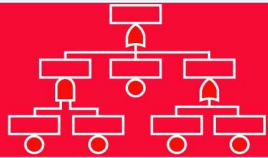

HAZOP

Hazard and Operability Study

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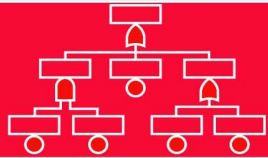
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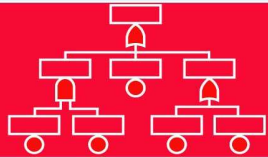
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A Hazard and Operability (HAZOP) study is a structured and systematic examination of a planned or existing *process* or *operation* in order to identify and evaluate problems that may represent risks to personnel or equipment, or prevent efficient operation.

The HAZOP technique was initially developed to analyze *chemical process* systems, but has later been extended to other types of systems and also to complex operations and to software systems.

A HAZOP is a qualitative technique based on *guide-words* and is carried out by a multi-disciplinary team (*HAZOP team*) during a set of meetings.



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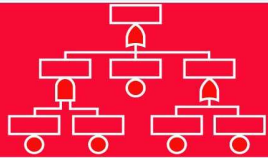
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The HAZOP study should preferably be carried out as early in the design phase as possible - to have influence on the design. On the other hand; to carry out a HAZOP we need a rather complete design. As a compromise, the HAZOP is usually carried out as a final check when the detailed design has been completed.

A HAZOP study may also be conducted on an existing facility to identify modifications that should be implemented to reduce risk and operability problems.



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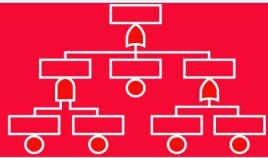
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HAZOP studies may also be used more extensively, including:

- At the initial concept stage when design drawings are available
- When the final piping and instrumentation diagrams (P&ID) are available
- During construction and installation to ensure that recommendations are implemented
- During commissioning
- During operation to ensure that plant emergency and operating procedures are regularly reviewed and updated as required

– From Kyriakdis (2003)



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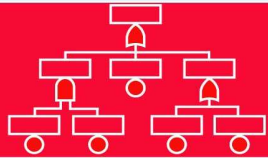
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- ❑ The basis for HAZOP was laid by ICI in 1963 and was based on so-called “critical examination” techniques
- ❑ First guide: “A Guide to Hazard and Operability Studies”, ICI and Chemical Industries Associations Ltd. 1977.
- ❑ First main textbook: Kletz, T. A.: “*Hazop and Hazan - Identifying and Assessing Process Industry Hazards*”, Institution of Chemical Engineers.
- ❑ See also: Kletz, T. A.: “Hazop – past and future”. *Reliability Engineering and System Safety*, **55**:263-266, 1997.



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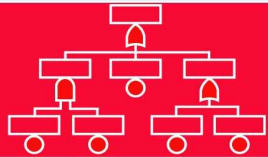
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- ❑ IEC 61882. *“Hazard and operability studies (HAZOP studies) – Application guide”*. International Electrotechnical Commission, Geneva.
- ❑ Crawley, F., M. Preston, and B. Tyler: *“HAZOP: Guide to best practice. Guidelines to best practice for the process and chemical industries”*. European Process Safety Centre and Institution of Chemical Engineers, 2000
- ❑ Kyriakdis, I.: *“HAZOP - Comprehensive Guide to HAZOP in CSIRO”*, CSIRO Minerals, National Safety Council of Australia, 2003



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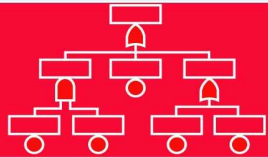
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- ❑ Process HAZOP
 - ❖ The HAZOP technique was originally developed to assess plants and process systems
- ❑ Human HAZOP
 - ❖ A “family” of specialized HAZOPs. More focused on human errors than technical failures
- ❑ Procedure HAZOP
 - ❖ Review of procedures or operational sequences
Sometimes denoted SAFOP - SAFE Operation Study
- ❑ Software HAZOP
 - ❖ Identification of possible errors in the development of software



