Workplace Safety and Health Guidelines

Process Hazard Analysis

WSHCOUNCIL

Contents

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1. Introduction

The chemical process industry comprises companies involved in the bulk manufacturing of oil and gas, petrochemical, food and pharmaceuticals. Through industrial processes, raw materials are converted into usable products such as petrol, plastics, cooking oil and medicine.

However, such industrial processes may pose process hazards that could result in catastrophic outcomes (e.g., a major fire, explosion or toxic release) if the process or material is not managed with care.

It is therefore critical to perform a Process Hazard Analysis (PHA) so as to identify process hazards as early as possible and put in place measures to control the hazards.

This publication introduces small- and medium- sized enterprises (SMEs) to PHA methodologies commonly used in the chemical process industry. Examples of industrial processes undertaken by SMEs include purification, dilution, mixing or blending and packaging operations.

Factory owners, SME plant managers, technical supervisors and operation or production personnel can use this publication to incorporate relevant aspects of PHA into their Workplace Safety and Health (WSH) management system as part of good process safety management (PSM).

1.1 Terms and Definitions

The following terms are used in this publication (see Table 1):

Term	Definition
Process	A batch or continuous manufacturing step or unit operation involving storage, handling, transfer or processing to convert raw materials into finished products.
Hazard	Any material or process with the potential to cause bodily injury or ill-health, damage to property or the environment, either by itself or interaction with other materials within the system, plant or process.
Hazard analysis	The identification of undesired events that lead to the materialisation of a hazard, the analysis of the mechanisms by which these undesired events could occur and usually the estimation of the likelihood and magnitude of any harmful effects.

Process hazard analysis (PHA)	A technical review method that uses a systematic approach to assess the hazards associated with a process operation.
Incident	An unplanned event or series of events and circumstances that may result in an undesirable consequence (e.g., fatality, injury, environmental and/ or property damage).
Process safety event (PSE)	An unplanned or uncontrolled loss of containment or build-up of material or energy from a process that resulted in or had the potential to result in an undesirable consequence.
Loss of containment	Release or escape of material, usually a gas or liquid intended to be contained within plant equipment or pipelines, to the environment. Loss of containment can vary from small releases (e.g., minor emissions or leaks) to very large releases (e.g., vessel or pipeline rupture).
Process safety management (PSM)	Application of management systems and controls (e.g., programmes, procedures, audits, evaluations) to a manufacturing or chemical process so that process hazards are controlled and process-related injuries and incidents are prevented.
Personnel safety	The prevention of injury or harm to personnel from incidents that are not process-related.
Risk	A measure of human injury, environmental change, reputation or economic loss in terms of the incident likelihood and extent of the loss or injury.
Risk management (RM)	The identification, assessment and prioritisation of WSH risks followed by the application of control measures to minimise the probability and/ or impact of undesirable WSH consequences. Assessments are typically reviewed at set intervals (e.g., at least once every 3 years), or when there are changes in a work process or activity, and upon any accident, a near miss or dangerous occurrence.
Layers of protection	A design approach that applies multiple safety layers on a hazard to prevent an initiating event (e.g., loss of cooling water) from developing into a process safety event or to mitigate the consequences of one when it happens.
Inherently safer design	A design approach that advocates the removal or reduction of a hazard at source, typically during the process design stage. This could be done by eliminating or reducing the hazardous material from the inventory or substituting a hazardous process for a less hazardous one. By eliminating process risks during the design stage, the need for additional layers of protection can be eliminated or minimised.
As low as reasonably practicable (ALARP)	A tolerable level of risk that cannot be reduced without further expenditure on costs disproportionate to the benefit gained or where the solution becomes impractical to implement.

Table 1: Terms and definitions in PSM.

1.2 Process Safety versus Personnel Safety

The emphasis of process safety is different from that of personnel safety. In general, measures taken to improve personnel safety have little impact on process safety. It is therefore important to understand the differences so that steps can be taken to specifically address process safety.

The following paragraphs highlight the key differences between process safety and personnel safety:

Process Safety

Process safety focuses on the prevention of incidents involving loss of containment (e.g., resulting in a toxic release, spill, fire or explosion) by ensuring that facilities are well designed, safely operated and properly maintained. It also involves ensuring that facilities are designed to be safe and engineered properly with safety systems in place to monitor and control process hazards.

Process safety may also be considered the result of a wide range of technical, management and operational systems working together to achieve a desired outcome. When the desired outcome is not achieved, a Process Safety Event (PSE) occurs (see Figure 1).

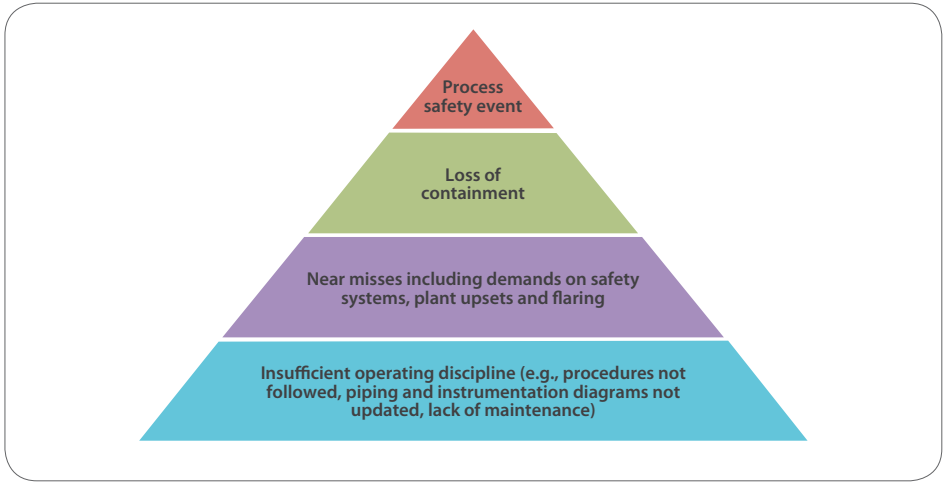

Figure 1: Process safety pyramid (adapted from CCPS[1]).

PSEs tend to be low-frequency, high-consequence events involving loss of containment (see Figure 2). They are catastrophic in nature and can result in multiple injuries and fatalities, and substantial damage to property and the environment.

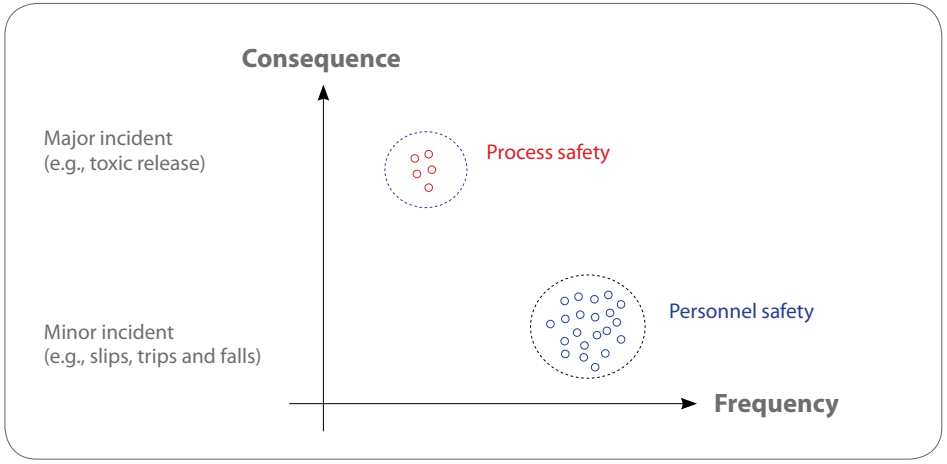

Figure 2: Process safety versus personnel safety.

[1]Center for Chemical Process Safety (CCPS), Process Safety Leading and Lagging Metrics - You Don't Improve What You Don't Measure, revised 2011.

PHA is an important way to identify and manage process safety risks. More information on PHA is provided in Section 1.3 and Chapter 2 of this publication.

Personnel Safety

On the other hand, personnel safety focuses on events that may cause injury or harm to the individual worker and/ or workers in the immediate work vicinity. As compared to process safety incidents, personnel safety incidents tend to be high-frequency, low-consequence events such as falls from height, struck by falling objects and slips, trips and falls.

Note:
Over-reliance on injury and/ or occupational disease incidence rates can lead to a false sense of security about process safety. While the rates are an indicator of WSH performance in terms of personnel safety and health, they are not an indicator of process safety.

1.3 Process Hazard Analysis

PHA (also known as Process Hazard Evaluation) is a method of technical risk assessment. It makes use of structured and systematic techniques to analyse industrial processes in order to identify hazardous situations or their initiating events, and assess their potential impact if improperly or inadequately managed or left uncontrolled.

When identifying hazardous situations or conditions that could lead to a PSE, consider the following:

- process equipment and their ability to cope with deviations from normal operating conditions;
- data accuracy of process monitoring instruments (e.g., temperature, pressure or flow sensor);
- reliability of safety devices (e.g., pressure relief valve, check valve, interlocks, cut-off system);
- integrity of primary containment (e.g., pipes, vessels, flexible hoses, gaskets or seals);
- unplanned loss of utilities (e.g., loss of steam or cooling water);
- compatibility between different materials that are introduced to the process;
- compatibility of process materials with the process equipment's material of construction;
- on-site activities undertaken by staff and/ or contractors and the possibility of human error; and
- impact of external factors (e.g., vehicle impact, impact of incident at a neighbouring plant, or a significant change in environmental conditions).

