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		JULY 2011
KLM Technology Group #03-12 Block Aronia, Jalan Sri Perkasa 2 Taman Tampoi Utama 81200 Johor Bahru Malaysia	SAFETY in PROCESS EQUIPMENT DESIGN (ENGINEERING DESIGN GUIDELINE)	Author: Rev 01 Aprilia Jaya
		Checked by: Karl Kolmetz

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INTRODUCTION

Scope

This design guideline covers the process safety issues in process equipment design including chemical, petrochemical, and hydrocarbon processing facilities. It helps engineers understand the basic design of process safety and increases their knowledge in prevention and reduces the risk that an accident might happen.

All the important parameters used in this guideline are well explained in the definition section which helps the reader understand the meaning of the parameters and the terms used.

The design consideration discusses methods of safety; 1. Inherent safety, 2. Hazard and Operability Analysis (HAZOP), 3. Material hazards and 4. Fire protection. The theory section includes the design process based on the material, fire protection, and explosion; including plant and unit layout, equipment spacing. Additionally an equipment review in which accidents might happen - such as a storage tank, distillation tower, reactors, piping systems, flare and flare piping systems.

It is clear that choices made early in design can reduce the possibility for large releases and can reduce the effects of releases by considering the variety of mitigation measures used to reduce the severity of the effects of a release,

The design of safety on process equipment may be influenced by factors, including process requirements, environmental regulations, location, process materials involved, make the process operations friendly and economic.

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General Design Considerations

The comparison of the safety of equipment is not straight forward. It depends on several features of both the process and the equipment. It can be evaluated from quantitative accident and failure data and from best engineering practice and recommendations.

Unit operations may include physical operations and further processing or preparation for further reactions or for shipment. These operations include mixing or separating, size reduction or enlargement, and heat transfer. General hazards in physical operations are:

1. Vaporization and diffusion of flammable liquids and gases
2. Spraying or misting of flammable liquids
3. Dispersion of combustible dusts
4. Mixing highly reactive chemicals
5. Increase in the temperature of unstable chemicals
6. Friction or shock of unstable chemicals
7. Pressure increase in vessels
8. Loss of inertant or diluents

Some of the safety elements that can be included on the flow sheets are:

1. Process materials properties
2. Process conditions (pressure, temperature, composition)
3. Inventory
4. Emergency and waste releases
5. Process control philosophy

When considering the design aspects of a project, it can be identified three approaches to fault management that are of particular importance:

1. System Architecture The system architecture has an enormous effect on the ability of a system to tolerate faults within it. It can provide some protection

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- against random component failure and some forms of systematic fault. It does not usually tackle the problems associated with specification faults.
2. Reliability Engineering. This is primarily concerned with the susceptibility of a system to random hardware component failures. However, some engineers believe that these techniques may also be applied to some systematic faults.
 3. Quality Management Considerations of quality cover all aspects of a system's life and are therefore of great importance to fault management.

In addition, good plant operating practice would include

1. Written instruction in the use of the hazardous substances and the risks involved.
2. Adequate training of personnel.
3. Provision of protective clothing and equipment.
4. Good housekeeping and personal hygiene.
5. Monitoring of the environment to check exposure levels. Consider the installation of permanent instruments equipped with alarms.
6. Regular medical checkups on employees, to check for the chronic effects of toxic materials.
7. Training of local emergency response personnel.

Certain types of processes, process conditions, or fluids handled introduce factors which affect the safety of the plant. These factors must be taken into consideration in the design. They include:

1. High-severity operating conditions, e.g., extremes of temperature or pressure.
2. Batch or cyclic processes or processes undergoing frequent startup and shutdown, where the opportunities for operating error are greater than normal.
3. Processes subject to frequent upsets by integration with other plants or where dangerous conditions may arise from utility failures.
4. Unstable processes, in which decompositions, temperature runaways, or other unstable reactions are possible

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5. Fluid solids processes, in which stable and safe operations depend on the effectiveness of fluidization of solids to prevent reverse flow, e.g., catalytic cracking.
6. Fluid properties and characteristics such as flammability, vapor pressure, auto-refrigeration, corrosion, erosion, toxicity, and chemical reactivity, including the variations in these properties which may occur at abnormal operating conditions.
7. Start up or shut down is an infrequent activity. Therefore, startup and emergency/normal shutdown procedures must be as simple and logical as possible. This must be incorporated into design considerations.
8. High noise evolution may pose communications problems and impair operator performance by creating additional stress.

