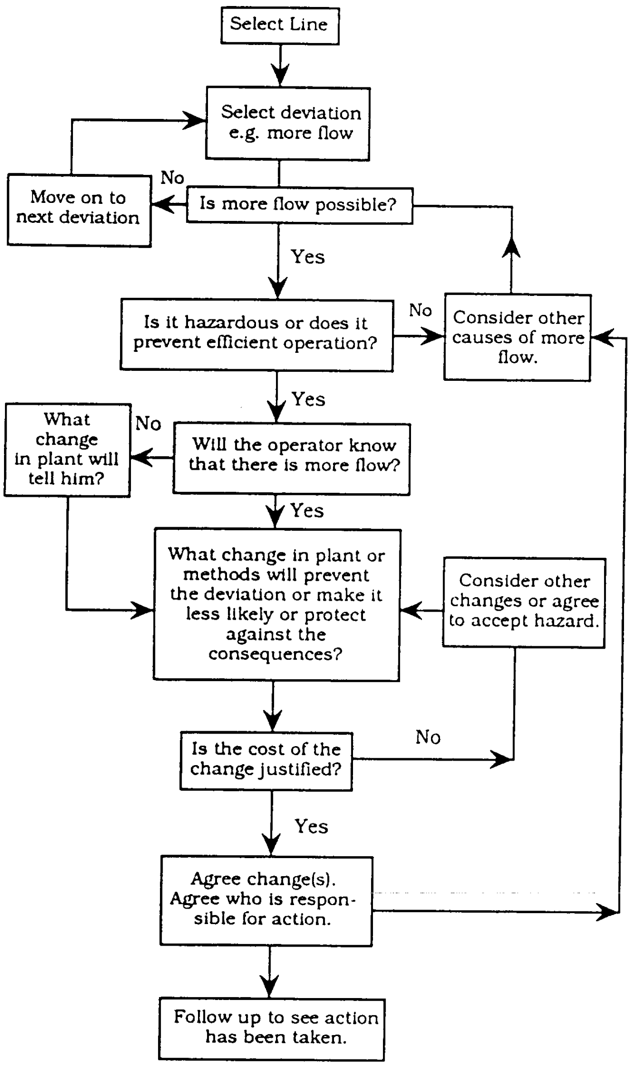

AER-5437

TSI 41-018

GUIDELINES FOR CONDUCTING HAZOP STUDIES

LOSS PREVENTION DEPARTMENT
SAUDI ARAMCO

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1.0

Review of HAZOP Technique

1.1 THE BASIC CONCEPT

In recent years, the use of the HAZOP (Hazard and Operability) study technique has increased enormously, particularly in the USA and Europe, and is indeed mandatory in some companies. The method is now well established as a means of identifying potential plant design hazards and operability problems.

The HAZOP technique is a highly disciplined procedure and attempts to identify how a process may deviate from the design intent. The emphasis in the HAZOP study is on identifying potential problems, not necessarily solving them. If, however, a solution is obvious during the study, it is recorded or incorporated immediately while the study is in progress. The "guide word" HAZOP technique is the most widely known and is one of the hazard identification techniques used by Saudi Aramco.

In a HAZOP study, a team of individuals systematically "brainstorms" the process under review in a series of meetings using a set of guide words to structure the review. The team is composed of individuals representing a variety of departments/specialties. This multi-disciplinary team concept allows the various viewpoints of the team members to stimulate the thinking of the other team members and results in creative thinking. Consequently, a more thorough review is achieved than would occur if members of the team individually reviewed the same process.

A typical HAZOP study team may consist of the representatives from the following disciplines:

- Inspection
- Instrumentation/Electrical
- Loss Prevention/Fire Prevention
- Maintenance
- Operations
- Operations/Process Engineering
- Other Specialists as required

The HAZOP study is conducted by systematically applying guide words with appropriate process parameters to the various lines and vessels in the plant (identifying deviations from the design intent of normal process conditions).