Once process hazards are identified, the next step of the PHA is to analyse the possible causes and consequences of each potential loss of containment episode. PHA documentation is completed by including a list of targeted control measures (i.e., follow-up actions) to be taken to improve process safety.

Various techniques that can be used to conduct a PHA include, but are not limited to:

- Checklist;
- What-If;
- What-If/ Checklist;
- Hazard and Operability (HAZOP) Study;
- Failure Mode and Effects Analysis (FMEA);
- Fault Tree Analysis (FTA);
- Bowtie Analysis; and
- Layer of Protection Analysis (LOPA).

Selecting the appropriate technique(s) will depend on a number of factors including complexity of the process, whether the process is unique or common industrially, and if a PHA had been conducted on the process before.

See Chapter 2 for more on the Checklist, What-If and HAZOP techniques. The FMEA, FTA, Bowtie Analysis and LOPA techniques are not included in the scope of this publication. The Bowtie Analysis and LOPA are advanced tools that may be applied after the Checklist, What-If or HAZOP techniques have been conducted to evaluate the effectiveness of existing and proposed control measures.

Suggested references:

- Carl S. Carlson, Effective FMEAs: Achieving Safe, Reliable and Economical Products and Processes Using Failure Mode and Effects Analysis, John Wiley & Sons, Inc. (2012).
- Clifton A. Ericson II, Fault Tree Analysis Primer, CreateSpace Inc. (2011).
- A. de Ruijter, F. Guldenmund, The Bowtie Method: A Review, Safety Science 88 (2016) 211-218.
- Center for Chemical Process Safety (CCPS), Layer of Protection Analysis: Simplified Process Risk Assessment, American Institute of Chemical Engineers (2001).

Risk Assessment and Process Hazard Analysis

Under the WSH (Risk Management) Regulations, all workplaces must carry out risk assessments (RAs) to identify and address the safety and health risks posed to any person who may be affected by activities in the workplace. For more information, see the *Code of Practice on WSH Risk Management* at www.wshc.sg.

While RA covers workplace risks that can affect both process and personnel safety, PHA places emphasis on process safety.

For a comparison between RA and PHA, see Table 2.

Risk assessment	Process hazard analysis
• Assessment is based on the work activity (including work involving process operations) being carried out. • Focus is on occupational safety and health and protecting workers from harm. Examples of occupational safety incidents include falls from heights, slips, trips and falls, and struck by moving objects. • Risk control revolves around reducing worker exposure to risks through the hierarchy of control. This is achieved primarily through elimination, substitution, engineering controls, administrative controls and use of personal protective equipment.	• Assessment is based on the process operation being carried out. • Focus is on process safety and the prevention of PSEs. Concern is on protecting workers from harm and preventing environmental and property damage. Examples of PSEs include major spills, toxic release, fire and explosion. • Risk control revolves around implementing layers of protection and/ or inherently safer design. This is achieved primarily through process design, use of engineering controls (e.g., control systems, alarm systems, safety devices) and assuring process integrity.

Table 2: Comparison between RA and PHA.

Companies managing process operations, including SMEs, are encouraged to carry out PHA so that process safety risks can be easily identified and the necessary measures put in place to prevent a PSE.

1.4 WSH Legislation pertaining to Process Safety

The WSH Act covers all workplaces in Singapore* across all sectors, including the process industry. Under the WSH Act, occupiers, employers, self-employed persons, principals and employees are required to take reasonably practicable measures to ensure the safety and health of all persons at the workplace.

Process safety is covered under the WSH Act and several of its subsidiary legislations. The subsidiary legislations that cover aspects of process safety include the WSH (Risk Management) Regulations, WSH (General Provisions) Regulations, WSH (Registration of Factories) Regulations 2008, WSH (Safety and Health Management System and Auditing) Regulations 2009, and the WSH (Major Hazard Installations) Regulations (which take effect from 1 September 2017).

For more information on these regulations, see Annex A.

*Except those listed under the Sixth Schedule (Exempt Persons at Work) of the WSH Act.

2. Conducting Process Hazard Analysis

This chapter introduces the qualitative PHA methods commonly used in the process industry. The specific methods covered in this publication are Checklist, What-If and HAZOP Study. See Table 3 for the advantages and disadvantages of using these PHA methods.

PHA method	Advantages	Disadvantages
Checklist	• Easy to use. • Cost-effective way to identify and analyse hazards. • Suitable for simple processes. • All items on the checklist can be systematically checked. • Good tool to familiarise new or inexperienced workers with the operational requirements.	• Quality of the checklist depends on the knowledge of the author or team developing the checklist. • Checklist can be too long for complex processes. • Items not in the checklist will be completely missed out or left unchecked. • Checklist may be used without actually conducting the necessary checks.
What-If	• Easy to use. • Versatile enough for many aspects of process design and operation. • May be used to detect items that are missing from a checklist. • Powerful technique if the analysis team is experienced.	• Requires upfront preparation. • Unstructured and may not be thorough enough to cover all possible scenarios. • Requires a multi-disciplinary team who understands the process well. • Technique is only as effective as the quality of the questions asked.
HAZOP	• Suitable for complex process. • Provides a structured and systematic framework for the review of the process, chemical, equipment, technology and human factors. • Allows potential risks to be thoroughly studied.	• Time-consuming. • Requires up-to-date process safety information. • Requires a multi-disciplinary team who understands the process well. • Needs a facilitator trained in the HAZOP technique. • Typically requires more resources than the Checklist and What-If methods.

Table 3: Comparison of different PHA methods.

Before going into the details of each method, it is essential to first understand how a PSE can occur. Appropriate risk control measures can then be put in place to prevent a potentially dangerous situation from escalating into an accident.

2.1 How Process Safety Events Occur

A PSE is defined as an unplanned or uncontrolled loss of containment or build-up of hazardous material or energy, resulting in undesired consequences such as fatalities, injuries, environmental and/ or property damage.

In general, a PSE can be divided into four key elements:

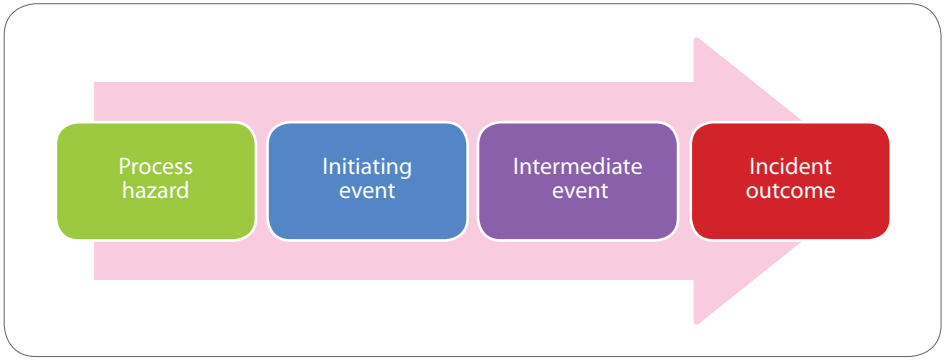

Figure 3: Elements of a process safety event.

For examples of each of the four elements of a PSE, see Tables 4 to 7.

Significant inventory of	Extreme physical condition
• Flammable material • Combustible material • Highly reactive material • Corrosive material • Toxic material • Oxidising material • Unstable material • Shock-sensitive material • Pyrophoric material • Asphyxiants • Inert gases	• High temperatures • Cryogenic temperatures • Temperature cycling • High pressures • Vacuum • Pressure cycling • Vibration • High voltage or current • Corrosion • Erosion

Table 4: First element of a PSE: Process hazard.

Process upset	
Process deviation • Pressure • Temperature • Flow rate • Level • Concentration • Composition or impurities • Phase change **Spontaneous reaction** • Runaway reaction • Decomposition • Polymerisation **Equipment malfunction** • Pumps or compressors • Sensors • Valves • Interlock failure	**Loss of utilities** • Cooling water • Steam • Electricity • Instrument air • Nitrogen **Human error** • Design • Construction • Operations • Maintenance • Inspection • Communication **Management system failure** • Training • Work practices • Supervision • Management of change

Containment failure	External events
• Process vessels or tanks • Pipes • Gaskets or seals	• Extreme weather • Impact of nearby accident • Sabotage

Table 5: Second element of a PSE: Initiating event (cause).

Propagating factors	Risk reduction measures
Equipment failure • Safety system failure **Domino effect** • Neighbouring vessel failure • Other material releases **Human error** • Fault diagnosis • Wrong decision • Omission **Sources of ignition** • Vehicles • Battery operated equipment • Smoking • Open flames • Hot surfaces • Electrical switches • Static electricity • Lightning	**Safety system** • Pressure relief system • Fire or gas detection system • Safety interlock or tripping system • Emergency isolation system • Backup system **Human response** • Alarm system • Control system • Isolation • Emergency shutdown **Mitigation system** • Flares • Dikes or bunds • Fire protection • Explosion protection • Toxic gas scrubber **Emergency response** • Warning sirens • Emergency procedures • Shutdown procedures • Personal protective equipment • Escape and evacuation • Emergency shelters

Table 6: Third element of a PSE: Intermediate event.

