Hazard and Operability (HAZOP)& Hazard Analysis Training

HAZOP Fundamental

A scenario…

- You and your family are on a road trip by using a car in the middle of the night. You were replying a text message while driving at 100 km/h and it was raining heavily. The car hits a deep hole and one of your tire blows. You hit the brake, but due to slippery road and your car tire thread was thin, the car skidded and was thrown off the road.

Points to ponder

What is the cause of the accident?

What is the consequence of the event?

What can we do to prevent all those things to happen in the first place?

(5 minutes for brainstorming ideas)

What other possible accidents might happen on the road trip?

Can we be prepared before the accident occurs?

Can we make it more systematic?

Parameter	Guideword	Possible Causes	Consequences	Action	Safeguard
Car speed	Too fast Too slow	Rushing	Skidded when emergency brake	- Slow down - Speed up	- ABS brake system - Safety belt - Air bag
Tire	No thread Less thread	Tire too old, often speeding and emergency break	Car skidded		- Check frequently - Have spare tire
Window visibility	Low Very low	Rain	Cannot see the road		
Car light	Dim No light			- Stop car - Go to nearest garage - Use emergency signal	
Road	With holes Rocky		Breaks the car tire		- Put a signboard - Street lights
Travel time	Night Foggy	No street light			- Travel during daylight

What is HAZOP?

- Systematic technique to IDENTIFY potential HAZard and OPerating problems
- A formal systematic rigorous examination to the process and engineering facets of a production facility
- A qualitative technique based on "guide-words" to help provoke thoughts about the way deviations from the intended operating conditions can lead to hazardous situations or operability problems
- HAZOP is basically for safety

  - Hazards are the main concern

  - Operability problems degrade plant performance (product quality, production rate, profit)
- Considerable engineering insight is required - engineers working independently could develop different results

Origin of HAZOP

- Initially prepared by Dr H G Lawley and associates of ICI at Wilton in 1960's.
- Subsequently C J Bullock and A J D Jenning from ChE Dept. Teeside Polytechnic under supervision of T.A. Kletz applied the method at higher institution (post-graduate level).
- In 1977, Chemical Industries Association published the edited version.

Later Development - HAZOP

- ICI expanded the procedure called HAZARD STUDY steps 1 to 6.
- The ICI six steps :
  - Project exploration / preliminary project assessment – to identify inherent hazards of process chemicals, site suitability and probable environmental impact.
  - Project definition – to identify and reduce significant hazards associated with items and areas, check conformity with relevant standards and codes of practices.

    USE CHECK LISTS

Later Development - HAZOP

- Design and procurement – to examine the PID in detail for identification of deviations from design intent capable of causing operability problems or hazards.
- During final stages of construction – to check that all recommended and accepted actions recorded in steps i, ii and iii implemented.
- During plant commissioning – to check that all relevant statutory requirements have been acknowledges and all installed safety systems are reliably operable.

Later Development - HAZOP

- During normal operation, some time after start-up – especially if any modification been made. To check if changes in operation has not invalidated the HAZOP report of step iii by introducing new hazards.

  This procedures are adopted fully or partly by many companies around the world.

Objective of HAZOP

- For identifying cause and the consequences of perceived mal operations of equipment and associated operator interfaces in the context of the complete system.

- It accommodates the status of recognized design standards and codes of practice but rightly questions the relevance of these in specific circumstances where hazards may remain undetected.

How and Why HAZOP is Used

- HAZOP identifies potential hazards , failures and operability problems.
- Its use is recommended as a principal method by professional institutions and legislators on the basis of proven capabilities for over 40 years.
- It is most effective as a team effort consists of plant and prices designers, operating personnel, control and instrumentation engineer etc.
- It encourages creativity in design concept evaluation.
- Its use results in fewer commissioning and operational problems and better informed personnel, thus confirming overall cost effectiveness improvement.

How and Why HAZOP is Used

- Necessary changes to a system for eliminating or reducing the probability of operating deviations are suggested by the analytical procedure.
- HAZOP provides a necessary management tool and bonus in so far that it demonstrates to insurers and inspectors evidence of comprehensive thoroughness.
- HAZOP reports are an integral part of plant and safety records and are also applicable to design changes and plant modifications, thereby containing accountability for equipment and its associated human interface throughout the operating lifetime.

How and Why HAZOP is Used

- HAZOP technique is now used by most major companies handling and processing hazardous material, especially those where engineering practice involves elevated operating parameters :
  - oil and gas production
  - flammable and toxic chemicals
  - pharmaceuticals etc
- Progressive legislation in encouraging smaller and specialty manufacturing sites to adopt the method also as standard practice.

Purpose of HAZOP

- It emphasizes upon the operating integrity of a system, thereby leading methodically to most potential and detectable deviations which could conceivably arise in the course of normal operating routine

  - including "start-up " and "shut-down" procedures

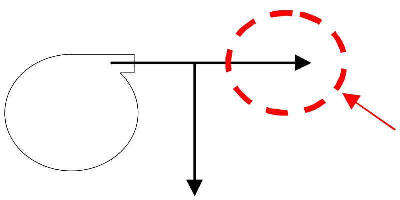
  - as well as steady-state operations.

- It is important to remember at all times that HAZOP is an identifying technique and not intended as a means of solving problems nor is the method intended to be used solely as an undisciplined means of searching for hazardous scenarios.

HAZOP - Hazard and operability

HAZOP keeps all team members focused on the same topic and enables them to work as a team

1 + 1 = 3

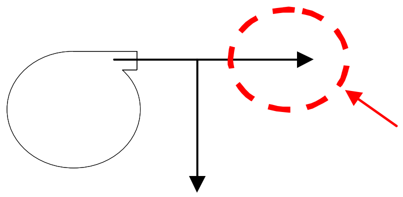


NODE: Concentrate on one location in the process

PARAMETER: Consider each process variable individually
(F, T, L, P, composition, operator action, corrosion, etc.)

GUIDE WORD: Pose a series of standard questions about deviations from normal conditions. We assume that we know a safe "normal" operation.

HAZOP - Hazard and operability



NODE: Pipe after pump and splitter

PARAMETER*: Flow rate

GUIDE WORD*: Less (less than normal value)

- **DEVIATION: less flow than normal**
- **CAUSE: of deviation, can be more than one**
- **CONSEQUENCE: of the deviation/cause**
- **ACTION: initial idea for correction/ prevention/mitigation**

A group members focus on the same issue simultaneously

Relevant Question About HAZOP

Question : How can one be certain to identify all possible deviations ?

Answer : No absolute certainty as the study is subjective and 100 % achievement in this context can have no significance. Any individual or corporate effort will yield results directly proportional to the appropriate background experience of those taking part.

However, with the appropriate levels of individual project-related expertise , such a procedure is fully capable of identifying at least 80 % of potential deviations which could rise during normal operation.

