Section 3.2

HAZOP

Process Control & Safety Group
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Content

- Introducing HAZOP
- Example of HAZOP Study: Flash Drum
- Workshop: Flash Drum Case Study

Objectives of HAZOP

HAZOP is a structured and systematic technique involving a multi-disciplinary team for examining a defined system, with the objective of:

- identifying potential hazards in the system. The hazards involved may include both those essentially relevant only to the immediate area of the system and those with a much wider sphere of influence, e.g. some environmental hazards;
- identifying potential operability problems with the system and in particular identifying causes of operational disturbances and production deviations likely to lead to nonconforming products.

Definition of Hazard & Operability

- Hazard - any operation that could possibly cause a release of toxic, flammable or explosive chemicals or any action that could result in injury to personnel.
- Operability - any operation inside the design envelope that would cause a shutdown that could possibly lead to a violation of environmental, health or safety regulations or negatively impact profitability.

Safety Issues

- To identify scenarios that would lead to the release of hazardous or flammable material into the atmosphere, thus exposing workers to injury
- To check the safety of the design
- To improve the safety of an existing and or modified facility

Operability Issues

- To decide where to build/install
- To check operating and safety procedures
- To verify that safety instrumentation is working optimally
- To facilitate smooth, safe prompt start-up & shut-down
- To minimize extensive last minute modifications
- To ensure trouble-free long-term operation
- Operability problems should be identified to the extent that they have the potential to lead to process hazards, result in an environmental violation or have a negative impact on profitability.
- In practice, more operability related recommendations are made in a HAZOP study compared to safety

Origin of HAZOP study

- HAZOP were initially 'invented' by ICI in the United Kingdom
- HAZOP started to be more widely used within the chemical process industry after the Flixborough disaster in 1974 that killed 28 people and injured scores of others
- The system was then adopted by the petroleum industry, which has a similar potential for major disasters.
- This was then followed by the food and water industries, where the hazard potential is as great, but of a different nature, the concerns being more to do with contamination rather than explosions or chemical releases.
- International Standard IEC61882 (HAZOP Studies Application Guide 2001

Principles of HAZOP

- A HAZOP study is a detailed hazard and operability problem identification process, carried out by a team.
- HAZOP deals with the identification of potential deviations from the design intent, examination of their possible causes and assessment of their consequences.
- Key features of HAZOP examination include the following.
  - The examination is a creative process. The examination proceeds by systematically using a series of guide words to identify potential deviations from the design intent
  - The examination is carried out under the guidance of a leader who ensure comprehensive coverage of the system under study
  - The examination relies on experienced specialists from various disciplines
  - The examination should be carried out in a climate of positive thinking and frank
  - discussion.
  - Solutions to identified problems are not a primary objective but are recorded for consideration by those responsible for the design.

When should a HAZOP be held

- During various stages of plant design
  - At the beginning of the project as a 'safety and environmental specification'
  - Towards the end of process definition, when the Process Flow sheets are available as a Safety and Environmental Review
  - When P&IDs are at 'Approved for Design' stage (Final design HAZOP)
- During construction site inspections ensure that recommendations arising from the HAZOP or other safety and environmental reviews are being implemented.
- A pre-commissioning study reviews plant procedures and perform a conventional safety audit
- Once operational, an audit of plant and procedures at regular interval ensures ongoing safety awareness

HAZOP study of existing plant

- Can be done at any time
- Mainly used to improve operating procedures or when modifying plant
- Sometimes used to identify possible improvements in plants where accident or incident rate is abnormally high
- Can be used in conjunction with plant safety audits
- Needs exceptional care to fully define the scope and aims of the study
- Despite detailed operation knowledge, much of the original design intent is often unknown

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 generate many failure events with insignificance consequences and generate many failure events which have the same consequences.
- 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.
- When identifying consequences, it tends to ignore contributions that can be made by operator interventions

4 Basic Sequential Steps

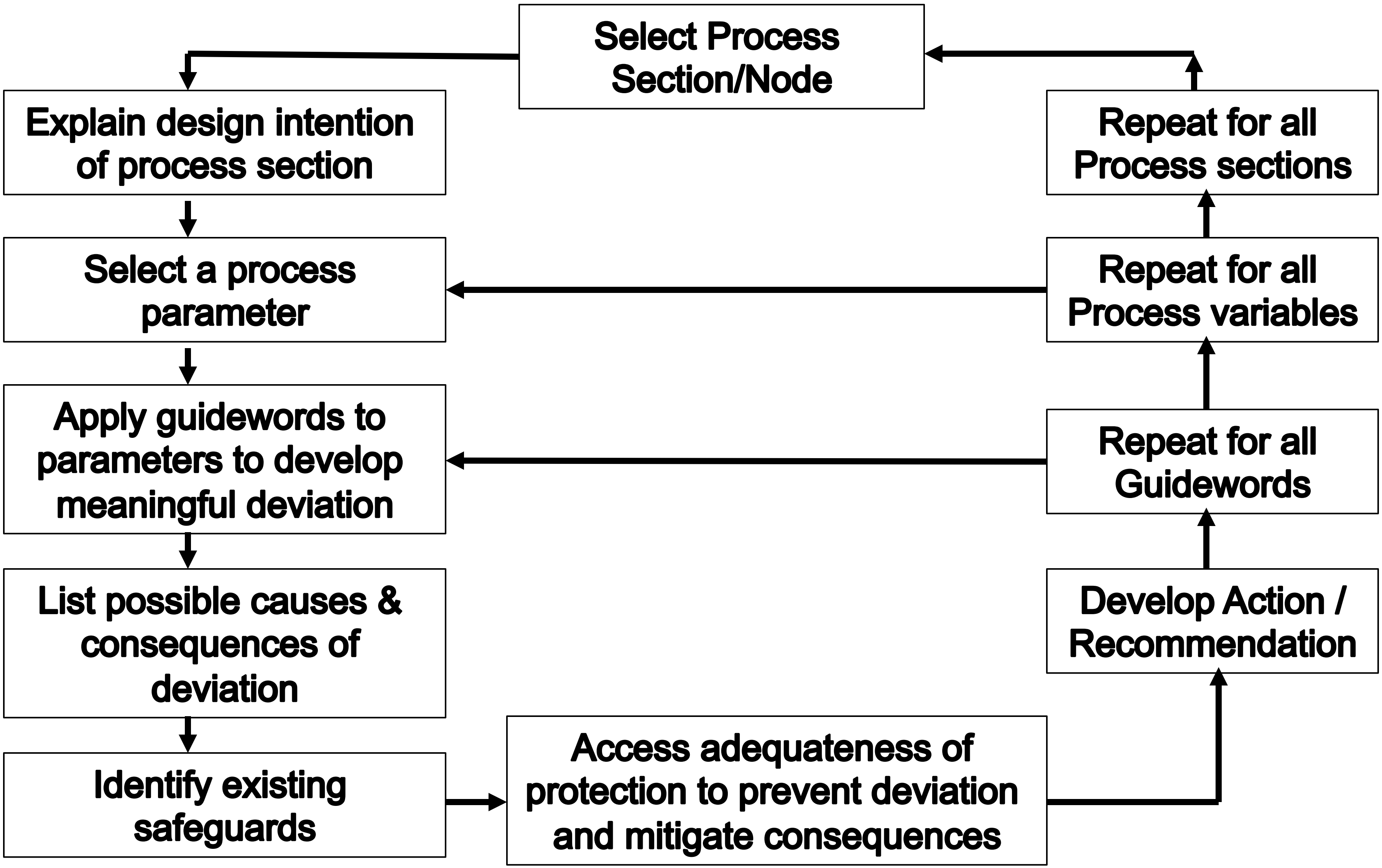
Definition
- Define scope and objectives
- Define responsibility
- Select team