The HAZOP technique is based upon the following fundamental principles:

- Obtain a full description of the process, including the intended design conditions.
- Systematically examine every part of the process to find out how deviations from those designed or specified can occur.
- Decide whether these deviations can give rise to hazards and/or operability problems.

These principles can be applied to operating process plants or to plants in various stages of design.

1.2 ROLE OF HAZOPS IN RISK ASSESSMENT

Before discussing the background and specifics of the HAZOP technique, it is important to have an understanding of the overall risk assessment process and where the HAZOP technique fits into this process.

In any risk assessment study, there are a number of distinct steps that make up the study. The general steps that are part of any risk assessment study are to:

- ❑ Establish the objectives of the study;
- ❑ Decide upon an overall scope;
- ❑ Select a technique that will meet your objectives;
- ❑ Organize a study team;
- ❑ Organize various aspects of the study;
- ❑ Conduct the study; and
- ❑ Document the results of the study.

The objectives, scope, study team, and the steps in organizing the study will be discussed in more detail later with respect to how they relate to a HAZOP study.

There are many contemporary techniques that are used on a world-wide basis for hazard analysis studies. In addition to the HAZOP method, the four most commonly used techniques in the process industries are:

Preliminary Hazards Analysis (PHA) - an initial screening exercise that can be used to identify, describe, and rank major hazards. This technique can also be used to identify possible consequences and likelihood of occurrence and provide recommendations for hazard mitigation.

Failure Modes and Effects Analysis (FMEA) - a detailed exercise in reviewing the precise types of failure that may be involved in a given accident. A ranking may also be added of which failure events may cause the most severe consequences.

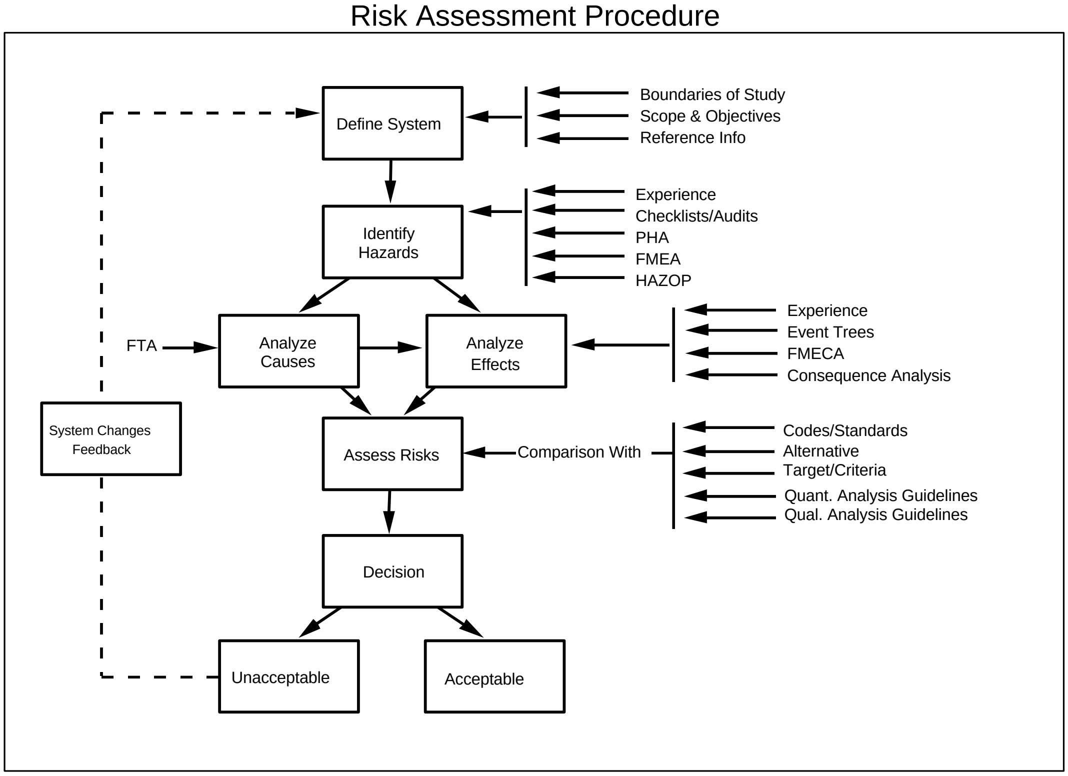
Fault Tree Analysis (FTA) - a method used normally for evaluating detailed component failure. This involves using a logic diagram or tree to establish the various sequence of events that are required to reach some ultimate event. With individual component failure rate data this technique can be used to quantify the probability of a given event.