Relevant Question About HAZOP

Separate consideration is demanded for other operating modes, such as commissioning, emergency shut-down procedures and isolation of equipment for maintenance or modification.

Once an installation is endorsed by a properly-conducted HAZOP study, it is these non-steady state circumstances which benefit particularly from the technique throughout the life time of the installation.

' Operability' must also consider the human factors involved as well as the prediction of equipment behavior.

Relevant Question About HAZOP

Apart from the uniformity of day-to-day activities , hazards which could cause major production interruptions and loss, possibly leading to costly incidents, need to be identified :

- Are there chemicals used in the plant which have not been classified as hazard because they are handled in small quantities, are assumed harmless, or are not considered to have long-term toxic effect upon employees?
- What hazardous materials are transported to or from the site ?
- What routes are taken ?
- What would be the consequences of accidental release?

Relevant Question About HAZOP

- What effluents are generated by the operation being carried out or contemplated ? What regulations require to be honored for their disposal?
- Are chemicals properly packaged & labeled?
- Are the consequences of product misuse made absolutely clear?
- Have all potential God-made events and man-made incidents (e. g breaches of security, sabotage, electric power failure) been considered?
- Are the codes and standards applicable to each facility and relating to its design , sitting and construction complied with? For example, in pressure vessel design.

Features of HAZOP Study

Subsystems of interest	line and valve, etc Equipment, Vessels
Modes of operation	Normal operation Start -up mode Shutdown mode Maintenance /construction / inspection mode
Trigger events	Human failure Equipment /instrument/component failure Supply failure Emergency environment event Other causes of abnormal operation, including instrument disturbance

Features of HAZOP Study

Effects within plant	Changes in chemical conditions
	Changes in inventory
	Change in chemical physical conditions
Hazardous conditions	Release of material
	Changes in material hazard
characteristics	
	Operating limit reached
	Energy source exposed etc.
Corrective actions	Change of process design
	Change of operating limits
	Change of system reliability
	Improvement of material containment
	Change control system
	Add/remove materials

Features of HAZOP Study

How would hazardous conditions detected ?	During normal operation Upon human failure Upon component failure In other circumstances
Contingency actions	Improve isolation Improve protection

Documents Needed for HAZOP Study

- For Preliminary HAZOP
  - Process Flow Sheet (PFS or PFD)
  - Description of the Process

- For Detailed HAZOP
  - Piping and Instrumentation Diagram (P & ID)
  - Process Calculations
  - Process Data Sheets
  - Instrument Data Sheets
  - Interlock Schedules
  - Layout Requirements
  - Hazardous Area Classification
  - Description of the Process

Before Detailed HAZOP

- The development of the detailed P&I Diagram is the last stage of the process design.

- The development will follow a normal standard procedure and include the following considerations :
  - Basic process control system - this is a closed loop control to maintain process within an acceptable operating region.
  - Alarm system - this is to bring unusual situation to attention of a person monitoring the process in the plant
  - Safety interlock system - this is to stop operation or part of the process during emergencies.
  - Relief system - this is to divert material safely during emergencies

P&ID

- A Piping and Instrumentation Diagram - P&ID, is a schematic illustration of functional relationship of piping, instrumentation and system equipment components.

- P&ID represents the last step in process design.

- P&ID shows all of piping including the physical sequence of branches, reducers, valves, equipment, instrumentation and control interlocks.
- P&ID is normally developed from process flow diagram (PFD).
- The P&ID are used to operate the process system.
- A process cannot be adequately designed without proper P&ID.

P&I D

A P&ID should include: (Basically every mechanical aspect of the plant with some exceptions)

- Instrumentation and designations
- Mechanical equipment with names and numbers
- All valves and their identifications
- Process piping, sizes and identification
- Miscellaneous - vents, drains, special fittings, sampling lines, reducers, increasers and swagers
- Permanent start-up and flush lines
- Flow directions
- Interconnections references
- Control inputs and outputs, interlocks
- Interfaces for class changes
- Seismic category
- Quality level
- Annunciation inputs
- Computer control system input
- Vendor and contractor interfaces
- Identification of components and subsystems delivered by others
- Intended physical sequence of the equipment

P&I D

A P&ID should not include:

- Instrument root valves
- control relays
- manual switches
- equipment rating or capacity
- primary instrument tubing and valves
- pressure temperature and flow data
- elbow, tees and similar standard fittings
- extensive explanatory notes