Preparation
- Plan the study
- Collect Data
- Agree style of study
- Estimate the time
- Arrange a schedule

Examination
- Divide system into parts
- Select a part and define design intent
- Identify deviation, consequences and causes
- Identify protection
- Identify possible remedial/mitigating measures
- Agree actions
- Repeat for each element/parameters and the each part of the system

Documentation and Follow up
- Record the examination
- Sign off the documentation
- Produce the report of the study
- Follow up that actions are implemented
- Re-study any parts of system if necessary
- Produce final output report

Typical HAZOP Procedure



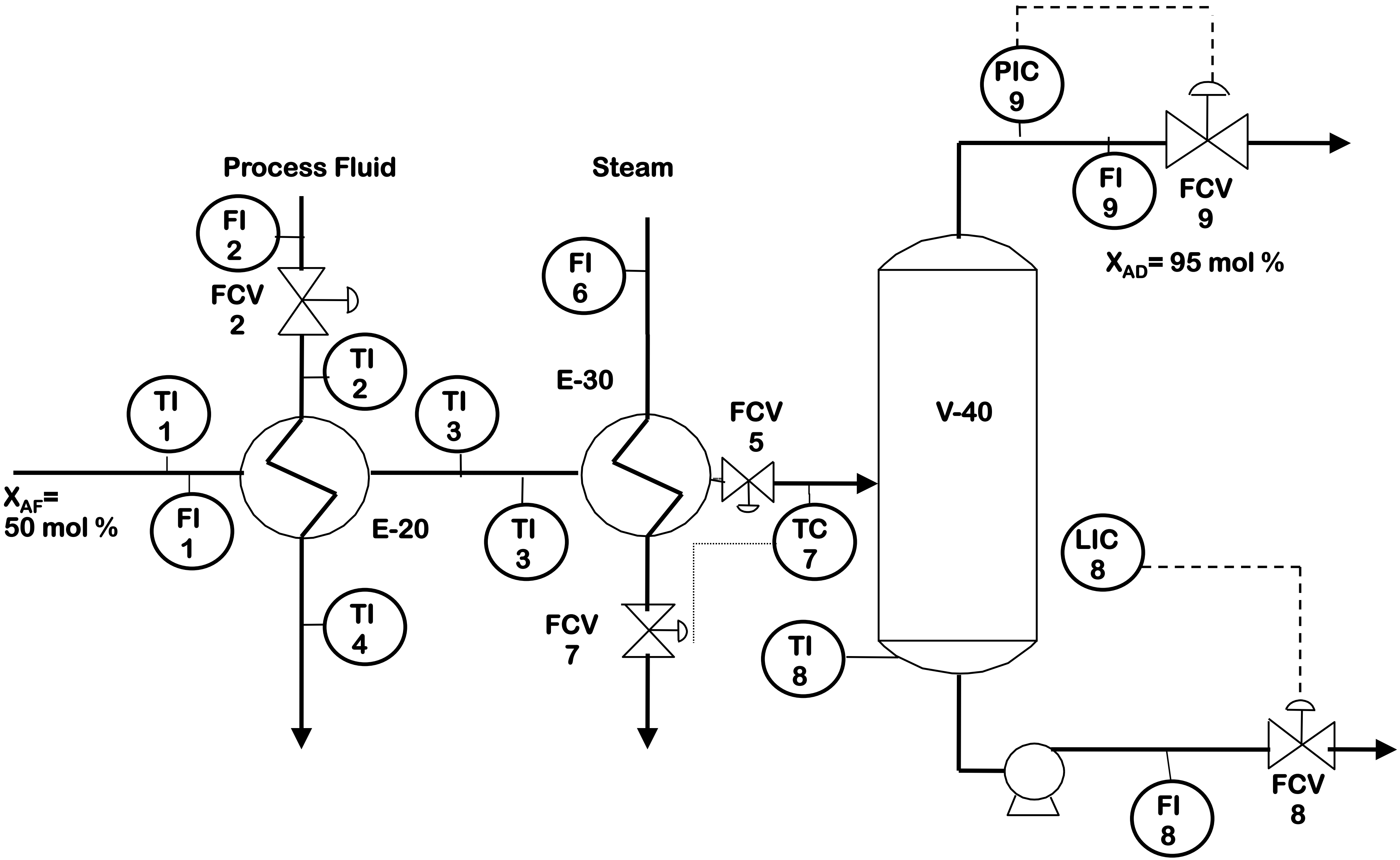
HAZOP Study Procedure

1. Select a Section/**Node**.
2. For each **Node**, carry out analysis
    - Take note of the **Design Intention**
    - Starting with a process **Parameter**, combine with the **Guidewords** to form possible **Deviation**.
    - For each Deviation, identify possible **Causes** and **Consequences**
    - Evaluate existing **Protection** (**Safeguard**) for adequacy
    - Suggest suitable **Action** and/or **Recommendation** to improve safety and operability of the plant
    - Continue with other guidewords and process parameters until fully examined before moving to the next node.
3. Record outcome in HAZOP Log-Sheet