Incident outcome	Potential damage or loss incurred
Fire • Pool fire • Flash fire • Jet fire **Explosion** • Confined explosion • Unconfined vapour cloud explosion (UVCE) • Boiling liquid expanding vapour explosion (BLEVE) • Fireball • Dust explosion **Toxic gas dispersion** **Missile damage**	**Fatality, injury or ill health** • Employees • Contractors • Visitors • Community **Business impact** • Damaged assets • Loss of materials • Production downtime • Poor reputation **Environmental impact** • Air pollution • Water pollution • Land contamination

Table 7: Final element of a PSE: Incident outcome (consequence).

2.2 Step-by-step Guide to Process Hazard Analysis

There are a few key steps to conducting a PHA, regardless of the method selected. For a step-by-step guide to carrying out a PHA, see Figure 4.

The first step in the PHA process is to select the process for analysis and clearly define the boundaries of the process. The next step is to assemble a PHA team of diverse backgrounds to analyse the process from multiple perspectives (e.g., engineering, operations, maintenance, etc.). For an existing facility, it is important to include frontline personnel who are knowledgeable about the process equipment and its operating procedures as well as the materials, chemicals and substances used. If the process is new, persons from a sister plant or similar work process should be on the PHA team.

During each PHA meeting, up-to-date Process Safety Information (PSI) must be available to support the analysis. PSI includes information on the following:

- Hazards associated with substances or materials used or produced by the process (e.g., toxicity information and chemical incompatibility data);
- Technology used in the process (e.g., process flow diagram, process chemistry and operating conditions); and
- Equipment used in the process (e.g., piping and instrumentation diagram, design codes and standards employed).

See Table 8 for more examples of information used to support a PHA.

- Facility plot plan
- Process flow diagrams
- Material inventory
- Process limits in terms of pressure, temperature, flow rate, concentration and so on
- Kinetic data for process reactions
- Safety, health and environmental data for raw materials, intermediates, products, by-products and wastes
- Safety data sheet (SDS)
- Safe work procedures
- Maintenance procedures
- Regulatory limits
- Applicable codes and standards
- Incident and near miss reports
- Population distribution data
- Building and equipment layout
- Piping and instrumentation diagrams (P&IDs)
- Control system and alarm descriptions
- Instrument loop and logic diagrams
- Valve and instrumentation data sheets
- Piping specifications
- Mechanical equipment data sheets
- Equipment catalogues
- Electrical area classification drawings
- Electrical classification of equipment
- Utility specifications
- Testing and inspection reports
- Relief system design basis
- Fire protection system design basis
- Emergency response plan
- Relevant industry experience

Table 8: Examples of PSI used for PHA.

Should a processing facility comprise more than one process, a good starting point for the PHA is to begin with the process that poses the greatest risk. This process may be singled out by reviewing its age and operating history, the severity of known process hazards, along with the number of employees affected.

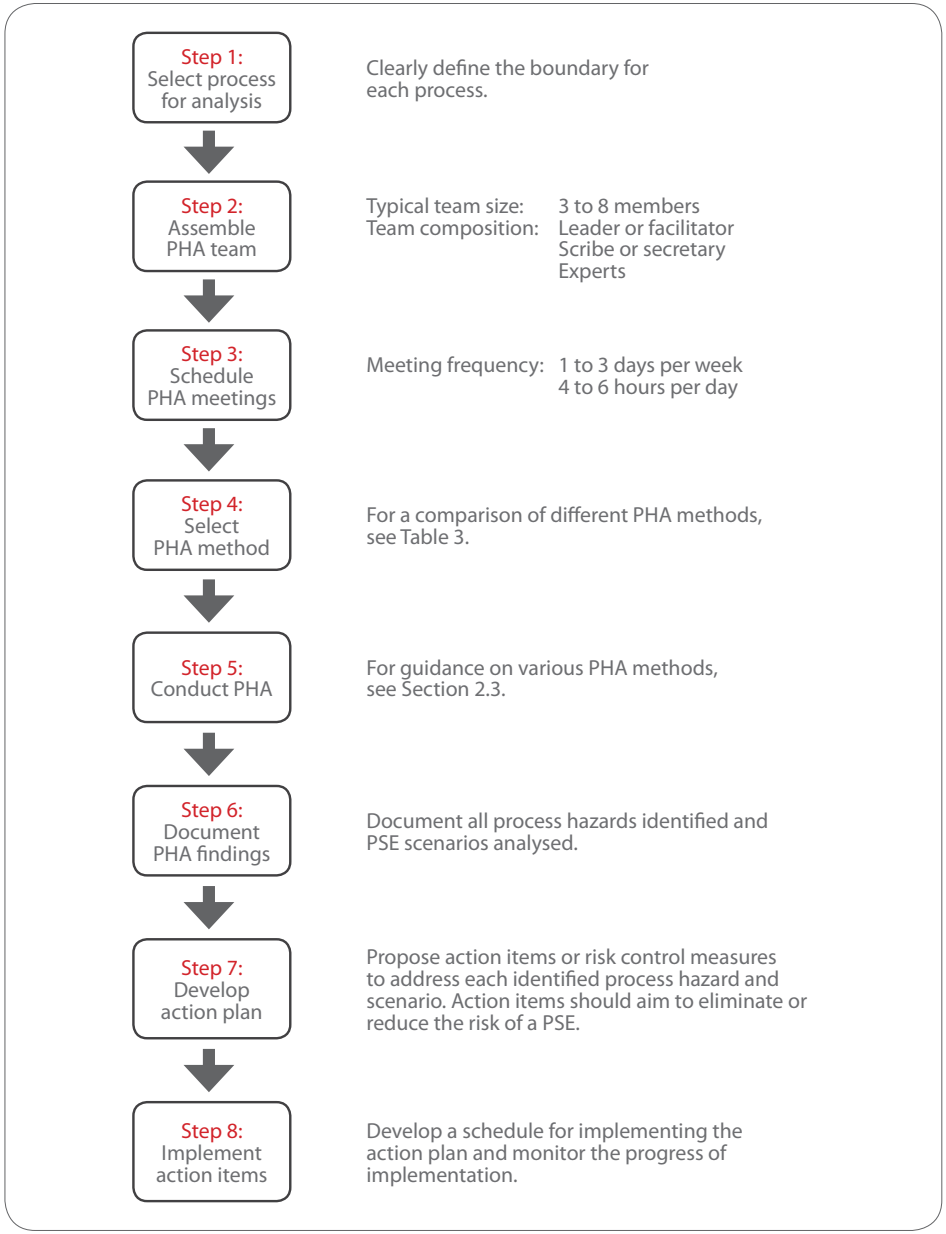

Figure 4: Steps to conducting a PHA.

2.3 Methods for Process Hazard Analysis

This section provides guidance on the following PHA methods commonly used in the process industry:

- Checklist;
- What-If;
- What-If Checklist; and
- HAZOP Study.

2.3.1 Checklist

A checklist is the simplest tool that can be used for hazard identification and analysis. It is also a means of passing on lessons learnt from experience. Checklists can be used to check against hazards to be assessed and tasks to be carried out to ensure that all workplace and process hazards have been identified and addressed. They may vary in the level of detail and are frequently used to indicate compliance with legal requirements or conformance to safety standards and industry practice.

A typical checklist comprises a written list of items or procedural steps to be verified in order to determine if the desired status of a process or work activity has been achieved.

A key advantage of using checklists is that they are easy to use and can be applied to any process or work activity. Checklists may also be used to help new or inexperienced workers familiarise themselves with the operational requirements of the task at hand.

Checklists, however, are limited by their author's experience. It is therefore ideal that checklists are developed by a PHA team comprising members with varied backgrounds and extensive experience with the process or work activity. Ultimately, the quality of the analysis depends on the quality of the checklist.

Checklists may not be thorough enough in some cases since it uses a non-analytical and non-interactive approach. This means that items not in the checklist will be completely missed out and left unchecked.

Creating a checklist

1. The checklist author (or team) typically starts by reviewing the PSI (including information on known hazards and the desired process status) and safe work procedures.
2. A list of checklist items (or questions) is then generated based on deviations or procedural deficiencies.

A completed checklist usually contains "Yes" or "No" answers to indicate compliance or conformance to the questions posed. Any deviation or deficiency may mean an unsafe condition or a procedural error exists, which would require immediate corrective action.

Checklists should be regarded as living documents to be updated when there are changes to internal (e.g., changes in the process or work activity) and external (e.g., changes in legislation or safety standard) conditions. Lessons learnt from past experience (e.g., following an accident

investigation) should also be weaved into the checklist as critical items to be checked to avoid recurrence.

For a non-exhaustive sample checklist for PHA, see Table 9. Readers are encouraged to use it as a starting point for developing their own customised checklist.

