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Maintenance and Changes

in Plants with High Safety Requirements

Practical Guidance

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THE INTERNATIONAL SOCIAL SECURITY ASSOCIATION (ISSA)

has more than 350 members (government authorities and public institutions) in more than 150 countries, half of whom are concerned with occupational safety. The headquarters of the ISSA is at the International Labour Organization in Geneva. Its main objective is the promotion and improvement of SOCIAL SECURITY in all parts of the world.

To intensify work safety in plants in the chemical industry, including the plastics, explosives, mineral oil, and rubber industries, the

INTERNATIONAL SECTION OF THE ISSA ON THE PREVENTION OF OCCUPATIONAL RISKS AND DESEASES IN THE CHEMICAL INDUSTRY

was set up in 1970. It has its chair and secretariat at the Berufsgenossenschaft der chemischen Industrie (Professional Association of the Chemical Industry), 69115 Heidelberg. Germany.

Homepage: http://chemistry.prevention.issa.int

To improve occupational safety and health in industrial plants, the

INTERNATIONAL SECTION OF THE ISSA FOR MACHINE AND SYSTEM SAFETY

was established in 1975. It handles matters relating to the safety of machinery, plant, and systems. It has its chair and secretariat at the Berufsgenossenschaft Nahrungsmittel und Gaststätten, 68165 Mannheim, Germany.

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ISSA International Section for the chemical Industry

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Preface

παντα ρει - [panta rei] - all things are in constant flux: This quotation of the Greek philosopher Heraklit (about 500 B. C.) also applies to process plants, which are constantly in a state of evolution and change. Complying with customer requirements, the implementation of new concepts, and continuous improvements within the framework of overall quality management demand a permanent innovation of plant and operations.

Maintenance, preserving well-established status, and changes, which constitute the basis for innovation and improvement, are the daily business of all employees responsible for process plants. While the focus of this brochure is on the operation of equipment and machinery, at the same time the health of employees and the protection of both the environment and the neighbourhood must also be taken into consideration. As indicated in various legal and technical standards, the relevant methods to ensure both occupational safety and plant safety are hazard analysis and risk assessment.

In practice, it is very difficult to ensure safety. The accident rate of maintenance work is still a major focus point, and changes in processes are still leading to serious accidents, some of them with considerable off-site effects. Besides the human tragedy involved with these accidents, the financial loss due to business interruption and image loss may jeopardize the future of hitherto successful companies. Moreover, managers in charge at the time of the accidents could face prosecution. Therefore, safety, with its social, legal and economical aspects must be an integral part of any overall business optimisation strategy.

The International Social Security Association (ISSA) is committed to increase the awareness of the risk that employees face due to accidents and work related diseases by means of know-how exchange, publications, and seminars. The ISSA also suggests proposals for the elimination of these risks. This brochure is focussed on hazards that are associated with maintenance and changes. It presents case studies and practical solutions to control such hazards. ■

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Contents

Problem

Machines and process plants are subject to ageing, wear and tear, i.e., to phenomena that affect many consumer products. Maintenance is the key measure to keep ageing and degradation under control in industrial installations. According to EN 13306, maintenance is used in this brochure for all technical and organizational measures that keep a machine or plant functioning or that restore its functionality after failure or damage. This comprises preventive maintenance, including servicing and functional checks as well as corrective maintenance, including repair and elimination of malfunctions.

Furthermore, this brochure deals with changes. Changes are deliberate modifications that are introduced actively in order to improve plants, processes and procedures. Sometimes changes are also introduced to eliminate process deviations.

Figure 1:
Maintenance and change of processes and plants affect the complex interaction between chemicals, technical installations, and operators

The processes addressed in this brochure are characterized by a complex combination of equipment, piping, chemical substances, process parameters and control actions by operators. Therefore, maintenance and changes always affect the complex interaction between chemicals, technical installations and human actions (figure 1). In this respect, occupational safety, plant and process safety with possible impacts on the environment and neighbours are equally important. To cover all these aspects, hazard analysis is the key tool.

Changes in plants are often carried out within a general maintenance campaign - in many cases in parallel to maintenance and by the same personnel. Therefore, maintenance and change are often not distinguishable in large plants. In some cases, temporary installations are necessary during maintenance work or part of a plant is temporarily shut down, which results in a (temporary) change of intended operation. The consequent implication on the safety of the process must be subject to a hazard analysis.

The risks associated with certain hazards may change during work on the plant, and new or higher risks may appear if changes are introduced in an uncontrolled manner or if the impact of changes is not adequately taken into consideration in the hazard analysis. Even apparently non-relevant modifications of a plant may have a significant impact on the safety concept and - in the worst case - could make the concept ineffective. Therefore, the special aspects of maintenance must be considered in the hazard analysis. Clearly defining the work related to maintenance and changes is another important aspect. This clear specification allows a more reliable identification of new hazards associated with the work to be carried out. The scope of the work, the starting time, the duration, and the appropriate tools must be specified in a work permit.

Problem

The objectives of this brochure are to

- raise the awareness of elevated risks associated with maintenance and changes and to
- suggest measures to ensure the safety of employees, neighbours, the environment, and assets during and after maintenance and changes, in particular through the application of appropriate tools and procedures.

The tools described here ensure a clear definition of **Who does What, When, How, and Why?** The clear definition of the relative procedures ensures that changes and maintenance are carried out according to a defined system and are correspondingly documented. The relevant principles are generally applicable, regardless of the size of the company.

The brochure is addressed to managers and supervisors who are responsible for planning and coordination of maintenance and changes, and also to the specialists and workers who actually carry out the work on site. General safety measures, such as the use of personal protective equipment, are not described in detail here. The methods for a systematic hazard analysis are described in detail elsewhere [1].

» **Any intervention in a process plant must be safe. This includes the period of practical work, any temporary installations and, of course, normal operation after the completion of the work.** «

Maintenance and Changes from Point of View of Plant Safety

»Many past accidents with harmful effects were caused by inadequately controlled maintenance or changes, combined with an unexpected process deviation and the unsuccessful attempt to take corrective "ad hoc" actions. Often an apparent profit in either time or money resulted in a disaster, with many fatalities.«

The FLIXBOROUGH Accident – 1974

In a chemical plant in Flixborough (UK) caprolactam was produced as a raw material for the manufacturing of nylon. Cyclohexane was continuously oxidized in a cascade of six reactors. After detecting a leak in reactor 5, where cyclohexane vapour escaped, the plant manager in charge decided to repair the leak and to bypass reactor 5 by means of a temporary transfer line from reactor 4 to reactor 6 during the repair work. This provisional

[Photo: dpa/picture-alliance]

Figure 2:
Explosion at Flixborough

installation was constructed under great time pressure. Because there were no pipes on stock with the appropriate standard diameter, pipes with a slightly smaller diameter were used in combination with flexible compensators. The mechanical stability of the temporary installation was not checked in detail.

On July 1st, 1974, the temporary connection broke and 50 tons of cyclohexane vapour escaped. The vapour cloud caught fire, resulting in an explosion with a total energy equivalent of 15 to 45 tons of TNT. The entire site of about 0.24 km^2 was completely destroyed, and the flames of the subsequent fire reached a height of 100 m. There were 28 fatalities and 89 people were injured. Within a radius of 3.5 km, 90 % of the houses were severely damaged.

The BHOPAL Accident – 1984

In the night of December 2nd, 1984, 20 tons of highly toxic methylisocyanate leaked out of a head tank of a herbicide production unit in Bhopal. In short time, the toxic gas spread into the surrounding residential areas, resulting in the most catastrophic effects a chemical disaster had caused up to that time:

- The number of fatalities increased from approx. 4,000 immediately after the gas escaped to about 7,000 within a few days and to a total of more than 20,000 in the long term.
- Approximately 100,000 people suffered permanent injuries
- In total, 570,000 people suffered "acknowledged" health damage

Twenty years after the accident, many papers were published, which gave details about the chain of events leading to the disaster [7, 8]. For example, the Frankfurter Allgemeine Zeitung (FAZ) published an article entitled "The Wounded City":

"... Within a short time, management of the concerned site in Bhopal had reduced the staff from 1,000 to 642. In the critical methylisocyanate unit, the staff was cut by 50 %. Untrained helpers took over tasks from well-qualified operators. Workers that were not able to understand the procedures written

[Photo: Greenpeace]

Figure 3:
The Bhopal plant
20 years later

in English were promoted to key functions. Maintenance intervals were extended; worn parts were replaced only once a year instead of every six months; small leaks were tolerated as long as they did not have a "critical" size. Adding to the negative effects of these factors was the decision of the two leading managers to reduce the functionality of the complex alarm and protection systems of the plant in order to save on electricity and cooling expenses.

When the remaining alarm signals were flashed on the evening of December 2nd, the operator did not react immediately. Not until a few hours later did the guards notice that water had entered the isocyanate tanks as a result of an incorrectly performed cleaning operation carried out in connection with damaged valves. The devastating chemical reaction could not be stopped as of that moment."

Maintenance and Changes from Point of View of Plant Safety

The PIPER ALPHA Accident – 1988

Piper Alpha was a large offshore platform in the North Sea. It was initially designed for oil production and was later modified for natural gas production. In addition to the fuel produced on the platform, the oil and gas from two other platforms was also pumped to the coast via Piper Alpha. In the summer of 1988, a new gas pipeline was built. At the same time several parts had to be repaired, because no maintenance work had been done for quite a while. In contrast to earlier practice, full production was not reduced while this work was going on.

There were two compressors installed on Piper Alpha, marked as A and B. They were used to compress the gas, in order to transfer it to the coast. Therefore, the compressors were of fundamental economic importance to the platform. On the morning of July 6th, 1988, a relief valve on compressor A was removed for maintenance. The relevant work permit had been issued by the manager in charge of the safety installations on the platform. Because the end of the shift had not completed the work, a worker closed the open pipe provisionally and indicated, on the permit form, that the compressor was not ready for operation. The form was delivered to the office of the safety department, without informing the head of production about the status of the compressor. That was a fatal mistake.

Late in the evening, compressor B failed unexpectedly. Unaware of the relevant status report, the production staff assumed that compressor A was ready for operation. The gas was transferred to the compressor, where it was released via the open pipe. The resulting explosive mixture caught fire and an initial explosion occurred. Because the platform was originally designed for oil production, the firewalls did not withstand the shock waves from the explosion, and they collapsed. This led to damage of some oil pipes and the spilling oil also caught fire. The fire might have soon burned out because oil production on Piper Alpha was immediately stopped, but workers on neighbouring platforms, following directives from management on the coast, continued production for economic reasons and thus continuously fed the fire.