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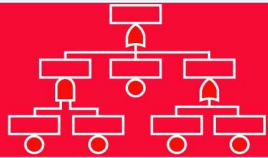
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HAZOP team and meetings



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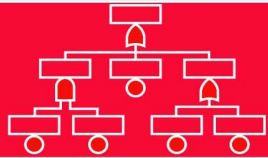
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□ HAZOP team leader

Responsibilities:

- ❖ Define the scope for the analysis
- ❖ Select HAZOP team members
- ❖ Plan and prepare the study
- ❖ Chair the HAZOP meetings
 - Trigger the discussion using guide-words and parameters
 - Follow up progress according to schedule/agenda
 - Ensure completeness of the analysis

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



Team members and responsibilities (2)

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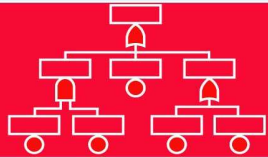
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□ HAZOP secretary

Responsibilities:

- ❖ Prepare HAZOP worksheets
- ❖ Record the discussion in the HAZOP meetings
- ❖ Prepare draft report(s)



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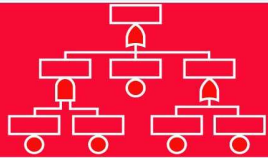
□ HAZOP team members

The basic team for a process plant will be:

- ❖ Project engineer
- ❖ Commissioning manager
- ❖ Process engineer
- ❖ Instrument/electrical engineer
- ❖ Safety engineer

Depending on the actual process the team may be enhanced by:

- ❖ Operating team leader
- ❖ Maintenance engineer
- ❖ Suppliers representative
- ❖ Other specialists as appropriate



How to be a good HAZOP participant

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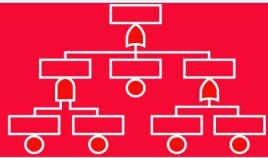
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- Be active! Everybody's contribution is important
- Be to the point. Avoid endless discussion of details
- Be critical in a positive way - not negative, but constructive
- Be responsible. He who knows should let the others know



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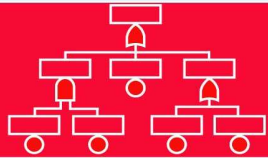
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Proposed agenda:

1. Introduction and presentation of participants
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 and 5)
7. Coarse summary of findings

Focus should be on potential hazards as well as potential operational problems

Each session of the HAZOP meeting should not exceed two hours.



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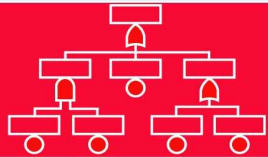
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The findings are recorded during the meeting(s) using a *HAZOP work-sheet*, either by filling in paper copies, or by using a computer connected to a projector (recommended).

The HAZOP work-sheets may be different depending on the scope of the study - generally the following entries (columns) are included:

1. Ref. no.
2. Guide-word
3. Deviation
4. Possible causes
5. Consequences
6. Safeguards
7. Actions required (or, recommendations)
8. Actions allocated to (follow-up responsibility)



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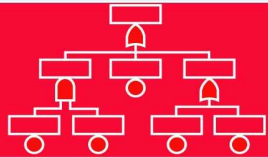
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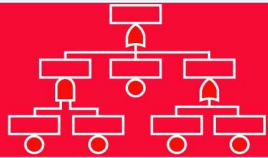
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As a basis for the HAZOP study the following information should be available:

- Process flow diagrams
- Piping and instrumentation diagrams (P&IDs)
- Layout diagrams
- Material safety data sheets
- Provisional operating instructions
- Heat and material balances
- Equipment data sheets Start-up and emergency shut-down procedures



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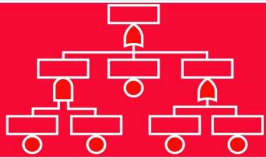
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1. Divide the system into sections (i.e., reactor, storage)
2. Choose a study *node* (i.e., line, vessel, pump, operating instruction)
3. Describe the *design intent*
4. Select a process *parameter*
5. Apply a *guide-word*
6. Determine cause(s)
7. Evaluate consequences/problems
8. Recommend action: What? When? Who?
9. Record information
10. Repeat procedure (from step 2)