Inherent safety

The inherent safety is the pursuit of designing hazards out of a process, as opposed to using engineering or procedural controls to mitigate risk. Therefore inherent safety strives to avoid and remove hazardous material and the number of hazardous operations in the plant rather than to control them by added-on systems. The inherent safety is best considered in the initial stages of design, when the choice of process route and concept is made.

Kletz (1984, 1991) has given Basic Principles of Inherent Safety as follows:

1. Intensification: Inventories can often be reduced in almost all unit operations as well as storage. This also brings reductions in cost, while less material needs smaller vessels, structures and foundations.
2. Substitution: Using a safer material in place of a hazardous one decreases the need for added-on protective equipment and thus decreases plant cost and complexity. It may be possible to replace flammable refrigerants and heat transfer with non-flammable ones, hazardous products with safer ones, and processes that use hazardous raw materials.
3. Attenuation: Carrying out a hazardous reaction under less hazardous conditions, or storing or transporting a hazardous material in a less hazardous form. Attenuation is sometimes the reverse of intensification, because less extreme reaction conditions may lead to a longer residence time.
4. Limitation of Effects: For instance equipment is designed so that it can leak only at a low rate that is easy to stop or control. Limitation of effects should be done by

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- equipment design or change in reaction conditions rather than by adding on protective equipment.
5. Simplification: Simpler plants are inherently safer than complex plants, because they provide fewer opportunities for error and contain less equipment that can go wrong. Simpler plants are usually also cheaper and more user friendly.
 6. Change Early: Identification of hazards as early as possible in the process design. The payback for early hazard identification can make or break the capital budget of a new process. This can be achieved by dedicated safety evaluation methodologies which are designed for preliminary process design purposes.
 7. Avoiding Knock-On Effects: Safer plants are designed so that those incidents, which do occur, do not produce knock-on or domino effects.
 8. Making Status Clear: Clear explanation of the chemistry involved in the process helps operating personnel to identify possible hazards.
 9. Making Incorrect Assembly Impossible: Assembled components must meet their design requirements so that incorrect assembly is difficult or impossible
 10. Tolerance: Equipment should tolerate mal-operation, poor installation or maintenance without failure.
 11. Ease of Control: A process should be controlled by the use of physical principles rather than added-on control equipment.
 12. Administrative Controls: Human error is the most frequent cause of the loss of containment. Training and certification of personnel on critical procedures are permanent considerations.

Factors Selected to Represent the Inherent Safety in Preliminary Process Design:

1. Heat of Reaction: Reactions in which large quantities of heat or gas are released are potentially hazardous, particularly during fast decomposition or complete oxidations.
2. Hazardous Substances: Hazardous substances present in the process are identified on the basis of their flammability, explosiveness and toxicity.
 - a. Flammability: The flammability of liquids depends on the lower flammability limit of the material and its vapor pressure in prevailing temperature. The liquid which has a flash point below the processing or storage temperature can give rise to a flammable mixture and is generally considered hazardous.