Example of HAZOP Study: Flash Drum

Case Study: Flash Drum

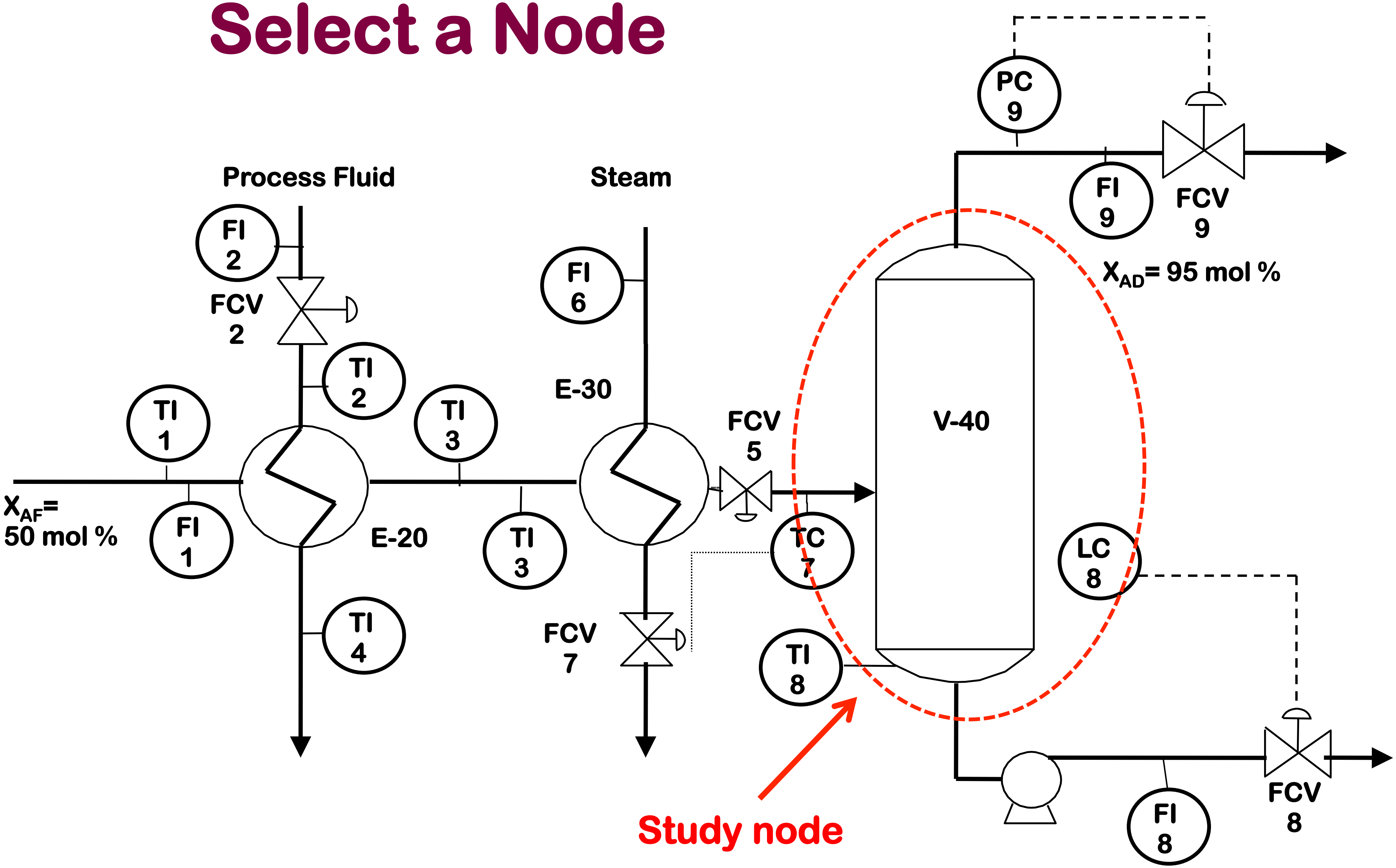
- To illustrate the HAZOP Study Procedure, consider the flash drum problem shown in the next page.
- The purpose of the plant is to separate multiple mixture of mostly A and B plus some other heavy components to produce main product leaving the top at 95 mol % of A. Steam at 5 bar is used to bring the temperature at the desired saturation temperature of 130 ^oC.
- Nominal operating conditions are as follows:
  - T_1= 70 ^oC, T_2= 120 ^oC, T_3= 100 ^oC, T_4= 110 ^oC, P_9 = 3 bar
- Conduct HAZOP Study to ascertain the adequacy of the plant safety and operability features


Process Fluid
Steam
FI 2
FCV 2
TI 2
FI 6
E-30
TI 1
TI 3
FCV 5
V-40
PIC 9
FI 9
FCV 9
X_{AD}= 95 mol %
X_{AF}= 50 mol %
FI 1
E-20
TI 3
TC 7
LIC 8
TI 4
FCV 7
TI 8
FI 8
FCV 8

Step 1 – Select a Node

- **Definition:** A node is the specific location in the process in which (the deviations of) the process intention are evaluated.
  - Examples might be: separators, heat exchangers, scrubbers, pumps, compressors, and interconnecting pipes with equipment
- Flash Drum Example
  - Separator as a node
  - Other nodes: process to process heat exchanger, utility heat exchanger
  - Alternatively, each process line can be taken as a node.

Select a Node



Consider the Flash Drum as the HAZOP Study Node, conduct HAZOP

Step 2 – Define the Design Intent

- **Definition:** Design Intent or Intention is the description of how the process is expected to behave at the Study Node.
- This is qualitatively described as an **activity** (e.g., feed, reaction, sedimentation) and/or quantitatively in the **process parameters**, like temperature, flow rate, pressure, composition, etc.
- Flash Drum Example:
  - To separate light components from the heavies (or to collect light component at the top product stream)

Step 3 – Prepare a HAZOP Log Sheet

Based on the selected NODE and the design intent of the node, HAZOP study is conducted. The output is summarized in HAZOP Log Sheet

Example: Simplified HAZOP Log Sheet

Node:
Design Intent:

Team:
P&ID No:

Deviation	Causes	Consequences	Protection	Action
Guideword + Parameter **Guideword: No, Less, More, reverse etc** **Parameter: Flow, temperature, level etc**	**Possible causes of the deviation**	**Effect of deviation of plant safety and operability**	**Safety provision already considered.** **- Prevent causes** **- prevent/ reduce consequence** **- monitor/ detect**	**Is the protection sufficient?** **If not, propose suitable action or recommendation**