The oil fire engulfed the huge gas pipes that connected the other platforms with Piper Alpha. Twenty minutes after the first explosion, the first gas pipe broke; half an hour later, the second one broke. Three tons of gas per second leaked out. The metal construction started to melt under the extremely high temperatures in the fireballs, and the platform finally collapsed. One hundred sixty-seven people died in the inferno. The Piper Alpha management did not initiate the evacuation of the platform, and the external rescue teams could not get to the platform due to the high temperatures. The oil transfer from the neighbouring platforms was stopped only after the gas explosions had occurred.

The catastrophe of Piper Alpha was the biggest accident, up to that time, on an off-shore platform. The causes determined by the investigation provide a key lesson on how a chain of mistakes and faulty design, operation, and management can result in a large-scale accident. In addition to the human tragedy, the accident also caused huge property loss and damage to the image of the company.

[Photo: dpa/picture-alliance]

Figure 4:
Explosion at Piper Alpha

Maintenance and Changes from Point of View of Plant Safety

In the above accidents three basic root causes can be identified that also apply to many smaller accidents in the process industry:

1. Inadequate design and planning regarding safety:

- when changing the piping
- upon changing organization and operational management
- when converting the platform from oil to gas production

2. Inadequate communication and emergency planning:

- when performing the work without observing internal safety standards
- when operating with a deficient safety management system containing insufficient alarm and emergency plans
- when applying a work permit system with incomplete information on all personnel/departments affected

3. Unwise decisions due to economic pressure:

- when continuing production during maintenance
- when reducing preventive maintenance and servicing and allowing for slow degradation of the installations
- when operating plant with untrained personnel, lacking experience and appropriate instruction
- when switching off protective systems and alarms

Foreseeable, but Overlooked Problems Related to Maintenance and Changes

When planning and carrying out maintenance, it is quite common that the objectives of the project or work are evident to everybody, but pitfalls can be overlooked. Many of the problems that appeared in past accidents could have been foreseen and prevented if a systematic analysis had been carried out beforehand. Often, errors in maintenance lead to unintended changes in the plant. In the Annex some accidents are described, where the safety concepts were made ineffective due to such changes.

As shown in the examples, intended changes in a plant may have adverse effects if the hazard analysis is not carried out properly. In particular, problems may result from a series of small changes: Although each of the changes may be considered to be non-relevant to safety, the combined effects could result in significant hazards.

Changes that frequently lead to safety problems if not properly analysed:

- **change of the construction material**
- **change of process parameters**
- **change of inerting procedures**
- **change of equipment parameters**

Where high hazard potentials are involved, even apparently negligible interventions may lead to highly dangerous situations. Conclusion:

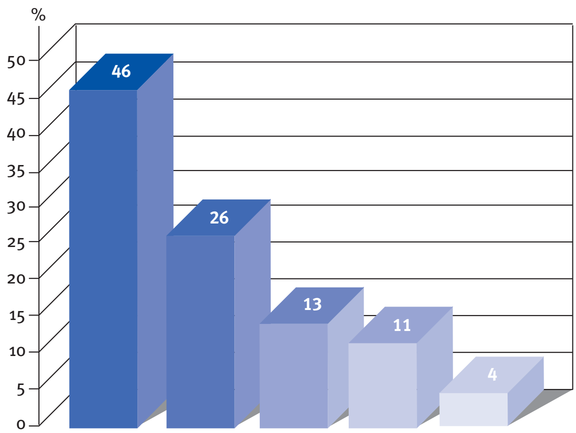
» **Deviations from planned and thought-out procedures are to be considered as changes in the safety concept of a plant and, therefore, must be subject to a hazard analysis!**

Unintended or rash changes must be avoided! «

Foreseeable, but Overlooked Problems Related to Maintenance and Changes

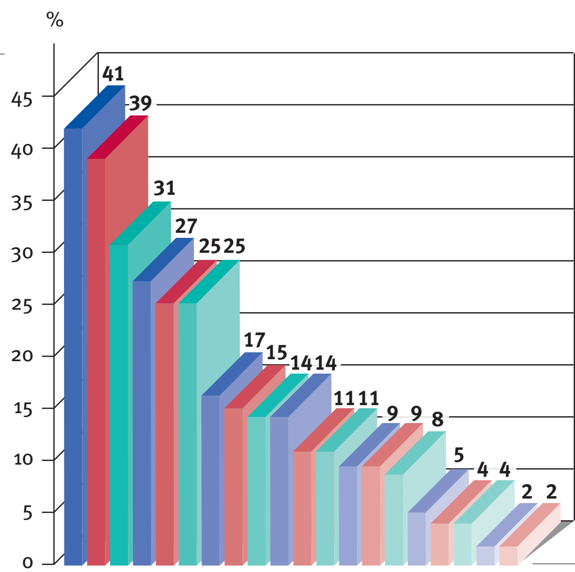
Figures 5 and 6 show a statistical analysis of 93 accidents regarding the phases of maintenance, significant causes and contributing factors [2].

Figure 5:
Frequency of accidents regarding to the phases of maintenance



Trouble shooting 46 %
Failure detection 26 %
Start up 13 %
Adjustements/Checks 11 %
Miscellaneous 4 %

Figure 6:
Significant causes and contributing factors of 93 accidents



Missing safety equipment 41 %
Intervention during full operation 39 %
Collaboration of several people 31 %
Hazard not recognized 27 %
Machine switched on 25 %
Automatical start up of machine 25 %
Short-term interaction 17 %
Missing knowledge 15 %
Release of accelarated energy 14 %
Standard operation 14 %
Adjustment of machine 11 %
Safety equipment desactivated 11 %
Sliding/Pitching 9 %
Stress 9 %
Working alone 8 %
Avoiding of hazard 5 %
Defective safety equipment 4 %
Short qualification 4 %
Changes 2 %
Fatigue 2 %

These figures - although of limited statistical relevance - allow the following conclusions:

- In about 75 % of the accidents, the intervention occurred during full operation of the plant or machine or during start-up
- In about 40 % of the accidents, the prescribed safety installations were not available or were switched off.
- In about 30 % of the accidents, several people worked at the same time in the plant and there was insufficient coordination among them.
- About 25 % of the accidents occurred during the search for the causes of a malfunction (accidents that occurred due to incorrect diagnosis of a malfunction were not listed separately)

From the point of view of safety, there are several factors that may lead to problems, in particular, while taking corrective actions in case of malfunctions. One important aspect is the postponement of maintenance work, which often leads to malfunctions. Due to economic and organizational factors, there is then great time pressure while corrective actions are being taken to make the system available again as fast as possible. Then, in order to save time,

- hazard analysis is made in a slapdash manner or it is not made at all.
- provisional installations or procedures are introduced.
- the documentation after the work is insufficient.

From major disasters of the past, statistical data of CRAM as well as from common sense and practical experience, some general safety measures for maintenance and changes can be deduced:

Source figures 5 and 6 [3]

Foreseeable, but Overlooked Problems Related to Maintenance and Changes

Fundamental Safety Measures for Maintenance and Changes:

- Systematic identification of hazards and assessment of the relevant risks for (temporary) start-up or shut-down of subsystems.
- Avoidance of foreseeable erroneous interventions by means of technical measures.
- Communication of the necessary know-how by means of description of the hazards, e.g., in manuals or operating procedures and through instruction of the personnel.
- Checking of protection systems for correct and effective functioning after completion of the work.
- Documentation of all implemented measures, in particular of the permanent or temporary changes.

For the implementation of these safety measures, any changes in the safety concept of the plant before, during and after the work must be identified. If there are any such changes, the so-called Management of Change (MOC) procedure must be applied. An essential element of this procedure is the so-called Plant Change Form, which explains how all issues relevant to safety and legal operating can be taken into consideration.

Even without any changes in the safety concept, a hazard analysis must be carried out before interventions in a plant are made. Relevant aspects are described in the Chapter on Safety Aspects for the Preparation and Execution of Work. The essential tool within this procedure is a work permit form, which explains what is to be done so that the existing safety concept is not be undermined or made ineffective during the work and that the work is safely carried out.

Ideally the two procedures described in the following chapters are the procedures, which are combined in a way such as to ensure safety permanently during all phases of the work to be done.

Management of Change

While know-how and experience together with systematic safety checks and hazard analysis ensure a high degree of safety for normal operation, special situations and operation status are less well covered, and therefore, need particular attention. A significant number of accidents have been caused by changes that were planned in detail, but were implemented without carrying out an appropriate hazard analysis regarding safety of workers or plant safety. Other important causes were failures in the communication between the parties involved in the project or deviations from the original plan.

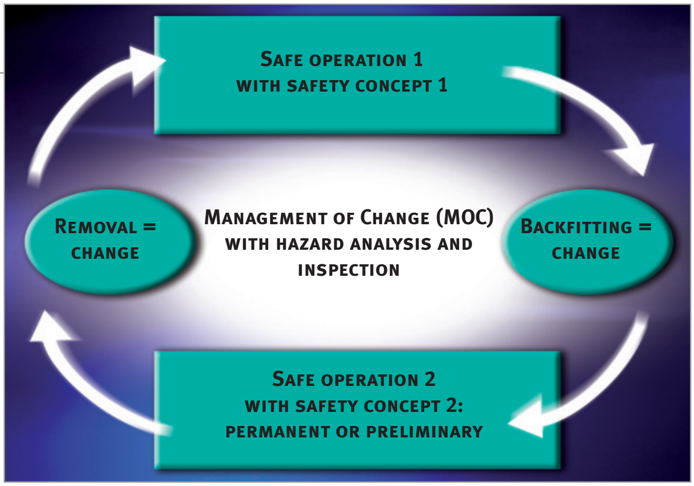
The basis for safe changes in a plant is a systematic Management of Change (MOC). The legal requirement for such a management system is based on the Directive on the Control of Major-Accident Hazards (COMAH, SEVESO II Directive) in Europe or the US Code of Federal Regulations, from which the term "MOC" is taken. The objective of such a system is to ensure safety both during the implementation of the change and for the new situation after the change has been made. MOC includes an "information system", to avoid communication failures. Within a sound MOC, the necessary measures for changes are defined in the planning phase. In complex plants, interdisciplinary teams might have to be formed to do this. Based on the preparation, the relevant project is then carried out safely, is well coordinated, and is thus also efficient.

» Even the best management systems cannot replace professional competence, know-how, and experience!

Management systems support specialists and experts to ensure a systematic and efficient approach, which avoids overlooking of relevant facts. «

Management of Change

Figure 7:
Management of Change – the safer way



Projects carried out under MOC allow transforming a plant from one safe status along a safe route to another safe status. There is no formal difference between permanent or temporary changes: Temporary installations may be removed after a certain period of time, but both the construction and the removal of the provisional installation are formally considered as changes (figure 7). Therefore, the MOC may be successfully applied even to preventive maintenance. In this way the well-established procedures and methods for work and plant safety are thus fully integrated into the change process.