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- b. Explosiveness: The use of industrial chemicals with less explosive potential makes the process more intrinsically safe. Most dangerous explosions come from large clouds of flammable material which find an ignition source.
 - c. Toxic Exposure: The toxic hazard is a measure of the likelihood of such damage occurring. It is determined by the frequency and duration of such exposure and the concentration of the chemical in exposure.
3. Corrosiveness: Corrosion reduces the reliability and integrity of plant. It reduces the strength of materials and causes leaks. Corrosion products affect process materials, moving parts, process efficiency and cause fouling. In the design of equipment corrosion is taken into account by the selection of material and corresponding corrosion allowance.
4. Chemical Interaction: Chemical interaction is based on the chemical reactivity of each substance with other substances present in the plant. As a potential process hazard, the chemical reactivity of any substance should be considered in the following contexts:
 - Reactivity with elements and compounds with which it is required to react in the process
 - Reactivity with atmospheric oxygen
 - Reactivity with water
 - Reactivity with itself, i.e. its propensity to polymerize, condense, decompose and explode
 - Reactivity with other materials, with which it may come in contact unintentionally in process, storage or transport
 - Reactivity with materials of construction, i.e. its corrosivity
5. Temperature: The use of high temperatures in combination with high pressures greatly increases the amount of energy stored in the plant. There are severe problems with materials of construction in high temperature plants That can make thermal stresses also in low temperature. These stresses need to be allowed for and, as far as possible, avoided.
6. Pressure: The use of high pressure greatly increases the amount of energy available in the plant. Whereas in an atmospheric plant stored energy is mainly chemical, in a high pressure plant there is in addition the energy of compressed permanent gases and of fluids kept in the liquid state only by the pressure.

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7. Equipment safety: Equipment safety tries to measure the possibility that a piece of equipment is unsafe. Equipment safety considers the safety of the equipment as such without interactions through the process with other equipment.
8. Safe Process Structure: The safe process structure means which operations are involved in the process and how they are connected together. It also describes how auxiliary systems such as cooling, heating or relief systems should be configured and connected to the main process. Therefore the safe process structure describes the safety of the process from system engineering point of view.

Hazard and Operability Analysis (HAZOP)

Hazard and Operability Analysis (HAZOP) is one of the most used safety analysis methods in the process industry. It is one of the simplest approaches to hazard identification. HAZOP involves a vessel to vessel and a pipe to pipe review of a plant. HAZOP is based on guide words such as no, more, less, reverse, other than, which should be asked for every pipe and vessel. HAZOP can be used in different stages of process design but in restricted mode.

A HAZOP is used to question every part of the process to discover what deviations from the intention of the design can occur and what their causes and consequences maybe. This is done systematically by applying suitable guide words. This is a systematic detailed review technique for both batch and continuous plants which can be applied to new or existing processes to identify hazards. A HAZOP study requires considerable knowledge of the process, its instrumentation, and its operation. The HAZOP procedure illustration can be shown in figure 1. A HAZOP study has three steps:

1. Defining the process
This step identifies the specific vessels, equipment, and instrumentation to be included in the HAZOP study and the conditions under which they are analyzed.
2. Performing the study
A HAZOP study focuses on specific points of a process called "study nodes," process sections, or operating steps. Depending on the experience of the study leader, the portion of a process included in a single study node can vary. The HAZOP team examines each study node for potentially hazardous process deviations. Process deviations are determined by combining guide words with the important process parameters. The established set of guide words is shown in Table 1.

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3. Documenting the results

The documentation of a HAZOP study is a systematic and consistent tabulation of the effects of process deviations. The study generates narratives about the normal operating conditions and analysis boundary conditions for each equipment item.

The effectiveness of a HAZOP will depend on:

1. The accuracy of information (including process and instrumentation diagrams P&IDs) available to the team information should be complete and up-to-date
2. How well the team is able to use the systematic method as an aid to identifying deviations
3. The maintaining of a sense of proportion in assessing the seriousness of a hazard and the expenditure of resources in reducing its likelihood
4. The competence of the chairperson in ensuring the study team rigorously follows sound procedures.

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Table 1: Guide Words for HAZOP studies

Guide Word	Meaning	Example
None of	Negation of Intention	No forward flow when there should be. Sequential process step omitted.
More of	Quantitative Increase	More of any relevant physical parameter than there should be, such as more flow (rate, quantity), more pressure, higher temperature, or higher viscosity. Batch step allowed to proceed for too long.
Less of	Quantitative Decrease	Opposite of "MORE OF"
Part of	Qualitative Decrease	System composition different from what it should be (in multi-component stream).
As well as	Qualitative Increase	More things present than should be (extra phases, impurities). Transfer from more than one source or to more than one destination.
Reverse	Logical Opposite	Reverse flow. Sequential process steps performed in reverse order.
Other than	Complete Substitution	What may happen other than normal continuous operation (start-up, normal shutdown, emergency shutdown, maintenance, testing, sampling). Transfer from wrong source or to wrong destination.

