:
- the escape of liquid to surface water
- the escape of flammable or explosive gas to atmosphere
- the escape of toxic gas.

What is the gas alarm drill?

Are all naked flames extinguished as part of the procedure?
Are all sources of ignition removed?
Is traffic diverted?
Is gas detection carried out etc.?
Is the alarm easily distinguished from the fire alarm?
Is there a readily visible wind sock to indicate the appropriate direction of retreat?

10.4 FIRE AND EXPLOSION

Despite numerous precautions the risk of fire and/or explosion cannot be excluded. Quick action is required if a fire or explosion is not to develop into a calamity.

Examples:
- is it possible to isolate a burning process unit from neighbouring units?
- is it possible to rapidly cut off the supply of flammable liquids and depressurize the burning unit?

10.5 PERSONAL PROTECTION

In addition to all the regular personal safety precautions necessary under normal circumstances, care must be taken to ensure that:
- there is a plan to safeguard personnel in case of escape of toxic flammable gas (closing windows, extinguishing of naked flames, indication of safe areas and if necessary the appropriate routes to follow, etc.)
- non-company personnel are provided with the same safety facilities as regular staff and are also aware of the procedure to follow in case of emergency
- medical treatment facilities are appropriate to the risks associated with the plant (number, situation and capacity).

10.6 TRAINING

Any emergency precautions are useless unless proper training is given to the people likely to be involved (including external emergency services).

10.7 COMMUNICATION SYSTEMS

Essential to the effectiveness of any emergency measures are delegation of command and the proper functioning of the communication system.

Examples:
- is there an alarm and control centre from which operations can be directed in an emergency situation?
- and is there a back-up control centre in case of failure of the first?
- are all telephone numbers and procedures known relating to the local emergency exchange and external emergency services (fire brigade, police and medical services)?

Is there a system whereby it is possible to obtain all the services by dialling only one number? Is there a separate telephone line?
- What back-up systems of communication are there if the telephone fails? Are personnel familiar with the use of these systems and do the systems function properly in conjunction with each other?

10.8 BRIEFING AND INFORMATION SERVICES

Expert and clear information should be given to publicity media.

N.B.
Emergency plans require regular revision in the light of changing circumstances.

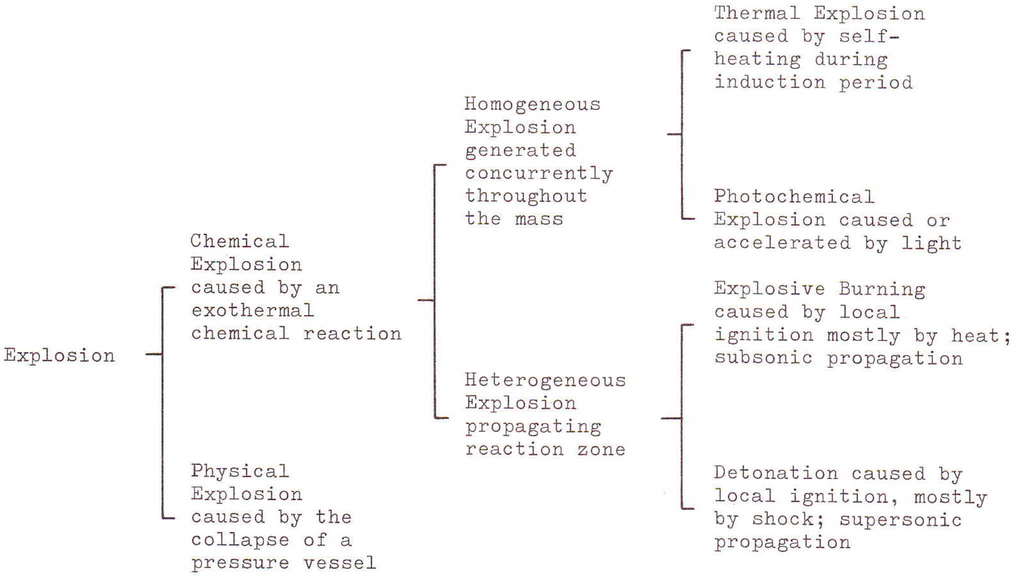
APPENDIX 1.

Explosion Prevention

Introduction

Physical explosion and chemical explosion

A distinction can be made between physical explosions and chemical explosions.
The disruption of a boiler is an example of a physical explosion.
A chemical explosion will come about as a result of a chemical reaction, releasing energy (heat) and hot, mostly gaseous reaction products.
An explosion prevention investigation with respect to a chemical explosion will therefore be focussed in particular on the chemical properties of the substance and thus on the question of whether the substance can undergo conversion associated with release of energy. For a demolishing effect the velocity of energy release is decisive, as well as the fact as to whether much gas will develop. The situation in which the substance finds itself plays an important part herein.
The various types of explosion can be divided schematically as follows.