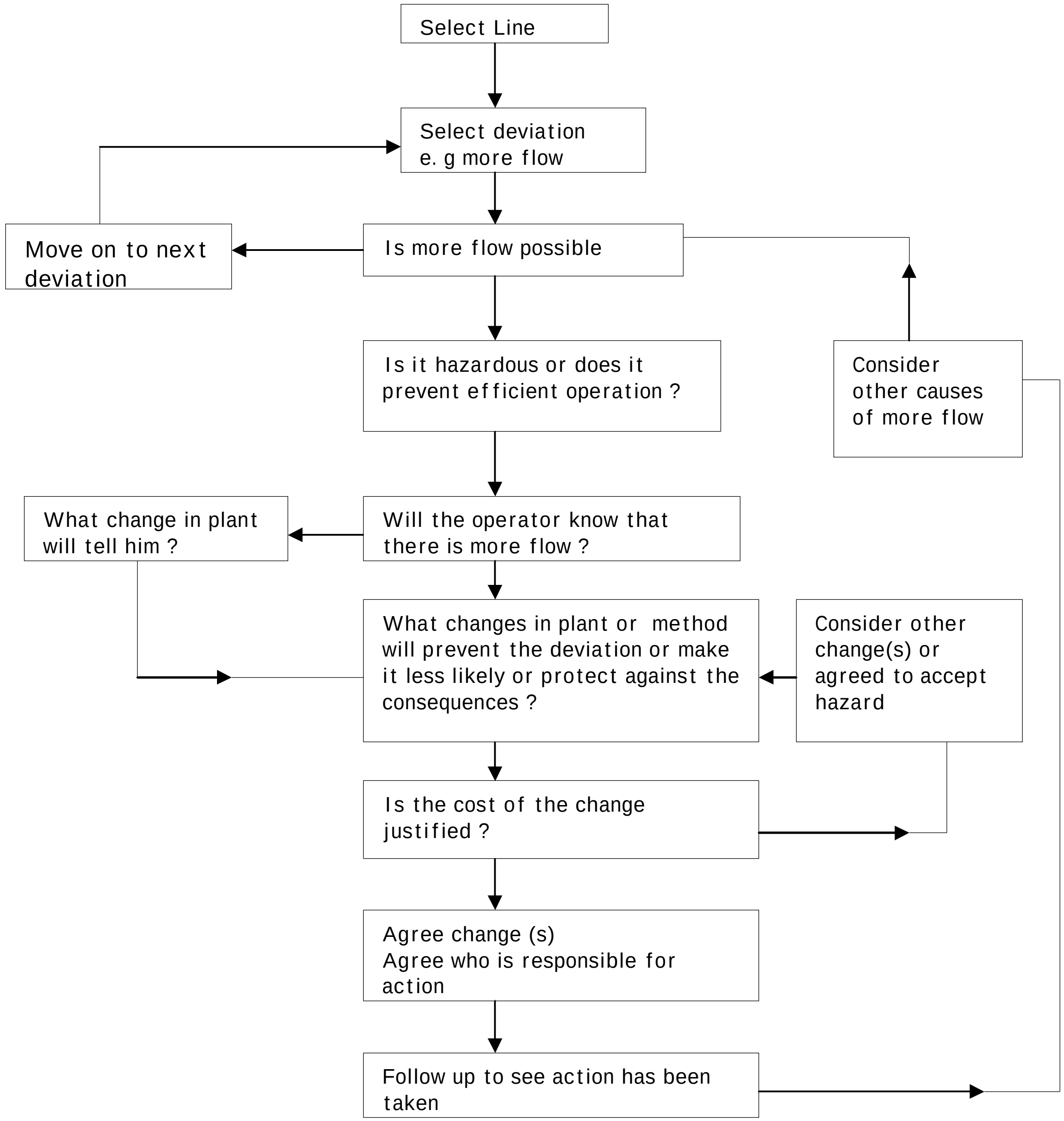
P&ID and Safety

- P&I Diagram
  - ISA Standard
  - DIN Standard
- Layers of protection

HAZOP Study Procedure

- Procedure in HAZOP study consist of examining the process and instrumentation (P&I) line diagram , process line by process line .
- A list of guide words is used to generate deviations from normal operation corresponding to all conceivable possibilities.
- Guide words covering every parameter relevant to the system under review :i.e. flow rate and quality, pressure, temperature, viscosity, components etc.
- Flowchart for application of HAZOP is shown in figure.

HAZOP Study Flow Chart



Guidelines for Division into Sections

- Choices of lines – P&ID must be divided logically. Not too many sections. Factors to be considered :
  - Each section should contain active components, which gives rise to deviations. E.g piping which contains control valves can give rise to flow deviations, heat exchangers can cause T deviations.
  - Materials in section – contain significant amount of hazardous materials.
  - Section based on process and states of materials. Only 1 process operation per 1 section.

Guidelines for Division into Sections

- General guidelines :
  - Define each major process component as a section. Usually anything assigned equipment number should be considered a major process component.
  - Define one line section between each major process component.
  - Define additional line sections for each branches off the main process flow.
  - Define a process section at each connection to existing equipment.

Guidelines for Division into Sections

- Supplementary guidelines
  - Define only one process section for equipment in identical service. However, pumps in different service with a common spare must be treated separately.
  - Define only one line at the end of a series of components if there are no other flow paths.
  - Define only one additional line section if there are alternative flow paths, regardless of how many branches there are.

Guidelines for Division into Sections

- Do not define line between major equipment items if there are no single active components that could cause deviations.
- Do not define sections for existing equipment that is upstream of new or modified equipment. Address malfunctions of such upstream equipment as deviations in the new or modified equipment.

HAZOP Study Procedure

GUIDE WORDS *

POSSIBLE CAUSES

DEVIATION (FROM DESIGN AND/OR OPERATING INTENT)

CONSEQUENCES

ACTION(S) REQUIRED OR RECOMMENDEED

Guide Words

NONE	No forward flow when there should be
MORE	More of any parameter than there should be, e.g more flow, more pressure, more temperature, etc.
LESS	As above, but "less of" in each instance
PART	System composition difference from what it should be
MORE THAN	More "components" present than there should be for example, extra phase, impurities
OTHER	What needs to happen other than normal operation, e.g. start up,shutdown, maintenance

Guide Words

NONE	e.g., NO FLOW caused by blockage; pump failure; valve closed or jammed : leak: valve open ;suction vessel empty; delivery side over - pressurized : vapor lock ; control failure
REVERSE	e.g., REVERSE FLOW caused by pump failure : NRV failure or wrongly inserted ; wrong routing; delivery over pressured; back- siphoning ; pump reversed
MORE OF	e.g., MORE FLOW caused by reduced delivery head ; surging ; suction pressurised ; controller failure ; valve stuck open leak ; incorrect instrument reading.

Guide Words

MORE OF	MORE TEMPERATURE, pressure caused by external fires; blockage ; shot spots; loss of control ; foaming; gas release; reaction;explosion; valve closed; loss of level in heater; sun.
LESS OF	e.g., LESS FLOW caused by pump failure; leak; scale in delivery; partial blockage ; sediments ; poor suction head; process turndown.
LESS	e.g., low temperature, pressure caused by Heat loss; vaporisation ; ambient conditions; rain ; imbalance of input and output ; sealing ; blocked vent .
PART OF	Change in composition high or low concentration of mixture; additional reactions in reactor or other location ; feed change.

Guide Words

MORE THAN	Impurities or extra phase Ingress of contaminants such as air, water, lube oils; corrosion products; presence of other process materials due to internal leakage ; failure of isolation ; start-up features.
OTHER	Activities other than normal operation start-up and shutdown of plant ; testing and inspection ; sampling ; maintenance; activating catalyst; removing blockage or scale ; corrosion; process emergency ; safety procedures activated ; failure of power, fuel, steam , air, water or inert gas; emissions and lack of compatibility with other emission and effluents.

HAZOP Study Form

HAZOP STUDY REPORT FORM
TITLE :

Sheet 1 of

LINE 1 :

DEVIATION	CAUSES	CONSEQUENCES	EXISTING PROVISIONS	ACTIONS, QUESTIONS OR RECOMMENDATIONS

HAZOP Study

HAZOP study are applied during :

- Normal operation
- Foreseeable changes in operation, e.g. upgrading, reduced output, plant start-up and shut-down
- Suitability of plant materials, equipment and instrumentation
- Provision for failure of plant services, e. g . steam, electricity, cooling water
- Provision for maintenance.

Strength of HAZOP

- HAZOP is a systematic, reasonably comprehensive and flexible.
- It is suitable mainly for team use whereby it is possible to incorporate the general experience available.
- It gives good identification of cause and excellent identification of critical deviations.
- The use of keywords is effective and the whole group is able to participate.
- HAZOP is an excellent well-proven method for studying large plant in a specific manner.
- HAZOP identifies virtually all significant deviations on the plant, all major accidents should be identified but not necessarily their causes.

Weakness of HAZOP

- HAZOP is very time consuming and can be laborious with a tendency for boredom for analysts.
- It tends to be hardware-oriented and process-oriented, although the technique should be amenable to human error application.
- It tends to generate many failure events with insignificance consequences and generate many failure events which have the same consequences.
- It stifles brainstorming although this is not required at the late stage of design when it is normally applied.
- HAZOP does not identify all causes of deviations and therefore omits many scenarios.