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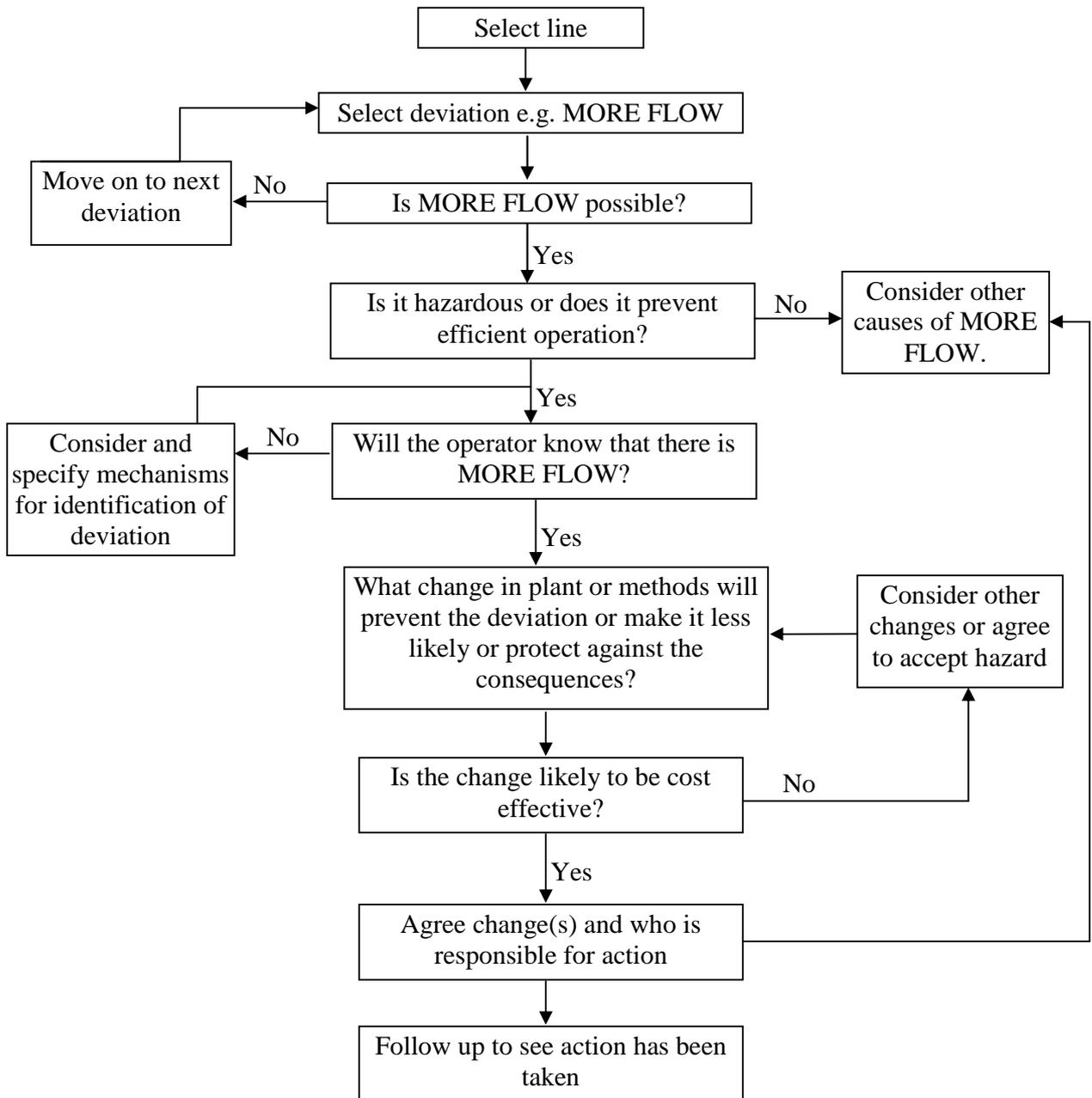


Figure 1: HAZOP Procedure Illustration

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Material Hazard

Information about the chemicals used in a process, as well as chemical intermediates, must be comprehensive enough for an accurate assessment of fire and explosion characteristics, reactivity hazards, safety and health hazards to workers, and corrosion and erosion effects on process equipment and monitoring tools. The information of material can be summarized in document of Materials Safety Data Sheet (MSDS).