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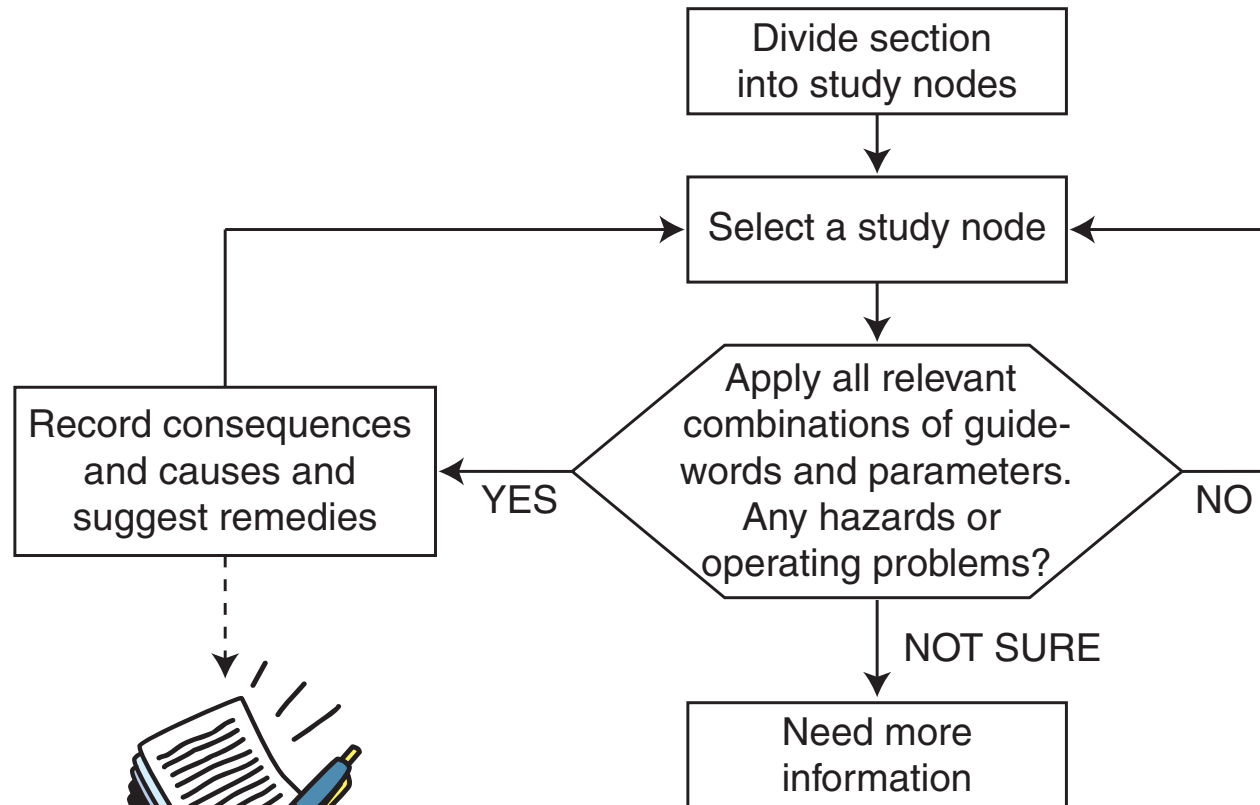
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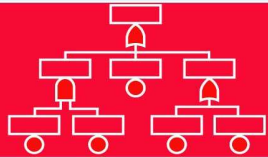
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The HAZOP procedure may be illustrated as follows:



HAZOP report





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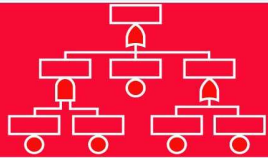
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The following modes of plant operation should be considered for each node:

- Normal operation
- Reduced throughput operation
- Routine start-up
- Routine shutdown
- Emergency shutdown
- Commissioning
- Special operating modes

– Based on Kyriakdis (2003)