» **During the planning and implementation of interventions such as the elimination of malfunctions, maintenance, and plant changes, the hazards occurring before, during, and after the work must be taken into consideration.** «

The Plant Change Form

In simple cases, all relevant information related to a plant change is summarized on a Plant Change Form. The form is a kind of checklist for making sure that all relevant points are taken into consideration and the relevant information is distributed to the appropriate parties.

The form should be combined with an instruction sheet on how to use it. Both the form sheet and the instruction sheet must be user-friendly, otherwise they will not be successfully used:

- The items and fields on the form must be specifically adjusted to the organization of the operating company
- The form should ensure a faithful and comprehensive risk assessment
- The form must not be overcrowded with text and boxes
- The focus must be on information of practical relevance
- The form must be subject to continuous improvement, and updates are required if needs change.

Therefore, there is no such thing as a "completely correct" form that can be applied in general everywhere. Plant change forms must be developed based on the specific needs and the type of operations so that they are useful and fulfil their function.

Typical Items on a plant change form:

- **Administration** (Sequential Number, Date, Plant, P&I Sheet)
- **Description of the Change** (What will be changed? Why? Objectives)
- **Additional Information** (Deadlines, cost)
- **Schedule:** Sequence of work: Planning, preparation, main work, auxiliary work, Termination. The form should be designed so that the work flow clearly appears from the entries.
- **Document Update** (P&I Sheets, permits, explosion protection documents, safety checks and hazard analyses)
- **Checks before Start-Up** (Process Controll System (PCS), pipes, pressure vessels, unloading points and filling stations)
- **Approvals** (with signature and date)

Plant Change Form (Part 1)			
Change-No:		Revision:	Date:
Plant:		**Title/short description of the project:**	
Unit:			
Building:			
Responsible for this Project:			
Change concerns: ☐ Process ☐ Plant ☐ New Product ☐ Changed Product ☐ Enhancement ☐ Removal			
Complete Description of the Change (incl. reason and intended goals):			
Additional informations (incl. time schedule ans costs) / number and content of appendices:			

Is an hazard analysis existing?	☐ yes ☐ no
if not: has an hazard analysis to be done?	☐ yes ☐ no
Does the change concern the safety concept?	☐ yes ☐ no
New / changed risk potentials:	Counter Measures:
Are provisional arrangements necessary (e. g. bypasses)?	☐ yes ☐ no
If yes: Does the arrangement concern the safety concept?	☐ yes ☐ no
New / changed risk potentials:	Counter Measures:

Reconciliation with competent departments					
Yes	no	Department	Date	Remarks of Department	Signature
☐	☐	Legal Authorisation			
☐	☐	Health & Safety			
☐	☐	Environment			
☐	☐	Process Control			
☐	☐	Quality			
☐	☐	Energy supply			
☐	☐				
☐	☐				

Authorisation of Change	Name	Date	Signature
Responsible for this Project			
Plant Manager			
Head of Engineering			
Work Permit necessary			☐ yes ☐ no
Plant Change Form (part 2) necessary			☐ yes ☐ no

Plant Change Form (Part 2)

Change-No:		Revision:	Date:
Plant:		**Title/short description of the project:**	
Unit:			
Building:			
Responsible for this Project:			

Dokuments to be revised					
Yes	no		Done by	Date	Signature
☐	☐	Legal Authorisation			
☐	☐	Hazard Analysis			
☐	☐	P&I Sheets			
☐	☐	Isometry			
☐	☐	Underground Charts			
☐	☐	Procedures			
☐	☐	Explosion Protection Document			
☐	☐	Documentation of Process Controll System			
☐	☐	Maintenance Plans			
☐	☐				
☐	☐				
☐	☐				
Documents finished					

Commissioning		Name	Date	Signature
Mechanical Completion	Responsible for Execution			
	Responsible for this Project			
	Plant Manager			

Approval prior to start up					
Yes	no		Done by	Date	Signature
☐	☐	Pressure vessels and piping			
☐	☐	Safety valves / rupture disks			
☐	☐	Safety instrumented system			
☐	☐	Monitoring and control system			
☐	☐	Energy devices			
☐	☐	Provisional arrangements rebuilt			
☐	☐	Test procedure			
☐	☐				
☐	☐				

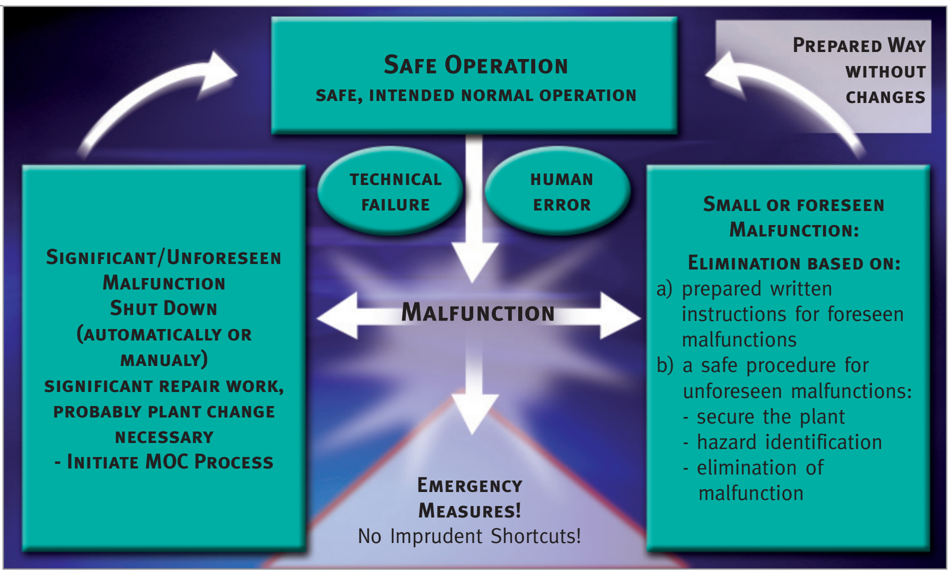
Authorisation of start up	Name	Date	Signature
Responsible for this Project			
Plant Manager			
Head of Engineering			

Management of Change and Elimination of Malfunctions

The MOC can be applied only for intended and planned changes, but not for offhand interventions during the elimination of malfunctions. A malfunction is a deviation from the intended operation due to a technical failure or human error. The plant is kept in a safe status by protection systems, organisational measures or an emergency shut down. The objective of measures to eliminate the malfunction is to restore normal (intended) operation. Such interventions require either clear procedures prepared in advance or the hazards must be analysed before taking action. Ill-advised shortcuts incur elevated risks!

If the malfunction cannot be eliminated in a simple way, e.g., because a change is necessary to improve safety and/or availability, the plant must be (partially) shut down and a change procedure that is in accordance with MOC must be initiated (figure 8).

Figure 8:
Management of Change and Elimination of Malfunctions



Hazard analysis can cover only scenarios that have been identified before. Plant changes can lead to malfunctions that are possibly not controlled by existing safety concepts. The systematic Management of Changes is an essential preventive instrument against overlooking such cases.

The aim of emergency measures, such as the intervention of the fire brigade, is primarily to mitigate damages; they are corrective actions to minimize downtime of production in case of malfunctions.

Planning Changes

Before implementing changes in plants, the situation during and after the work must be analysed: This implies answering questions such as the following:

- Will the change have an impact on the safety concept and the legal operation permit?
- Will there be any risks for the workers?
- Will it be necessary to amend the emergency management?
- Will it be necessary to re-assess the fire and/or explosion risks?
- Will it be necessary to amend the supply of power and auxiliaries (pressurized air, nitrogen)?
- Will there be effects on product quality?
- Will it be a permanent or a temporary change?

The safety concept of a plant must be effective over the entire life cycle of a plant. If necessary, it must be adjusted to take into account the following: changes, maintenance, mothballing, and dismantling.

Planning changes comprises the following steps:

- Description of the planned changes
- In case of fundamental or significant changes: Discussion with an interdisciplinary team of specialists
- Identification of safety-relevant aspects during and after the change
- Determination of appropriate safety measures
- Approval of the change by the line management

The determination of appropriate safety measures should be made in a well-defined, systematic way, such as to ensure a coherent safety level, irrespective of the size and type of the change project and also irrespective of the people involved. Obviously, the resources required for this step increase with the extent of the project.

Planning steps for new plants/installations:

Feasibility study

- Principal suitability of the site (location, environment, neighbourhood, external [public] emergency organization)
- Infrastructure at site (internal emergency organization, qualification of personnel)
- Local (public) infrastructure, e.g., waste disposal, water treatment plant, transport connection

Preliminary planning

- Hazardous characteristics of substances (flammability, toxic potential, corrosive properties, long-term adverse health effects) taking into consideration the quantities handled and stored, as well as the process conditions (temperature, pressure, concentration)
- Basic concept of the plant (open air plant, building, batch or continuous process)
- Positioning in the site (space required, existing buildings, new buildings)
- Required additional infrastructure, e.g., waste disposal, water treatment plant, transport connection

Basic design

- Containment concept (load bearing structure, openings, separation of subunits, pressure venting)
- Disposition of equipment (positioning inside buildings, access for operation, maintenance and cleaning)
- Planning of the workplace (pathways, escape routes, emergency exits, lighting, ventilation and air conditioning)
- Hazard analysis (systematic identification of hazards and assessment of risks)
- Process control system (basic process control system, monitoring system, safety instrumented system, safety instrumented mitigation systems)
- Explosion protection concept (ex-zones, elimination of ignition sources, constructive explosion protection)
- Fire protection concept (constructive, preventive, mitigation measures)

Detail design

- Detailed definition of safety measures (functional specification and description of safety installations)
- Zoning (ex-zones, safety distances, noise zones, radiation zones)
- Ergonomic/user-friendly design (arrangement of control elements, man-machine interfaces, procedures, facilitation of maintenance and servicing)
- Emergency Installations (first aid, fire fighting, rescue installations, emergency showers)
- Adjustment of safety measures to any modifications relative to basic design, update of the documentation

Construction/Installation

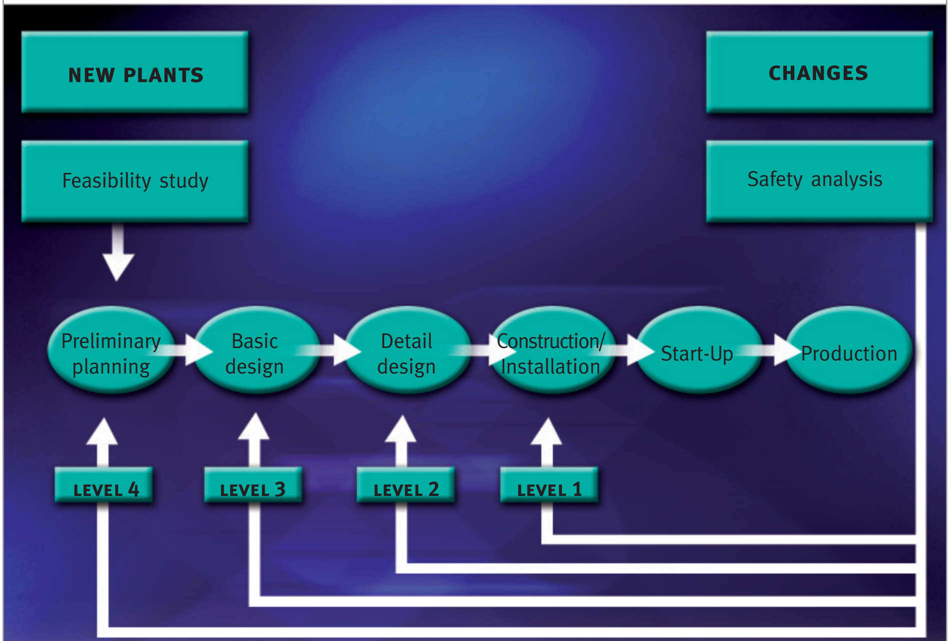
- Realization of detail design

Start-Up

- Check for correct installation
- Functional checks of all safety installations, Pressure checks, etc.