Much damage by explosions can be largely prevented by applying appropriate measures and provisions, a number of which will be broadly treated in this appendix. For the quantitative effects of explosions reference is made to expert establishments in this field.

1. TYPES OF CHEMICAL EXPLOSION

1.1 Thermal explosion

Self-heating takes place when a substance is stored or processed at such a temperature that the heat development - caused by chemical reactions of the substance - exceeds the heat dissipation. If self-heating only occurs locally in the substance (e.g. in a solid) a fire or a deflagration (explosive burning, see 2.2) may ensue.
In the case of homogeneous self-heating (e.g. in a liquid) the self-heating may give rise to a thermal explosion whereby alle the substance reacts simultaneously and at the same speed.
The effect of a thermal explosion depends to a large extent on the nature of the situation.

1.2 EXPLOSIVE BURNING (DEFLAGRATION)

If a local reaction is brought about by heating a substance and this reaction is capable of sustaining itself by forming a reaction zone - which propagates through the substance without air or oxygen being required during this propagation - then this phenomenon is called explosive burning or deflagration of the substance. The reaction zone propagates through the substance by means of heat transfer. The rate at which this takes place is called the linear burning rate.
This linear burning rate increases with pressure.
Explosive burning, which in open air often looks like an "ordinary", fire, can be extinguished by a drastic cooling of the reaction zone (e.g. with water), but not by the exclusion of air.

Special attention is merited with respect to explosive burning of a gas/air or dust/air mixture, called a gas explosion and a dust explosion respectively.
In most cases this concerns a mixture of an inflammable gas, vapour or dust, and air.
We distinguish a lower and an upper explosion limit. Below the lower explosion limit there is a lack of inflammable material, whereas above the upper explosion limit flame propagation is no longer possible either, owing to the inhibiting action of the excess fuel.
The explosive region lies between the explosion limits. The minimum energy required for the ignition of an explosive gas/air, vapour/air or dust/air mixture is called the minimum ignition energy. An additional hazard of a dust explosion lies in the possibility of the pressurewave of a primary explosion whirling up dust elsewhere so that another dust/air mixture is formed which is ignited by the flame of the primary explosion.
The effects of these socalled secondary explosions are often disastrous.

1.3 DETONATION

If a local reaction in a substance is brought about by a shock and this reaction can sustain itself by the formation of a reaction zone which propagates through the substance at supersonic speed then this phenomenon is called a shockwave. The reaction zone is propagated through the substance by means of this shockwave. The rate at which this takes place is called the detonation velocity. A distinction is to be made between detonability and sensitivity to detonation. The effect of a detonation is invariably highly destructive, which destroying effect is utilized in explosives. In the surrounding air a shock wave comes about which is manifested as a bang.
In some cases a transition from a deflagration into a detonation may take place, also in the case of gas and dust explosions.

2. EXPLOSION PREVENTION

2.1 PREVENTION OF PHYSICAL EXPLOSIONS

A vessel or a pipeline containing a material under high pressure may suddenly collapse although considerations based on the conventional theory of strength of materials do not give cause for this. This type of explosion can be avoided by taking measures to prevent initiation of low-stress fractures in the material. An alternative solution is to select a material in which progression is limited once a fracture has been initiated.
Attention should be paid in this case to possible metal deterioration by welding, aging, temperature fluctuations, neutrons radiation etc., and to the effect of creep, fatigue, corrosion etc.

2.2 PREVENTION OF THERMAL EXPLOSIONS

Thermal explosions can be prevented by taking care that the temperature of the substance remains at all times below the socalled critical temperature (e.g. hazard of exposure to direct radiation of the sun). By critical temperature is meant the temperature at which the heat generation vs. temperature curve meets the heat loss vs. temperature curve.
In addition flegmatizers may be added to the substance.

2.3 PREVENTION OF EXPLOSIVE BURNING (INCLUDING GAS AND DUST EXPLOSIONS)

Explosive burning can be avoided by taking

care that the substance is not subject to local heating (including heat of friction, for instance). Gas and dust explosions can be avoided by taking care to prevent the occurrence of explosive concentrations (e.g. by dosing an inert gas), and by eliminating ignition sources that are strong enough to supply at least the minimum ignition energy of the explosive mixture.
When eliminating ignition sources heed should also be given to

- the hazard of build-up of static electricity;
- the possibility of mechanical sparks;
- the transport of glowing particles from elsewhere in the installation.