Event Tree - a method for providing the event logic of an event. This frequently results in diagrams that can aid in reviewing interrelationships between events.

The overall risk assessment process diagram (Figure 1) is intended to put these techniques, along with others, into perspective within the overall risk assessment procedure. The risk assessment procedure encompasses a number of steps, the first of which is the need to identify hazards. Identification of hazards can be done by a number of approaches, one of which is the HAZOP technique.

Figure 1

Risk Assessment Procedure



Hazard **identification** and hazard **assessment** are often confused with each other. The former is strictly intended to achieve a better awareness of the hazards of a facility or operation. The latter is an attempt to evaluate the potential severity or likelihood of the incidents and to determine the best course of action if the current level of risk is considered unacceptable.

1.3 BACKGROUND OF HAZOP TECHNIQUE

The HAZOP study technique was developed by Imperial Chemical Industries (ICI) in the United Kingdom over 20 years ago. Since than, the technique has been modified, improved, and applied to many different processes, both continuous and batch.

Since its inception, the use of the HAZOP study technique has increased enormously, particularly in Europe, and more recently in the U.S., and is becoming mandatory for all existing and new processes and projects. Legislation in some countries is driving this effort.

In addition, plant processes have become larger, more complex and have spread on a fairly large scale to developing countries. Society in general has become much more sensitive to the exposures created by these plants. There is tremendous pressure on the management of process industry companies to prevent incidents, particularly if they could involve third parties.

Over the last few years, a number of Saudi Aramco facilities have been HAZOPed. These facilities include Abqaiq plants 106 (UA Spheroids) and 462 (South NGL), the Khuff Gas High Pressure DGA Unit at Shedgum Gas Plant and three plants within Ras Tanura Refinery. HAZOP studies for other plants have also been planned. Using the HAZOP technique for proposed plants helps ensure that process safety and operability issues are addressed during design, while a HAZOP study of existing plant can assist management where an assessment of the major hazards of the facility is required for compliance with corporate policy.

The basis behind the HAZOP technique is that; a Hazard and Operability (HAZOP) study attempts to identify how a process may deviate from the design intent. In other words, a hazard is assumed to occur only if the process deviates from its design.

The emphasis in the HAZOP study is on identifying potential hazards, not finding solutions to reduce them. This is a fundamental concept in the use of the HAZOP technique. A team of engineers often will attempt to engineer a solution to reduce the risks of a newly recognized problem. This must be avoided during the HAZOP session, to keep the study moving. However, if obvious solutions are apparent, the team can propose these.

The technique is a highly disciplined procedure. It is concerned only with the adequacy of a proposed design and not with the merits of alternative designs.

Attributes

The HAZOP technique is qualitative. It is not intended, nor is it necessary, to apply quantitative probability numbers to the hazards that are identified. However, risk ranking schemes may be used to prioritize the recommendations.

The technique is a guide word approach. The guide words are used to provide structure to the technique.

A HAZOP study is not the same as a traditional P&ID review. A P&ID review is intended to assure that the design has the proper instrumentation, piping, materials, etc., to operate as designed. A team of designers reviews the drawings and checks their design work for completeness without a rigid methodology for doing so. A HAZOP team reviews a system that is designed to operate normally and then considers all types of deviations to the normal conditions using a very structured approach. The HAZOP can cover both safety and operating problems.

Note that in a HAZOP study the operability part may be as important as the hazard part. Our studies are normally concerned with the hazards a process creates, but the operability of the unit can be studied as well. For this reason, the benefits of HAZOP go beyond hazard identification.

Advantages

There are a number of advantages to the HAZOP technique.