Process HAZOP worksheet

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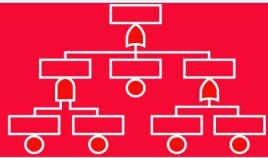
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Study title:						Page: of			
Drawing no.:			Rev no.:			Date:			
HAZOP team:						Meeting date:			
Part considered:									
Design intent:			Material: Source:			Activity: Destination:			
No.	Guide-word	Element	Deviation	Possible causes	Consequences	Safeguards	Comments	Actions required	Action allocated to

– Source: IEC 61882



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❑ Node

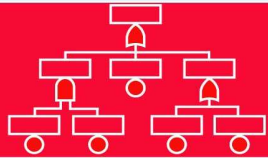
A node is a specific location in the process in which (the deviations of) the design/process intent are evaluated. Examples might be: separators, heat exchangers, scrubbers, pumps, compressors, and interconnecting pipes with equipment.

❑ Design Intent

The design intent is a description of how the process is expected to behave at the 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.

❑ Deviation

A deviation is a way in which the process conditions may depart from their design/process intent.



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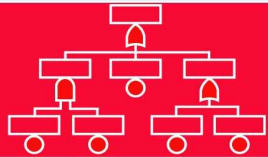
❑ Parameter

The relevant parameter for the condition(s) of the process (e.g. pressure, temperature, composition).

❑ Guideword

A short word to create the imagination of a *deviation* of the design/process intent. The most commonly used set of *guide-words* is: no, more, less, as well as, part of, other than, and reverse. In addition, guidewords like too early, too late, instead of, are used; the latter mainly for batch-like processes. The *guidewords* are applied, in turn, to all the *parameters*, in order to identify unexpected and yet credible *deviations* from the design/process intent.

Guide-word + Parameter → Deviation



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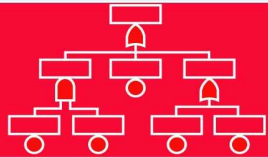
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❑ Cause

The reason(s) why the *deviation* could occur. Several *causes* may be identified for one *deviation*. It is often recommended to start with the causes that may result in the worst possible consequence.

❑ Consequence

The results of the *deviation*, in case it occurs. *Consequences* may both comprise process hazards and operability problems, like plant shut-down or reduced quality of the product. Several *consequences* may follow from one cause and, in turn, one *consequence* can have several *causes*



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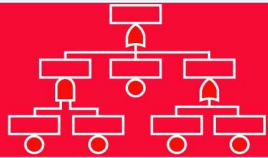
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❑ Safeguard

Facilities that help to reduce the occurrence frequency of the *deviation* or to mitigate its *consequences*. There are, in principle, five types of *safeguards* that:

1. Identify the deviation (e.g., detectors and alarms, and human operator detection)
2. Compensate for the deviation (e.g., an automatic control system that reduces the feed to a vessel in case of overfilling it. These are usually an integrated part of the process control)
3. Prevent the deviation from occurring (e.g., an inert gas blanket in storages of flammable substances)
4. Prevent further escalation of the *deviation* (e.g., by (total) trip of the activity. These facilities are often interlocked with several units in the process, often controlled by computers)
5. Relieve the process from the hazardous deviation (e.g., pressure safety valves (PSV) and vent systems)



Process parameters

Process parameters may generally be classified into the following groups:

- ❑ Physical parameters related to input medium properties
- ❑ Physical parameters related to input medium conditions
- ❑ Physical parameters related to system dynamics
- ❑ Non-physical tangible parameters related to batch type processes
- ❑ Parameters related to system operations
These parameters are not necessarily used in conjunction with guide-words:
 - ❖ Instrumentation
 - ❖ Relief
 - ❖ Start-up / shutdown
 - ❖ Maintenance
 - ❖ Safety / contingency
 - ❖ Sampling

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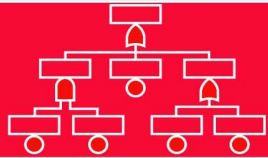
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Examples of process parameters

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Pressure

Temperature

Mixing

Stirring

Transfer

Level

Viscosity

Reaction

Composition

Addition

Separation

Time

Phase

Speed

Particle size

Measure

Control

pH

Sequence

Signal

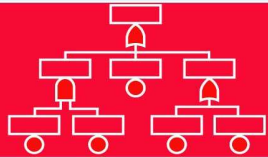
Start/stop

Operate

Maintain

Services

Communication



Guidewords

The basic HAZOP guide-words are:

Guide-word	Meaning	Example
No (not, none)	None of the design intent is achieved	No flow when production is expected
More (more of, higher)	Quantitative increase in a parameter	Higher temperature than designed
Less (lessof, lower)	Quantitative decrease in a parameter	Lower pressure than normal
As well as (more than)	An additional activity occurs	Other valves closed at the same time (logic fault or human error)
Part of	Only some of the design intention is achieved	Only part of the system is shut down
Reverse	Logical opposite of the design intention occurs	Back-flow when the system shuts down
Other than (other)	Complete substitution - another activity takes place	Liquids in the gas piping

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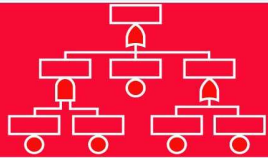
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Additional guidewords

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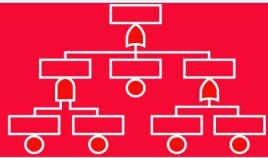
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Guide-word	Meaning
Early / late	The timing is different from the intention
Before / after	The step (or part of it) is effected out of sequence
Faster / slower	The step is done/not done with the right timing
Where else	Applicable for flows, transfer, sources and destinations



Guideword + parameter

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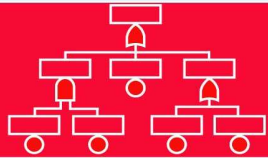
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Some examples of combinations of guide-words and parameters:

- ❑ **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**
Ambient conditions - failed exchanger tubes - fire situation - cooling water failure - defective control - internal fires

– Many more examples in Kyriakdis (2003)



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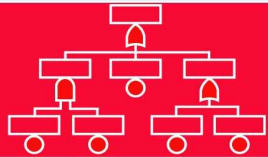
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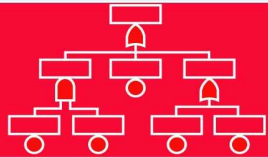
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A procedure HAZOP is an examination of an existing or planned operation (work) procedure to identify hazards and causes for operational problems, quality problems, and delays.

- Can be applied to all sequences of operations
- Focus on both human errors and failures of technical systems
- Best suited for detailed assessments, but can also be used for coarse preliminary assessments
- Flexible approach with respect to use of guide-words



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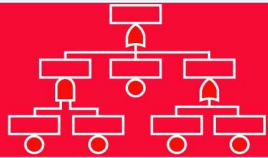
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Conclusions

- ❑ Breakdown of operation (work) procedure to suitable steps
- ❑ Define intention of each step
- ❑ Establish boundary conditions

else as
conventional Process HAZOP

- ❑ Apply guide-words to intention and boundary conditions for each step.



Guidewords

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[Team](#)

[Process HAZOP](#)

[Procedure HAZOP](#)

[What is a procedure HAZOP?](#)

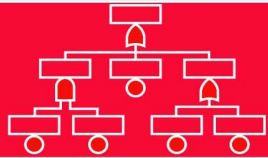
[Procedure](#)

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Guide-word	Meaning
No (not, none)	None of the design intent is achieved
More (more of, higher)	Quantitative increase in a parameter
Less (less of, lower)	Quantitative decrease in a parameter
As well as (more than)	An additional activity occurs
Part of	Only some of the design intention is achieved
Reverse	Logical opposite of the design intention occurs
Other than (other)	Complete substitution - another activity takes place



Alternative guidewords - (1)

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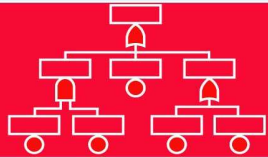
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Guide-word	Meaning
Unclear	Procedure written in confusing and ambiguous fashion
Step in wrong place	Procedure will lead to actions out of correct sequence or recovery failure
Wrong action	Procedure action specified is incorrect
Incorrect information	Information being checked prior to action is incorrectly specified
Step omitted	Missin step, or steps too large, requiring too much of the operator
Step unsuccessful	Step likely to be unsuccessful due to demands on operator
Interference effects from others	Procedure-following performance likely to be affected by other personnel carrying out simultaneous tasks (usually when co-located)

