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KLM Technology Group
#03-12 Block Aronia,
Jalan Sri Perkasa 2
Taman TampoiUtama
81200 Johor Bahru
Malaysia

Kolmetz Handbook
Of Process Equipment Design

SAFETY IN PROCESS EQUIPMENT DESIGN INHERENT SAFER DESIGN

(ENGINEERING DESIGN GUIDELINE)

Co Author:

Rev 01- Aprilia Jaya
Rev 02 - YulisSutianingsih
Rev 03 - Aprilia Jaya

Editor / Author:

Karl Kolmetz

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INTRODUCTION

Scope

This Engineering Design Guideline covers safety issues in process equipment design including chemical, petrochemical, and hydrocarbon processing facilities. It assist personnel to understand the basic concepts of process safety and increase the knowledge of prevention and reduce the incidents that might happen.

The design consideration discussed is methods of safety; 1. Inherently safer design,2. Hazard and Operability Analysis (HAZOP) 3. Material hazards and 4. Fire protection. Reviewed are plant and unit layout, equipment spacing and some equipment which in which incidents might happen such as storage tank, distillation, reactors, piping system, flare and piping system.

It is clear that choices made early in design can reduce the possibility for large releases and may reduce the effects of releases. One should consider the variety of mitigation measures to reduce the severity of the effects of a release,

General Design Considerations

The comparison of the safety of equipment is not straightforward. It depends on several features of both process and equipment themselves. It can be evaluated from quantitative accident and failure data and from 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 inertants 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 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 fitted 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
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.

Figure 1 presents the causes of losses for the largest chemical accidents. One of the largest causes of a loss in a chemical plant is due to mechanical failure. Failures of this type are usually due to a problem with maintenance. Pumps, valves, and control equipment will fail if not properly maintained.

The second largest cause is operator error. For example, valves are not opened or closed in the proper sequence or reactants are not charged to a reactor in the correct order. Process upsets caused by, for example, power or cooling water failures account for 11% of the losses. While figure 1 presents a survey of the type of hardware associated with large accidents.

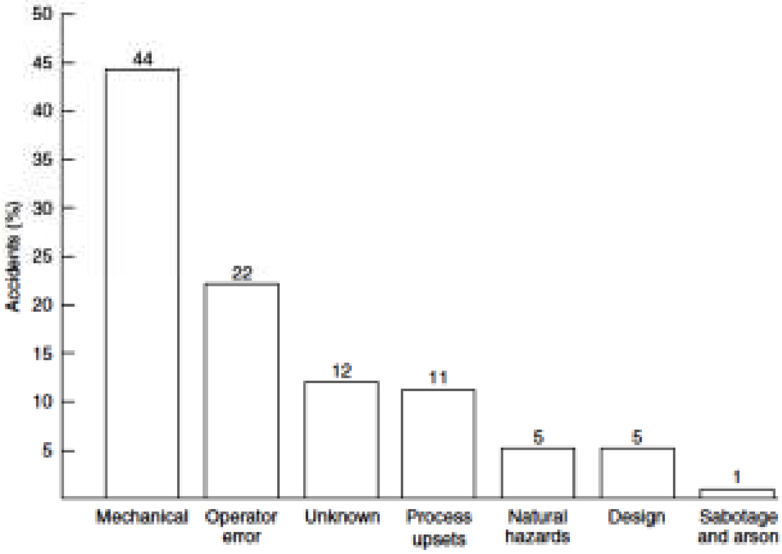

Figure 1: Causes of losses in the largest hydrocarbon-chemical plant accidents (13)