- Easy of learn.
- Stimulates creativity and generates ides.
- Systematic and thorough procedure.
- Participants gain valuable knowledge of process.
- Readily acceptable to regulatory authorities.

Limitations

There are some limitations to the use of this technique.

- The success of the review is highly dependent on the accuracy of drawings and data.
- It requires the right mix of team members with the proper technical experience and insight.
- It is tiring and difficult to perform over extended periods and leads to something we call “brain burnout.”
- For a smooth, effective study, it requires the commitment of the team, and management, for the duration of the study. A HAZOP study is difficult to conduct when team members are changed or key team members don’t attend.

HAZOP Variances

Several variants to the guide word HAZOP exist. The two variants frequently used are:

- Knowledge-based HAZOP
- Checklist HAZOP

The knowledge-based HAZOP is a specialization of the guide word HAZOP in which the guide words are modified by the team's knowledge. This knowledge base is used to compare the design to established basic design intentions that have been developed and documented from previous experience. The premise of this HAZOP version is that the organization has appropriate design standards that the team members are familiar with. This approach incorporates all the company's previous experience. The guide word method can be used to augment this approach to ensure that new problems are not overlooked when new aspects of the process are involved.

The creative checklist HAZOP technique was developed to address two issues: 1) the need for a study earlier in the design based only on the materials to be used, and 2) the need for a study that can review interactions resulting from the proximity of the units of the plant, and interaction with the environment. In this technique, materials are first compared to a hazards checklist (fire, explosion, toxicity, reactivity, etc.) and the team determines which hazards are relevant. Hazardous materials are inventoried. Each unit of the site is then associated with the hazards list generated to produce a series of hypothetical “unit hazards.” If the team judges that a given unit hazard is real, they identify potential actions and/or guidelines that should be followed in the subsequent design phase to minimize risks. Such a study can enable decisions on location to be made in the preliminary design stage.

1.4 GUIDE WORD HAZOP TECHNIQUE

Since HAZOP technique is so systematic and highly structured, it is necessary to use certain terms in a precise and disciplined way. The most important of these terms are:

Intention

The intention defines how the part of the process (being studied) is expected to operate. This can take a number of forms and can be either descriptive or diagrammatic.

Causes

There are the reasons why deviations might occur. Once a deviation has been shown to have a conceivable or realistic cause, it can be treated as meaningful.

Consequences

These are the results of the deviations should they occur.

Hazards

These are the consequences which can cause damage, injury or loss.

Note

A section of a process unit generally consisting of piping and vessels that allows the study team to HAZOP equipment in an organized fashion.

Guide Words

The guide words are the tools that are used to systematically direct the HAZOP study. They are words or phrases that, when considered together with a parameter, form a hypothetical deviation for the team to consider. The basic guide words and phrases are; NO, LESS, MORE, REVERSE, PART OF, AS WELL AS, and OTHER THAN. These are defined below:

Guide Word	Meaning
NO	Negation of the design intent (e.g., no flow when there should be; no pressure when there should be
LESS	Less of a physical property than there should be —quantitative decrease (e.g., lower flow rate than there should be)
MORE	More of a physical property than there should be —quantitative increase
PART OF	Composition of the system (stream) is different than it should be —qualitative decrease (e.g., less of one component)
AS WELL AS	More components present than there should be—qualitative increase (e.g., extra phase or impurities present)
REVERSE	Logical opposite of the design intent (e.g., reverse flow)
OTHER THAN	Complete substitution (e.g., transfer of a material other than the material intended; transfer of a material to a location other than intended)

Parameters

Process parameters, such as, FLOW, PRESSURE, TEMPERATURE, LEVEL, QUANTITY, and TIME, describe the process intention of vessels, piping or other equipment in specific terms. All relevant parameters are considered, but the aforementioned parameters may be appropriate for more situations. Parameters can be considered as of two types. Specific parameters, such as those mentioned above, describe the physical aspects of the process. General parameters, such as REACTION, MAINTENANCE, ADDITION, and others, describe operations more so than physical aspects of the process. Both specific process parameters and general process parameters may be considered during the study.