Sample Checklist for Process Hazard Analysis

	Process materials	Yes	No
1	Use of hazardous materials has been eliminated or substituted with safer alternatives where possible.		
2	Inventory of hazardous material (if any) has been kept to a minimum.		
3	Materials of construction for pipes and vessels are compatible with the materials stored and/ or the materials being processed.		
	Pumps	**Yes**	**No**
1	Design pressure of the pump casing is higher than the maximum discharge pressure of the pump.		
2	Maximum discharge pressure of the pump cannot exceed the design pressure of downstream piping and equipment.		
3	Maximum upstream design temperature cannot exceed the design temperature of the pump.		
	Instrumentation and control	**Yes**	**No**
1	All process instruments and control devices are designed to be fail-safe.		
2	All safety-critical process instruments or control devices have been identified and are listed with an explanation of their safety function and alarm set points.		
3	Every safety-critical process instrument or control device is backed up by an independent instrument or device operating in a different manner.		
	Pressure relief	**Yes**	**No**
1	All equipment are protected from over-pressurisation by relief devices.		
2	Relief devices (at least one, if installed in series) are set at or below the design pressure of the equipment being protected.		
3	Maximum back pressure for each relief device has been accounted for and its relief area adjusted accordingly.		
	Operations	**Yes**	**No**
1	Complete set of safe work procedures for start-up, normal operation, shutdown, process upset and emergencies are available for operator use.		
2	Safe work procedures are regularly reviewed and revised to keep in line with changes and all known errors are immediately corrected.		
3	Operators are trained on new safe work procedures whenever there are revisions in operational procedures.		
	Maintenance	**Yes**	**No**
1	Documented safe work procedures are available for the following types of maintenance-related work: • hot work; • hot tapping; • opening of process lines; • confined space entry; • blinding or de-blinding before and after maintenance or vessel entry; • digging and power excavation; • cranes and heaving lifting; • electrical work; and • work undertaken by contractors.		
2	Preventive maintenance schedule is adequate to ensure the reliability of safety-critical equipment and instrumentation.		
3	Work platforms (permanent or temporary) have adequate clearance for safe maintenance work to be carried out.		

Table 9: Sample checklist for conducting a PHA using the Checklist method.

2.3.2 What-If

The What-If method is a creative brainstorming approach to examine a process or operation. This method can be used for many aspects of process design and operation such as:

- Raw materials
- Intermediate products
- End products
- Storage
- Material handling
- Processing conditions
- Operating procedures
- Work practices

The What-If method may be carried out using any of the following approaches:

- Following the process flow from beginning to end (e.g., from raw material introduction to finished product output).
- Focusing on a specific type of undesired consequence that may have an impact on process safety, occupational safety or public safety.
- Focusing on a specific area of workplace safety or health concern (e.g., fire and explosion protection, loss of containment, emergency response).

Through the What-If method, "what-if" questions are posed to address possible PSEs and/or accident scenarios. Though it can be carried out by an experienced individual, a small multi-disciplinary team (comprising 3 to 5 members) is recommended for a more rigorous analysis.

The What-If method involves three key steps:

Key step	Activity or format
1. Preparation	• Facility walkaround • Interview personnel • Gather process safety information • Prepare seed questions
2. Brainstorming and Discussion	• Members to voice out safety concerns and undesired events • Develop list of "what-if" questions • Address each "what-if" question one at a time by identifying existing safeguards and recommending suitable actions to reduce risks
3. Documentation	• See Table 11 for a suggested worksheet format.

Table 10: Key steps of the What-If method.

What-if question	Cause(s)	Consequence or hazard	Existing safeguard(s)	Recommended action
What if the pump stops running?				
What if the operator closes the wrong valve?				
What if the flow transmitter drifts?				
What if the pressure relief valve lifts?				

Table 11: Suggested worksheet format for the What-If method.

Example of conducting a PHA using the What-If method

What-if question
What if the raw material concentration is wrong?

Consequence or hazard
If the inlet acid concentration is doubled, the ensuing reaction would give rise to an exotherm that is difficult to control, resulting in a temperature runaway with the potential to cause a vessel rupture.

Cause
Higher acid concentration in feedstock due to an upstream process upset.

Existing safeguards
- Temperature control loop linked to a cooling water jacket surrounding the reaction vessel; and
- Pressure relief device that discharges into the flaring system.

Recommended action
Prevent the reaction exotherm from going out of control by implementing the following engineering controls:
- Concentration control loop to ensure that the inlet acid concentration is no more than 1.25 times the desired concentration level at all times;
- High temperature and pressure alarm interlocked to a reaction quenching system; and
- Emergency shutdown system.

Figure 5: Conducting a PHA using the What-If method.

Users of the What-If method must be aware of its limitations. Results will depend very much on the experience of the analysis team. The method is also fairly unstructured and may not be thorough enough to cover all possible PSEs and/ or accident scenarios.

2.3.3 What-If/ Checklist

The What-If/ Checklist method is a hybrid of the What-If method (see Section 2.3.2) and the Checklist method (see Section 2.3.1). It combines the systematic feature of the Checklist method with the brainstorming feature of the What-If method to improve the quality of PHA.

The What-If/ Checklist method capitalises on the strengths and compensates for the shortcomings of each approach. For example, if a PHA checklist is incomplete, then the analysis may not effectively address a hazardous condition or situation. The What-If method serves to encourage the PHA team to evaluate other possible PSEs and/ or accident scenarios that may have been missed out when the checklist was developed. In this way, any hazard or item that is missing from an existing PHA checklist may be readily detected and the checklist updated as necessary.

The suggested worksheet format for the What-If/ Checklist method is similar to the one used for the What-If method (see Table 11), with extra rows added to indicate the need to brainstorm for other possible "what-if" scenarios that may have been missed out. See Table 12 for the proposed worksheet format for the What-If/ Checklist method.

What-if question	Cause(s)	Consequence or hazard	Existing safeguard(s)	Recommended action
What if the pump stops running?				
What if the operator closes the wrong valve?				
What if the flow transmitter drifts?				
What if the pressure relief valve lifts?				
What-if …				

Table 12: Suggested worksheet format for the What-If/ Checklist method.

Example of conducting a PHA using the What-If/ Checklist method

A cooling water system (see Figure 6) consists of a cooling water storage tank, a cooling water pump, and three cooling water coolers which exchange heat with seawater. The seawater is supplied directly from the sea at around 1.4 barg and it is returned to the sea via a seawater drain. The level of the cooling water storage tank is automatically maintained through industrial water make-up. The cooling water system operates at around 3 barg at pump discharge.

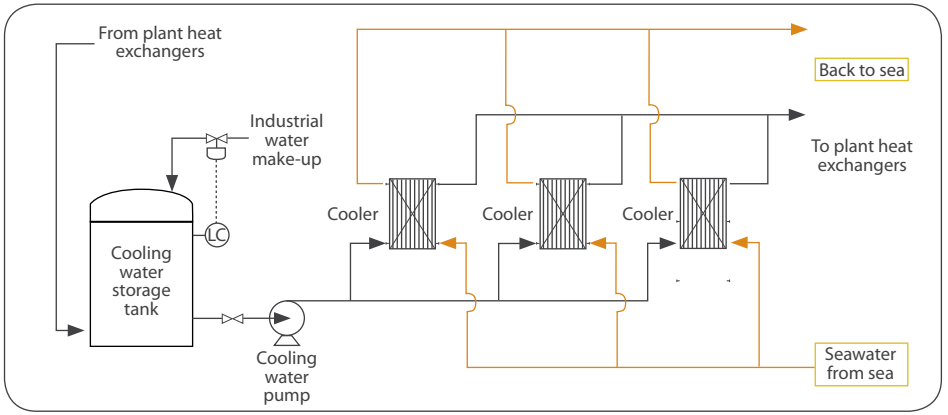

Figure 6: Process flow diagram of a cooling water system.

What-if question	Cause(s)	Consequence or hazard	Existing safeguard(s)	Recommended action
What-if there is a leak of cooling water from the piping circuit?	Leak due to corrosion of piping or its accessories (e.g., fittings, valves, flanges).	Drop in cooling water storage tank level can result in potential pump suction loss. This could lead to pump damage, loss of production and plant shutdown.	1. Automatic control of cooling water storage tank level using industrial water make-up. 2. Operator performs routine check during each shift.	Install a low level alarm on cooling water storage tank by October 2017.
What-if the industrial water Level Control Valve (LCV) is stuck open?	Mechanical failure of the LCV.	Overflow of cooling water storage tank, causing wastage of industrial water and higher utility costs.	1. Preventive maintenance is conducted on the LCV. 2. Operator performs routine check during each shift.	
What-if there is no industrial water make-up to the cooling water storage tank?	The LCV closed due to mechanical failure.	Drop in cooling water storage tank level can result in potential pump suction loss. This could lead to pump damage, loss of production and plant shutdown.	Preventive maintenance is conducted on the LCV.	See above on installation of a low level alarm on cooling water storage tank.
What-if there is a blocked flow of cooling water to the suction of the cooling water pump?	Manual valve on the outlet of cooling water storage tank is inadvertently closed.	Loss of cooling water flow to cooling water pump can cause pump suction loss. This could lead to pump damage, loss of production and plant shutdown.	Operator performs routine check during each shift.	Install a low pressure alarm on cooling water pump discharge header by October 2017.
What-if the cooling water pump trips or fails?	Electrical or mechanical failure of the pump.	No flow or reduced flow of cooling water can cause an increase in the temperature of the cooling water supply. This could lead to loss of production and plant shutdown.	Preventive maintenance is conducted on the pump and its motor.	Install an auto-start standby pump by December 2017 to maintain cooling water pump discharge header. Pump capacity of the standby pump must be the same as existing pump.
What-if …				

Table 13: Example of conducting a PHA on a cooling water system using the What-If/ Checklist method.