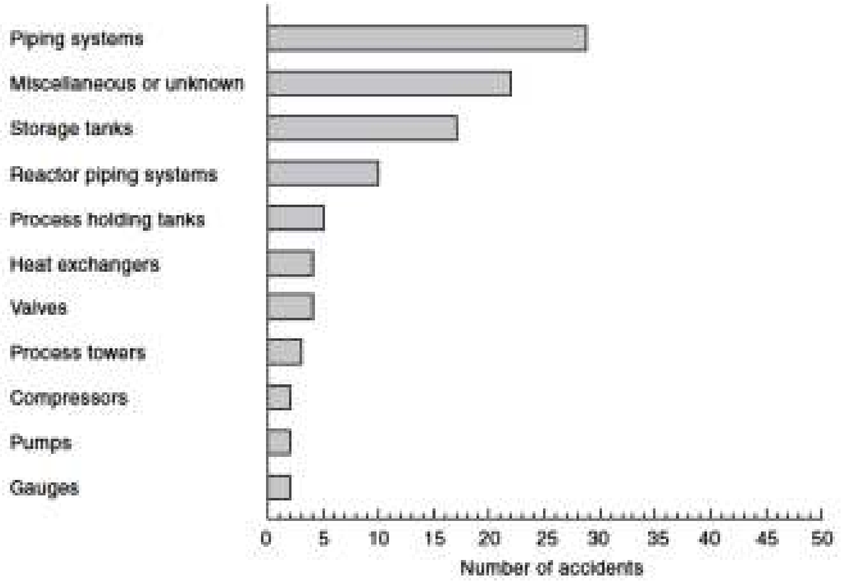

Figure 2 : Hardware associated with largest losses(13)

A. Safety Requirements

Safety Requirements Specification is a specification that contains all the requirements of the safety instrumented functions that have to be performed by the safety instrumented systems. The safety requirements should have a safe state whereas described as a state of the process when safety is achieved. In some cases, the process may have to go through a number of states before the process enters the final safe state. Actions necessary to keep a safe state in the event of detected fault(s) should be described. The description must address safe state details regarding process actions needed, in example:

- Sequential shutdown.
- Which process valve(s) is needed to perform a specific action during the safe state.
- Fluid flow choices that need to be started or stopped.
- Stop, start or continue operation of rotating elements (motors, pumps,etc).

The safety requirements had to have proof-test interval due to the importance of the process application since the proof-test interval affects the design of the application. It is more advisable to perform a proof test when the process (factory) is stopped. Important activities during this time involving:

- Describe the proof test procedures.
- Investigate if additional safety measures (monitoring, redundancy etc) has to be adapted during the proof test interval.
- Investigate if human aspects could also affect the safety during the proof test especially if the consequences could be catastrophic if the proof test goes wrong.
- Specify the required proof tests during the life-cycle.
- The proof test activity must be documented.

The safety requirements had also to have response time. The response time is specifically for the SIS (safety Instrumented system), should also to be stated. Parameters that affect the response time including:

- The process related (such as time and dead time for process response).
- Process control (time delay and sampling time).

Other factors (in addition of mechanical engineering substances like Friction, Inertia, and Wear).

B. Safety Program

The word ‘safety’ used to mean the older strategy of accident prevention through the use of personal-protection-equipment such as hard hats, safety shoes, and a variety of rules and regulations. The main emphasis was on worker safety. Today, safety has a meaning more as a ‘loss prevention’ which included the action of: (1) Hazard identification, (2) Technical evaluation and (3) The design of new engineering features to prevent loss. Safety, hazard, and risk are frequently-used terms in chemical process safety. Their description are:

- Safety.
  As mentioned, safety is a loss prevention, the prevention of accidents through the use of appropriate technologies to identify the hazards of a chemical plant and eliminate them before an accident occurs.

- Hazard.
  A chemical or physical condition that has the potential to cause damage to people, property, or the environment.

- Risk.
  A risk defined as a measure of human injury, environmental damage, or economic loss in terms of both the incident likelihood and the magnitude of the loss or injury.

Figure 1 shows a successful safety program requires several ingredients involving :

- System.
  To record what require to be done to have an outstanding safety program and also to record that the needed tasks are done.

- Attitude.
  The participants should have a positive attitude which will influence the others. This point includes the willingness to do some the thankless work that is required to success.

- Fundamentals.
  The participants also should understand and use the fundamentals of chemical process safety in the design, construction and operation of their plants.

Figure3. Ingredients for successful safety program.

- Experience.
  Everyone must receive lessons learned from every event and experience of history, this action will prevent a repeat event on the next time after the accident occurred. For the employees, they should read and understand the case histories of past accidents and ask people in their own and other departments for their experience and advice.

- Time.
  This point should be taken for recognizing the safety. Including time to study, time to do the work properly, time to record the result, time to share the experiences, and also time to train or to be trained.