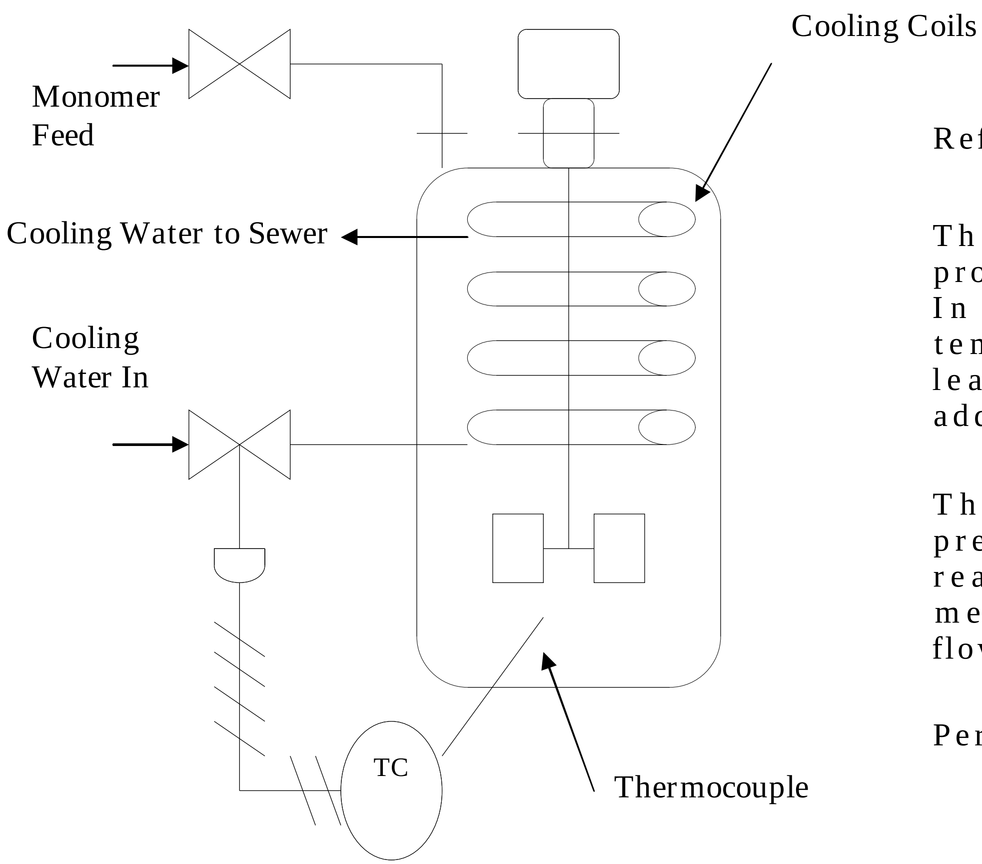
Weakness of HAZOP

- It takes little account of the probabilities of events or consequences, although quantitative assessment are sometime added. The group generally let their collective experiences decide whether deviations are meaningful.
- HAZOP is poor where multiple-combination events can have severe effects.
- It tends to assume defects or deterioration of materials of construction will not arise.
- When identifying consequences, HAZOP tends to encourage listing these as resulting in action by emergency control measures without considering that such action might fail. It tends to ignore the contribution which can be made by operator interventions

Managing HAZOP

How to manage HAZOP

Preliminary HAZOP Example



Refer to reactor system shown.

The reaction is exothermic. A cooling system is provided to remove the excess energy of reaction. In the event of cooling function is lost, the temperature of reactor would increase. This would lead to an increase in reaction rate leading to additional energy release.

The result could be a runaway reaction with pressures exceeding the bursting pressure of the reactor. The temperature within the reactor is measured and is used to control the cooling water flow rate by a valve.

Perform HAZOP Study

Preliminary HAZOP on Reactor - Example

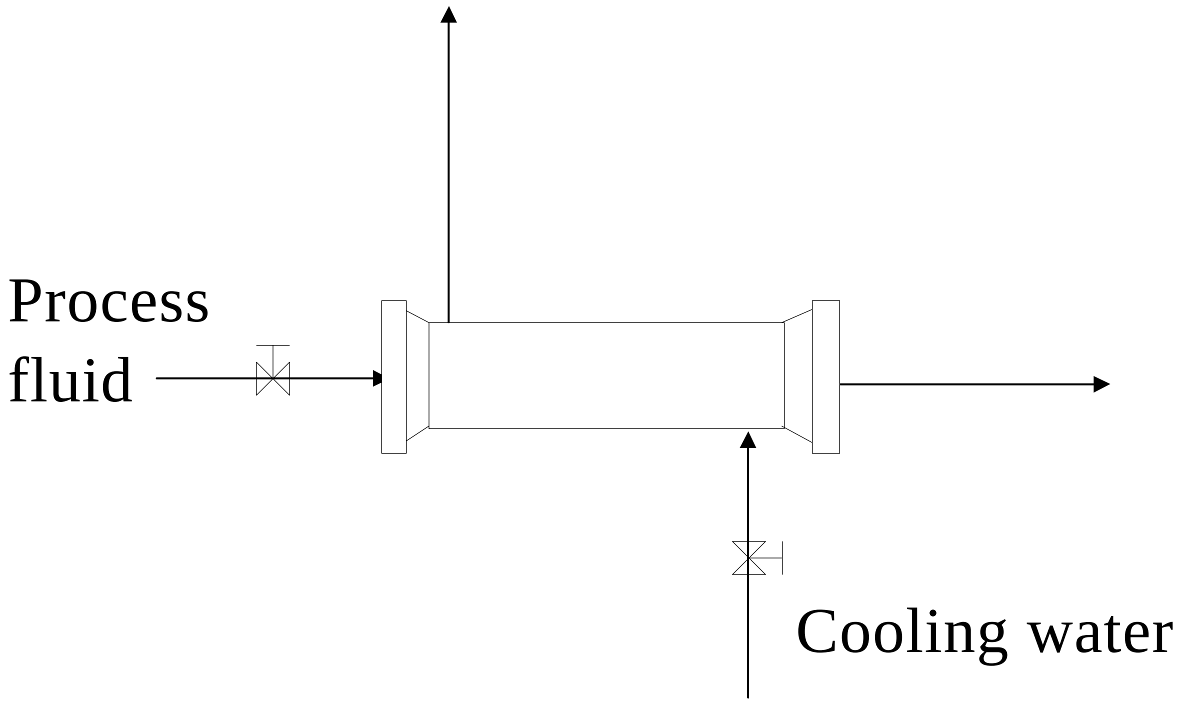
Guide Word	Deviation	Causes	Consequences	Action
NO	No cooling		Temperature increase in reactor	
REVERSE	Reverse cooling flow	Failure of water source resulting in backward flow		
MORE	More cooling flow			Instruct operators on procedures
AS WELL AS	Reactor product in coils			Check maintenance procedures and schedules
OTHER THAN	Another material besides cooling water	Water source contaminated		