Management of Change

The necessary depth of the safety analysis required depends on the effect of a plant change on the safety concept:



Level 1: The activity is not safety critical and can, therefore, be implemented without a detailed analysis, just by observing the "state of the art".
Example: Replacement "in-kind", i.e., an old part is replaced by an identical new part.

Level 2: The change has significant implications on safety. Before implementation, the need for adjusting the safety concept must be analysed.
Examples: replacement of a part by a non-identical part, temporary shut-down of protective systems.

Level 3: The change is safety critical. Before implementation, a systematic hazard analysis must be carried out, and the safety concept must be adjusted according to the results of this analysis.
Examples: changes of process steps, use of provisional installations or systems.

Level 4: The change entails a fundamental change of the safety concept. Prior to implementation, a systematic hazard analysis must be carried out, and a new safety concept must be developed according to the results of the analysis.
Examples: partial replacement of a plant, use of flammable solvents instead of water.

For large projects, a formal request must be worked out and submitted to the management. In many companies, safety, health, and environmental aspects have to be addressed in this request. For smaller projects, a tried-and-tested approach is to call together a team, e.g., the plant manager, the plant engineer and a safety specialist, in order to assess the safety relevance of the intended changes and the need for safety measures. A feasibility study, preliminary planning and even basic design are rarely necessary in these cases, i.e., the project actually starts with a detailed design phase.

When planning changes and/or maintenance work, technical safety assessment is essential. This assessment can be made based on checklists, using the "what-if" approach or other well-established methods [1]. Some plants have introduced checklists, by means of which the staff can determine the safety relevance of the planned changes and is made aware of situations where support from specialists should be asked for.

The essential question to be answered within the technical safety assessment is whether the planned work will affect the safety concept of the plant. This is done based on the pevious hazard analyses safety checks. It is essential to take all phases of the project into consideration, and to have a special focus on the interface between the areas directly involved in the changes and the neighbouring areas in which normal operation continues. Experience shows that accidents are often caused by problems at such an interface.

Shut-down of Subunits of a Plant and Total Shut-Downs

Where shut-downs occur at regular intervals, they are part of the normal operation and, therefore, the relevant processes must be well defined and documented in manuals and written procedures based on the fundamental safety design of the plant. These procedures must take into consideration foreseeable changes, e.g., annual temperature variations.

Shut-down of subunits of a plant and total shut-downs may have a fundamental impact on the safety concept of a plant. During shut-downs, the plant is transferred to a new, temporary status, and after a certain period of time, the original status is restored again. As mentioned above, the safety concept of a running plant is, in most cases, different from the safety concept applied during downtime. The transition from one concept to the other must be planned step by step in a safety assessment.

When shutting-down subunits, special attention should be given to possible interference with the units, which are still in operation.

» If one part of the plant is running normally, and another part is shut down, measures must be in place to protect the entire plant from running out of control. «

Clearance of Plants after Changes

Clearance for start-up of a changed plant must be given only if

- all documents concerning the change have been updated, the minimum requirement being red-ink entries, made manually
- all necessary checks have been completed, the operators are informed about the effects of the plant change and measures related to the change,
- all necessary permits by authorities have been approved

Examples of documents that must be updated after changes are:

- Hazard- and Risk-Assessments, Safety Report, Explosion Protection Document
- Fire Protection Plans, Emergency Plans and Escape Routes
- Inventories for Equipment, Substances, Auxiliaries and Air Emissions
- List of required Checks on Vessels and other Installations
- Manufacturing Documents, Manuals, Operating procedures
- Layout Plans, Disposition Plan and P&I Sheets
- List of Machines, Apparatus, Piping, Alignment
- Inventory of Sensors/Functional Specifications, List of Limit Values for Alarms and Switches
- List of Safety Valves and Blanking Disks
- Maintenance Plan, Schedules for Shifts, and Sensor Checks

Changes (including plans, schemes, maps, and drawings) initially committed to paper constitute the basis on which changes are approved and safety assessment is made. However, cases are known where, in fact, the physical changes made in reality were not identical to those in the plans. Therefore, it is imperative to make sure that plans and reality match. Before initiating start-up, the staff directly involved in the operation, the personnel of neighbouring plants, and infrastructure services employees must be informed.

Safety Aspects for Preparation and Execution of Work

Beside the Management of Change focussing on interactions with the safety concept of a plant, the safe execution of works is of major importance.

Before carrying out work in a plant, hazards emanating from the plant, the equipment, the tools, and auxiliaries must be identified. Examples:

- Hazardous materials: toxic, corrosive, asphyxiant, flammable, explosive
- Moving mechanical parts that are potential hazards: shearing, pressing, cutting, or stitching parts
- Uncontrolled movement of mechanical parts due to unexpected start of drives or due to the release of potential energy (gravity, loaded springs, kinetic energy, compressed gas)
- Electricity
- Hot or cold surfaces
- Work in high places: on ladders, stools, scaffolds

During the elimination of malfunctions the following points further increase risk:

- Malfunctions are not foreseen, i.e.; they occur at an unexpected time when staff is not in attendance. Due to the broad variety of possible malfunctions, it is almost impossible to gather experience in handling any specific kind of malfunction.
- Incomplete knowledge of the current system status after a malfunction or of the actual cause of a malfunction results in work under unknown conditions. Often, corrective actions are initiated without knowing the actual origin of a malfunction.
- If conditions are undefined, and if there is a lack of complete control of the situation, imprudent ad hoc decisions are likely to be taken. Sometimes one's own capabilities are overrated.
- The efforts required and the time needed for elimination of malfunctions are often underestimated, and as a result, the plant and the work environment are not appropriately secured, e.g., cordoned-off, isolated from energies, etc.

- Workers that are not familiar with a plant and its equipment (in particular workers from other facilities) are less aware of the hazards and sometimes apply inadequate procedures or the incorrect tools.
- The aspects of maintenance and elimination of malfunctions are often not appropriately considered in the design of plant and machines. This leads to difficult working conditions.

The risk factor time pressure can be reduced by preventive maintenance and the application of statistical methods to predict possible failures and to take corrective action in time. Systematic diagnostic procedures facilitate the identification of causes for malfunctions and make it possible to carry out corrective actions in a safer way.

[Photo: BASF/Jedermann-Verlag]

Safety Aspects for Preparation and Execution of Work

Basic Requirements for the Safety Concept of a Plant Related to Accident Prevention during Elimination of Malfunctions:

- The various aspects of maintenance and the elimination of malfunctions must be appropriately considered in the design of plant and machines (access, mounting, and dismounting of replacement parts)
- Qualified and experienced staff for operation and maintenance must be available. Qualification must be kept up-to-date and staffing must be sufficient.
- A sufficient number of replacement parts, suitable tools, and appropriate auxiliaries must be available.
- Manuals, procedures, and instructions must be communicated both between the operating staff and the maintenance crew, and among all parties engaged in maintenance and repair.
- Safe working conditions must be ensured, irrespective of time pressure and limited financial resources. This is achieved on the basis of an appropriate safety assessment.
- Evaluation of existing experience to develop and permanently improve safe procedures

Safety Measures required for Preparation and Execution of Work

Analysis of the present situation and hazard analysis

- Inspection of the plant or installation on-site and survey of the present status
- Definition of the target status and the necessary intermediate steps
- Hazard analysis for the work

Definition of the work to be done

- Definition of the work phases and the relevant safety measures
- Selection of the required parts and tools
- Issuing written work orders

Organization of the working team

Selection and instruction of qualified personnel:

- Appointment of a team leader or a technical supervisor
- Determine internal and external specialists to be involved
- Assign a coordinator (between different teams, between operation and maintenance, etc)
- Designate the chief supervisor and determine stationing of safety and security guards

Secure the work prepare for emergency

- Put the plant in a safe status
- If possible, separate activities of production and maintenance in time or space
- Provide safe access to the workplaces (platforms, scaffolds, anti-fall guards, rails)
- Provide appropriate personal protection equipment (PPE)
- Fill out work permit form and obtain the necessary approvals, involve the line management
- Ensure coordination (between different teams, between operation and maintenance, etc)

Important:

- Start work only if it can be done safely
- Ensure coordination and interchanging of information
- Document work progress
- In case of interruptions, do not restart without informing all parties concerned.

Safety Aspects for Preparation and Execution of Work

The Work Permit Form

In order to prevent errors during the execution of work, appropriate systems are applied. An important example is the work permit system, which allows a systematic assessment of the hazards, even in complex situations. The core tool of the system is the work permit form, which should be combined with an instruction sheet on how to use it. Moreover, the permit system requires the training of employees in its application and a clear assignment of responsibilities within the system.

The work permit form comprises a checklist of hazards that are typical for the operation of the company, and the relevant safety measures for the preparation and the execution of the work, as well as the requirements for the documentation of the work. The form must be checked and approved by the line manager in charge before starting the work. The working team receives a copy of the signed form, and must strictly adhere to its specifications. After completion of the work, the copy is returned to the issuer – if necessary with remarks. Only the person who issued the form can approve clearance for start-up after the work.

For certain special types of work, such as entry into confined spaces in vessels, hot work (welding) etc., law requires a permit form. A permit system is a prerequisite for safe execution in complex plants and installations. An example of a work permit form is shown on the following pages. It should be noticed that the specific hazard of an operation must be considered when developing such a form. Therefore, it may be appropriate to use different forms for different plant types or different kinds of work.