- Personnel.
  The participants should have a feeling that they are involved with the system. Thus, made them to gain responsibility to contribute to the safety program. The program should have the commitment from all levels within the organization. Nonetheless, concern of safety should be high as or equal as the process production.

C. Engineering Ethics

Engineers are responsible for minimizing losses and providing a safe and secure environment for the company and for the employees. This responsibility involving themselves, family, fellow workers, community, and the engineering profession.

D. Statistics

Accident and Loss which occurred during the running of process plant should be statistically accounted. It is important, since the statistic data will show the measurement of the effectiveness of safety programs either in general or specific topics. These statistics are also valuable for determining whether a process is safe or whether a safety procedure is working effectively.

There are tons of statistical methods that available to characterize accident and loss performance. Nonetheless, there is standard method which could generally use for all required aspects. They are only averages and could not reflect the potential for single episodes involving substantial losses.

The most used systems are:

- OSHA incident rate.
- Fatal Accident Rate (FAR).
- Fatality rate or deaths per person per year.

All of the three methods report the number of accidents and/or fatalities for a fixed number of workers during a specified period.

- OSHA incident rate.
  OSHA stands for the Occupational Safety and Health Administration of the United States government. The OSHA incidence rate is based on cases per 100 worker years. A worker year is assumed to contain 2000 hours (50 work weeks/year x 40 hours/week). The OSHA incidence rate is therefore based on 200,000 hours of worker exposure to a hazard. The OSHA incidence rate is calculated from the number of occupational injuries and illnesses and the total number of employee hours worked during the applicable period. The calculation for this method as follows :

$$OSHA\ incidence\ rate = \frac{Number\ of\ injuries\ and\ illnesses\ x\ 200{,}000}{\begin{array}{c}Total\ hours\ worked\ by\ all\ employees\\ during\ period\ covered\end{array}}$$

  An incidence rate can also be based on lost workdays instead of injuries and illnesses. The equation for this case following :

$$OSHA\ incidence\ rate = \frac{Number\ of\ lost\ workdays\ x\ 200{,}000}{\begin{array}{c}Total\ hours\ worked\ by\ all\ employees\\ during\ period\ covered\end{array}}$$

The OSHA incidence rate provides information on all types of work-related injuries and illnesses, including fatalities. This provides a better representation of worker accidents than systems based on facilities alone.

- Fatality Accident Rate (FAR).
  FAR is generally used for the British Chemical Industry. This statistics reports the number of fatalities based on 1000 employees working their entire lifetime. The employees are assumed to work a total of 50 years. Hence, the FAR is based on 10^8 working hours. The final equation for this method is :

$$FAR = \frac{Number\ of\ fatalities\ x\ 10^8}{\begin{array}{c}Total\ hours\ worked\ by\ all\ employees\\ during\ period\ covered\end{array}}$$

- Fatality rate.
  Fatality rate system is described as an independent of the number of hours actually worked and reports only the number of fatalities expected per person per year. This approach is useful for performing calculations on the general population, where the number of exposed hours is poorly defined. The applicable equation is :

$$Fatality\ rate = \frac{Number\ of\ fatalities\ per\ year}{\begin{array}{c}Total\ hours\ worked\ by\ all\ employees\\ during\ period\ covered\end{array}}$$

Both of the OSHA and FAR methods are depend on the number of exposed hours. An employee working a ten-hour-shift is at greater total risk than one working an eight-hour shift. A FAR can be converted to fatality rate if the number of exposed hours is known. The OSHA incidence rate cannot be readily converted to a FAR or fatality rate due to the injury and fatality information.

Table 2 and 3 show the typical accident statistics for various industries of each kind of method style. Approximately half these deaths are due to ordinary industrial accidents such as being run over, and the falling event, meanwhile the other half is about chemical exposure topic.

Table 2. Accident Statistics (for Various Industries)

Industry	OSHA incident rate		FAR deaths	
	1985	1998	1986	1990
Chemicals and related products.	0.49	0.35	4.0	1.2
Motor Vehicle.	1.08	6.07	1.3	0.6
Steel.	1.54	1.28	8.0	
Paper.	2.06	0.81		
Coal Mining.	2.22	0.26	40	7.3
Food.	3.28	1.35		
Construction.	3.88	0.6	67	5.0
Agricultural.	4.53	0.89	10	3.7
Meat products.	5.27	0.96		
Trucking.	7.28	2.10		
All manufacturing.		1.68		1.2

The FAR illustrates that if 1000 workers begin employment in the chemical industry, 2 of the workers will die as a result of their employment throughout all of their working lifetime. One of these deaths caused by the direct chemical exposure. On the other hand, 20 of these same 1000 people would die as a result of nonindustrial accidents and 370 die because of the disease. Of those from disease, 40 people will die as a direct result of smoking.