The MSDS contains the information needed to begin analyzing materials and process hazards, to understand the hazards to which the workforce is exposed, and to respond to a release of the material or other major incident where emergency response personnel may be exposed to the material.

The process design engineer should always collect the MSDS of every component used in the process, including solvents, acids, bases, adsorbents, etc., at as early a stage in the design as possible. The information in the MSDS can be used to improve the inherent safety of the process, for example, by eliminating incompatible mixtures or substituting less hazardous chemicals as feeds, intermediates, or solvents. The MSDS information can also be used to ensure that the design meets regulatory requirements on vapor recovery and other emissions. The MSDS usually contains the following sections:

1. Chemical product and company information: chemical name and grade; catalog numbers and synonyms; manufacturer's contact information, including 24-hour contact numbers.
2. Composition and information of ingredients: chemical names, CAS numbers and concentration of major components of the product.
3. Hazards identification: summary of the major hazards and health effects.
4. First aid measures: procedures for contact with eyes and skin or by ingestion or inhalation.
5. Firefighting measures: information on firefighting, extinguishing media, flammability data, National Fire Protection Association ratings.
6. Accidental release measures: procedures for dealing with leaks or spills.
7. Handling and storage: procedures for transfer, storage, and general use of the material.

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8. Exposure controls and personal protection: required engineering controls such as eyewashes, safety showers, ventilation, etc.; OSHA PEL data; required personal protective equipment.
9. Physical and chemical properties. Information must include, at a minimum:
 - a. Toxicity information
 - b. Permissible exposure limits
 - c. Physical data such as boiling point, freezing point, liquid/vapor densities, vapor pressure, flash point, autoignition temperature, flammability limits, solubility, appearance, and odor
 - d. Reactivity data, including potential for ignition or explosion
 - e. Corrosivity data, including effects on metals, building materials, and organic tissues
 - f. Identified incompatibilities and dangerous contaminants
 - g. Thermal data (heat of reaction, heat of combustion).
10. Stability and reactivity: conditions that cause instability, known incompatible materials, hazardous decomposition products.
11. Toxicological information: acute effects, LD50 data, chronic effects, carcinogenicity, teratogenicity, mutagenicity.
12. Ecological information: ecotoxicity data for insects and fish, other known environmental impacts.
13. Disposal considerations: requirements for disposal under the Resource Conservation and Recovery Act (RCRA; see Chapter 14).
14. Transport information: shipping information required by the U.S. Department of Transport as well as other international bodies.
15. Regulatory information: U.S. federal and state, European, Canadian, and international regulations listing the material; includes TSCA listing, Clean Air Act, and Clean Water Act limits.
16. Additional information: date of creation and revisions, legal disclaimers.

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Table 2: Typical material characteristic

Property	Characteristics
General Properties	Boiling point Vapor pressure Freezing point Molecular weight Critical pressure and temperature Electrical conductivity Fluid density and viscosity Thermal properties enthalpy, specific heat, heat of mixing
Reactivity	Reactivity with water or air Potential for sudden violent reaction Sensitivity to mechanical or thermal shock Polymerization Compatibility with materials of construction and other process materials
Flammability	Flash point Autoignition temperature Flammability limits Self -heating Minimum ignition energy
Toxicity	Threshold limit values Emergency exposure limits Lethal concentration Lethal dose Exposure Effects
Stability	Thermal stability Chemical stability Shelf life Products of decomposition

The design engineer should consider the preventative aspects of the use of hazardous substances.

1. Substitution: of the processing route with one using less hazardous material or substitution of toxic process materials with nontoxic or less toxic materials. Replacement of volatile organic solvents with aqueous systems or less hazardous

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- organic materials improves safety of many processing operations and final products.
2. Containment: sound design of equipment and piping, to avoid leaks. For example, specifying welded joints in preference to gasketed flanged joints that are liable to leak or suffer materials incompatibility problems.
 3. Prevention of releases: by process and equipment design, operating procedures and design of disposal systems.
 4. Ventilation: use open structures or provide adequate ventilation systems.
 5. Disposal: provision of effective vent stacks to disperse material vented from pressure relief devices or use of vent scrubbers. Collection and treatment of sewer and runoff waters and liquids collected from relief systems.
 6. Emergency equipment and procedures: automated shutdown systems, escape routes, rescue equipment, respirators, antidotes (if appropriate), safety showers, eye baths, emergency services.