HAZOP Study Form / Log Sheet

PLANT:
NODE :
DESIGN INTENT:

DATE:
DESCRIPTION:

DEVIATION	CAUSES	CONSEQUENCES	PROTECTION	ACTIONS OR RECOMMENDATIONS

PARAMETER	GUIDE WORD	DEVIATION	CAUSES	CONSEQUENCES	PROTECTION	COMMENT	ACTION	ACTION PARTY

DEVIATION	CAUSES	CONSEQUENCES	S	L	RISK	SAFEGUARDS	COMMENTS	ACTIONS	ACTION PARTY

Step 4 – Define Deviation

- Deviation is a way in which the process conditions may depart from their INTENTION / DESIGN INTENT
- Causes of deviations
  - Human error - which are acts of omission or commission by an operator, designer, constructor or other person creating a hazard that could possibly result in a release of hazardous or flammable material.
  - Equipment failure - in which a mechanical, structural or operating failure results in the release of hazardous or flammable material.
  - External Events - in which items outside the unit being reviewed affect the operation of the unit to the extent that the release of hazardous or flammable material is possible. External events include upsets on adjacent units affecting the safe operation of the unit (or node) being studied, loss of utilities, and exposure from weather and seismic activity.

Deviation	Causes	Consequences	Protection	Action

Deviations

- Unwanted activities: refer to Elements of the process. If the the element (process step, set point of the variables/ parameters), if this is not satisfied, then there is a deviation.
  - Corrosion
  - Contamination
  - Sand Accumulation
  - Erosion
- Guideword+Parameter = Deviation
  - MORE+Pressure = More Pressure/High Pressure
- External Events
  - Heavy Rain
  - Typhoon

Guidewords + Parameter = Deviation

Some examples of combinations of guide-words and parameters:

- NO FLOW
  - Wrong flow path – blockage – incorrect slip plate – incorrectly fitted return valve – burst pipe – large leak – equipment failure – incorrect pressure differential – isolation in error
- MORE FLOW
  - Increase pumping capacity – increased suction pressure – reduced delivery head – greater fluid density – exchanger tube leaks – cross connection of systems – control faults
- MORE TEMPERATURE (High Temperature, Higher Temperature)
  - Ambient conditions – failed exchanger tubes – fire situation – cooling water failure – defective control – internal fires

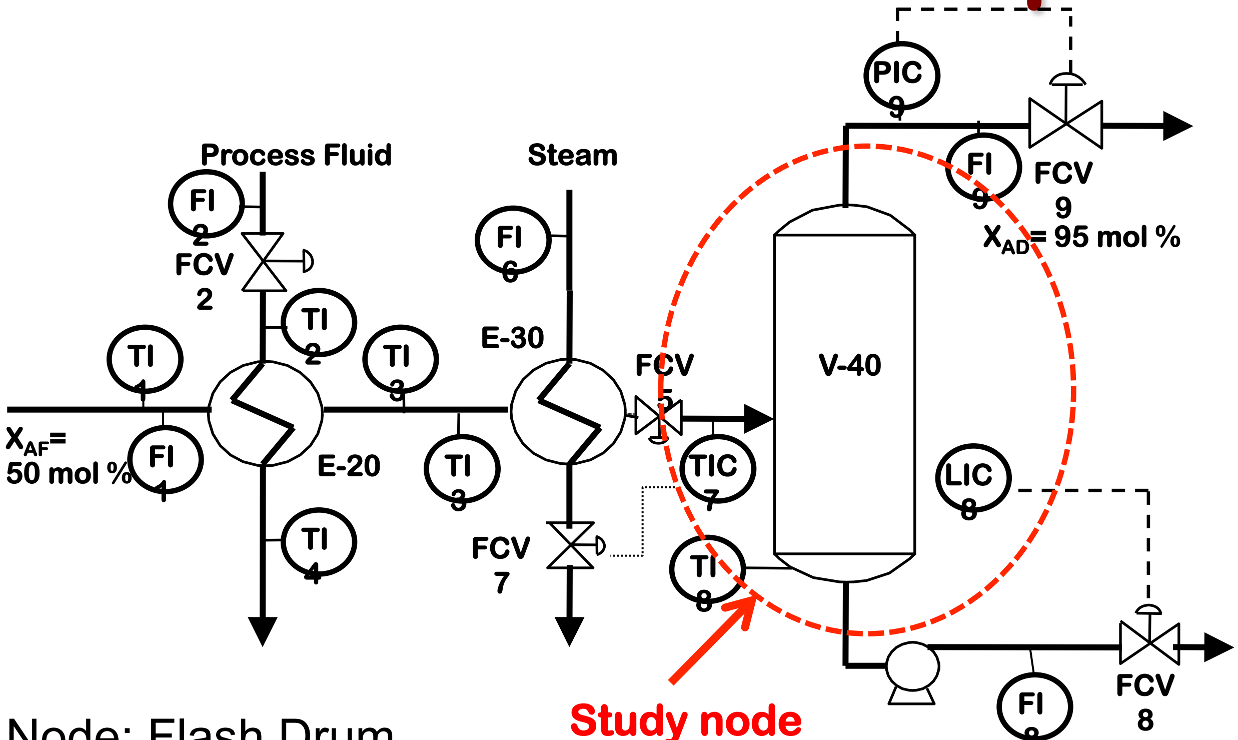
GUIDEWORDS

Guide Word	Meaning
NO OR NOT	Complete negation of the design intent
MORE	Quantitative increase
LESS	Quantitative decrease
AS WELL AS	Qualitative modification/increase
PART OF	Qualitative modification/decrease
REVERSE	Logical opposite of the design intent
OTHER THAN	Complete substitution
EARLY	Relative to the clock time
LATE	Relative to the clock time
BEFORE	Relating to order or sequence
AFTER	Relating to order or sequence

Deviations = Guideword + Variable

Guide Word / Variable	No	Low	High	Part Of	As Well As	Other Than	Reverse
Flow	No flow	Low flow	High flow	Missing ingredient	Impurity	Wrong material	Reverse flow
Level	Empty	Low level	High level	Low interface	High interface	-	-
Pressure	Open to atmosphere	Low pressure	High pressure	-	-	-	Vacuum
Temperature	Freezing	Low temp.	High Temperature	-	-	-	Auto refrigeration
Agitation	No agitation	Poor mixing	Excessive mixing	Irregular-mixing	Foaming	-	Phase separation
Reaction	No reaction	Slow reaction	"Runaway reaction"	Partial reaction	Side reaction	Wrong reaction	Decom-position
Other	Utility failure	External leak	External rupture	-	-	Start-up Shutdown Maintenance	-