Table 3. FAR Statistics

Activity	FAR (deaths/10^8 hours)	Fatality rate (deaths per person per year)
Voluntary activity		
Staying at home	3	
Traveling by		
Car	57	17 x 10-5
Bicycle	96	
Air	240	
Motorcycle	660	
Canoeing	1000	
Rock climbing	4000	4 x 10-5
Smoking (20 cigarettes/day)		500 x 10-5
Involuntary activity		
Struck by meteorite.		6 x 10-11
Struck by lighting (U.K)		1 x 10-7
Fire (U.K)		150 x 10-7
Run over by vehicle		600 x 10-7

Table 3 lists the FARs for various common activities. The table is divided into voluntary and involuntary risks. Based on these data, it appears that individuals are willing to take a substantially greater risk if it is voluntary. It is also evident that many common everyday activities are substantially more dangerous than working in chemical plant.

E. Acceptable Risk & Public Perceptions

Every chemical process has a certain amount of risk associated with it. Engineers should make every effort to minimize risks within the economic constrains of the process. Nonetheless, the engineer should never design a process that they think will result in certain human loss or injury, despite any statistics.

The general public has great difficulty with the concept of acceptable risk. The major objection is because to the involuntary nature of acceptable risk. Chemical plant designers who specify the acceptable risk are assuming that these risks are satisfactory to the civilians living near the plant.

F. Hazard and Operability Analysis (HAZOP)

A hazard is an inherent physical or chemical characteristic that has the potential for causing harm to people, property, or the environment. In chemical processes, It is the combination of a hazardous material, an operating environment, and certain unplanned events that could result in an accident

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 analysed.

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 4.

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.

Table 4. 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.