2.3.4 Hazard and Operability Study

The purpose of a HAZOP study is to review a process or operation systematically to identify circumstances or situations that could lead to undesirable consequences.

More specifically, a HAZOP study is a structured methodology to:

- identify deviations and corresponding hazards or operability problems in process plants;
- determine possible causes of the deviation and its consequences; and
- decide on the action(s) needed to prevent the deviation, improve safety and avoid operational problems.

The method works on the premise that a process will work well when it is operating at normal conditions, and that any deviation may result in a PSE or workplace accident, or compromise the plant's productivity.

A HAZOP study may be used to examine a process plant at the design stage (i.e., a new plant) or whilst it is in operation (i.e., an existing plant). The method applies equally well to continuous and batch operations. It is also frequently applied to assess the impact of a change in the process before implementing the change.

HAZOP Study Procedure

The HAZOP study, begins with gathering updated Piping and Instrumentation Diagrams (P&IDs), Process Flow Diagrams, and other PSI documents which explain the design intent. A series of guidewords and design parameters (see Table 14) are then used to systematically help the HAZOP team brainstorm the causes and consequences of process deviations that could arise during daily operations.

The guidewords and design parameters in Table 14 are applied to specific sections of a P&ID and the HAZOP study is complete when all sections of the P&ID are covered.

The possible causes and consequences of every process deviation must be determined in order to identify the actions necessary to eliminate the risk or reduce it to a level As Low as Reasonably Practicable (ALARP).

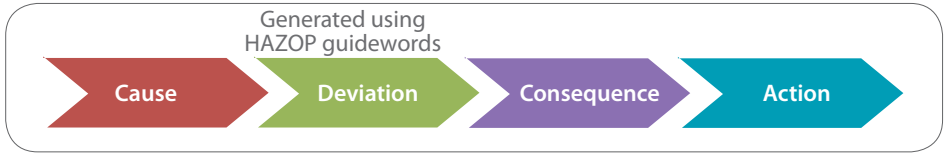

Figure 7: Determining the cause(s), consequence(s) and action(s) required for every deviation.

Guideword / Design parameter	NONE	LESS OF	MORE OF	REVERSE	PART OF	AS WELL AS	OTHER THAN
Flow	No flow	Low flow	High flow	Back flow	Wrong concentration	Extra phase	Misdirected flow; wrong material
Level	Empty tank	Low level	High level		Wrong tank	Presence of foam	
Temperature	Heater failure	Low temperature	High temperature	Cooler failure		Fire/ explosion	
Pressure	Atmospheric pressure	Low pressure	High pressure	Vacuum	Wrong source	Extra source	Source failure
Concentration	Missing additive	Low concentration	High concentration	Reverse ratio	Wrong additive	High/ low density	Presence of contaminant
Other	Utility failure	Too little mixing	Too much mixing			Static build-up	
Special	Startup	Shutdown	Sampling	Testing	Maintenance		

Table 14: Table of process deviations systematically generated by HAZOP guidewords and design parameters.

To find out how a HAZOP study is conducted, see Figure 8.

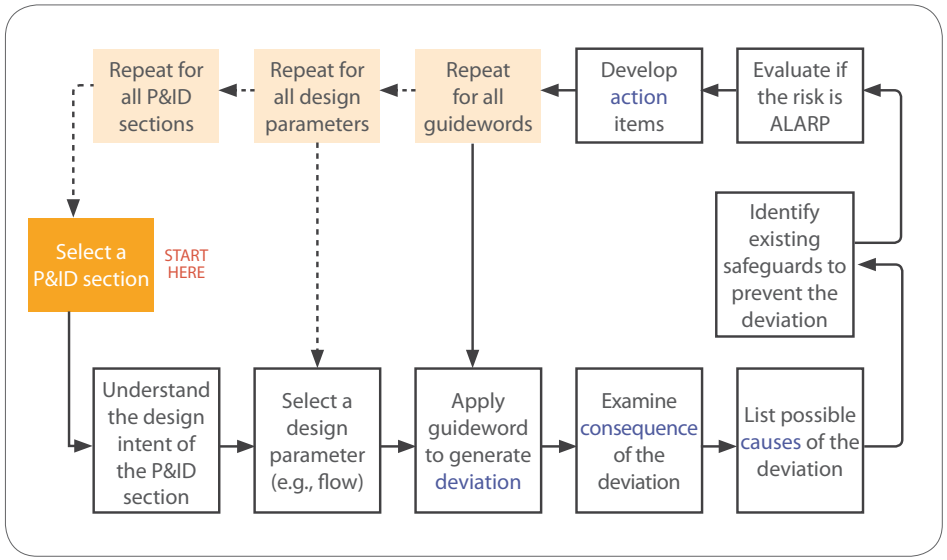

Figure 8: How a HAZOP study is carried out.

For an example on how HAZOP is carried out starting with a design parameter and guideword, see Table 15.

Design parameter:	Flow
Guideword:	NONE
Deviation:	No flow
Questions:	1. Can there be no flow?
	2. Does no flow give rise to hazardous operation or operational problems?
	3. What are the possible consequences?
	4. What are the causes of no flow?
	5. Can no flow be prevented? What actions should be taken to prevent no flow?

Table 15: Example for HAZOP guideword (NONE) and design parameter (flow).

Note:
Wherever possible, the proposed action to be taken should prevent the deviation (e.g., the installation of a fail-open control valve or an auto-start standby pump to prevent "no flow"). Alternative actions include installing a low flow alarm or incorporating a recirculation line for pump protection. While these alternative actions offer early warning of a possible "no flow" situation and can prevent pump damage in the event of "no flow" due to discharge-side blockage, they have little or no impact in preventing the original deviation.

Once the questions for "no flow" are sufficiently considered, the analysis continues for the same design parameter (flow) but for other possible flow deviations such as "low flow", "high flow", "back flow", and so on.

Upon completing the analysis for design parameter (flow), the HAZOP team moves on to the next design parameter (e.g., level, temperature, pressure), until all design parameters are exhausted.

The HAZOP study is complete when every vessel and pipeline has been thoroughly analysed (i.e., line-by-line analysis) and all sections of the P&ID are covered.

See Annex B for deviations commonly encountered in process plants. Annex C provides a summary of typical causes of common process deviations.

Organising a HAZOP study team

Conducting a HAZOP study effectively requires a multi-disciplinary team of experts who has extensive knowledge of the design, operation and maintenance of the plant under review. This will ensure that all identified problems and their solutions can be rigorously considered from various perspectives.

HAZOP team

HAZOP facilitator
HAZOP scribe (secretary)

Participants

Commissioning manager (new plant)
Plant manager (existing plant)
Design engineer
Project engineer
Process chemist
Process engineer
Instrument and control engineer
Electrical engineer
Operations technologist
Maintenance technologist
WSH officer

Figure 9: Typical make-up of a HAZOP team.

The ideal team size is between 5 to 8 members, excluding the HAZOP facilitator and scribe.

Role of HAZOP facilitator

The HAZOP facilitator conducts the HAZOP study session and is responsible for leading the study review and controlling the quality and extent of the analysis and action plan. These include:

- Ensuring that suitable personnel are selected for the HAZOP team;
- Deciding on the division of the P&ID into sections suitable for reviewing one at a time;
- Leading the questioning in accordance with the appropriate design parameters and guidewords;
- Guiding the scribe on the information that needs to be recorded; and
- Ensuring that appropriate actions are proposed to mitigate the identified risk(s).

Role of HAZOP scribe

The HAZOP scribe (secretary) records the HAZOP information and needs to be familiar with the HAZOP study method and software used to capture key points and decisions made during discussion. The scribe is also responsible for preparing the HAZOP study report.

Figure 10: Role of HAZOP facilitator and scribe.

HAZOP discussions are expected to take 1½ to 3 hours for each process vessel or pipeline. To maintain effectiveness of the discussions, HAZOP meetings are typically kept short at about 3 hours per session but organised several times a week.

A HAZOP study on a large project may take several weeks to months, even with several teams working in parallel. Actual duration will depend on plant size and complexity.

While a HAZOP study method requires time and effort, it provides a structured and systematic framework for reviewing a process and allows potential risks to be thoroughly studied.

HAZOP Study Report

The HAZOP study report is a key document pertaining to process safety. See Table 16 for suggested items to be included in a HAZOP study report.