Deviations

These are departures from the design intention which are discovered by systematically applying the guide word/parameter combinations to study the process.

Figure 2 combines a sample of the guide words and process or design parameters into a matrix of common deviations that will be considered during the HAZOP review. As can be seen from the chart, some guide word/parameter deviations are not meaningful, such as "reverse temperature" or "as well as pressure." The HAZOP Team should document which deviations were used and which deviations were considered "not meaningful."

Figure 2

Deviation Matrix

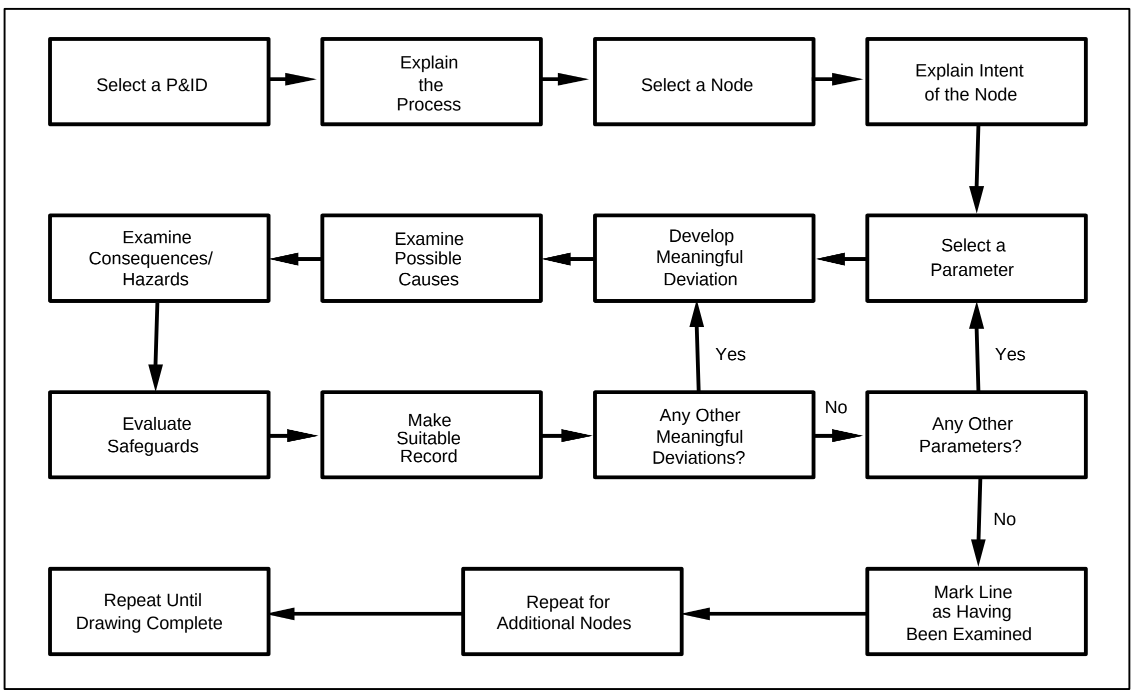
Guide Words / Design Parameter	More Of	Less Of	None Of	Reverse	Part of	As Well As	Other Than
Flow	High Flow	Low Flow	No Flow	Back Flow	Wrong Concentrations	Contaminants	Wrong Material
Temperature	High Temp	Low Temp					
Pressure	High Press	Low Press					
Level	High Level	Low Level	No Level				

Study Session

The heart of the HAZOP technique is the team meetings, or study sessions. The routine of the study sessions is shown in Figure 3. Because of the importance of the study sessions, the major steps involved in these sessions are reviewed below.