Fire Protection

Fire protection systems are expected to meet a combination of purposes. Designing a fire protection system requires knowing the purposes it must serve.

To prevent the fire accidents, the performance equipment design should be planned very well. The Guide presents a process for performance-based design centered around the following major steps:

1. Defining the Project Scope
2. Identifying the Fire Safety Goals
3. Defining Stakeholder and Design Objectives
4. Developing Performance Criteria
5. Developing Design Fire Scenarios
6. Developing Trial Designs
7. Evaluating Trial Designs
8. Selecting the Final Design

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When a fire detection system is needed, the following guidelines should be followed to ensure acceptable performance:

1. Review possible fire scenarios: what fuels are involved, where the fire might start, how fast it might spread.
2. Where the rapid spread of the fire is likely, automatic actuation of protective systems should be specified.
3. When a flame detector is used, a dual sensor IR-IR or UV-IR flame detector is preferred to reduce the potential for false alarm and is required when the detector will automatically activate a suppression system.
4. IR flame detectors are preferred for hydrocarbons. When the fuel contains little or no carbon, a single UV detector or heat detector is preferred.
5. Flame detectors should be located no greater than 35 ft (10 m) from possible fire sources. Flame detectors should be positioned to see the base of the fire not just the flames above it.
6. Enough flame detectors must be deployed to avoid blind spots and to account for loss in sensitivity away from the detector's central axis.
7. To avoid false alarms from sources outside the risk area, flame detectors should not have a view of the horizon.

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Figure 2: Failure in Safety Management

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DEFINITIONS

Accident - An event or sequence of events that results in undesirable consequences

Back Pressure - The pressure on the discharge side of a pressure relief valve. Total back pressure is the sum of superimposed and built-up back pressures.

Bonding – The permanent joining of metallic part to form an electrically conductive path which will assure electrical continuity and the capacity to safely conduct any current likely to be imposed.

Continuous Reactors - Reactors that are characterized by a continuous flow of reactants into and a continuous flow of products from the reaction system. Examples are the Plug Flow Reactor and the Continuous-flow Stirred Tank Reactor

Design Capacity - The capacity used to determine the required area of a relief device based on the limiting contingency.

Design pressure - The pressure in the equipment or piping under consideration at the most severe combination of coincident pressure, temperature, liquid level and vessel pressure drop expected during service, which results in the greatest required component thickness and the highest component rating

Explosion - A release of energy that causes a pressure discontinuity or blast wave.

Failure - An unacceptable difference between expected and observed performance.

Flammability Limits - The range of gas or vapor amounts in air that will burn or explode if a flame or other ignition source is present.

Flash point - The lowest temperature at which a liquid exposed to the air gives off sufficient vapor to form a flammable mixture near the surface of the liquid, or within the test apparatus used, that can be ignited by a suitable flame.

Hazard - An inherent chemical or physical characteristic that has the potential for causing damage to people, property, or the environment. In this document it is typically the combination of a hazardous material, an operating environment, and certain unplanned events that could result in an accident.

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Hazard Analysis - The identification of undesired events that lead to the materialization of a hazard, the analysis of the mechanisms by which these undesired events could occur and usually the estimation of the consequences.

Hazard and Operability Study (HAZOP) - A systematic qualitative technique to identify process hazards and potential operating problems using a series of guide words to study process deviations.

Hazardous Material - In a broad sense, any substance or mixture of substances having properties capable of producing adverse effects of the health or safety of human beings.

Human Error - Any human action (or lack thereof) that exceeds some limit of acceptability (that is, an out-of-tolerance action) where the limits of human performance are defined by the system.

Inert Gas - A noncombustible, nonreactive gas that renders the combustible material in a system incapable of supporting combustion.