Section of the HAZOP study report	Suggested content
Cover	• Report title • Name of organisation • Type of process • Process location • Proposed operation or existing facility • Name of person responsible for the report • Report date
Summary	• Report scope • Process overview • Conclusions • Recommendations • Implementation timetable
Contents	• Table of contents • List of figures, tables or appendices
Glossary	• Glossary of terms • List of abbreviations
Scope of report	• Aim of the report • Purpose of the study • Instrumentation and equipment symbols
Facility description	• Facility overview – Plot plan – Process flow block diagram – Description of each process step – Plant operating conditions – Materials used or stored • List of P&IDs with the plant and line numbers used in the study
Plant hazards and existing safeguards	• Hazards summary – Material hazards (feedstock, intermediate or product) – Equipment hazards • Plant situations and process conditions likely to result in a PSE

	• Overview of existing safeguards – safe work procedures – operator competency and training – instrumentation, alarm and control system – plant protection systems (e.g., pressure relief, quenching, firefighting) – backup systems (e.g., uninterruptible power supply) – emergency shutdown or remote shutdown procedures – emergency response plan • Summary of issues highlighted for review outside the HAZOP study
HAZOP team members	• List of HAZOP participants and their departments and designations • Dates and duration of meetings • Attendance record
HAZOP methodology	• Overview of method adopted • Deviations from the standard method (if any)
HAZOP guidewords	• List of guidewords and parameters used • Explanation of specialised words used under design parameters "Other" and "Special"
HAZOP analysis	• Results of HAZOP study discussion (including details on deviations, causes, consequences and proposed actions) • Criteria used to determine if follow-up action is required • List of deviations where the decision of no action was made and their corresponding justification • List of deviations where further consequence or risk analysis was considered necessary before a decision can be made. Decisions made after further analyses (if available) should also be given.
Recommendations and action plan	• Summary of proposed actions or control measures • Justification of actions taken or not taken • Timetable for implementation • Name and designations of persons responsible for implementation • Status of actions taken at the time of the report
Annex	• Copy of engineering drawings studied (e.g., P&IDs, process flow diagrams) • Technical data used • Calculations performed to support a decision • Correspondence between departments and with external parties (e.g., contractors, vendors)

Table 16: Proposed HAZOP study report sections and the suggested content for each section.

A suggested worksheet for conducting a HAZOP analysis is provided in Figure 11. See Annex D for an alternative template that includes risk evaluation components as recommended in the *Code of Practice on WSH Risk Management*.

Those involved in HAZOP are encouraged to use available software tools that can help them to record HAZOP discussions and create HAZOP reports more easily.

HAZOP Worksheet

Project title: _____

HAZOP facilitator: _____ Project no.: _____

HAZOP team : _____ P&ID no.: _____

_____ Revision no. : _____

_____ Section no.: _____

_____ Line no.: _____

_____ Date : _____

_____

_____ Design parameter : ☐

_____

Guideword	Deviation	Causes	Consequences	Existing safeguard(s)	Action	By
NONE						
LESS OF						
MORE OF						
REVERSE						
PART OF						
AS WELL AS						
OTHER THAN						

Figure 11: Suggested worksheet for a HAZOP analysis.

HAZOP Example

Figure 12 shows a completed HAZOP analysis worksheet for the cooling water system shown in Figure 6.

HAZOP Worksheet

Project title: Cooling water system
HAZOP facilitator: Mr Loh
HAZOP team : Mr Lim
Mr Hong
Mr Han
Mr Hung
Mr Murali
Ms Chng

Project no.: A46
P&ID no.: 321
Revision no. : 2.1
Section no.: 2
Line no.: 1
Date : 31 Dec 2017
Design parameter : Flow

Guideword	Deviation	Causes	Consequences	Existing safeguard(s)	Action	By
NONE	No flow	Manual valve on outlet of cooling water storage tank is inadvertently closed.	Loss of cooling water flow to cooling water pump can cause pump suction loss. This could lead to pump damage, loss of production and plant shutdown.	Operator performs routine check during each shift.	Install a low pressure alarm on cooling water pump discharge header by October 2017.	Mr Lim
		Cooling water pump trips due to electrical or mechanical failure of pump.	No flow or reduced cooling water flow can cause an increase in the temperature of the cooling water supply. This could lead to loss of production and plant shutdown.	Preventive maintenance is conducted on the pump and its motor.	Install an auto-start standby pump by December 2017 to maintain cooling water pump discharge header. Pump capacity of the standby pump must be the same as existing pump.	Ms Chng
		No industrial water make-up to cooling water storage tank as Level Control Valve (LCV) is closed due to mechanical failure.	Drop in cooling water storage tank level can result in potential pump suction loss. This could lead to pump damage, loss of production and plant shutdown.	Preventive maintenance is conducted on LCV.	Install a low level alarm on cooling water storage tank by October 2017.	Mr Hong
LESS OF	Less flow	Leak of cooling water due to corrosion of piping or its accessories (e.g., fittings, valves, flanges).	Drop in cooling water storage tank level can result in potential pump suction loss. This could lead to pump damage, loss of production and plant shutdown.	1. Automatic control of cooling water storage tank level using industrial water make-up. 2. Operator performs routine check during each shift.	See above on installation of a low level alarm on cooling water storage tank.	
MORE OF	More flow	Industrial water LCV is stuck open due to mechanical failure of LCV.	Overflow of cooling water storage tank, causing wastage of industrial water and higher utility costs.	1. Preventive maintenance is conducted on LCV. 2. Operator performs routine check during each shift.		

Figure 12: Example of HAZOP analysis on a cooling water system.

HAZOP for Batch Processes

A batch process is one in which successive chemical and/ or physical operations are carried out in a single vessel (under varying time-dependent conditions) until the feed changes into product.

For batch processes, HAZOP guidewords may be applied to vessels and pipelines, as well as the batch operating steps (e.g., mixing or heating) and sequence of batch operations.

For example, if the batch instruction indicates that 1 ton of component A is to be charged into a vessel, the following scenarios must be considered:

- No component A charged
- Less component A charged
- More component A charged
- Component A charged at wrong concentration
- Additional substance charged along with component A
- Missing operating step
- Wrong operating sequence

Note that deviations for batch operations may also arise when there are variations in the time taken (including the rate of change) for each processing step.

The What-If method (see Section 2.3.2) may also be used on batch processes.

2.4 Limitations of Process Hazard Analysis

Although PHA methods are widely used for hazard identification, they have their limitations. It is important to be aware of the following limitations when carrying out a PHA:

Limitation #1

The quality of a PHA will only be as effective as the PHA team's ability to recognise hazards. If a hazard is not recognised, the PHA will be no help in minimising it. It is therefore critical to select personnel with the expertise and necessary process experience to be in the PHA team.

Limitation #2

PHA may not account for multiple failures.

Limitation #3

PHA typically do not address events external to the process (e.g., crane collapse, vehicle crash).

Limitation #4

Following a PHA, a PSE can still occur if the recommendations are inadequate or if the action plan is not effectively implemented.

Limitation #5

Safety-critical information contained in PHA reports needs to be shared with employees, contractors and neighbouring communities so that disaster prevention is possible. This is to allow all stakeholders to understand their roles in emergency preparedness and put in place necessary measures to achieve a higher state of readiness.

Knowing these limitations will help PHA teams to address and/ or compensate for them wherever possible when carrying out a PHA. To overcome the limitations of any one method, PHA teams may combine approaches (e.g., HAZOP in combination with What-If/ Checklist) within the same PHA.

To ensure that PHA recommendations are adequate, further analysis is recommended such as conducting Bowtie analysis or LOPA following a HAZOP.

For a PHA to be successful, there must be commitment on three key areas:

1. Commitment to keep PSI up-to-date and accurate.
2. Commitment to select persons with the right expertise or experience to participate in PHA sessions.
3. Commitment to document PHA results (including recommendations and management's response to each recommendation) and ensure action items are resolved in a timely manner.

Ensuring proper implementation of action plans is as important as carrying out the PHA itself. It is important to note that process risks can only be managed if action plans are meticulously followed through and actually implemented on-site.

3. Revalidating Process Hazard Analysis

Under the WSH (Registration of Factories) Regulations 2008, factories under Group B are required to submit their PHA documents to the Ministry of Manpower (MOM) during initial factory registration and subsequent renewal of registration every 5 years. This is to ensure that PHA documents are revalidated at least once every 5 years, and are up-to-date and consistent with the current process. See Annex A for more information on the WSH (Registration of Factories) Regulations 2008.

The objective of a PHA revalidation is to produce an updated PHA that adequately identifies and controls the process hazards as they are currently understood, and ensures that existing safeguards are adequate. All known changes since the last PHA must be evaluated to confirm that any new hazards associated with the changes have been accounted for in the updated PHA.

The concept of revalidation can be described in simple terms as follows:

Revalidating PHA means that an existing PHA is to be thoroughly reviewed so that it can be declared valid again.

Considerable time and effort would have gone into conducting the existing PHA. Ideally, the revalidation effort will be an incremental effort. The PHA will only need to be updated to reflect changes or new hazards that have arisen since the prior PHA was conducted. This helps to protect the initial investment in time and effort by building on portions of the existing PHA that are still relevant.

A revalidated PHA serves to address the following:

- New information or knowledge based on the latest research or lessons learnt (e.g., from recent incident investigations);
- Gaps (e.g., failure to address a certain requirement) or deficiencies (e.g., a missed accident scenario) in the existing PHA;
- Changes in the process (e.g., new processing sequence) or equipment (e.g., due to equipment being replaced);
- Changes in internal (e.g., company procedure for conducting a PHA) or external (e.g., regulations) requirements; and
- On-site (e.g., due to plant expansion and a new control centre) or off-site (e.g., a new neighbouring process plant or storage facility) changes that may have introduced new risks and/ or changed the at-risk population.