Figure 3

Study Sessions



1. Select a Vessel/Line & Explain Intent

The study is conducted by reviewing one P&ID until all lines and equipment have had all appropriate guide words and parameters applied, then continuing on to all other P&IDs until all have been completed. One method used is to start at the beginning of the process and follow it through to the end. To insure all team members have an understanding of the portion of the process under review, the first step is to have someone, usually the operations representative or the process engineer, briefly explain the purpose and operation of the equipment on the drawing under review. The first vessel to be reviewed is selected and again a brief review of the specific operation of the equipment within the node is given. The actual study goes line by line, vessel by vessel. When the first line is selected, the intent of the line is specifically discussed so that the relevant parameters, such as flow, pressure, temperature, etc., are clear to all team members. A clear understanding of the design intent and the parameters is necessary for development of meaningful deviations.

2. Apply Guide Words/Parameters & Develop Deviations

The objective of the HAZOP study is to identify hazards and operability problems. A premise of the HAZOP technique is that a problem can only exist if the process deviates from the design. The guide words are therefore combined with the design parameters to develop deviations. For example, the guide word, “NO”, may be combined with the design parameter, “FLOW”, to develop the deviation, “NO FLOW.” Likewise, the other guide words would be combined with the “FLOW” parameter to develop deviations such as “LESS FLOW”, “REVERSE FLOW”, etc.

3. Evaluate Causes of Deviations

Since a large number of deviations could be developed, only meaningful ones are to be considered as realistic, potential problems. A meaningful deviation can be defined as one which has realistic causes, and a consequence which could create a hazard.

After developing a deviation, the team determines if the deviation has realistic causes.

4. Evaluate Consequences & Safeguards

For each of the deviations with a realistic cause, the consequences must be evaluated. At this step the interaction of the team members becomes most important. The direct and indirect consequences of the deviation are carefully considered. Also, any safeguards which could prevent the occurrence of the event or mitigate the consequences, if it occurs, are discussed and documented. Where additional information is needed to evaluate the consequences or the team is unsure of what the consequences may be, a note is made to investigate it further. The decision to gather more information is taken by the team leader and efforts are made to resolve the majority of the outstanding items during the course of the study.

5. Record Results and/or Recommendations

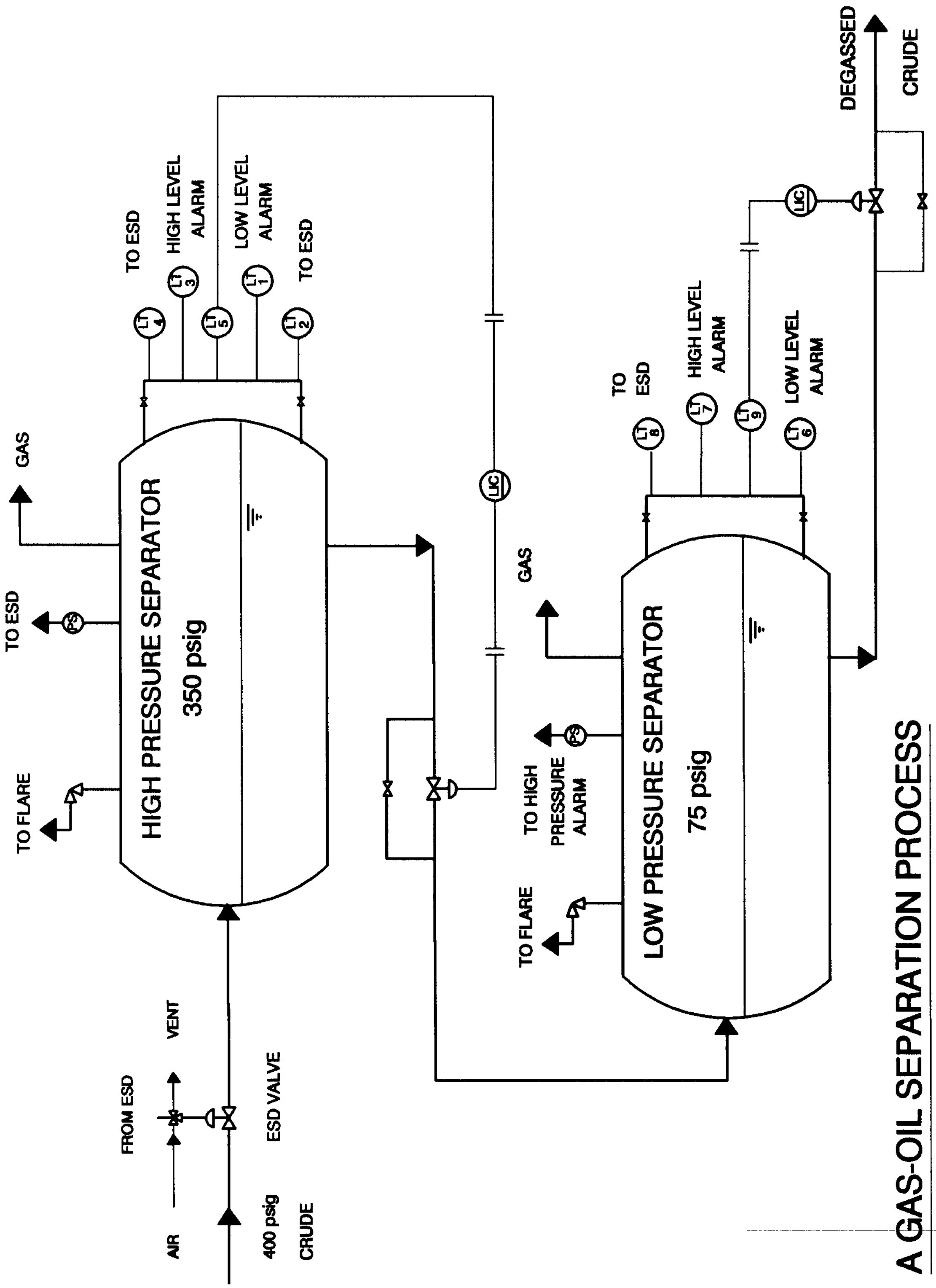
The deviations, causes, consequences, safeguards, items for additional review, recommendations, etc., are recorded on suitable forms. A variety of forms are used for this purpose. Documentation of the study and the forms available for doing so are discussed in more detail in later sections of this manual.