Preliminary HAZOP on Reactor – Answer

Guide Word	Deviation	Causes	Consequences	Action
NO	No cooling	**Cooling water valve malfunction**	Temperature increase in reactor	**Install high temperature alarm (TAH)**
REVERSE	Reverse cooling flow	Failure of water source resulting in backward flow	**Less cooling, possible runaway reaction**	**Install check valve**
MORE	More cooling flow	**Control valve failure, operator fails to take action on alarm**	**Too much cooling, reactor cool**	Instruct operators on procedures
AS WELL AS	Reactor product in coils	**More pressure in reactor**	**Off-spec product**	Check maintenance procedures and schedules
OTHER THAN	Another material besides cooling water	Water source contaminated	**May be cooling inefffective and effect on the reaction**	**If less cooling, TAH will detect. If detected, isolate water source. Back up water source?**

Case Study – Shell & Tube Heat Exchanger

- Using relevant guide works, perform HAZOP study on shell & tube heat exchanger



HAZOP on Heat Exchanger – Answer 1

Guide Word	Deviation	Causes	Consequences	Action
Less	Less flow of cooling water	Pipe blockage	Temperature of process fluid remains constant	High Temperature Alarm
More	More cooling flow	Failure of cooling water valve	Temperature of process fluid decrease	Low Temperature Alarm
More of	More pressure on tube side	Failure of process fluid valve	Bursting of tube	Install high pressure alarm
Contamination	Contamination of process fluid line	Leakage of tube and cooling water goes in	Contamination of process fluid	Proper maintainance and operator alert
Corrosion	Corrosion of tube	Hardness of cooling water	Less cooling and crack of tube	Proper maintainence

HAZOP on Heat Exchanger – Answer 2

Guide Word	Deviation	Causes	Consequences	Action
NONE	**No cooling water flow**	**Failure of inlet cooling water valve to open**	**Process fluid temperature is not lowered accordingly**	**Install Temperature indicator before and after the process fluid line** **Install TAH**
MORE	**More cooling water flow**	**Failure of inlet cooling water valve to close**	**Output of Process fluid temperature too low**	**Install Temperature indicator before and after process fluid line** **Install TAL**
LESS	**Less cooling water**	**Pipe leakage**	**Process fluid temperature too low**	**Installation of flow meter**
REVERSE	**Reverse process fluid flow**	**Failure of process fluid inlet valve**	**Product off set**	**Install check valve (whether it is crucial have to check?)**
CONTAMINATION	**Process fluid contamination**	**Contamination in cooling water**	**Outlet temperature too low**	**Proper maintenance and operator alert**

HAZOP - Hazard and Operability

ATTITUDE CHECK

All of these terms! This stupid table! I hate HAZOPS. Why don't we just learn the engineering?