Flash Drum Example - Deviation



Consider the drum **Pressure** as the Parameter and **MORE** as the guideword

Node: Flash Drum
Design Intent: To produce 95% pure A as top product

Team: AA, etc
P&ID No: XX-X

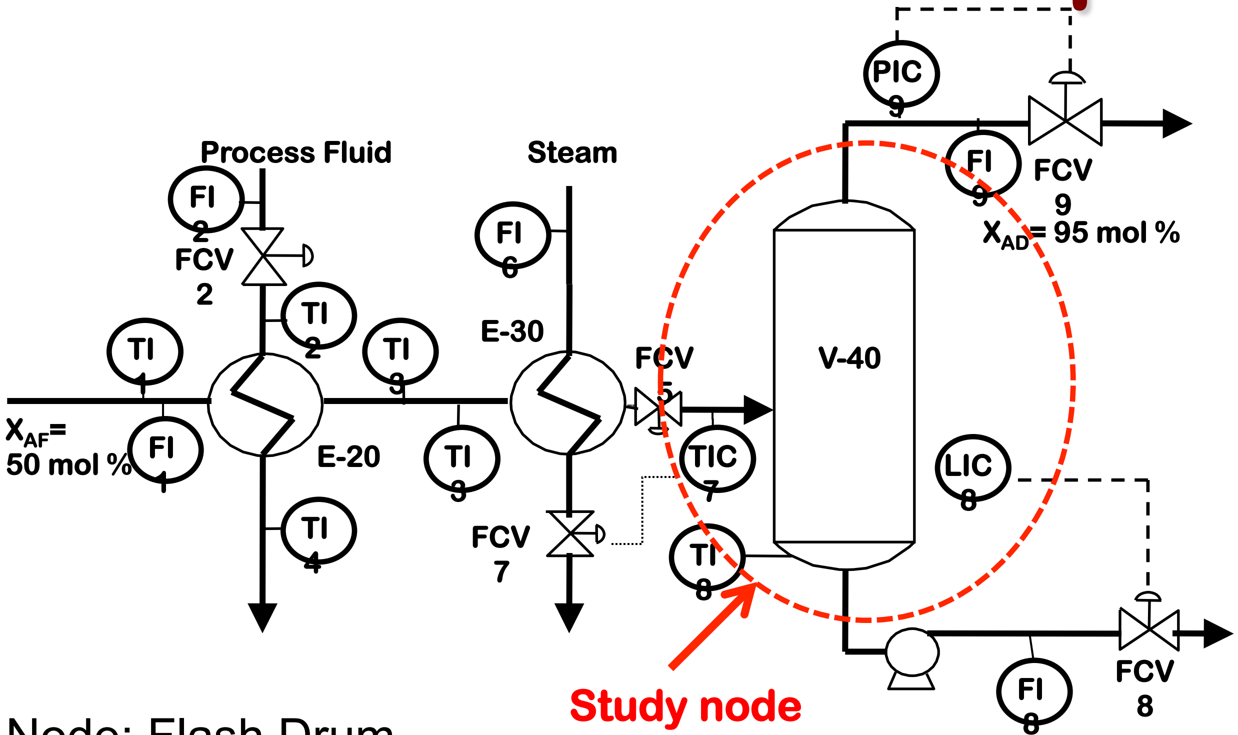
Deviation	Causes	Consequences	Protection	Action
MORE + PRESSURE **High Pressure (More Pressure)**				

Step 5 – Identify Causes

- **Definition:** Causes are the reason(s) why the DEVIATION occur
- More than one CAUSES can be identified for one DEVIATION.
- Causes normally come from among the “process inputs”, i.e., independent variables, or failure of some devices etc
- Causes may be within the boundary or outside the boundry of the node

Deviation	Causes	Consequences	Protection	Action

Flash Drum Example - Causes



There are many possible causes: inside/ outside the drum system

Node: Flash Drum
Design Intent: To produce 95% pure A as top product

Team: AA, etc
P&ID No: XX-X

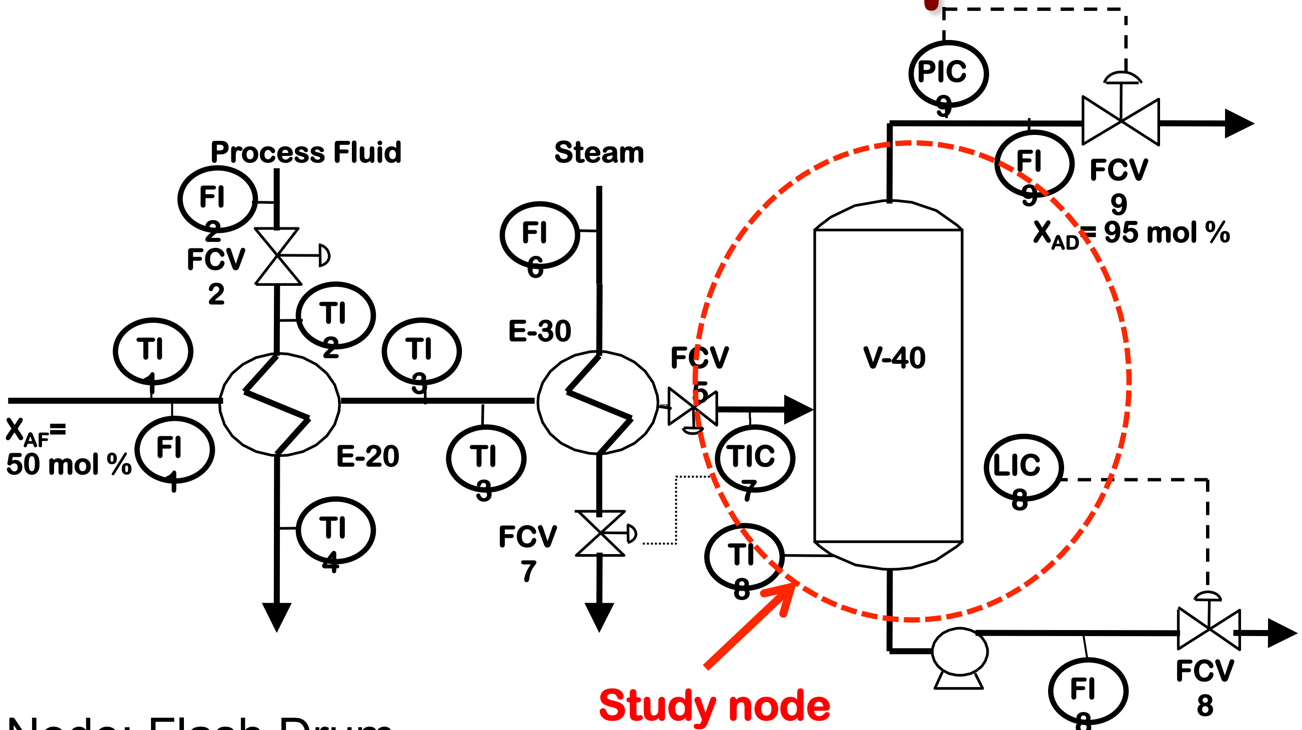
Deviation	Causes	Consequences	Protection	Action
MORE + PRESSURE High Pressure (More Pressure)	• **FCV9 stuck closed** • **Feed partially vapor** • **Feed Temperature High**			