In most cases, the effort required to revalidate an existing PHA will be much less than conducting an entirely new PHA.

3.1 Conducting Process Hazard Analysis Revalidation

The key steps in PHA revalidation are:

STEP 1: Consolidate information on the process

Examples of information used to support PHA revalidation include:

- Existing PHA report;
- Resolution completion report for the recommendations in the existing PHA report;
- Process safety information such as P&IDs (current and those used in the existing PHA);
- Management of Change (MOC) documentation;
- Summary of changes in regulatory or company requirements;
- WSH Management System (WSHMS) or PSM audit results;
- Accident and near miss incident investigation reports;
- Process upset reports;
- Latest research findings;
- Findings from safety reviews; and
- WSH committee reports.

STEP 2: Evaluate the existing PHA

Areas for evaluation include:

- Composition and qualifications of the team conducting the existing PHA;
- Appropriateness of the PHA method used;
- Adequacy of the existing PHA in addressing process hazards;
- Thoroughness and completeness of the existing PHA; and
- Gaps or deficiencies in the existing PHA.

STEP 3: Assess changes or incidents since previous PHA

Changes in a processing facility include changes in:

- Process (e.g., due to technology improvements, change in processing sequence, capacity increases);
- Operating procedures (including procedures for non-routine operations); and
- Equipment.

Key sources for identifying change include:

- MOC documentation;
- P&ID comparison;
- Procedures comparison;
- Record of implemented recommendations for the existing PHA;

- Purchasing history;
- Equipment log and maintenance records; and
- Staff interviews.

Process incidents include:

- Accidents;
- Near misses; and
- Significant process upsets.

Key sources for identifying incidents include:

- Accident investigation reports;
- Records on loss of containment episodes;
- Near miss incident records;
- Control room data log and trend charts; and
- Staff interviews.

STEP 4: Update the PHA

Carry out the update to address all new knowledge, changes, gaps and deficiencies identified in the earlier steps. See Figure 4 on the steps to conducting a PHA as they apply to PHA revalidation as well.

To ensure quality and rigour in the analysis, the PHA revalidation team should have the same range of expertise as the team that conducted the existing PHA. The revalidation team members need not be the same members as before.

3.2 Documenting Process Hazard Analysis Revalidation

A clear, concise and thorough PHA revalidation report is essential to ensure proper documentation and effective communication of the PHA results. The documentation of the revalidated PHA should mirror the existing PHA report in both format and content.

A PHA revalidation report minimally includes the following items:

1. Identify the process unit or section examined;
2. List members of the PHA revalidation team;
3. List the documents examined (e.g., existing PHA report, P&IDs being compared, MOC records, incidents since the previous PHA);
4. Describe the PHA method used for the revalidation; and
5. Document the PHA revalidation results and recommendations.

See Table 16 for suggested items to be included in a PHA revalidation report.

Recommendations arising from the revalidation should be resolved in a timely manner.

To prevent lapses in follow-up, companies can create a completion timeline for each additional control that needs to be implemented (e.g., control measures to address a high severity scenario to be implemented within two weeks).

Companies may consider documenting the following to ensure on-site implementation:

- How the recommendation is to be resolved;
- Person responsible for the follow-up;
- Timeline for completion;
- Progress report until the recommendation is resolved; and
- Date when the recommendation is resolved.

The PHA report and subsequent revalidation reports are valuable sources of information to those responsible for controlling process hazards.

An effective PHA revalidation report is critical as it will simplify future revalidation and form the basis for key decisions made by subsequent PHA revalidation teams. As per industry practice, documentation of the PHA and actions taken should be kept throughout the life of the process.

4. References

Workplace Safety and Health Act

- *WSH (Risk Management) Regulations*
- *WSH (General Provisions) Regulations*
- *WSH (Registration of Factories) Regulations 2008*
- *WSH (Safety and Health Management System and Auditing) Regulations 2009*

Codes of Practice

- *Code of Practice on WSH Risk Management*
- *CP 79: 1999 Code of Practice for Safety Management System for Construction Worksites*

Singapore Standards

- *SS 506–1: 2009 OSH Management Systems – Part 1: Requirements*
- *SS 506–2: 2009 OSH Management Systems – Part 2: Guidelines for the implementation of SS 506 : Part 1 : 2009*
- *SS 506–3: 2013 OSH Management Systems – Part 3: Requirements for Chemical Industry*

WSH Guidance Documents

- *WSH Guidelines on Process Safety Performance Indicators*
- *Guidebook on Process Safety by Singapore Chemical Industry Council*
- *WSH Manual for Marine Industries*

Others

- *American Petroleum Institute (API) RP 754: Process Safety Performance Indicators for the Refining and Petrochemical Industries*
- *Center for Chemical Process Safety (CCPS), Process Safety Leading and Lagging Metrics - You Don't Improve What You Don't Measure, revised 2011*
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5. Acknowledgements

Supporting organisations	Contributors
Singapore Institution of Safety Officers	Mr Niranjan Masurekar (Niri)
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Singapore Chemical Industry Council	Ms Priscilla Tan
Ministry of Manpower	Mr Dave Lir
Workplace Safety and Health Council	Mr Edison J Loh

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6. Annex

Annex A: WSH Legislation pertaining to Process Safety

Process safety is covered under the WSH Act and the following subsidiary legislations:

- WSH (Risk Management) Regulations;
- WSH (General Provisions) Regulations;
- WSH (Registration of Factories) Regulations 2008;
- WSH (Safety and Health Management System and Auditing) Regulations 2009; and
- WSH (Major Hazard Installation) Regulations.

WSH (Risk Management) Regulations

These regulations stipulate that employers, self-employed persons and principals in all workplaces must conduct risk assessment and take reasonably practicable steps to eliminate any foreseeable safety and health risk to any person who may be affected by his or her undertaking.

Risk assessment is defined as the process of evaluating the probability and consequences of injury or illness arising from exposure to the identified hazard, and determining the appropriate measures for risk control.

PHA encompasses various risk assessment methods applied on a process operation in order to identify process hazards and determine the risk control measures that need to be put in place to prevent a PSE.

WSH (General Provisions) Regulations

These regulations cover the following aspects of process plant operations:

- Electric generator, motor, transmission machinery and other machinery;
- Electrical installation and equipment;
- Tanks, structures, sumps and pits;
- Storage of goods;
- Explosive or flammable dust, gas, vapour or substance;
- Steam boilers, steam receivers, air receivers and refrigerating plant pressure receiver;
- Pressure vessels;
- Pipes, pumps and compressors;
- Gas plants;
- Prevention of fire;
- Toxic dust, fumes and other contaminants; and
- Hazardous substances.

WSH (Registration of Factories) Regulations 2008

These regulations require factories engaging in high risk activities to register their premises with MOM and obtain a Certificate of Registration (CR) before starting operations. This requirement applies to any factory that falls into any of the classes of factories described in Part I or Part II of the First Schedule of these regulations.

Factory registration may be one-time or renewable depending on whether the factory falls under Group A or Group B:

Group A: One-time registration	**Group B:** Renewable registration (renewable every five years)
• Construction worksites • Shipyards • Wafer fabrication factories • Pharmaceutical factories • Metalworking factories employing more than 100 people	• Refineries • Petrochemical plants • Bulk storage terminals with storage capacity of 5,000 or more cubic metres of toxic or flammable liquid • Chemical plants manufacturing fluorine, chlorine, hydrogen fluoride, carbon monoxide or synthetic polymer

Table A.1: Factory registration requirements.

Factories under Group B are required to submit their PHA documents (e.g., HAZOP and FMEA) to MOM during initial registration and for subsequent renewal every five years.

For more information on factory registration, please refer to the MOM website at www.mom.gov.sg.

WSH (Safety and Health Management System and Auditing) Regulations 2009

These regulations require factories to appoint a WSH auditor to audit their Safety and Health Management System (SHMS). The implementation of a SHMS will help ensure the safety and health of every person at work in the factory.

Workplaces to implement a safety and health management system

- Any premises which is a worksite.
- Any premises which is a shipyard.
- Any factory engaged in the manufacturing of fabricated metal products, machinery or equipment, and in which 100 or more persons are employed.
- Any factory engaged in the processing or manufacturing of petroleum, petroleum products, petrochemicals or petrochemical products.
- Any premises where the bulk storage of toxic or flammable liquid is carried on by way of trade or for the purpose of gain and which has a storage capacity of 5,000 or more cubic metres for such toxic or flammable liquid.
- Any factory engaged in the manufacturing of:
  - fluorine, chlorine, hydrogen fluoride or carbon monoxide; and
  - synthetic polymers.
- Any factory engaged in the manufacturing of pharmaceutical products or their intermediates.
- Any factory engaged in the manufacturing of semiconductor wafers.

Figure A.1: List of workplaces where a SHMS is mandatory (as per 2nd Schedule of WSH (Safety and Health Management System and Auditing) Regulations 2009.