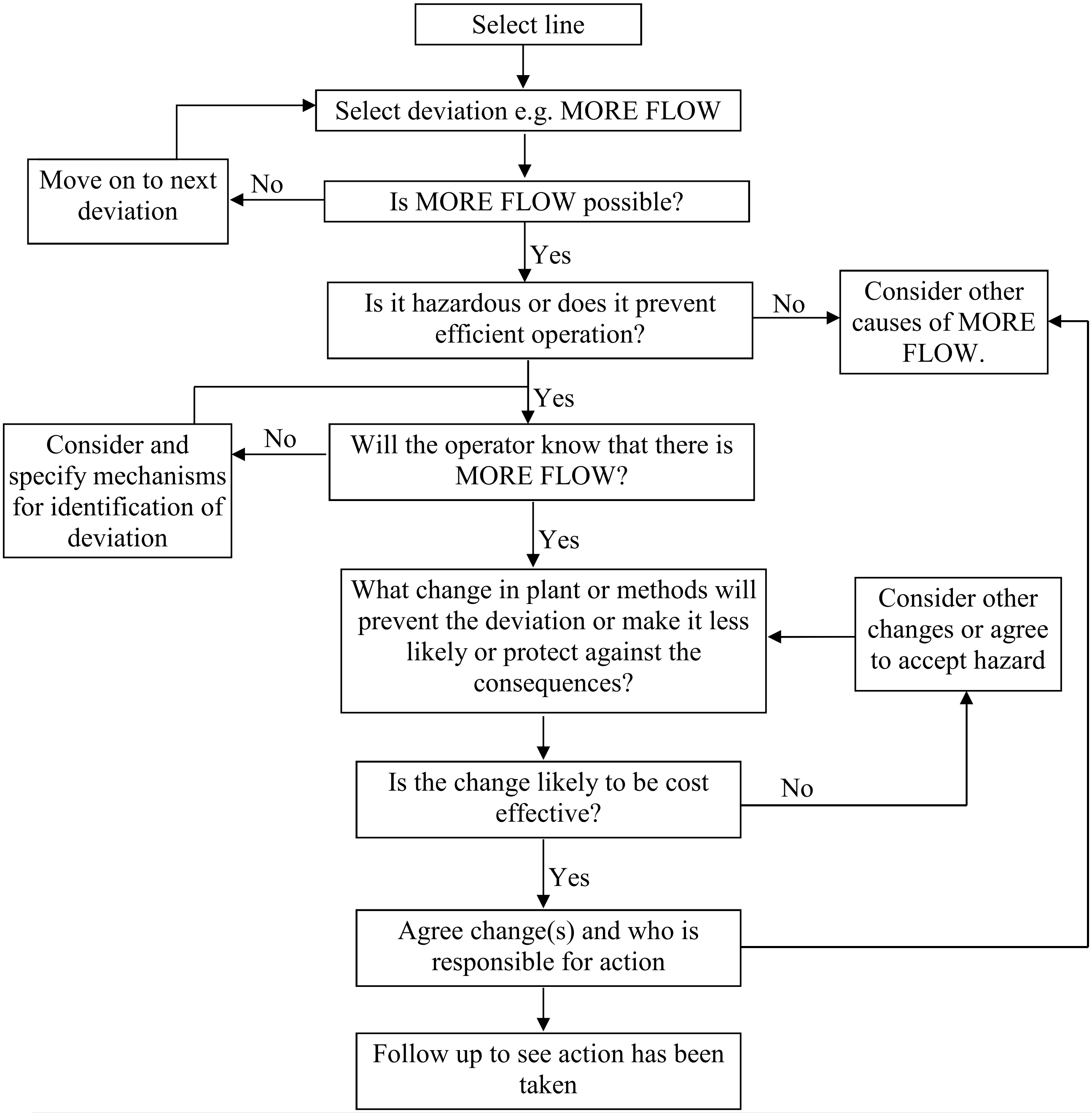
Select line
Select deviation e.g. MORE FLOW
Move on to next deviation
No
Is MORE FLOW possible?
Yes
Is it hazardous or does it prevent efficient operation?
No
Consider other causes of MORE FLOW.
Yes
Consider and specify mechanisms for identification of deviation
No
Will the operator know that there is MORE FLOW?
Yes
What change in plant or methods will prevent the deviation or make it less likely or protect against the consequences?
Consider other changes or agree to accept hazard
Is the change likely to be cost effective?
No
Yes
Agree change(s) and who is responsible for action
Follow up to see action has been taken

Figure 4. HAZOP Procedure Illustration

G. 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 summarize in document of Materials Safety Data Sheet (MSDS).

The MSDS contains the information needed to begin analysing 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.
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.

Table 5. 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 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.

H. Fire and Gas 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. Basically the system consists of field-mounted detection equipment and manual alarm stations, a system logic unit for processing of incoming signals, alarm and HMI units. The system shall be able to process all input signals in accordance with the applicable Fire Protection Data Sheets or Cause & Effect charts.

The fire and gas detection systems shall automatically start active fire protection systems as appropriate, initiate shutdowns and alarm personnel both audibly and visually throughout platform of a fire (incipient or confirmed) condition or a hydrocarbon gas or a toxic gas release. The Guide presents a process for performance-based design centeredaround 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

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.

Fire detectors shall cover all applicable facilities envisaged in the project. The following types of fire detectors shall be provided.

- Combination Infra-red (IR)/ Ultra Violet (UV) flame detectors
- UV flame detectors
- Heat detectors – rate compensated point source type or linear heat detection type
- Fusible plugs and
- Smoke detectors-ionization type or optical type.

The automation fire detection system shall be supports by manual call pints distributed about all the facilities as envisaged in the project to enable personnel to raise an alarm.When a fire detection system is needed, the following guidelines should be followed to ensure acceptable performance

- Review possible fire scenarios: what fuels are involved, where might the fire start, how fast might it spread.
- Where the rapid spread of the fire is likely, automatic actuation of protective systems should be specified.
- 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.
- IR flame detectors are preferred for hydrocarbons. When the fuel contains little or no carbon, a single UV detector or heat detector is preferred. Heat sensing devices are viable alternatives in either case provided the potential flame location is well known and the sensing device can be located nearby.
- Flame detectors should be located no greater than 35 ft (10 m) from possible fire sources. At 35 ft (10 m), the detector should respond in ten seconds to a 1 ft^2 (0.1 m^2) pan fire of the expected material on fire.
- Flame detectors should be positioned to see the base of the fire not just the flames above it.
- Enough flame detectors must be deployed to avoid blind spots and to account for loss in sensitivity away from the detector's central axis.
- To avoid false alarms from sources outside the risk area, flame detectors should not have a view of the horizon.