Step 6 – Identify Consequences

- **Definition:** The consequences which would arise, both from the effect of the deviation and, if appropriate, from the cause itself.
- Consequences may both comprise process hazards and operability problems, like plant shutdown.
- More consequences can follow from one cause and, in turn, one consequences can have several causes
- Consequences are focused on the node. It is normally the “respond” of the equipment within the node, sometimes followed by the effect outside the node, and should therefore be addressed

Deviation	Causes	Consequences	Protection	Action

Flash Drum Example - Consequence



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Node: Flash Drum
Design Intent: To produce 95% pure A as top product

Team: AA, etc
P&ID No: XX-X

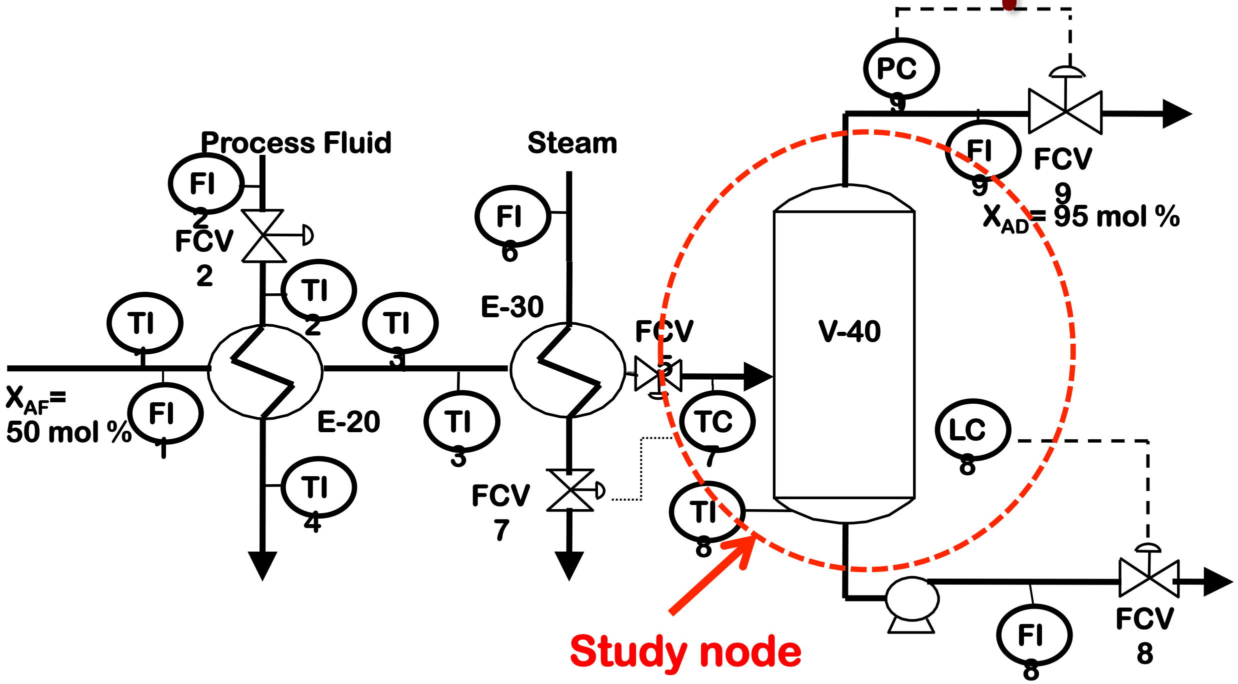
Deviation	Causes	Consequences	Protection	Action
MORE + PRESSURE **High Pressure (More Pressure)**	• **FCV9 stuck closed** • **Feed partially vapor** • **Feed Temperature High**	**V40 over-pressure with risks of explosion**		

Step 7 – Identify Protection/Safeguards

- Definition: Safeguards are facilities that help to reduce the occurrence frequency of the DEVIATION or to mitigate its CONSEQUENCES.
- There are, in principle, five types of SAFEGUARDS:
  - Facilities that identify the DEVIATION, e.g. alarm instrumentation and human operator detection.
  - Facilities that compensate the DEVIATION, e.g., an automatic control system
  - Facilities that prevent the DEVIATION to occur, e.g. an inert blanket gas in storages of flammable substances.
  - Facilities that prevent a further escalation of the DEVIATION, e.g., by (total) trip of the activity (SIS facility)
  - Facilities that relieve the process from the hazardous DEVIATION. These comprise for instance: pressure safety valves (PSV) and vent systems.

Deviation	Causes	Consequences	Protection	Action

Flash Drum Example - Protection



- There is a pressure control (PC9), temperature control (TC7),
- Are these adequate?
- If Not, propose action to be taken.