Inherently Safe - A system is inherently safe if it remains in a nonhazardous situation after the occurrence of nonacceptable deviations from normal operating conditions.

Intrinsically Safe - Equipment and wiring which is incapable of releasing sufficient electrical or thermal energy under normal or abnormal conditions to cause ignition of a specific hazardous atmospheric mixture or hazardous layer.

Maximum Allowable Working Pressure (MAWP) - Is the maximum (gauge) pressure permissible at the top of a vessel in its normal operating position at the designated coincident temperature and liquid level specified for that pressure.

Operating pressure - The gauge pressure to which the equipment is normally subjected in service.

Overpressure - Overpressure is the pressure increase over the set pressure of the relieving device during discharge, expressed as a percentage of set pressure.

Pressure Relief Device - A device actuated by inlet static pressure and designed to open during an emergency or abnormal condition to prevent the rise of internal fluid pressure in excess of a specified value. The device may also be designed to prevent excessive vacuum.

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Pressure Relief Valve – This is a generic term applying to relief valves, safety valves or safety relief valves. Is designed to relieve the excess pressure and to recluse and prevent the further flow of fluid after normal conditions have been restored.

Process Safety - A discipline that focuses on the prevention of fires, explosions, and accidental chemical releases at chemical process facilities. Excludes classic worker health and safety issues involving working surfaces, ladders, protective equipment, etc.

Process Safety Management - A program or activity that involves the application of management principles and analytical techniques to ensure process safety in chemical facilities. The focus is on preventing major accidents rather than dealing with classic worker health and safety issues.

Risk - The combination of expected likelihood or probability and consequence or severity (effect event) of an accident

Safety - A general term denoting an acceptable level of risk of, relative freedom from and low probability of harm.

Spacing and Layout - A well laid-out plant (including adequate equipment spacing, adequate drainage, "fire breaks" to establish separation between fire risk areas), limits the geographical extent of a fire and allows effective fire fighting access.

Toxic material - One which has the inherent ability to cause adverse biological effects.

Validation - The activity of demonstrating that the safety-instrumented system under consideration, after installation, meets in all respects the safety requirements specification for that safety-instrumented system.

Venting - Emergency flow of vessel contents out the vessel. The pressure is reduced by venting, thus avoiding a failure of the vessel by over pressurization. The emergency flow can be one-phase or multiphase, each of which results in different flow and pressure characteristics

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THEORY

The Design Process

Design plays a part in each phase of the development lifecycle. According to the STARTS Guide [STARTS 1987] the design process may be divided into four distinct activities:

1. Abstraction: the operation of generalizing, of identifying the essentials;
2. Decomposition: the process of reducing an object into a number of simpler, smaller parts; analysis of interactions, interfaces and structures; modularization;
3. Elaboration: the operation of detailing, adding features;
4. Decision making: identification and selection of alternative strategies.

Here a few elements of the design process.

1. Top Level or Architectural Design

In safety-related applications, the top-level architectural design is also necessary to allocate the various safety requirements, identified in early phases of the development, to appropriate safety-related systems or subsystems. In general these will include systems based on a number of technologies and may include mechanical, hydraulic or electrical subsystems, as well as both programmable and non-programmable electronic sections. Wherever possible safety features should be implemented using the simplest possible elements.

2. System Partitioning for Safety

The way in which a system is partitioned is fundamental to the provision of safety. One of the important aspects of partitioning is that it aids comprehension of the system. A well partitioned system is much easier to understand.

3. Detailed Design

Following the process of decomposition performed in the top-level design phase comes the detailed design of the various functions of each module. The process of decomposition is often iterative, with modules being broken down successively into

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small sub-modules, each with its own specification. The techniques used in the detailed design phase will be greatly affected by the overall development methods and tools being used.

4. Safety Kernels and Firewalls

In some cases safety can be enhanced by the use of safety kernels or firewalls. A safety kernel consists of a relatively simple arrangement, often a combination of hardware and software. Its small size and lack of complexity enable it to be developed into a trusted subsystem that can be used to ensure the critical safety functions of a system. The success of this arrangement depends on the ability of the designer to protect the kernel from outside influences.