Consequence

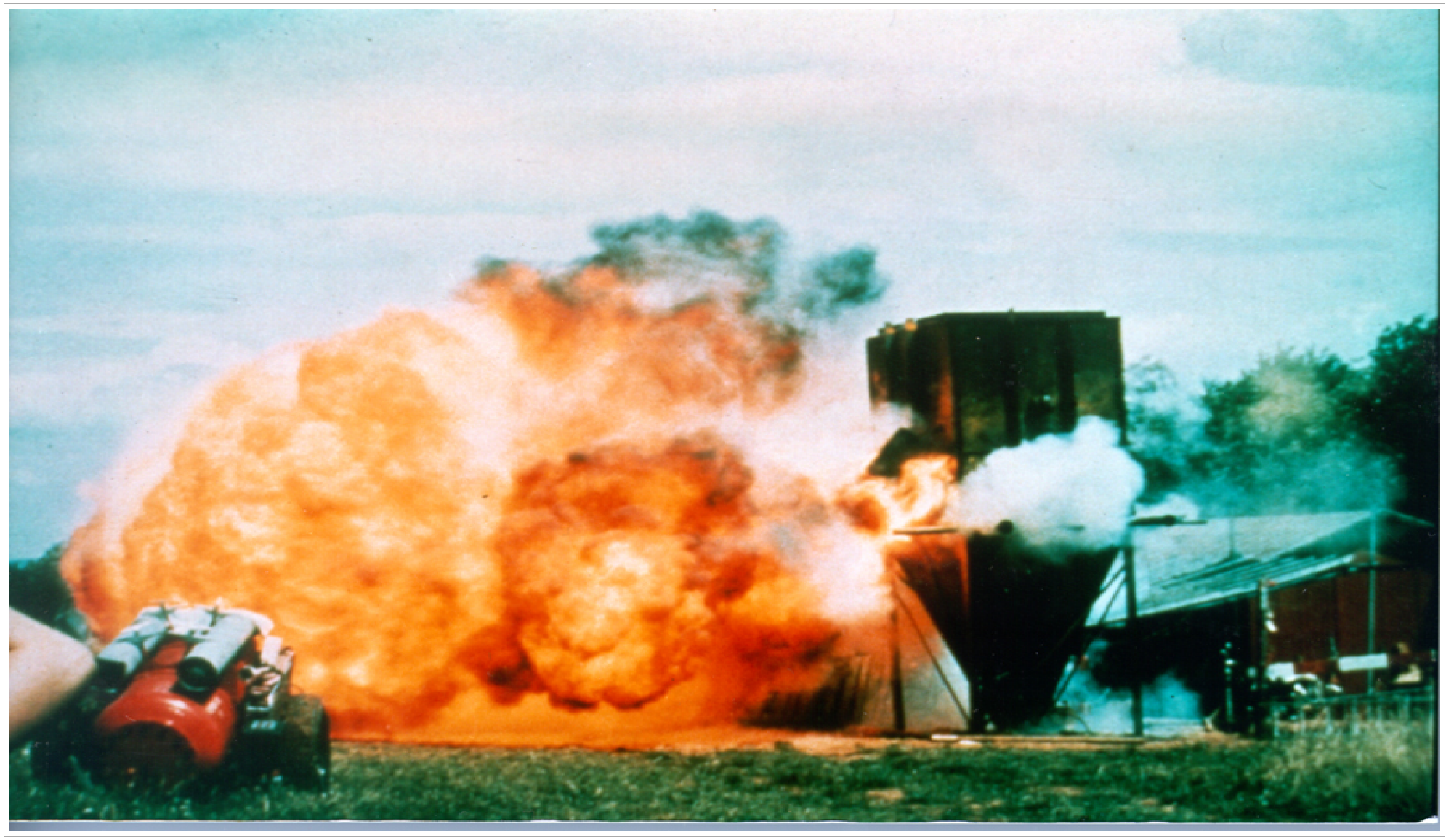
Nodes

Guide words

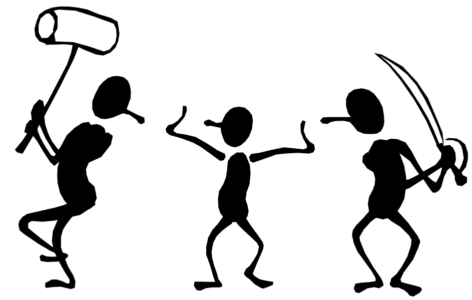
Parameters

Deviation

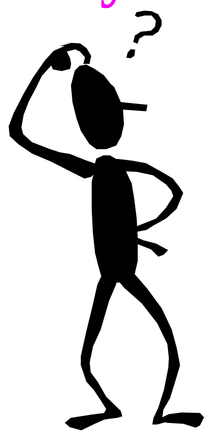

I suppose that I should have done that HAZOP Study!



HAZOP - Hazard and Operability



You are responsible for the safety team.



Without HAZOP

How will you focus all members of a team on the key issues in a systematic manner?

HAZOP Management

Planning for HAZOP Study

What is required?

- Define objectives and scope – define TOR and scope of work.
  - To new design – applied to a detailed design.
  - To existing design – identify hazards not previously identified probably because not being HAZOPED.
  - To plant modification
- Select team members. Two types of person needed :
  - Detailed technical knowledge of the process.
  - Those with knowledge and experience of applying highly structured, systematic HAZOP approach.

Planning for HAZOP

- Prepare for the study. Need sufficient information :
  - Process Flow Sheet (PFS or PFD)
  - Piping and Instrumentation Diagram (P & ID)
  - Process Calculations
  - Process Data Sheets
  - Instrument Data Sheets
  - Interlock Schedules
  - Layout Requirements
  - Hazardous Area Classification
  - Operating instructions

Planning for HAZOP

- Prepare for the study. Need sufficient information :
  - Safety procedures documents
  - Relief/venting philosophy
  - Chemical involved
  - Piping specifications
  - Previous HAZOP report

Planning for HAZOP

- Carry out the study
- Record the results (may need a secretary)
- Follow-up of actions noted
  - final report contain resolution of all recommended actions
  - must appoint someone as leader to check progress of action
  - team may meet again if answers to questions do not simply lead to an action
  - team may meet again if significant design changes in interim report

Team Characteristics

- Members share common objectives.
- Everybody contributes and knows his/her roles, not leader dependent too much.
- Each members values and respects contribution of others.
- Members learn while they work.
- Over a period of time, individual contribution level are more or less equal.
- Disagreement are worked through by discussion.
- The use of voting procedures is sparing and normally only last resort if highly necessary.
- Members enjoy team meetings.

Questioning Techniques

- Open questions
  - Help person being asked to think – use words how, what and why.
- Closed questions
  - To focus on an issue or problem. Start with words who, when, where.
  - Required answer yes or no only.
- Question mix
  - Mix between open and closed questions.

Questioning Techniques

- Things to avoid
  - Ambiguous or vague questions.
  - Double barelled/multiple questions.
  - Long complicated questions.
  - Interrogation type of questions.
  - A loaded questions – implied judgement.

Responsibility of HAZOP Team Members

HAZOP leader

- Plan sessions and timetable
- Control discussion
- Limit discussion
- Encourage team to draw conclusion
- Ensure secretary has time for taking note
- Keep team in focus
- Encourage imagination of team members
- Motivate members
- Discourage recriminations
- Judge importance issues

Checklist for HAZOP Leader

- Always prepare study program in advance.
- Agree on the format or form to be used.
- Prepare follow up procedures.
- Brief members about HAZOP during first meeting.
- Stop the team trying to redesign the process.
- HAZOP is a team exercise. Do not let anybody (including the leader himself to dominate).

Checklist for HAZOP Leader

- If conflict arises, handle with care.
- Avoid long discussions by recording areas which need to be resolved outside meeting.
- Leader must be strong, yet diplomatic.
- Speak clearly. Make you point.
- Better have experience working as team member previously.
- Do not skip anything….some time small things may cause big accident.

Responsibility of HAZOP Team Members

HAZOP Secretary

- Take adequate notes
- Record documentations
- Inform leader if more time required in taking notes
- If unclear, check wording before writing
- Produce interim lists of recommendations
- Produce draft report of study
- Check progress of chase action
- Produce final report

Responsibility of HAZOP Team Members

Process Engineer

- Provide a simple description
- Provide design intention for each process unit
- Provide information on process conditions and design conditions
- Provide a simple description
- Provide design intention for each process unit
- Provide information on process conditions and design conditions

Responsibility of HAZOP Team Members

Mechanical Design Engineer

- Provide specification details
- Provide vendor package details
- Provide equipment and piping layout information

Instrument Engineer

- Provide details of control philosophy
- Provide interlock and alarm details
- Provide info on shutdown, safety features

Responsibility of HAZOP Team Members

Plant Engineer or Manager

- Provide information on compatibility with any existing adjacent plant
- Provide details of site utilities and services
- Provide (for study on existing plant) any update on maintenance access and modifications

Shift Operating Engineer or Supervisor

- Provide guidance on control instrumentation integrity from an operating experience view point
- Provide (for study on existing plant) information on plant stability at the specified control parameters
- Provide information on experienced operability deviations of hazard potential

Responsibility of HAZOP Team Members

Chemist

- Provide details of process chemistry
- Provide details of process hazards (polymerisations, byproducts, corrosion etc)

Project Engineer

- Provide details of cost and time estimation and also budget constraints.
- Ensure rapid approval if required

Hazard Analysis Methodologies

Hazard Analysis Methodologies

- What-If
- Checklist
- What-If/Checklist
- Hazard and Operability Study (HAZOP)
- Failure Mode and Effects Analysis (FMEA)
- Fault Tree Analysis
- An appropriate equivalent methodology

What- I f

- Experienced personnel brainstorming a series of questions that begin, "What if…?”

- Each question represents a potential failure in the facility or misoperation of the facility

What- I f

- The response of the process and/or operators is evaluated to determine if a potential hazard can occur
- If so, the adequacy of existing safeguards is weighed against the probability and severity of the scenario to determine whether modifications to the system should be recommended

What-If – Steps

1. Divide the system up into smaller, logical subsystems
2. Identify a list of questions for a subsystem
3. Select a question
4. Identify hazards, consequences, severity, likelihood, and recommendations
5. Repeat Step 2 through 4 until complete

What-If Question Areas

- Equipment failures
  - What if … a valve leaks?
- Human error
  - What if … operator fails to restart pump?
- External events
  - What if … a very hard freeze persists?