Work Permit Form

Scope and Validity

Activity:	**Description of the work:**
❒ Entry into vessel/confined space ❒ Hot work ❒ Construction/Demolition ❒ Other:	....
Location: Plant/Unit: .... Building: .... ☒ Instruction on site Supervisor: .... Tel.: .... ❒ Coordinator required Coordinator: .... Tel.:	**Execution by:** ❒ Plant staff ❒ Facility management ❒ Contractor company: .... Supervision by: .... ❒ Instruction done on: .... by: .... Contractor signature: ....
Duration: on: .... from: .... a.m./p.m. to .... a.m./p.m.	**Signatures:** Approval of the work: .... Approval by plant representative: .... Approval by the coordinator: ....
Extension: on: .... from: .... a.m./p.m. to .... a.m./p.m.	**Signatures:** Approval by plant representative: .... Approval by the coordinator: ....

Work Preparation (mark if applicable, sign when done)

Hazardous materials present ❒ yes ❒ no Last substance in plant: .... toxic / corrosive / irritant / flammable / oxidizing / explosive ❒ emptying ❒ cleaning and rinsing with .... Signature: ____________	**Mechanical drives** ❒ yes ❒ no ❒ switch off Signature: ____________ ❒ lockout/tagout: .... Signature: ____________ **Heating/Cooling System** ❒ yes ❒ no ❒ switch off Signature: ____________ ❒ lockout/tagout: Signature: ____________
Ventilation required ❒ yes ❒ no Duration: .... Type: .... Signature: ____________	**Electrical Installations** ❒ yes ❒ no ❒ isolation ❒ blind fuses ❒ lockout/tagout: Signature: ____________
Monitoring required ❒ yes ❒ no Substance: .... Method: .... Limits: > ..... % Oxygen / ..... % LEL Additional Measures required ❒ no ❒ yes (→ page 2) Signature: ____________	**Radiation Sources** ❒ yes ❒ no ❒ switch off Signature: ____________ ❒ lockout/tagout: Signature: ____________ **Cordoning off/blocking** ❒ yes ❒ no ❒ Access: .... Signature: ____________ ❒ Rails: .... Signature: ____________ ❒ .... Signature: ____________
Pressurized Systems ❒ yes ❒ no ❒ relief Signature: ____________ ❒ isolation by ❒ blanking disk ❒ blind flanges ❒ .... Signature: ____________ ❒ **depressurised** Signature: ____________ **Rescue Measures** required ❒ yes ❒ no ❒ Rescue harness system: .... ❒ Fall protection, fixed at:	**Fire Protection Measures** ❒ yes ❒ no ❒ Covering combustible material and openings within a radius of ... m Signature: ____________ ❒ inform fire brigade Signature: ____________ ❒ Prepare mobile extinguishers in work area Type: ... No.: ... Signature: ____________ ❒ Shut off fire detection system from: ... to: .... h Signature: ____________

Special measures required ❒ no
❒ yes (e.g. check of energy or product pipes, other hazards)
....

Measures to be taken during work (mark if applicable)	
Chemical residues present ❒ yes ❒ no ❒ use dust filter ❒ use dust/gas mask type .... ❒ use SCBA ❒ time limit for filter/SCBA .... ❒ keep filters ready for escape ❒	**Personal Protective Equipment** ❒ Safety glasses ❒ Goggles ❒ Face shield ❒ Gloves; material: .... ❒ Apron ❒ Rubber boots ❒ Full protective suit; material: .... ❒ ....
Explosive atmosphere possible ❒ yes ❒ no ❒ ensure ventilation ❒ monitor the concentration of..................... Test Intervall:	**Fire Hazard** ❒ yes ❒ no ❒ provide a fire guard by ❒ plant ❒ contractor ❒ ....
❒ **Supervision of the work required** provided by ❒ plant ❒ contractor ❒ **Safety guard required** provided by ❒ plant ❒ contractor	
Special Measures required ❒ no ❒ yes (e.g., special requirements for tools, construction materials)	
Work completed as planned ❒ yes Signature: ____________ ❒ Remarks	
FIREBRIGADE NUMBER:	***AMBULANCE NUMBER: ....***
EMERGENCY PLANT NUMBER:	

Approval after Work (mark if applicable, sign when done)	
Tools/instruments/auxiliaries removed ☒ yes Signature:	**Remove cordon/blocking** ❒ yes ❒ no ❒ Access: .... Signature: ____________ ❒ Rails: .... Signature: ____________ ❒........................ Signature: ____________
Mount isolation ❒ yes ❒ no Signature: ______________	
Mechanical drives ❒ yes ❒ no ❒ switch to normal operation Date: .... Signature: ______________	**Radiation specialist** ❒ yes ❒ no ❒ switch to normal operation Date: .... Signature: ____________
❒ **Fire detection system** to be activated .... a.m./p.m. Signature: ______________ **Fire guard** required ❒ yes ❒ no from ..... h to ..... h by .... ❒ Fire brigade/gate/guards informed Signature: ____________	**Electrical power** ❒ yes ❒ no ❒ switch to normal operation ❒... Date: .... Signature: ____________ **Pressurized equipment** ❒ yes ❒ no ❒ leak test ❒ .... Date: .... Signature: ____________
Special measures required ❒ no ❒ yes (e.g. special precautions regarding cleaning, drying of the work area)	
Handover from contractor to plant: Date: .... Signature: ____________ Remarks:	
Work accepted by supervisor: Date: .... Signature: ____________ Remarks:	
Completion confirmed by coordinator: Date: .... Signature: ____________ Remarks:	
Plant clear for operation: Date: .... Signature: ____________ Remarks:	

Safety Aspects for Preparation and Execution of Work

An Example of Safe Shut-Down: The Safety Switch

Many accidents occur under special operating conditions of machines like cleaning, setting-up, retooling, adjusting, or elimination of malfunctions, because the machines are unexpectedly restarted due to human error or technical failures, or because accumulated energy, e.g., loaded springs, pressurized gas, is suddenly released.

Under such operating conditions, hazardous energies must be safely switched off. Stored energies have to be eliminated or secured. However, turning off the main switch is not possible, if e.g., some control functions must remain active during the work. In such cases, a special safety switch should be provided. By means of the safety switch, the energy supply to hazardous elements, e.g., stirrers in vessels, drives of conveyors, etc. can be selectively shut off and the unattended or unauthorized restart of these elements can be avoided. Maintenance and cleaning can be safely carried out under these conditions. The provision of local safety switches for each functional unit eliminates the need for elaborate remote interventions in power supply systems that are sometimes complex.

The basic concept of safety switches for electrical power can be applied to all other auxiliary energies, e.g., vapour, pressurized air, or inert gas supply) or media, e.g., breathing air, water, by locking the respective valves in a defined safety position.

Safety Aspects for Preparation and Execution of Work

Adjustments and Start-up

It is also good practice to install a selection switch for different operating modes of a plant or a machine that can be safely locked in any position.

In the set-up or maintenance mode, the following protection functions must be active:

- The automatic activation of moving parts triggered by sensors must be locked.
- All movements can be activated only by continuous activation of the control switch (self-resetting push button, "dead man's control")
- Hazardous movements of parts are restricted to a "safe mode", e.g., limited speed, reduced power, step mode.
- Combined control of moving parts from different control elements possibly leading to hazardous movements is disabled.

Another highly typical hazard is the sudden start of machines after re-connection to power. In order to prevent this, appropriate safety elements must be applied, e.g., self-opening switches or fuses that disconnect power lines to the actors when pressing the STOP control, the EMERGENCY STOP control, or in case of a power failure, and that can be re-activated only by deliberately pressing the START control. After pressing the EMERGENCY STOP control, restart must be possible only if the EMERGENCY STOP control is unlocked.

Measures after Completion of the Work

After completing the work, the plant must be handed over to the operating unit in a safe and operative status. The work carried out, the replaced parts, and any unresolved problems must be communicated and documented. Many accidents and malfunctions that occurred immediately after handover prove that this is a critical process.

Required Measures after Completion of the Work:

- Clear and tidy up the work area, remove trash and contaminants
- Empty collection pits, re-fill siphons
- Close bleeding valves and secure them
- Re-install safety systems and switch them on
- Disarm temporary safety measures, remove barriers and signposts
- Inform the operating staff about the status of the plant and any changes

Also:

- Check the proper functioning of the plant
- Check all installations, in particular the safety systems
- Clearance for use by the line management of the plant

Important:

- Cleaning agents must be compatible with the construction material and chemical substances to be handled in the plant
- Only authorized personnel may remove interlocks and barriers after completing the work.
- Start-up must not be initiated before clearance for use has been approved

Everybody involved in the change process is responsible for safety - both the maintenance specialists and the operators.

Safety Aspects for Preparation and Execution of Work

The Relevance of the Safety Culture

The safety culture of a company is decisive for successful and sustainable improvements in safety. The high importance of safety that is not sacrificed for short-term profits must be clearly communicated to all employees. Within the framework of company safety standards, each individual has to make the decision to act according to his own responsibility. This requires clear leadership by the management and regular instruction of the employees.

Recently, numerous publications describing new strategies for plant maintenance have appeared. In most cases, the economic factors are the focus of these considerations. However, the human factor should not be overlooked. Why would an operator service a machine or a plant, or check it for unapparent wear and tear when it is still running well? What would be the preconditions necessary for somebody to carry out maintenance work in a safe way, despite the fact that it would increase his workload, in comparison to unsafe behaviour?

» **People act in a way that is more clever than wise.** «

Optimism instead of Prevention

People's thoughts and actions are generally short-term oriented and optimistic: As long as a plant, technical equipment, or procedures work well, people do not care very much about them, and they assume that the present status will continue smoothly into the near future. Their readiness to spend energy in preventive maintenance is low, except when they are aware of a high risk associated with the failure of the system in question. In general, they do not expect to be involved in an accident. "Accidents happen to others, not to us, because we take care!" As most of us think like this, prevention is not inherently ingrained in our minds.

When considering the lessons of numerous accidents (some are presented in this brochure) one would expect that even greater attention would be paid to prevention. Many serious accidents could have been prevented if appropriate precaution had been taken. Unfortunately, our experience has shown just the opposite. Considering the large number of unsafe actions and unsafe situations we are faced with daily, the number of resulting accidents is rather small. We unconsciously learn from this that unsafe behaviour has, in general, no negative consequences, and we underestimate the risks. Thus, as an example, preventive maintenance is forgotten and everything works fine, sometimes even over years. This experience makes us careless. We simply neglect the fact that an accident could happen. Furthermore, we tend to overestimate our capability to control a situation. We believe that we can take corrective action in case of an incipient deviation. However, objects falling from tilting piles on pallets, the spray of hot steam or explosions are always faster!

While underestimating the risks and overestimating their own capability, many people believe that the requirements of accident prevention are inordinate. This must be taken into consideration when taking measures to foster motivation for safe behaviour.