1.5 A SIMPLE EXAMPLE

This is an example of a simplified GOSP (Gas Oil Separation Plant). It consists of a High Pressure Production Trap (HPPT) and a Low Pressure Production Trap (LPPT). The incoming crude pressure is 400 psig at a flow rate of 150 MBD. The crude goes through pressure letdown before being shipped to another plant for stabilization. This HAZOP example shows how a HAZOP worksheet would be filled out for the high pressure trap which is defined as node 1. The parameters of level and pressure are covered by this example.

Notice how each cause is directly related to some specific piece of equipment associated with or connected to the HPPT.

The worksheet section entitled BY is used to assign responsibility. The initials used are **PTF** - the Project Task Force (Project Management), **ENG** - Operations Engineering, and **OPS** - Operations.



A GAS-OIL SEPARATION PROCESS

HAZOP-PC 2.02 Worksheet

Company: SAUDI ARAMCO
Facility: GOSP

Page: 1

Session: 1 02-27-91 Revision: 0 02-27-91 Dwg#:
Node: 1 High Pressure Separator
Parmeter: Pressure Intention: Maintain 350 psig

GW	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	BY
More	Higher Pressure	1) Closed valve or PIC malfunction in overhead system	1) Possible vessel overpressure	1) PSV to flare and high pressure shutdown	1) Ensure PSV and PS set pressures is adequate	PTF
		2) Fire Exposure	2) Possible vessel failure	2) Same as No. 1 above	2) Ensure PSV is designed to handle full fire exposure	PTF
Less	Lower Pressure	3) PSV sticks open	3) Economic loss to flare	3) Annual PSV maintenance program		
		4) PIC in overhead system malfunctions	4) Negligible			
		5) Loss of crude feed	5) Negligible			

Session: 1 02-27-91 Revision: 0 02-27-91 Dwg#:
Node: 1 High Pressure Separator
Parmeter: Level Intention: Maintain 50% Liquid Level