What-If – Summary

- Perhaps the most commonly used method
- One of the least structured methods
  - Can be used in a wide range of circumstances
  - Success highly dependent on experience of the analysts
- Useful at any stage in the facility life cycle
- Useful when focusing on change review

Checklist

- Consists of using a detailed list of prepared questions about the design and operation of the facility
- Questions are usually answered "Yes" or "No"
- Used to identify common hazards through compliance with established practices and standards

Checklist Question Categories

- Causes of accidents
  - Process equipment
  - Human error
  - External events
- Facility Functions
  - Alarms, construction materials, control systems, documentation and training, instrumentation, piping, pumps, vessels, etc.

Checklist Questions

- Causes of accidents
  - Is process equipment properly supported?
  - Is equipment identified properly?
  - Are the procedures complete?
  - Is the system designed to withstand hurricane winds?
- Facility Functions
  - Is is possible to distinguish between different alarms?
  - Is pressure relief provided?
  - Is the vessel free from external corrosion?
  - Are sources of ignition controlled?

Checklist – Summary

- The simplest of hazard analyses
- Easy-to-use; level of detail is adjustable
- Provides quick results; communicates information well
- Effective way to account for 'lessons learned'
- NOT helpful in identifying new or unrecognized hazards
- Limited to the expertise of its author(s)

Checklist – Summary (cont’d)

- Should be prepared by experienced engineers
- Its application requires knowledge of the system/facility and its standard operating procedures
- Should be audited and updated regularly

What-If/Checklist

- A hybrid of the What-If and Checklist methodologies
- Combines the brainstorming of What-If method with the structured features of Checklist method

What-If/Checklist – Steps

- Begin by answering a series of previously-prepared 'What-if' questions

- During the exercise, brainstorming produces additional questions to complete the analysis of the process under study

What-If/Checklist – Summary

- Encourages creative thinking (What-If) while providing structure (Checklist)
- In theory, weaknesses of stand-alone methods are eliminated and strengths preserved – not easy to do in practice
- E.g.: when presented with a checklist, it is typical human behavior to suspend creative thinking

HAZOP

Hazard and Operability Analysis

- Identify hazards (safety, health, environmental), and
- Problems which prevent efficient operation

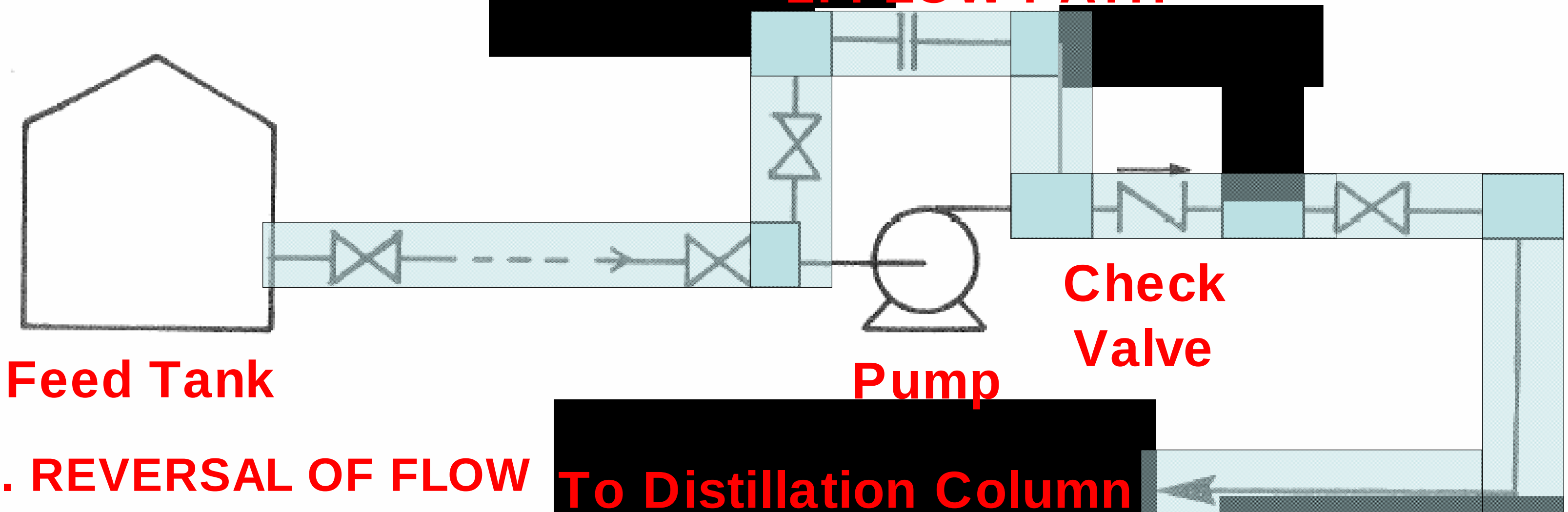
HAZOP

1. Choose a vessel and describe intention
2. Choose and describe a flow path
3. Apply guideword to deviation
   - Guidewords include **NONE, MORE OF, LESS OF, PART OF, MORE THAN, OTHER THAN, REVERSE**
   - Deviations are expansions, such as **NO FLOW, MORE PRESSURE, LESS TEMPERATURE, MORE PHASES THAN** (there should be),

HAZOP

4. Can deviation initiate a hazard of consequence?
5. Can failures causing deviation be identified?
6. Investigate detection and mitigation systems
7. Identify recommendations
8. Document
9. Repeat 3-to-8, 2-to-8, and 1-to-8 until complete

HAZOP



4. Distillation materials returning via pumparound

5. Pump failure could lead to REVERSAL OF FLOW

6. Check valve located properly prevents deviation

7. Move check valve downstream of pumparound

Loss of Containment Deviations

- Pressure too high
- Pressure too low (vacuum)
- Temperature too high
- Temperature too low
- Deterioration of equipment

HAZOP's Inherent Assumptions

- Hazards are detectable by careful review
- Plants designed, built and run to appropriate standards will not suffer catastrophic loss of containment if ops stay within design parameters
- Hazards are controllable by a combination of equipment, procedures which are Safety Critical
- HAZOP conducted with openness and good faith by competent parties

HAZOP – Pros and Cons

- Creative, open-ended
- Completeness – identifies all process hazards
- Rigorous, structured, yet versatile
- Identifies safety and operability issues

- Can be time-consuming (e.g., includes operability)
- Relies on having right people in the room
- Does not distinguish between low probability, high consequence events (and vice versa)

FMEA – Failure Modes, Effects Analysis

- Manual analysis to determine the consequences of component, module or subsystem failures
- Bottom-up analysis
- Consists of a spreadsheet where each failure mode, possible causes, probability of occurrence, consequences, and proposed safeguards are noted.