There are two kinds of fire control; passive and active fire protection system. Passive fire protection shall be applied to critical structures, boundaries, vessel and equipment. While the active fire protection systems shall be to contain/reduce the effects of smoke and radiation and extinguish fires as appropriate.

Below are the passive fire protection systems

1. Fire protection of vessels and equipment. Vessels, pipework and supports may fail before depressurisation, passive fire proofing shall be applied as necessary to vessels, pipework between vessel and shutdown/blowdown valves, and their supports
2. Fire protection of shutdown valves. All shutdown valves shall be designed as fire-safe and shall be of a fail-closed design with spring return actuator. While blowdown valves shall be fire-safe and fail-open type.
3. Fire protection of supports for vessel. Any supporting structure shall be fire proofed.
4. Fire protection of structural steel
5. Fire protection of proofing materials. It shall be either epoxy intumescent, subliming type or fibre containing panels and type approved for duration and ratings identified. The materials shall be suitable for use in an offshore environment, have an operational life of design life of platform, does not degrade by absorbing water.

Below are the active fire protection systems

1. Water deluge systems to cool areas and equipment that may be affected by radiated heat from a fire and prevent escalation and also to protect personnel from radiation at the bridge crossing.

   The deluge systems shall be designed to supply at least the following application rates in accordance with API 2030

Items	Deluge rate(litres/min per m2 of exposed surface area.)
Air fin coolers	10.2
Compressors, pumps and other hydrocarbon handling equipment.	20.4
Pressure vessel and heat exchangers	10.2
General coverage area	4.1

2. Water monitors to support fixed fire protection systems to cool process areas and equipment that may be affected by radiated heat from a fire, provide local cooling at jet fire impingement areas on vessels, and prevent escalation. Below are requirements for firewater monitors:
   - Portable fire monitors shall be designed for offshore use and shall be secure on plating or grating.
   - Each portable monitor shall be capable of flow rate of 900 liters per minute at 7Kg(G)
   - be suitable for supply by two hydrants hoses connected to a hydrant
   - Portable monitors shall be capable of either supplying firewater alone or firewater/foam mixture utilizing foam concentrate inductors
   - Monitor nozzle and other components shall be suitable for use with firewater/ foam mixture.
   - Portable monitors shall be compatible with firewater systems on existing system.
3. Foam is used where there is a risk of a pool fire.Manual foam firefighting shall be provided by portable monitors and hydrants/hoses
4. Fire water pumps. The firewater pump shall be capable of supplying the maximum credible demand. Below should be considered for fire water pumps

   - The firewater pump shall be located as far as practicable from hazardous inventories of the platform.
   - The firewater pump shall be provided with a day tank for its diesel supply. The day tank shall be provided with a fuel- shut-off valve located close to the tank,
   - The pump shall be contained in an enclosure or dedicated room and shall be provided with its own fire water suppression and automatic detection system.
   - A dedicated air receiver shall be provided if compressed air is used as one of the means of starting the diesel
   - Provision shall be made for testing of firewater pumps via an overboard discharge.

- It shall be possible to start the firewater pump even if no other systems on the platform are operational.
- The firewater pump shall have two independent starting system.
- The air receiver shall be sized for 180 seconds continuous cranking of the pump without recharging.

5. Fire water distribution ringmain. It shall be located in the optimum location to protect from the effects of hydrocarbon fires and explosions. Below should be considered forringmain.
    - shall be provided with sufficient manual isolation valves.
    - shall be designed to accommodate the maximum shut-in head of the pump with no relief valves fitted to protect the pipe work.
    - The ringmain shall be constructed from corrosion resistant material
    - The ringmain shall be sized so that at least 65% of the design pressure for the largest fire scenario at a flow 50% in excess of the design flow can be supplied with one section of the ringmain isolated.