– Adapted from B. Kirwan



Alternative guidewords - (2)

Parameter	Guide-word / deviation
Time	Too early, too late
Sequence	Wrong sequence, omissions, wrong action
Procedure	Not available, not applicable, not followed
Measurement	Instrument failure, observation error
Organization	Unclear responsibilities, not fitted for purpose
Communication	Failed equipment, insufficient/incorrect information
Personnel	Lack of competence, too few, too many
Position	Wrong position, movement exceeding tolerances
Power	Complete loss, partly lost
Weather	Above limitations - causing delayed operation

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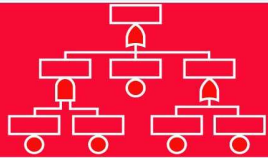
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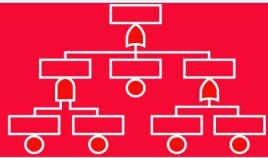
Reporting

Report contents

Review meetings

Conclusions

Reporting and review



Report contents

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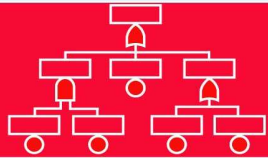
Conclusions

Summary

1. Introduction
2. System definition and delimitation
3. Documents (on which the analysis is based)
4. Methodology
5. Team members
6. HAZOP results
 - Reporting principles
 - Classification of recordings
 - Main results

Appendix 1: HAZOP work-sheets

Appendix 2: P&IDs (marked)



Review meetings

Introduction

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Reporting

Report contents

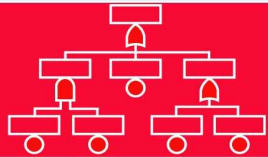
Review meetings

Conclusions

Review meetings should be arranged to monitor completion of agreed actions that have been recorded. The review meeting should involve the whole HAZOP team. A summary of actions should be noted and classified as:

- Action is complete
- Action is in progress
- Action is incomplete, awaiting further information

– Based on Kyriakdis (2003)



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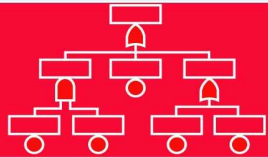
HAZOP Results

Advantages

Success factors

Pitfalls

Conclusions



HAZOP Results

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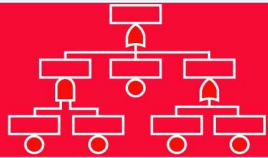
HAZOP Results

Advantages

Success factors

Pitfalls

- ❑ Improvement of system or operations
 - Reduced risk and better contingency
 - More efficient operations
- ❑ Improvement of procedures
 - Logical order
 - Completeness
- ❑ General awareness among involved parties
- ❑ Team building



Advantages

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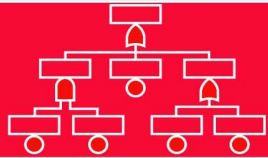
HAZOP Results

Advantages

Success factors

Pitfalls

- Systematic examination
- Multidisciplinary study
- Utilizes operational experience
- Covers safety as well as operational aspects
- Solutions to the problems identified may be indicated
- Considers operational procedures
- Covers human errors
- Study led by independent person
- Results are recorded



Success factors

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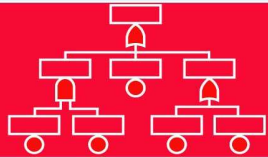
HAZOP Results

Advantages

Success factors

Pitfalls

- ❑ Accuracy of drawings and data used as a basis for the study
- ❑ Experience and skills of the HAZOP team leader
- ❑ Technical skills and insights of the team
- ❑ Ability of the team to use the HAZOP approach as an *aid* to identify deviations, causes, and consequences
- ❑ Ability of the team to maintain a sense of proportion, especially when assessing the severity of the potential consequences.



Pitfalls and objections

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HAZOP Results

Advantages

Success factors

Pitfalls

- Time consuming
- Focusing too much on solutions
- Team members allowed to divert into endless discussions of details
- A few of the team members dominate the discussion
- “This is my design/procedure”
 - Defending a design/procedure
 - HAZOP is not an audit
- “No problem”
- “Wasted time”