Node: Flash Drum
Design Intent: To produce 95% pure A as top product

Team: AA, etc
P&ID No: XX-X

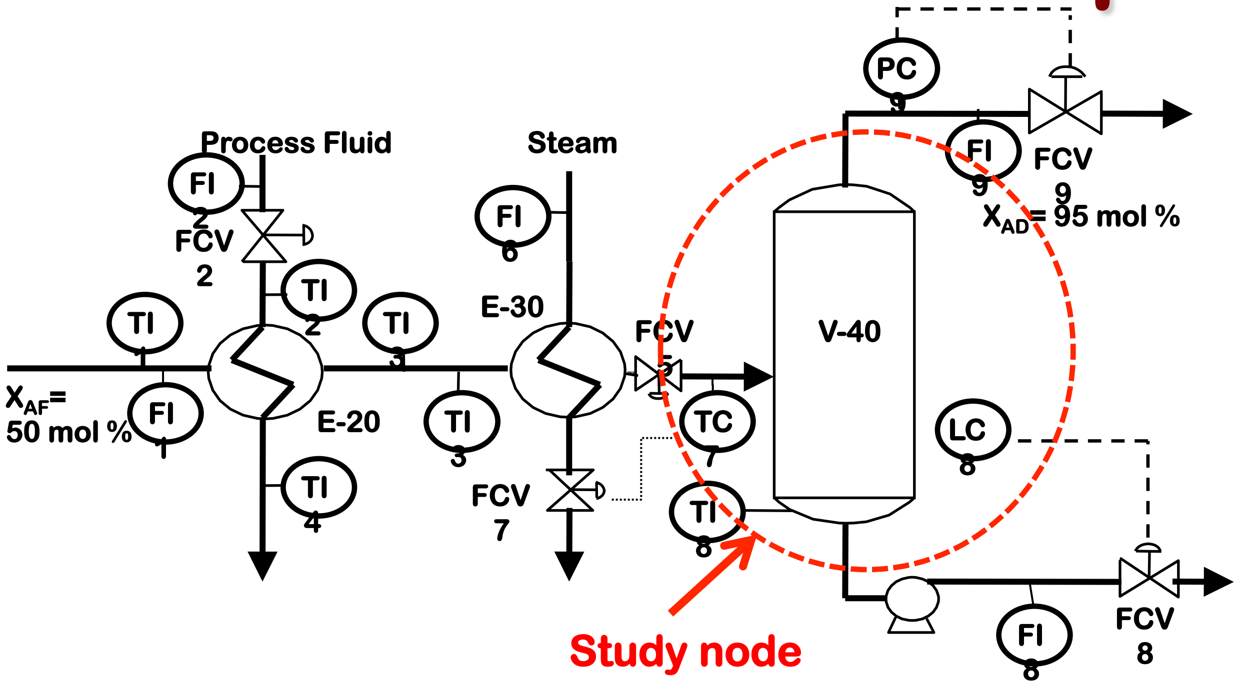
Deviation	Causes	Consequences	Protection	Action
MORE + PRESSURE High Pressure (More Pressure)	• FCV9 stuck closed • Feed partially vapour • Feed Temperature High	V40 over-pressure with risks of explosion	PC9, TC7	

Step 8 – Action/Recommendation

- **Definition:** Activities identified during HAZOP study for follow-up.
- Based on a credible HAZOP scenario identified during the study, the existing protection is assessed.
  - if the protective measures are deemed to be adequate, then no action is needed and words to that effect are recorded in the Action column (e.g. adequate protection).
  - If existing protections are not adequate, Action should be recommended. These may comprise technical improvements in the design, modifications in the status of drawings and process descriptions, procedural measures to be developed or further in-depth studies to be carried out.
- Actions fall into two groups:
  - Actions that remove the cause.
  - Actions that mitigate or eliminate the consequences.

Deviation	Causes	Consequences	Protection	Action

Flash Drum Example - Action



- Recall the Layer of Protection: BPCS, Alarm, SIS, Relief
- What is needed here?
- Relief valve is needed
- Add High Pressure Alarm, PAH & PAHH

Node: Flash Drum
Design Intent: To produce 95% pure A as top product

Team: AA, etc
P&ID No: XX-X

Deviation	Causes	Consequences	Protection	Action
MORE + PRESSURE High Pressure (More Pressure)	• FCV9 stuck closed • Feed partially vapour • Feed Temperature High	V40 over-pressure with risks of explosion	PC9, TC7	Add relief Valve, PAH, PAHH

Step 9: Comments

- Various additional columns can be added to the HAZOP Log Sheet.
- Comments
  - Any remarks to be given to the ACTIONS/RECOMMENDATIONS or which, in another way, showed up during the HAZOP sessions.

Step 10: Action Party

- Action Party is the responsible party to follow up /act on the recommendation
- also typically identified and noted in the HAZOP Sheet.
- This is