FMEA – Failure Mode Keywords

- Rupture
- Crack
- Leak
- Plugged
- Failure to open
- Failure to close
- Failure to stop
- Failure to start
- Failure to continue
- Spurious stop
- Spurious start
- Loss of function
- High pressure
- Low pressure
- High temperature
- Low temperature
- Overfilling
- Hose bypass
- Instrument bypassed

FMEA on a Heat Exchanger

Failure Mode	Causes of Failure	Symptoms	Predicted Frequency	Impact
Tube rupture	Corrosion from fluids (shell side)	H/C at higher pressure than cooling water	Frequent – has happened 2x in 10 yrs	Critical – could cause a major fire

- Rank items by risk (frequency x impact)
- Identify safeguards for high risk items

FMEA – Failure Modes, Effects Analysis

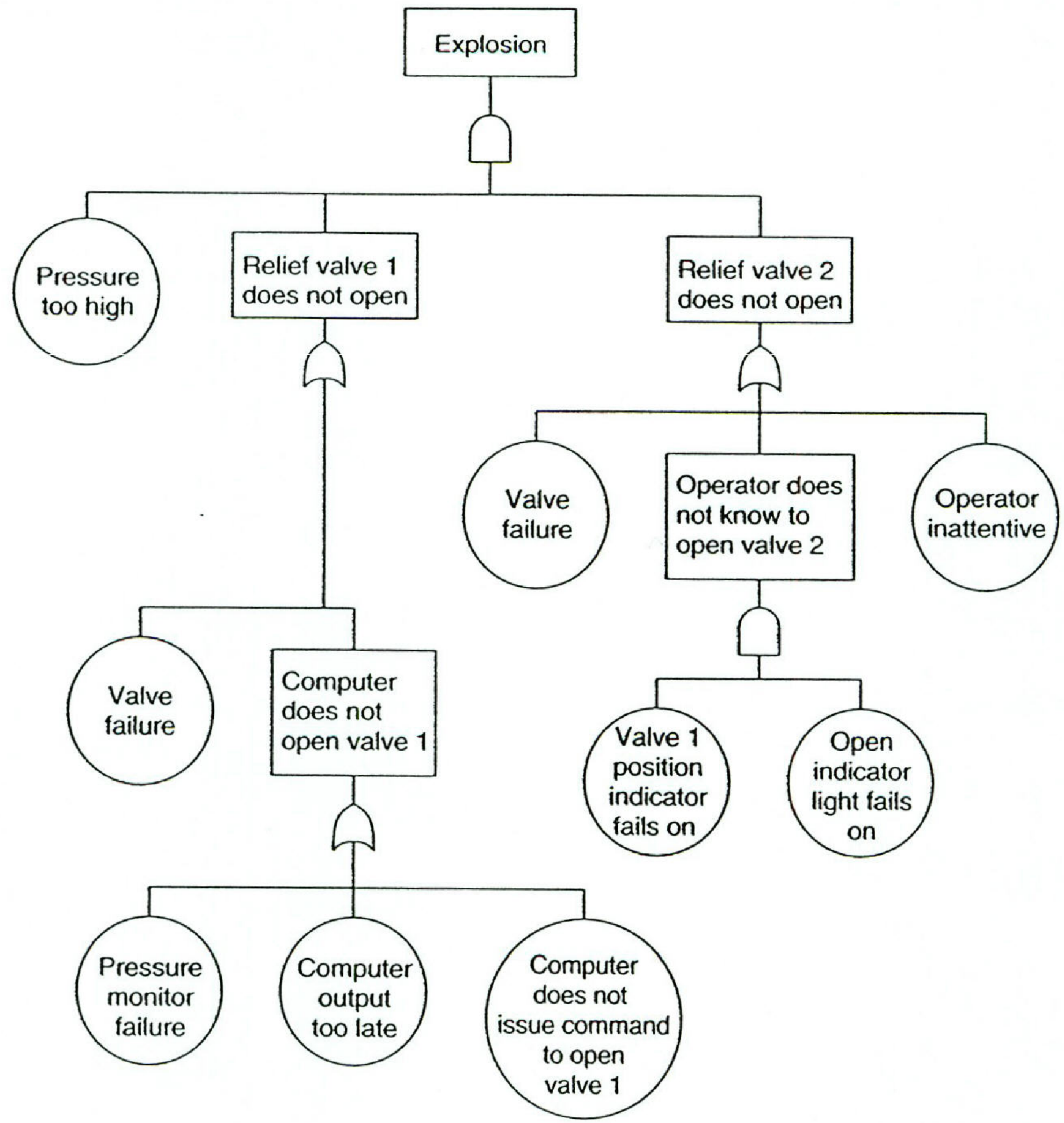
- FMEA is a very structured and reliable method for evaluating hardware and systems.
- Easy to learn and apply and approach makes evaluating even complex systems easy to do.
- Can be very time-consuming (and expensive) and does not readily identify areas of multiple fault that could occur.
- Not easily lent to procedural review as it may not identify areas of human error in the process.

Fault Tree Analysis

- Graphical method that starts with a hazardous event and works backwards to identify the causes of the top event

- Top-down analysis

- Intermediate events related to the top event are combined by using logical operations such as AND and OR.


Explosion
Pressure too high
Relief valve 1 does not open
Relief valve 2 does not open
Valve failure
Operator does not know to open valve 2
Operator inattentive
Valve failure
Computer does not open valve 1
Valve 1 position indicator fails on
Open indicator light fails on
Pressure monitor failure
Computer output too late
Computer does not issue command to open valve 1

Fault Tree Analysis

- Provides a traceable, logical, quantitative representation of causes, consequences and event combinations
- Amenable to – but for comprehensive systems, requiring – use of software
- Not intuitive, requires training
- Not particularly useful when temporal aspects are important

Accident Scenarios May Be Missed by PHA

- No PHA method can identify all accidents that could occur in a process
- A scenario may be excluded from the scope of the analysis
- The team may be unaware of a scenario
- The team consider the scenario but judge it not credible or significant
- The team may overlook the scenario

Summary

Despite the aforementioned issues with PHA:

- Companies that rigorously exercise PHA are seeing a continuing reduction is frequency and severity of industrial accidents

- Process Hazard Analysis will continue to play an integral role in the design and continued examination of industrial processes

Using What You Learn

- The ideas and techniques of Process Hazard Analysis will be immediately useful in upcoming recitation exercise on Hazard Evaluation

- Expect to be part of a Process Hazard Analysis Team early on in your professional career

Where to Get More Information

- Chemical Safety and Hazard Investigation Board's web site: www.csb.gov
- MPRI web site: www. Mpri.lsu.edu/main/
- Crowl and Louvar – Chemical Process Safety: Fundamentals with Applications
- Kletz – HAZOP & HAZAN: Notes on the Identification and Assessment of Hazards