The SHMS audit frequency for factories is specified in Table A.2:

Description of workplace	Frequency of audit
Any factory engaged in the manufacturing of fabricated metal products, machinery or equipment, and in which 100 or more persons are employed	At least once every 12 months
Any factory engaged in the processing or manufacturing of petroleum, petroleum products, petrochemicals or petrochemical products	At least once every 24 months
Any premises where the bulk storage of toxic or flammable liquid is carried on by way of trade or for the purpose of gain and which has a storage capacity of 5,000 or more cubic metres for such toxic or flammable liquid	At least once every 24 months
Any factory engaged in the manufacturing of • fluorine, chlorine, hydrogen fluoride or carbon monoxide; and • synthetic polymers.	At least once every 24 months
Any factory engaged in the manufacturing of pharmaceutical products or their intermediates	At least once every 24 months
Any factory engaged in the manufacturing of semiconductor wafers	At least once every 24 months

Table A.2: Audit frequency based on factory type (as per 3rd Schedule of WSH (Safety and Health Management System and Auditing) Regulations 2009.

The SHMS audit is to be conducted in accordance with the WSH Act and its subsidiary legislations, and relevant Singapore Standards or other standards, codes of practice or guidance documents issued or approved by the WSH Council. See Table A.3 for a list of relevant SHMS audit guidance documents for different workplaces.

Workplace	Guidance document(s) for SHMS audit
Shipyards	WSH Manual for Marine Industries
Construction worksites	Singapore Standard SS 506–1: 2009 OSH Management Systems – Part 1: Requirements; or CP 79: 1999 Code of Practice for Safety Management System for Construction Worksites; or Construction Safety Audit Scoring System (ConSASS)
Metalworking factory	Singapore Standard SS 506–1: 2009 OSH Management Systems – Part 1: Requirements; or WSH Guidelines on Implementation of Safety Management System for Metalworking Industry
Semiconductor wafer fabrication plant	Singapore Standard SS 506–3: 2013 OSH Management Systems – Part 3: Requirements for Chemical Industry
Oil refinery or petrochemical plant	
Pharmaceutical plant	
Bulk storage terminal	

Table A.3: Guidance documents for SHMS Audit for various workplaces.

For chemical manufacturing companies, the following workplaces are required to submit their SHMS audit findings to MOM based on *Singapore Standard SS 506: Part 3 OSH Management Systems – Requirement for Chemical Industry*:

- A factory that processes or manufactures petroleum, petroleum products, petrochemicals or petrochemical products;
- A factory that manufactures pharmaceutical products or their intermediates;
- Any premises that store toxic or flammable liquids at a storage capacity of 5,000 or more cubic metres; and
- A factory that manufactures fluorine, chlorine, hydrogen fluoride, carbon monoxide and synthetic polymers.

Note:
Singapore Standard SS 506: Part 3 OSH Management Systems – Requirement for Chemical Industry contains elements relevant to process safety management. They include hazard identification, risk assessment and risk control, operating procedures and safe work practices, mechanical integrity and reliability, control of hazardous substances, and management of change.

WSH (Major Hazard Installation) Regulations

These regulation introduce the safety case regime for Major Hazard Installations (MHIs). Scheduled to take effect from September 2017, the regime serves to streamline existing regulatory requirements for safety, health and the environment.

The MHI regulations require that a consolidated safety case be submitted to the Major Hazards Department (MHD). The MHD is a joint-government department led by MOM and comprises officers from National Environment Agency, Singapore Civil Defence Force and MOM.

Key components of a safety case include:

- Major accident prevention policy;
- Safety and health management system;
- Process hazards analysis;
- Quantitative risk assessment;
- Technical aspects (e.g., preventive and mitigation measures);
- Emergency response plan; and
- ALARP demonstration.

Under the safety case regime, companies classified as MHIs must demonstrate that appropriate measures have been taken to reduce risks to ALARP.

Additionally, MHIs are required to share relevant information on the nature and extent of risks imposed on neighbouring installations in order to mitigate potential domino effects in the event of a major accident. This is to allow companies in the vicinity to take these additional risks into account during risk management and emergency response planning.

Annex B: Common Process Deviations

Major operating limits

- Flow
- Temperature
- Pressure
- Level
- Chemical reactivity
- Mechanical stresses

Other operating limits

- Corrosion
- Erosion
- Resistance
- Fouling
- Cavitation
- Vibration
- Hammer
- Loadings
- Expansion
- Contraction
- Thermal or mechanical shock
- Cycles of activities
- Environmental factors

Material physical characteristics

- Viscosity
- Miscibility
- Melting or boiling point
- Density
- Vapour density
- Phase
- Appearance
- Particle size

Chemical composition

Hazard characteristics of mixtures

Reactions

- Extent and type
- Side reactions
- Catalyst behaviour (e.g., activity, toxicity, decomposition)
- Planned or unplanned reactions
- Contaminants
- Corrosion products
- Reaction runaway
- Combustion or explosion

Time

- Contact time
- Sequence
- Design cycle

Local effects

- Distribution
- Mixing
- Hot spots
- Overheating
- Resonance
- Stress on bearings
- Lubricating faults
- Vortex generation
- Blockage
- Slugs
- Sedimentation
- Stagnation
- Adhesion
- Crushing
- Grinding
- Separation

Failure to contain materials

- Spillage
- Leakage
- Vented material

Construction

- Defective materials of construction
- Plant incomplete
- Plant unsupported
- Plant not aligned
- Plant not on level ground

Major deviations

- Startup or shutdown
- Maintenance or inspection
- Planned changes in normal operations
- Supply or equipment failure
- Demand change
- Unplanned ignition source
- Process disturbance
- Loss of communication
- Human error
- Climatic effects

Annex C: Typical Causes of Process Deviations

Deviation	Typical causes or initiating events
NO FLOW	Isolation in error, wrong routing, blockage, incorrectly fitted non-return valve (NRV), large leak, equipment failure (e.g., control valve, isolation valve, pump, vessel), incorrect pressure differential, delivery side overpressure, vapour lock, or service failure.
REVERSE FLOW	Defective non-return valve, siphon effect, incorrect differential pressure, two way flow, emergency venting, incorrect operation, pump reversed, or service failure.
MORE FLOW	Increased pumping capacity, increased suction pressure, reduced delivery head, greater fluid density, exchanger tube leaks, restriction orifice plates deleted, cross connection of systems, control faults, control set wrong, open bypass, more quantity, service failure, or abnormal opening.
MORE TEMPERATURE	Ambient conditions, fouled or failed exchanger tubes, less cooling, cooling water failure, defective control, fire situation, reaction control failure, connected high temperature source, or energy from machines.
MORE PRESSURE	Surge problems, leakage from interconnected high pressure system, gas breakthrough, inadequate venting, thermal overpressure, failed open control valves, explosion, fire, imbalance of input and output, external pressure, water hammer, or positive displacement pumps.
LESS FLOW	Line restriction, partial blockage, defective pumps, cavitation, fouling of vessels, valves, restrictor or orifice plates, density or viscosity problems, incorrect specification of process fluid, less quantity, small leak, service failure, or abnormal opening.
LESS TEMPERATURE	Ambient conditions, reducing pressure, fouled or failed exchanger tubes, loss of heating, rain, connected cold source, or auto refrigeration.
LESS PRESSURE	Vacuum condition, condensation, gas dissolving in liquid, restricted pump or compressor suction line, undetected leakage, vessel drainage, or imbalance of inflow and outflow.

Deviation	Typical causes or initiating events
PART OF	Incorrect feedstock, incorrect separation failures, change in reaction, emergency discharge, leaking isolation valves, leaking exchanger tubes, inadequate process control, lack of mixing, or missing component.
AS WELL AS	Incorrect routing, interconnected systems, effect of corrosion, wrong additive, ingress of air, water, lube oil, shutdown and start up conditions, carryover of solid or liquid, inert gas failure, internal leaks, or extra phase.
OTHER THAN	Start up and shutdown, testing and inspection, relief sampling, service failure, planned abnormal operations (e.g., purging, blowdown, catalyst activation), maintenance, unusual emissions and effluents, static generation, or domino effect.
CHANGE IN TIME OF OPERATION	Valves open too much, too long, too short, and wrong duration or sequence.
RELIEF	Failure of relief systems, or poor choice of relief valve discharge location.
MEASUREMENT	Measurement error in temperature, pressure, level or flow.
PROTECTION	Protection failure, protection missing or reduced, or sabotage.
EXTERNAL HAZARDS	Act of God, extreme weather, external interference, or external event.

HAZOP Worksheet

Project title: _____

HAZOP facilitator: _____
HAZOP team : _____
_____
_____
_____
_____

Project no.: _____
P&ID no.: _____
Revision no. : _____
Section no.: _____
Line no.: _____
Date : _____

Design parameter : ☐

Process hazard identification				Risk evaluation				Risk control				
Guideword	Deviation	Causes	Consequences	Existing risk controls	S	L	RPN	Action (Additional controls)	S	L	RPN	By
NONE												
LESS OF												
...												

Legend: S = Severity, L = Likelihood, RPN = Risk prioritisation number

[Ref: Code of Practice on WSH Risk Management]

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