Safety Aspects for Preparation and Execution of Work

Behaviour during Maintenance Work as a Result of a Cost/Benefit Analysis

Our behaviour is driven in general by needs and wishes. We constantly rate alternatives on the basis of costs and benefits. Which action satisfies our needs and wishes most at the lowest cost? The alternative with the best rating is chosen, and if it ends up successfully, the decision is considered to be correct, and we will act in the same way next time. In case of a failure, we will try another alternative next time.

The decision-making mechanism is illustrated in the example below dealing with the elimination of a malfunction without securing the machine. The employee has basically two alternatives:

Safe behaviour:
He switches off the machine according to the manual and starts the corrective action.

- **Advantage: He follows the rules and he can work safely**
- **Disadvantage: It takes more time; it is more tedious and the production loss is higher**

Unsafe behaviour: He carries out the work while the machine is running

- **Advantage: The work takes less time and production loss is negligible**
- **Disadvantage: He violates the rules and is exposed to a higher risk**

What does the cost/benefit analysis look like? The employee estimates the likelihood of various scenarios:

1. Is it likely that I will be injured if I work on the running machine?

   Possible assessment: I know the machine, and I can take care of myself. Thus the likelihood is very small.

2. Is it likely that my supervisor will catch me during the unsafe and illegal action?

   Possible assessment: My supervisor has to do administrative work most of the time. So it is unlikely that he will make a control tour just now.

3. Is it likely that I will be penalized by sanctions, in case the violation of rules is discovered?

   Possible assessment: Basically, it is in the interest of the company to keep production losses as low as possible.

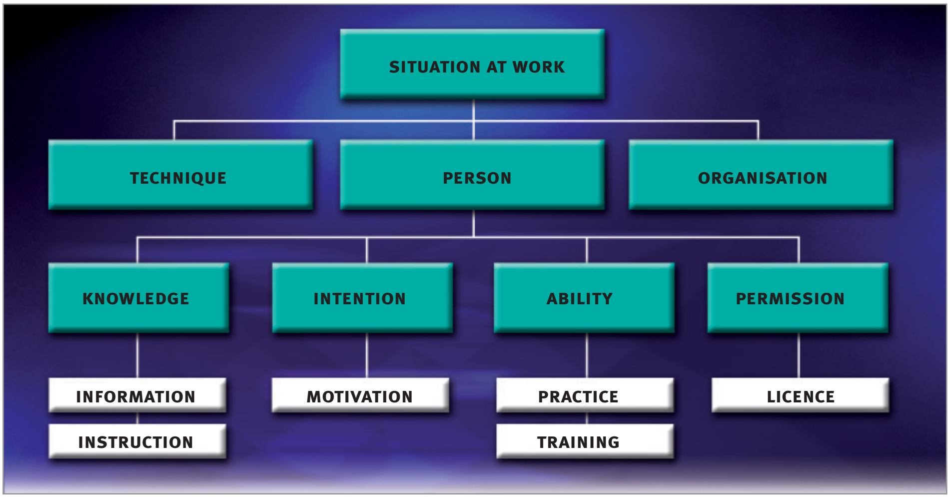
4. Is it likely that the production losses will be noticed if I stop the machine as prescribed?

   Possible assessment: Production losses in that order of magnitude are readily identified.

In practice, this assessment will be made totally unconsciously and very fast. If asked for an explanation, the employee will mention "cost/benefit optimisation." He will prefer the procedure that apparently has a maximum of advantages and a minimum of disadvantages. The decision will depend very much on his experience, his knowledge, and the safety culture of the company. If his assessment looks like that in the example above, he will most likely decide for the unsafe behaviour.

Let us look at the possible effects of a good safety culture on his decision. His assessment under point 2 will be different if the supervisors and managers are present in the plant, and he will certainly assess point 3 differently if unsafe behaviour is not tolerated in the company and violations of the rules are subject to substantial sanctions. Raising the awareness for risks and making it clear that safety and profitability have the same importance in the company can further foster the decision for safe behaviour.

Figure 9:
Psychological factors of safe behaviour



For supervisors this means:

Improvement and Extension of Safety Information and Training for the Staff: It is not sufficient simply to tell the employees what is hazardous. In addition, they must be trained to identify hazards themselves. Therefore, they must also be able to recognize typical errors and pitfalls in assessing risks. Although one can understand people might perceive safety rules as being overly conservative, there must be a clear commitment on the part of management to enforce these rules. The underlying reasons for the rules should be discussed and explained in order to raise acceptance. The negative, even catastrophic, effect of unsafe behaviour for each individual must be made clear. In this respect, case histories of victims of accidents that occurred in similar plants are more effective than elaborate theoretical presentations.

Delegation to specialists: As it is very difficult to foresee everything, it is sometimes necessary to establish the basis for safe work in a short time. This requires a professional use of checklists and other tools by specialists.

Clear Planning: Mankind has been very successful in learning by "trial and error." Improvisation runs in the blood of the human being. However, when it comes to safety, imprudent improvisation must be replaced by clear planning.

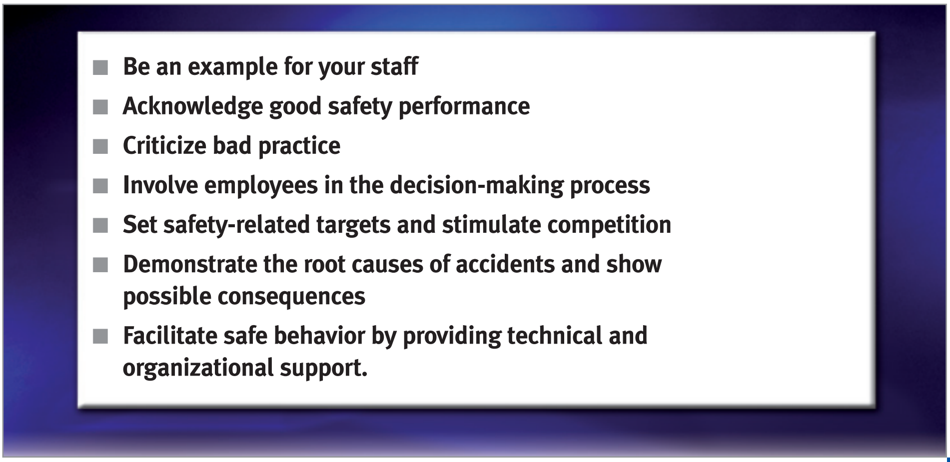
Clear Leadership: Irregular behaviour must not be tolerated. The management has to behave in an exemplary manner and must foster compliance with the rules by compliments and acknowledgment. This implies a regular high profile of the management in the plant.

Taking modern trends into consideration: Highly dynamic technological development gives the impression that preserving maintenance is outdated, because the average lifetime of plant and equipment is getting shorter and shorter. From a safety point of view, the message must be very clear. Even within the limited period of use, preventive maintenance must be carried out systematically.

Involvement: If we expect employees to assume responsibility for safe operation, we must involve them in the decision-making process, in particular in the planning of maintenance.

Feedback: In case of unsafe behaviour, the underlying reasons should be identified. If these reasons are justified, improvements must be made to eliminate this source of accidents. If the reasons are not convincing, they must be clearly rejected and safe behaviour must be enforced.

Figure 10:
Motivation as a key success factor



Case 1

LACK OF SCHEDULING

During excavations at an industrial site, underground power cables were damaged. This resulted in a short circuit and a blackout.

In another case, an excavator broke an underground pipeline for natural gas. Gas leaked out and an explosion occurred.

- *Installations that apparently do not belong to the plant under construction (power cables, gas pipes) may be affected by the work and, consequently, safety can also be affected.*
- *Careful preparation that takes site plans into consideration is required if earthwork is to be carried out.*

Case 2

PUMP UNDER PRESSURE

A pump for circulation of a hot product in a refinery was out of order and had to be repaired. The pump was switched off; the valves on both sides were closed, and the empty space in the pipes between the valves was rinsed.

Nevertheless, when he opened the cover of the pump, the fitter was sprayed with the hot product. In one of the valves, deposits of polymerised product had formed, so that the valve could not be closed tightly. Thus, after emptying and rinsing the pump, the hot product flowed back into it. [9]

- Insufficient hazard analysis before the work.
- Because the cleaning had been done long before the work was started, the system was not in a defined status when the pump was opened.

- *The effectiveness of safety measures (in this case reducing the pressure) must be confirmed immediately before starting the work.*
- *When opening previously used equipment, there is always the risk of a release of residual matter.*
- *A single valve is not sufficient to safely isolate pressurized equipment, in particular if its tightness is doubtful.*

Case 3

Lack of briefing

Welding was to be done during maintenance work on a pipe rack. Since the plant supervisor suffered from acrophobia, he gave instructions to the fitter while he was on the ground floor. Up on the pipe bridge, the fitter mixed up the pipes, and a corrosive liquid leaked out, causing him severe skin burns.

- *Instructions to workers must be given on the spot.*

Case 4

Opening a hot plant

On a dryer for polymer pellets, a rubber collar was leaking and had to be replaced. According to the relevant written procedure, the dryer had to be flushed with nitrogen and the temperature had to be lowered from 180 °C to 50 °C before it was opened. When the dryer was opened, some residual product at the bottom of the dryer caught fire and an explosion occurred.

Examining recorded data, staff later found out that, at 125 °C, the nitrogen had been switched off and the dryer had been opened.

- *Well-meant expediting of the process in violation of clear instructions.*

- *Start work only after process parameters are within the prescribed range.*

Case 5

Mix-up of switches

In a small brewery, the malt was not kibbled as required due to damage to the mill. After this deviation had been identified, there was great concern about the quality of the batch that was being brewed. In this hectic phase, the stirrer drive of the brewing pan was not disconnected from power after stirring. On the following day, the son of the owner started cleaning the pan. He switched on the water and climbed into the container. When the cleaning was finished, he called his mother, to switch off the water pump.

Unfortunately, the switches for the pump and for the stirrer were close to each other. Thus, his mother mixed up the switches and instead of switching off the water, she switched on the stirrer, which normally was safely isolated from power. The man was severely injured, and eventually lost a finger.

- *The plant was not safely isolated from (electrical) energy.*

- *Before starting work, the plant/equipment must be safely cut off from hazardous energies.*

- *Control elements located close to each other are easily mixed-up. Therefore, a clear identification, e.g., colour-coded labels, is necessary.*

Case 6

Erroneously activated stirrer

In a production site for animal food, the operator noticed a malfunction of a mixer. He called the supervisor and informed the plant manager about the deviation. The operator turned off the main switch of the mixer. Then the supervisor opened the mixer for inspection. At this point, the plant manager arrived. He thought that the mixer was not safely isolated from power and was stopped only due to the limit switches of the cover. The colour code on the main switch led to a severe misinterpretation by the plant manager. He thought that the green colour position was "ON". However, the green colour was used to indicate the safe position, i.e., the "OFF" position. Only in this position the switch could have been locked.

He turned the main switch on again, and by doing so, he actually switched the mixer on again. The supervisor's left-hand thumb was squeezed and then sheared off by the mixer arm.