5. Design for Maintainability

Although it may not always be immediately apparent, good maintainability is often a prerequisite of safety. One factor that is often overlooked in the operation of safety-critical systems is the impact of maintenance induced failures. Evidence from a number of sources suggests that there is a significant probability that maintenance operations will not be completed satisfactorily and may lead to new and seemingly unrelated faults.

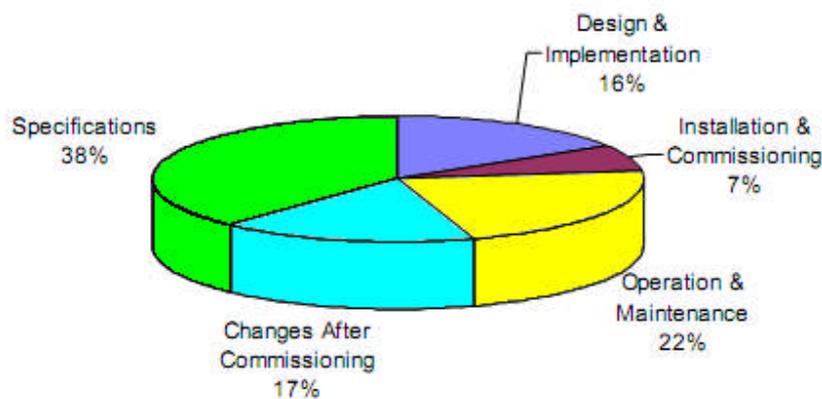


Figure 3: Causes of Control System Incidents

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Additional design safety features for design process:

1. Reducing the potential for uncontrolled release of flammable / toxic materials by:
 - a. Selection of superior quality machinery or materials of construction.
 - b. Selection of special machinery features such as seal-less pumps, submerged pumps, canned pumps, or oil mist lubrication.
 - c. Reduce the risk of failure of small piping connections or vulnerable equipment by specifying features such as:
 1. Minimizing the number and extent of small piping connections.
 2. Increasing mechanical strength by using larger pipe sizes [say 2 in. (50 mm)].
 3. Combining multiple connections into a single valve nozzle of larger size at the vessel.
 4. Additional gusseting and bracing.
 5. Replacing gage glasses with level indicators.
 6. Provision of excess flow valves or restriction orifices in small piping such as instrument connections.
2. Provision of additional instrumentation, alarms, and surveillance devices (e.g., closed circuit television, vibration alarms, toxic gas detectors, combustible gas, or fire detectors) to identify potential emergency situations and actuate alarm or corrective devices
3. Designing safety equipment for on-stream maintenance, so that maintenance can be carried out on it while keeping the plant fully protected at all times
4. Provision of fire protection and emergency facilities by increased spacing, additional fireproofing and/or fire fighting facilities, additional facilities for emergency shutdown, isolation, depressuring, or removal of flammable inventory. For some chemical processes storage or handling of highly toxic materials may require features such as secondary enclosures (building a vessel around the equipment) for catching leaks, or facilities for neutralizing blow down discharges, or others.

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Site Selection

Plant sitting plays an important role in process safety. Safety considerations may take precedence over other factors, possibly causing otherwise attractive sites to be eliminated for process or general safety concerns. Important factors in plant sitting typically include the following items:

1. Population density around the site
2. Occurrence of natural disasters, such as earthquake, flood, hurricane
3. Accessibility to raw materials
4. Accessibility to markets
5. Transportation
6. Availability of land
7. Availability of power and utilities
8. Labor
9. Interface required with other plants
10. Government policies, such as sitting permits and investment incentives
11. Means of effluent disposal

A process safety management program initiated during the development phases of a new project will identify and explain the nature of hazards associated with the proposed plant. A site can be selected after considering many of the recognized hazards. Some important safety considerations are listed in below.

1. Adequate buffer space between the plant site and vulnerable communities and public facilities
2. Presence of other hazardous installation nearby
3. For highly toxic materials make the material in the plant as a sub process just prior to mixing the material into the main process. Inventory is then made up of less toxic precursor materials.
4. Emergency response support
5. Adequate water supply for fire fighting
6. Stable power supply

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