2.4 THE PREVENTION OF DETONATIONS

Detonation can be avoided by ensuring that the substance is not subjected to shock load. Apart from this, addition of an inert substance (flegmatizer) may render the substance less sensitive to detonation, or may even yield a product that is not drtonable at all.

3. LIMITATION OF THE EFFECTS OF EXPLOSIONS

Despite all preventive measures the occurrence of explosions cannot be entirely ruled out. If, contrary to expectation, an explosion should occur, then it is necessary to suppress the developing explosion when and wherever possible by means of, for instance, explosion suppression systems and mechanical flame arrestors. If this is not feasible, destruction of the installation in which the explosion takes place is to be prevented at all costs. The fact is, that as a consequence of the rapid pressure build-up and the resultant explosion pressure certain parts of an installation or of a building are subject to forces that go far beyond the design values. This often results in the collapse of the construction, with the possibility of severe injurey or loss of life.
In many cases use can be made of relief devices which at a sudden pressure increase will rapidly allow so large an opening that the pressure in the installation or in the room will not exceed the pressure that the construction can withstand. Examples are explosion doors in boilers, bursting panels in chemical installtions, and blow-out walls and roofs of light construction in factories and similar buildings. Proper functioning of these relief devices is governed by the pressure-time history of the explosion, the surface of the relief opening, the collapse pressure of the relief device and the capacity and the strength of the installation inside the factory.
In particular safety measures are to be taken to protect personnel in the direct neighbourhood, especially operators in, for instance, control rooms, against the effects of possible explosions.
The measures may vary - depending on the situation - from installing special glass in special rebates, to the construction of completely explosionproof control rooms.
Equipment in the neighbourhood of a potentially dangerous situation could be protected by erecting an explosion wall that is capable of withstanding the maximum expected load to be expected.
Rooms and parts of equipment in which there is a potential explosion hazard should be kept separated as far as possible (fire-doors rotary valves etc.).

APPENDIX 2. INSTRUMENTAL AND SELF-ACTING SAFEGUARDS

1. INTRODUCTION

Instrumental and self-acting safeguards should be regarded as a necessary contribution to safety. Wherever possible preference should be given to self-acting safeguards.
As a weapon against pressure transgression a self-acting safeguard can not yet be omitted.
As a low water level protection, in for instance boilers, only Leger cones are self-acting safeguards.
As a means against temperature transgression a self-acting safeguard is rarely suitable. Only in those cases where it is a question of saturated vapour will it be feasible to prevent temperature transgression by means of a safety valve.

In many chemical processes, however, instrumental protection, i.e. a protective action by devices consequential to impulses of measuring instruments, is a necessity. This is either because no self-acting safeguard can be devised, or because human intervention would be too slow.

In special cases it may be useful - in order to prevent major process interruptions or emissions - to install instrumental protection together with self-acting safeguarding systems.

2. BASIC PHILOSOPHY

The purpose of control technique in the process industry is to keep operating conditions within preset limits.

2.1 The narrowest limits apply to the conditions for normal operations. Automatic control systems endeavour to retain these limits.

2.2 The widest admissible limits (transgression of which presents a hazard or a substantial loss) are retained by safeguarding systems.

2.3 The coincidence of conditions that would lead to both an inadmissible limit transgression and failure of a safeguarding system could result in a catastrophe. It is necessary to reduce this coincidence probability to an acceptable order of magnitude.

2.4 Instrumental devices which further reduce the probability of coincidence are:
- signalising
- selection controls
- limit controls
- locking devices

They constitute a defence line between normal operation and the final safeguard.

2.5 There are additional reasons for applying the means mentioned under 2.4 wherever possible. First of all it may be undesirable to rely on just one line of defence. In the second place the initiation of a safeguard could give cause to a drastic change in conditions which is preferably avoided. Thirdly the systems mentioned under 2.4 may reduce production loss.

2.6 A multiple execution (unjustly called redundancy) is a means of substantially increasing dependability and decreasing coincidence probability. However, together with the technical benefits. The economic aspects have to be considered.

2.7 Broadly speaking it is wrong a safeguarding problem as a summation of individual, incidental problems.
As with every problem associated with process control one should regard the safeguarding of the system as a coordinated system.

2.8 In addition tot 2.7 it is essential that every process design is proceeded by a thorough study of all possible conditions that could give cause to hazardous coincidences; this study is called a disturbance analysis.
The reasoning that has led to the outcome of the analysis must be documented.

3. ORGANIZATIONAL GUIDELINES

3.1 Since an alteration may entail a change in the system, the consequence of each change must be checked by means of a disturbance analysis. Here too reporting is necessary.

3.2 Every instrumental safeguarding and signalising system should be accompanied by a documented and systematically arranged checking system. The instrumental safeguarding system should be so designed as to enable checks. When checking the instrumental safeguarding system safe operability should be ensured.