- *The main switch was not locked at the OFF position.*
- *The drive of the mixing arm was directly connected to the main switch; there was no additional switch for selective operation of the arm.*

- *Only qualified personnel may carry out operation of equipment after all involved partners have been informed.*
- *Labelling of safety systems must be clear and "ergonomic".*
- *The isolation of the plant from potentially hazardous energies must be secured against unintended and unexpected reconnection.*

Case 7

UNEXPECTED START-UP

In the inlet funnel of a biogas plant, a water spray system had to be installed in order to improve the smooth transfer of the biomass to the screw conveyor below. A worker was mounting the clamps of the water pipe when a metal part fell into the funnel. He tried to get it out and stepped into the funnel. Suddenly, the conveyor screw started turning, his feet were squeezed and severely injured.

It turned out that an ultrasound sensor mounted above the funnel automatically triggered the screw. When the worker entered the funnel, the sensor sent a "funnel-full signal", which started the screw.

- *Before starting work, the plant/equipment must be safely cut off from hazardous energies.*

Case 8

MIX-UP OF SPARE PARTS

In an autoclave a nitro-compound was reduced with hydrogen to aniline. It was known that the highly exothermic and violent decomposition reaction of the starting material was catalysed by non-ferrous metal. Therefore, the autoclave was made completely from stainless steel. After several weeks of smooth operation, a thermocouple in the autoclave failed. A mechanic of the maintenance staff replaced the sensor, which was mounted inside a protective tube.

When mounting the protective tube with the new sensor, the mechanic, by mistake, used screws made of brass instead of the original steel screws. During the next batch the nitro compound came into contact with the brass and decomposition was induced, leading to a rapid increase in pressure, the rupture of the bursting disk, and the release of chemicals.

- *Segregated storage and specific separate ordering and supply can avoid mixing up spare parts.*
- *The risk of mixing up spare parts can further be reduced by clearly informing the involved employees about the reason for a specific selection of materials.*
- *Where the potential effects of a mix-up are harmful, double checks of the replacement parts by a supervisor should be considered.*

Case 9

Activating a screw conveyor

During a functional check of a dryer, the entire plant, including the heater and the exhaust fan, were switched off. While the dryer was still warm, the maintenance team started to check the feeding screw conveyor. Some residual paste clinging to the screw fell into the dryer, where the solvent evaporated. The pressure increased to such an extent that the bursting disk ruptured and vapour escaped. [9]

- *The checking procedure was not carefully developed and planned.*

- *Functional checks (=changes of the operation mode) are always subject to previous hazard analysis or safety checks.*
- *Possible deviation from the planned procedure (in this case the presence of product residues containing solvent) must be considered in these analyses.*

Case 10

Switching off the heating

A substance with a melting point of 40°C was stored in a heated tank. The tank was inerted with nitrogen. In connection with repair work, the tank was emptied as far as possible and the heating of the pressure control valve was switched off. As a result, the flame arrestor above the pressure control valve was blocked by crystallized material. The pressure in the tank increased due to the continuous inflow of nitrogen, and finally the tank wall was deformed.

- *The protection concept of a plant (in this case pressure control valve and flame arrestor) must be checked for deviations that could jeopardize its proper functioning.*
- *A clear description of the safety concept and of the result of the safety analysis are important parts of the manual and the safety instructions, which allow the employees to identify possible effects in case of interventions.*
- *To ensure a high reliability of safety-critical installations (heating of pressure control valve), a technical monitoring system may be required that shuts down the plant or triggers an alarm in case of failure.*

Case 11

Opening an inerted plant

The conveyor belt of a production plant for polymer intermediates was enclosed in a case in order to reduce the emission of methanol vapour to air. At several points in the case, nitrogen was fed in to avoid the formation of an explosive atmosphere.

When the plant was shut down due to damage elsewhere, the shift supervisor took the "opportunity" to identify the cause of an unusual noise close to the conveyor belt. He opened the inspection flaps without flushing the container first with steam, as prescribed in the relevant procedure. Shortly after opening the flap an explosion occurred.

- *Violation of safety regulations in the alleged interest of the company.*

- *The protection concept (here avoidance of an explosive atmosphere) must be clear to all involved employees.*
- *Even very short interventions (just have a look) can make a safety concept worthless.*
- *There must be one clear message: Nobody will be rewarded for fast but unsafe actions.*

» A safety culture is not based on good will alone; safe behaviour must become second nature to everybody in the company. «

Case 12

Mix-up of flanges

A tar-like substance was stored in a 250-cubic-meter tank. After a long operation period, it was assumed that contaminants had settled in the tank and formed deposits on the bottom. Thus, it was decided to clean the tank. The tank was emptied and then isolated from the rest of the plant. For the cleaning process, a special overpressure protection system together with a pressure indicator in the control room and a new filling line were installed.

In order to dissolve the deposits, hot condensate (approx. 130 °C) was carefully blown into the tank. The overheated liquid evaporated and expanded within the tank. This expansion was expected and the gas should have been released via the overpressure protection system, which had been tested by spot-checks before the cleaning operation. After two hours the tank roof blew off.

It turned out that the overpressure protection system had been connected to the wrong flange on the roof: The system had erroneously been flanged on a dip pipe. With increasing liquid level in the tank (due to the condensate) the gases could no longer escape and the pressure in the tank increased until the roof was torn off.

- *Mix-up of flanges and insufficient checking of the pressure control system.*

- *The correct design and functioning of protective systems must be checked after installation.*

Case 13

Change of vent line

The vent line of a condensate tank ended near a stairway. Due to the emission of vapour at this point, use of the stairway was significantly impeded. Therefore, the vent line was extended over the roof. Due to this extension, the vapour was cooled below the dew point. Because the diameter of the vent line was too narrow, the resulting condensate flooded the line. One day, the line had to be opened for maintenance and the condensate splashed all of a sudden.

- *Plant change without a systematic hazard analysis*

- *Even apparently small changes must be correctly planned.*
- *The safety aspects of any changes in a plant must be systematically assessed.*

Case 14

Change of heating

A thermally instable intermediate was produced in a stirred reactor. The safety concept was based on thermal stability tests performed in a test laboratory, which showed that the decomposition of the intermediate could be safely avoided by maintaining the temperature below 50 °C. The temperature in the reactor was, therefore, continuously monitored, and there was an interlock, automatically switching off the warm water supply to the jacket when the temperature limit was reached.

During a plant change, the bottom outlet of the vessel was equipped with steam heating. The steam system was also connected to the jacket. Normally, steam flew around the bottom outlet and the condensate was returned to the boiler. However, one day, a ball valve in the condensate return line was partially closed. Steam was pressed into the jacket and the reactor content was heated above the critical temperature. A thermal run-away reaction was induced, resulting in an explosion and subsequent fire. Two employees were severely injured; 15 suffered minor injuries. Property damage amounted to several million.

- *The change (steam heating connected to the jacket) was not analysed in view of possible impacts on the safety concept (the jacket temperature was too high).*

- *Even apparently small changes can make a safety concept worthless, and therefore, they must be subject to a hazard analysis.*

Case 15

Prolongation of cleaning frequency

During the routine replacement of a safety valve on a polymerisation vessel, a jet flame shot out. The subsequent investigation revealed that the procedure for rinsing the pipe to the safety valve had been changed recently. After the pipe had been rinsed once a day for years without finding any deposits, it was decided to reduce the cleaning frequency to once per month. During this extended period, a film of so-called popcorn-polymer was formed in the pipe, which, coming into contact with air, spontaneously ignited when the safety valve was replaced.

- *An organizational safety measure (daily cleaning) was changed to save time.*

- *The change of maintenance intervals must be done in small steps and under systematic control of the effects of each step.*

» **Even apparently minor changes and apparent improvements must be subject to a hazard analysis.** «

Case 16

Frozen product pipe

Acrylic acid was stored in an outside tank. In order to ensure an even distribution of the inhibitor and control the temperature, the acid was constantly circulated through an external heat exchanger. The pipes of this circuit traversed the neighbouring building.

One day, a power failure occurred. The circulation pump stopped, and the heating in the building also failed. The temperature decreased in short time, because part of the building roof had been removed due to ongoing construction work. In the non-isolated parts of the piping, the acrylic acid crystallized and blocked the pipe. The temperature control was mounted in an area where the acid was still liquid, and thus, the local crystallization could not be identified in the control room. After about 20 minutes, the plant was started again. Due to the blockage, the pump became overheated and the strongly exothermic polymerisation of acrylic acid was initiated in the pump. After re-melting of the crystals in the pipe, the circuit apparently worked properly again, but polymer germs were now transferred from the pump to the tank where they further catalysed the polymerisation. After an induction period of four days, the polymerisation self-accelerated to a run-away and led to the rupture of the tank and a subsequent fire.

- *The effect of the change in the neighbouring building (open roof) on the safety concept of the tank was not identified. The combination of two deviations (open roof, power failure) had not been taken into consideration.*

- *Changes, e.g., construction work in the neighbourhood may have an impact on the safety concept of plants.*
- *Temporary changes (open roof) must be analysed as carefully as permanent changes.*
- *Often, hazardous situations are the result of the combination of several factors and deviations.*

Case 17

FROZEN VENTING PIPE

In a tank farm for liquefied gas, a spherical container was subjected to a pressure test with water. During the test, steam entered the off-gas pipe network, through which the gases were conducted to an off-gas incineration unit. Due to the very low outside temperature, ice formed in the valves and the network was blocked.

Shortly after this, another sphere was depressurised, and gas flowed back into the first sphere because the pipes to the incinerator were blocked. As some flanges were leaking, gas escaped, causing an explosion hazard. The situation was brought under control by immediate heating of the frozen valves with steam.

- *The combination of external conditions (weather, low temperature) with humidity was not taken into consideration.*

- *Auxiliary material must be removed from the plant after the maintenance.*
- *The effect of external conditions on substances and auxiliary media must be considered in all operating modes.*

Case 18

Non-coordinated trouble shooting

A malfunction occurred in a packing machine in a dairy. The fitter was called to eliminate the problem. After a short time, the machine was repaired. The fitter closed the protective covers and gave his OK for re-starting the machine.

After a few operating cycles, the malfunction occurred again. The fitter immediately removed the protective shields. However, assuming the operator had noticed the problem, he did not secure the machine against restart. Also, he had not formally organized the second interruption with the production staff. Since the operator could not see the fitter, he switched the machine on again for another cycle. Since the fitter was already working inside the machine frame, he was hit by moving parts and suffered severe head injuries.