The plant design must therefore aim to minimize the damage. This is achieved by providing means to stop the release of flammable or hazardous materials as quickly as possible, by enabling the plant to withstand fire exposure without further failure while a fire is being extinguished, and by providing effective firefighting facilities. The essential components of a plant design which are used to minimize the damage resulting from fires and explosions are listed below.

1. 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 firefighting access.
2. Fireproofing - Fireproofing of structural steelwork, vessels, and vessel supports provides protection against failure from fire exposure and additional release of fuel. Fireproofing is also employed to ensure the continued functioning of certain emergency systems under fire exposure

3. Blast Protection - Central control/computer rooms, main electrical substations, certain instrument houses, and other refinery buildings are designed to withstand a certain size explosion in the plant.
4. Fire Fighting Facilities - Adequate fixed and mobile firefighting facilities must be provided and be capable of meeting extinguishing and equipment cooling requirements for fires in all processing and offsite areas.
5. Emergency Facilities - Emergency facilities are required to reduce the release of flammable material feeding a fire as rapidly as possible. These facilities comprise remote shutdowns for certain items of equipment, emergency isolation and means of de-pressuring and removal of flammable inventory and water flooding capability.

Typical actions from fire gas detection and protection (FDP) systems are:

1. Alert personnel
2. Release firefighting systems
3. Emergency ventilation control
4. Stop flow of minor hydrocarbon sources such as diesel distribution to consumers.
5. Isolate local electrical equipment (may be done by ESD)
6. Initiating ESD and PSD actions
7. Isolate electrical equipment
8. Close watertight doors and fire doors

Figure 5. Failure in Safety Management

I. 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.

An inherent safe plant relies on chemical and physical parameter to prevent accidents rather than on control systems, interlocks, redundancy, and special operating procedures to prevent accidents. Inherently safer plants are also more tolerable of errors and are often the most cost effective system that usually applied in plant. The process that does not need a complex safety interlocks and also elaborate procedures is simpler, easier to operate, and more reliable. Reducing the dimension or equipment sizing and operating at less severe temperature and pressure condition will lead to decreasing its capital and operating costs.

As in general, on the most literature explained that the safety of process is relies on multiple layers of protection. First layer is the process design features, and the next layer contains of many key factors in example : Control systems, interlock, shutdown systems, protective system, alarms, and emergency response plans.

Thus, inherent safety is a part of all layers of protection. However, the best approach to prevent accidents is to add process design features to prevent hazardous situations. An inherently safer plant is often more tolerant for human errors and abnormal condition during running the process. The major approach to inherently safer process designs is divided into the following classifications (description included) :

- Intensification.
  The most effective way of designing inherently safer plants is by intensification. Intensification step could be described as choosing and using smaller amounts of hazardous material. Thus, it will limit the damage in the incidents that occur. Intensification is also the preferred route to inherently safer design, as the reduction in inventory results in a smaller and cheaper plant.

- Substitution.
  Substitution step generally implied if intensification step is not possible to apply. Substitution means as replacing a hazardous material by a less one. In example using cyclohexane rather than benzene as a solvent. Blended component of mixture will cause a silent potential hazards that mostly people did not realize. Nonetheless, substituting a less substance for mixture component will lead to a safer composition of mixture.

- Attenuation.
  A third method is called Attenuation. Attenuation means using hazardous materials in the least hazardous form. In example is storing a liquefied toxic or flammable materials at a low operating condition (low temperature and low pressure). The function of this action to decrease the leak rate through a hole and avoid the evaporation process of materials.

- Limitation of effects.
  Limitation of effects constraint the available energy or the equipment design effect rather than by adding on protective equipment. In example is handling corrosive liquids by plastic container (or plastic-coated) rather than other material construction which heated by an electric immersion heaters. Once the liquid level falls, exposing part of the heater, the container wall could get so hot and lead to a fire. The inherently safer solution is to use a source of heat that less hot to ignite the plastic like low-pressure steam or low-energy electric heaters.

- Simplification / error tolerance.
  Simplification is to made a system not only modest by its look but also from its function. Put the equipment orderly at the place where it should be is one of the example, such in piperack position and layout. This action will give an advantage such as easier access to people during the process and give benefit from the aesthetic point of view.

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.

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 non-combustible, 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.

Pressure Relief Valve – This is a generic term applying to relief valves, safety valves or safety relief valves. Is designed to relief 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