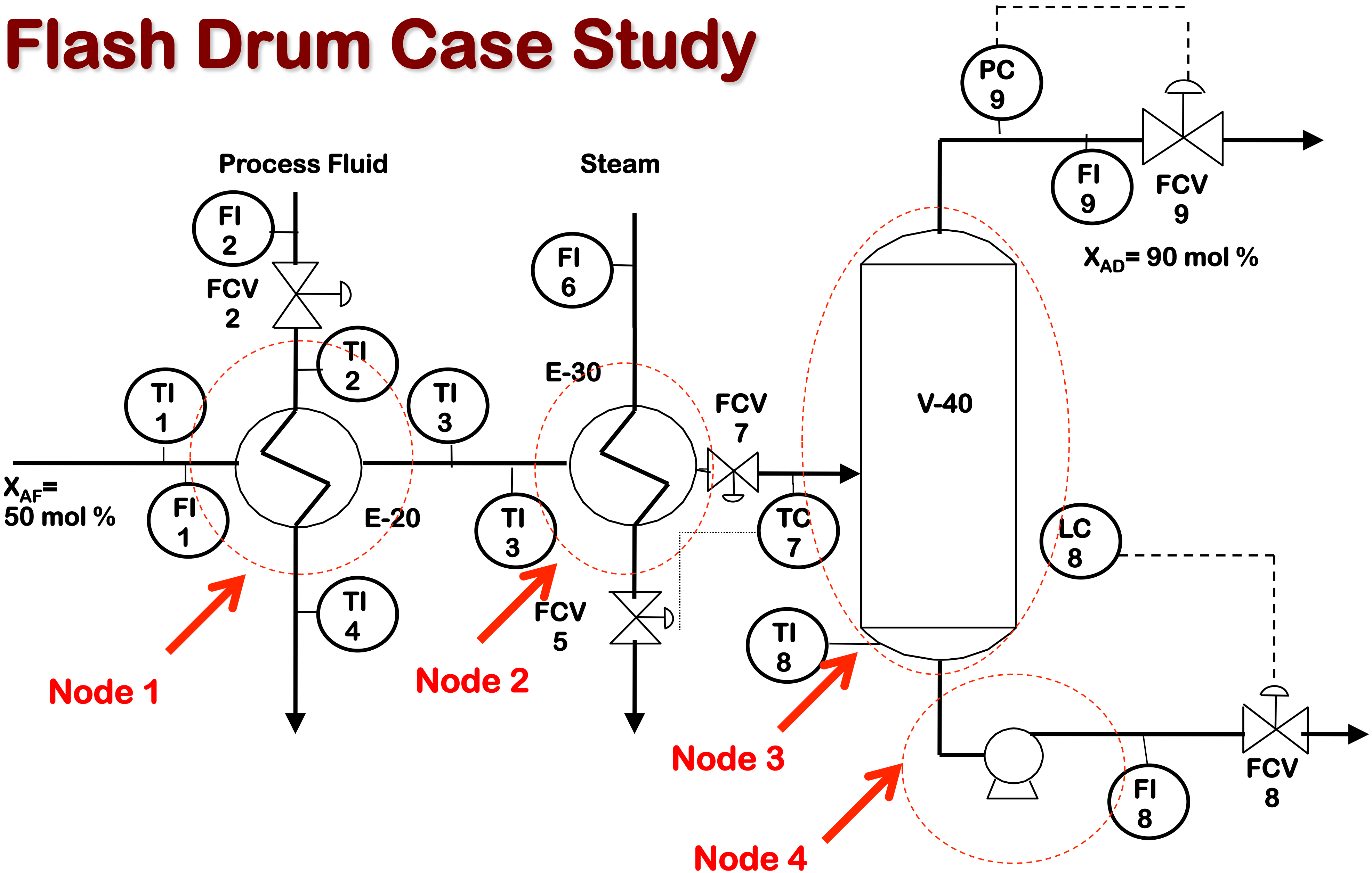
WORKSHOP PROBLEM

(Flash Drum)

HAZOP Workshop: Flash Drum Case Study

- For the Flash process discussed, consider the following Nodes and carry out HAZOP Study on the given process parameter
  - Node 1: Heat Exchanger E20
    - Parameter: Outlet Temperature of the main process stream (stream no 3 as indicated by TI3
  - Node 2: Heat Exchanger E30
    - Parameter: Outlet Temperature of the main process stream (stream no 7 as indicated by TI7
  - Node 3: Flash Drum V40
    - Parameter: Liquid level in V40
  - Node 4: Process Line 8
    - Parameter: Flow of (stream no 8 as indicated by FI8
- Use all the Guidewords (No, MORE, LESS)

Flash Drum Case Study



HAZOP Log Sheet – Flash Drum Case Study

Node. 1. Heat Exchanger E20

Parameter	Guide word	Deviation	Causes	Consequences	Protections	Action
Outlet Temperature T3	More	Higher Tempe-rature				
Outlet Temperature T3	Less	Lower Tempe-rature				

HAZOP TEAM

HAZOP Study Team

- Independent leader (e.g., not from plant studied)
  - Preferred but complete independence not essential
- HAZOP Secretary/Scribe
  - Taking notes and prepare report
- Project engineer
  - Provide engineering input
- Operations representative
  - Plant operation
- Discipline engineers
  - Process
  - Instrument/ electrical
  - Mechanical/ maintenance
  - Project Engineer
- Other Specialists
  - Chemist, etc

Responsibility of HAZOP Leader

The leader should be independent (i.e. has no responsibility for the process and/or the performance of operations)

- 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

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- Discourage recriminations
- Judge importance issues

Checklist for HAZOP Leader

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

Checklist for HAZOP Leader

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

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 Secretary / Scribe)

- 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
- **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

Project Engineer

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

Chemist

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

HAZOP Meeting

HAZOP Meeting

- Proposed Agenda:
  1. Introduction & presentation of participation
  2. Overall presentation of the system/operation to be analyzed
  3. Description of the HAZOP approach
  4. Presentation of the first node or logical part of the operation
  5. Analyze the first node/ part using the guide-words and parameters
  6. Continue presentation and analysis (steps 4 & 5)
  7. Coarse summary of findings
- Required Items for HAZOP Meeting
  - P & IDs , PFD, Heat and Material Balances
  - Logic Diagrams, Equipment Data Sheets, Material Safety Data Sheets
  - Plant Layout, Hazardous Area Layouts

HAZOP – The Critical Success Factor

- The HAZOP process is based on the principle that a team approach to hazard analysis will identify more problems than when individuals working separately combine results. The HAZOP team is made up of individuals with varying backgrounds and expertise.
- The expertise is brought together during HAZOP sessions and through a collective brainstorming effort that stimulates creativity and new ideas, a thorough review of the process under consideration is made.

How to be a good HAZOP participant

- Be active! Everyone contribution is important
- Be to the point. Avoid endless discussion of details
- Be critical in a positive way – not negative, but constructive
- Be responsible. He who knows should let the other know

HAZOP Leader's Report

HAZOP Leader’s report

Typical Content

- Introduction
- Quality of Study
- Areas of Potential Weakness
- Comments Applicable to the Whole Plant
- Major and Priority Findings
- Further Studies Required (QRA, Reliability, etc)
- Highlight Areas for Next HAZOP
- Reports and Comments for Other Safety Meetings
- Appendices (including worksheets, drawings)

HAZOP Report

- Introduction
  - Background of the project
  - Purpose of the reports
  - Term of reference
  - Timing and Scheduling of Meetings
  - Team Composition
  - Study Method – any variations to normal HAZOP should be highlighted
  - Areas not Covered

HAZOP Report

- Quality of Study
  - Assess quality of meetings in terms of Team composition, Experience of the team and their performance during the HAZOP session
- Areas of Potential Weakness
  - Lack of Specialists
  - Incomplete drawings
  - Incomplete information

HAZOP Report

- Comments Applicable to the Whole Plant
  - General Issues discovered should be listed and introduced, together with their significance for the progress of the project
- Major and Priority Findings
  - Many number of actions may be suggested in a HAZOP study, however, major and important findings *e.g. Top 10) should be highlighted.
- Further Studies Required (QRA, Reliability, etc)
  - If the team recommends a further studies such as QRA etc to be carried out, then it should be noted

HAZOP Report

- Highlight Areas for Next HAZOP
  - Identification of areas that are unsolved should be made for the use of the Leader of subsequent HAZOPs or by the project safety co-ordinator
- Reports and Comments for Other Safety Meetings
  - The HAZOP report should give details of issues or action points that in the opinion of the team have a direct relevance to other project safety meetings.
- Appendices (including worksheets, drawings)
  - The appendices should contain: list of guidewords used, node list, worksheets, drawings, list of background reference documents



END OF

SECTION 3.2