- *Starting work on a machine without clear communication between maintenance and operating staff.*
- *Machine not secured against re-start.*

- *Work must not be started/continued until all concerned parties are informed.*
- *Machines with potentially hazardous energies must be secured against unintended and unexpected restart.*

Case 19

Acetone in chlorine pipe

After extensive maintenance work on a chlorine pipe, the pipe was cleaned with acetone. After operation had been resumed, a violent reaction between chlorine and residual acetone occurred. The reaction resulted in self-ignition and a fire inside the pipe. This so-called chlorine-iron fire is well known in connection with chlorine pipes, where chlorine comes into contact with organic material. [9]

- *Hazardous interaction between chemicals, construction materials and auxiliary media (cleaning agents) should be systematically identified using a hazard matrix.*

Case 20

COVERED FLANGES

A storage container with a volume of 1,000 m^2 was prepared for scrapping. It was cleaned with water and steamed. In order to reduce the emission of malodorous fumes, somebody had covered the open flanges with aluminium foil.

During a violent thunderstorm, the temperature decreased rapidly. The vapour inside the tank condensed on the cold walls. As the foil impeded the inflow of air through the flanges, the pressure inside fell below the critical level and the container collapsed. Property loss would have been substantial if the plant had not been decommissioned anyway.

- *Well-meant action (covering the flanges to reduce emissions) foiled the safety concept.*

- *Ad-hoc interventions are not permitted; such actions must be coordinated and analyzed with all involved parties.*
- *Weather effects are to be considered in all open air plants.*

Case 21

NON-FILLED SIPHON

In a production plant for dyestuffs, a fan had to be replaced in an off-gas duct. During the repair work, the water in a hydraulic seal was removed. Therefore, there was a direct connection between the off-gas line and the sewerage system of the plant. The water was not replenished before restarting the plant. Thus phosgene - a highly toxic by-product of the reaction - escaped into the sewerage system.

- *Maintenance staff: Reactivate safety installations after the work.*
- *Operators: Control the work and the plant after handover.*
- *Plant designers: Facility function check of safety installations according to appropriate design.*

Case 22

Forgotten grounding connections

After completion of maintenance work in a transformer unit of a power plant, the service team in charge of the operation approved the relevant net element for operation, despite the fact that the grounding connections mounted during the maintenance work had not been completely removed. This resulted in a short circuit, which led to a substantial blackout.

- *Maintenance staff: Deactivate temporary safety installations after the work.*
- *Operators: Check the work and the plant after handover.*
- *Plant Designers: Consider the effect of a local short-circuit on the entire network*

Case 23

Omitted packing parts

The SO_3 gas produced during the distillation of oleum was absorbed in a packed column operated with sulfuric acid. During repair work on the column, some packing parts fell to the bottom of the column, from which they were flushed into the bottom outlet. The pipe was blocked and the column slowly filled with sulfuric acid. When the liquid level reached the gas inlet, a violent reaction occurred. The glass column broke and gas escaped.

- *Maintenance staff: After completion of the work, foreign bodies, tools, contaminants and auxiliary materials must be removed from the plant.*
- *Operators: Control the work and the plant after handover.*
- *Plant Designers: Overfilling protection must be carried out.*

Case 24

Forgotten protective tube

During the revision of a storage tank, the technician in charge took the level meter out of the protective tube, removed it and stored it in a safe place. Since the protective tube obstructed further work, a fitter, who disposed of it without proper labelling, removed it later. After the work was done, the level meter was re-installed without the protective tube. The cable holding the instrument was, therefore, exposed to corrosive media in the container and was damaged. [9]

- *Maintenance staff: Coordination of the work between different teams is very important. Check the work and the plant before handover.*
- *Operators: Check the work and the plant after handover.*

Case 25

Cover not fixed

Two filters were operated in "tandem-mode", i.e., the product flow was alternately directed to one or the other. Shortly after repair and cleaning of one of the filters, a leak occurred, and a reaction mixture spilled below the splash-shield on the filter.

It turned out that the maintenance work had not been completed. Actually, the filter had been left open and warning tags were put on it. Three days after cleaning, somebody provisionally shut the cover of the filter, closed the splash-shield and removed the warning tags. So the filter looked as though it was ready for operation, although the cover was not fixed. There were no written instructions for re-starting the operation of the filter. [9]

- *Never remove warning tags without consultation.*
- *Operators: Do not start operation until after the work and the plant have been checked and formal clearance has been given.*

Further accidents are described in Ref [4].

Glossary

Hazard and Risk

In common daily speech the terms hazard, hazard potential and risk are used with varying meanings, often depending on local costoms. In this brochure, the definitions below are used following international standards:

Risk refers to the hazard considered. It is a function of the extent of the potential damage and the probability of occurrence of the damage. The risk is evaluated based on a risk analysis and a risk assessment. (see EN 1050)

Safety Concept

The safety concept of a plant consists of all technical and organizational measures – including human factors – which ensure safe operation.

Maintenance

Maintenance comprises all technical and administrative measures that either preserve or restore the faultless functioning of a plant, an installation, or a machine. This consists of preventative maintenances, including servicing and functional checks, and corrective maintenance, including repair and elimination of malfunctions.

Changes of plants, installations or procedures

The term change comprises all permanent and temporary alterations of plants, installations, or related procedures, by which

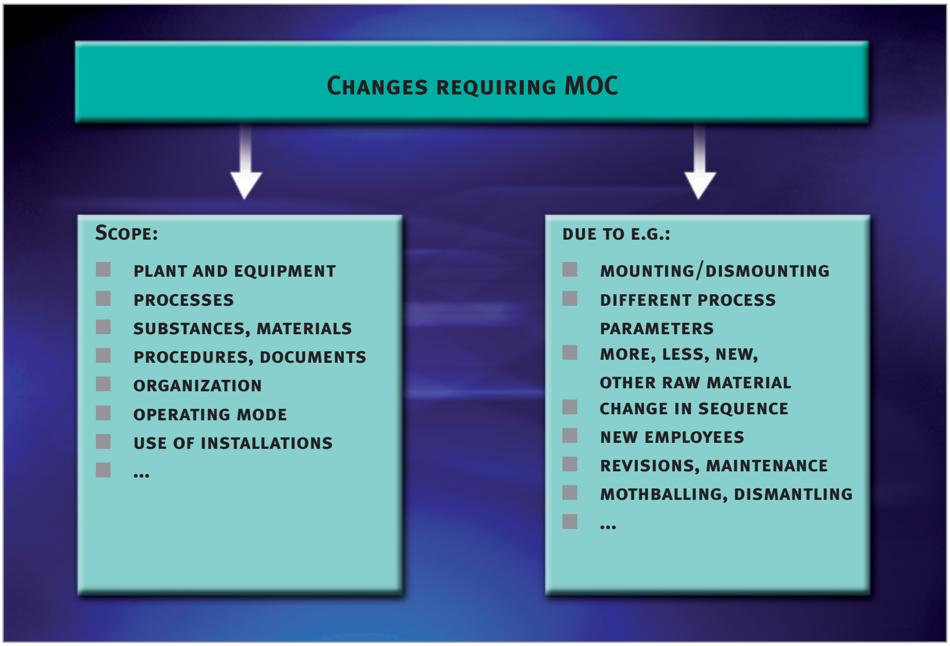
- Buildings or structures
- Apparatus, pipes, and installations as well as their use
- Defined process parameters, e.g., pressure, temperature, hold times
- Manuals, instructions, e.g., regarding intervals for cleaning and servicing
- Construction materials
- Safety-relevant functions and instruments
- Capacities and emissions

are modified, added or eliminated and which have an effect on the safety or the operation permit. Changes include also test runs, mothballing and scrapping.

Moreover, the term change also includes alterations related to

- Organization
- Contractors
- Infrastructure
- Down-sizing or expansion of the staff or substantial alterations of the responsibility
  - in production or maintenance
  - of safety specialists and/or members of the emergency services, e.g., due to increased complexity of plants

Changes is thus used both for apparently small modifications that require only minor interventions and safety measures, and for substantial technical or organizational alterations associated with extensive planning and work activities.



Management of Change (MOC)

MOC is a systematic process to ensure the transition from an initially safe state to a new – again safe – state, along a safe path. The new state may be permanent or temporary.

Safety Switch

In this brochure the term safety switch is used for switches that allows selectively cutting off of the energy supply to hazardous elements, e.g., stirrers in vessels, drives of conveyors, etc., and to avoid the unattended or unauthorized restart of these elements [5]. While the entire system or machine is switched off when the main switch is turned off, control elements, which must remain in operation during maintenance or checks, remain activated when the safety switch is turned off. Other terms used for this type of switches are [6]: revision switch, servicing switch, repair switch etc.

References

Brochures and Publications

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[6] Schalteinrichtungen für die Sicherheit der an der Maschine tätigen Personen.
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[9] Database www.dechema.de/ereignis_db

Standards

EN 1050	Safety of machinery – Principles for risk assessment
EN 13306	Maintenance terminology
EN ISO 12100	Safety of Machinery – Basic terminology and methodology
EN ISO 13849	Safety of machinery -– Safety-related parts of control systems
IEC 60204	Safety of Machinery – Electrical Equipment of Machines
IEC 60447	Basic and safety principles for man-machine interface
IEC 60812	Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)
IEC 61882	Hazard and Operability Studies (HAZOP Studies)
ISO 4413	Hydraulic fluid power
ISO 4414	Pneumatic fluid power
ISO 14118	Safety of Machinery – Prevention of Unexpected Start-Up

Notice

Notice

Notice

THE ISSA AND THE PREVENTION OF OCCUPATIONAL ACCIDENTS AND DISEASES

The ISSA Permanent Committee on the Prevention of Occupational Risks and Diseases brings together occupational safety specialists from all over the world. It promotes international cooperation in this field. It coordinates the activities of the eight international sections for the prevention of occupational risks and diseases, which are active in various industries and in agriculture, and which have their secretariats in various different countries. Three further sections are concerned with information technology in the field of occupational safety, with relevant research, and with education and training for the prevention of occupational accidents and diseases.

The activities of the international sections of the ISSA comprise:

- the international exchange of information between bodies concerned with the prevention of occupational risks,
- the organization of meetings of committees and working parties, round-table discussions, and colloquia at international level,
- the performance of surveys and studies,
- the promotion of research,
- the publication of pertinent information.

MEMBERSHIP OF THE INTERNATIONAL SECTIONS

Each international section of the ISSA has three categories of members:

- Full Member
  Full members and associate members of the ISSA, Geneva, and other non-profit organizations can apply for membership as a Full Member.
- Associate Member
  Other organizations and companies can become Associate Members of a section if they have specialized knowledge of the area for which the section is responsible.
- Correspondent
  Individual experts can become Corresponding Members of a section.

Further information and application forms are available directly from the secretariats of the individual sections.

AT LEAST ONE OF THESE ISSA SECTIONS ON THE PREVENTION OF OCCUPATIONAL RISKS CORRESPONDS TO YOUR OWN FIELD OF INTEREST: DO NOT HESITATE TO CONTACT ITS SECRETARIAT

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