3.3 Technical guidelines for designing safeguarding and signalising systems are indispensable. The aim hereby should be simplicity and standardization which by homogeneity and clarity will diminish the probability of faulty design, execution, operation and testing.

3.4 The whole should be accompanied by organizational measures to secure a proper functioning of the entire system, which may be laid down in guidelines and instructions. The responsibility for observing these should lie in the hierarchic line of the production staff.

3.5 Every intervention or change in the safeguarding or signalising system should be documented as to time, date and place, and provided with a signature. This applies first and foremost to taking out of commission for checking purposes.

3.6 It is desirable that the documentation of all process safeguarding systems is within reach of all concerned.

4. TECHNICAL GUIDELINES

4.1 INSTRUMENTAL SAFEGUARDING

4.1.1 More so than in the case of process control reliability, quality and accuracy should be leading principles in the selection, design and execution of instrumental safeguarding systems.

4.1.2 The question whether a multiple system is more efficient and cheaper than a single system must be avluated in each case.
Multiple systems offer the possibility of quicker, better and less frequent checks (saving in cost) with, in addition, increased dependability.

4.1.3 Every instrumental safeguard should be investigated whether it has to be self-resetting or not.

4.1.4 By preference the normally energised system should be applied for instrumental safeguarding systems.
When the normally energised system is applied this should be at least as reliable as an alternative normally energised system.

4.1.5 "Fail-safe" solutions should be preferentially selected.

4.2 ALARM SYSTEMS AND SIGNALIZING SYSTEMS

4.2.1 In a centralised control system optical signalisation is necessary in order to

- distinguish and localize abnormal conditions
- indicate in what operating condition the process is.

4.2.2 Each transition from a normal to an abnormal condition detected by the signalising system should be indicated by an optical signal, whether or not in conjunction with an acoustic one. Only after it has been established what abnormal condition has actuated the signal, may the signal be removed. As long as the normal condition has not been resumed the abnormal condition should remain visible in the signalising system.

4.2.3 The signalising system should comprise the following possibilities

- with intricate process control it is efficient to be able to trace the first signal from a series (socalled "first up" signal)
- this "first up" signal must not be caincelled due to other actions in the control or signalising system.
- each fault signal should have its own indicator lamp
- each indicator lamp should be furnished with its own nameplate indicating its function
- each signal should be provided with its own switch or push button (this means in practice that the indicator lamp is to be incorporated in the switch or in the push button);
- there should be a provision to run a quick and easy check on all indicator lamps.

4.2.4 The sequential order of the optical signalising system should be clear and unambiguous.

4.3 LOCKING SYSTEMS

4.3.1 If the coincidence of certain actions or conditions constitute a hazard or may give cause to serious material damage, such coincidence must be prevented by applying (inter) locking systems.

4.3.2 Locking systems should be conveniently and logically arranged, and in addition it should be a simple procedure to check their functions.

4.3.3 Sometimes locking systems and instrumental safeguarding systems prevent processes from being put into operation. In nearly all those cases it is necessary to temporarily circumvent, short, or block the circuits in question, in brief to discontinue the normal functions temporarily. Preferably such a blocking of the function should be automatically removed as soon as this is possible; thus automatically restoring the normal function. An acceptable alternative is to discontinue the function by pushing a button whose release will immediately restore the normal function.
The blocking of a normal function will invariably have to be made clearly recognizable.

4.4 FURTHER RECOMMENDATIONS

4.4.1 In intricate systems - such as the combination of signalising, instrumental safeguarding and locking - by and large provisions will have to be made to facilitate the tracing of faults.

4.4.2 When checking instrumental safeguarding systems of installations that are in operation problems will arise; this is particularly true if the normally energised system has been applied.
Designs whereby a temporary blocking can easily be applied and forgotten are odious.
If the necessity of frequent checks is known in advance due account is to be taken of this

from the outset; 1 out of 2 and 2 out of 3 systems may offer a solution in this respect. When an instrumental safeguarding system is out of operation this should be made clearly recognisable.

4.4.3 Putting instrumental safeguarding and signalasing circuits out of operation should preferably be done from a central point. The best place for this is the control room. The systems should be so designed that they cannot easily be put out of commission by unauthorized persons (further see 3.4 and 3.5).

4.4.4 The safeguarding action following a command from a safeguarding measuring circuit is carried out by a control device(solenoid valve, quick acting valve, motor switch). This control device must never be blocked in its operation.
Constructions promoting such blocking - such as handwheels that can be disengaged - are prohibited here for this reason.

4.4.5 Even more attention has to be paid to the availability and quality of the requisite electric supply and pneumatic feed to safeguarding systems than to provisions for normal process control.