GW	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	BY
No/Less	No/Less Level	1) Malfunction of LT-5 or plugged level leg	1) Gas blow-thru to Low Pressure Separator	1) Independent level transmitters for low level alarm & shutdown	1A) Review the need for SEPARATE level taps for the LLA/LLSD transmiters	PTF
					1B) Review	ENG

HAZOP-PC 2.02

Worksheet

Company: SAUDI ARAMCO

Facility: GOSP

Page: 2

Session: 1 02-27-91 Revision: 0 02-27-91 Dwg#:

Node: 1 High Pressure Separator

Parmeter: Level Intention: Maintain 50% Liquid Level

GW	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	BY
					failure modes of LT's	
					1C) Car-seal valves in level legs open	OPS
		2) Open by-pass around LICV or LICV fails open	2) Same as No. 1 above	2) Same as No. 1 above	2A) Determine failure mode of LICV	PTF
					2B) Add by-pass valve to Start-up checklist	OPS
More	Higher Level	3) Malfunction of LT-5 or plugged level leg	3) Liquid carry-over to HPS overhad system	3) Independent Level transmitters for high level alarm & shutdown	3) Review the need for SEPARATE level taps for the HLA/HLSD trransmitters	PTF
		4) LICV Fails Closed or LT-9 Malfunctions	4) Same as No. 3 above	4) Same as No. 3 above		

2.0 Procedure for Conducting a HAZOP Study

2.1 DEFINITION OF OBJECTIVES AND SCOPE

Objectives

The first step which should be taken is to establish the objectives of the HAZOP study. Discussions with management should clearly establish these objectives. Sufficient time should be spent defining the objectives in writing and obtaining management's approval. This will save a considerable amount of time and/or rework at a later stage.

Plant management may sometimes initiate a study simply to satisfy a corporate or legislative request. However, more specific objectives are needed to successfully conduct the study.

There are a variety of possible objectives for conducting a HAZOP study. It may be to identify any significant hazardous exposures in the local vicinity of the process in question, to identify exposures that may impact the entire unit, to identify exposures that may affect all plant personnel, or even to identify exposures that may affect the surrounding community. It may be to review a process design to ensure that adequate safeguards have been incorporated, that no serious design errors or omissions have been made, that there are no obvious procedural problems, and/or that the design complies with required codes and standards. In summary form, typical objectives are shown in Figure 4.

The major point to be reemphasized is that the study objectives should be clearly stated, documented, and agreed upon prior to conducting the study.

Figure 4

Typical Objectives

Typical Objectives

- Identify Hazards
  - Fire/Explosion
  - Toxicity
- Identify Exposures
  - Local
  - Entire Facility
  - Surrounding Community
- Review Design
  - Safeguards
  - Errors/Omissions
  - Procedural Problems
  - Compliance With Code/Standards

Scope

Similar to establishing the objectives of the study, the scope needs to be defined and documented. The scope could be limited to a specific unit, process, or piece of equipment, or include the entire facility. It could also be limited to a specific material; for instance, “All equipment processing or storing material X.” The scope of the review also depends on factors such as whether the process is of a proven design or new technology, whether a new unit is being built or an existing unit is being modified. In summary form, typical scope items are shown in Figure 5.

In addition to stating what is included in the scope, consider clearly stating what is **not** included in the study scope.

An example of HAZOP study objectives and scope follows:

Figure 5

Typical Scope

Typical Scope

- Scope of Review
  - Entire Facility
  - Individual Unit
  - Process within Unit
  - Piece of Equipment
- Extent of Analysis
  - Proven/Existing Process
  - New Technology/Design
  - Plant Modification

Example Objectives and Scope for Abqaiq Plant 106 Study

Objectives

The objectives of this study are to identify process related hazards and to pinpoint specific safeguards which are used to control/eliminate the hazards. If the team considers the safeguards to be insufficient, recommendations for improvements and/or follow-up studies will be offered. This study will be directed and documented by use of the HAZOP procedure.

The hazards to be considered will be process related and will generally be limited to those related to the toxic and flammable properties of the process fluids. Systems such as emergency isolation valves, drainage, fireproofing, fire water systems, and pressure relief and emergency depressurization systems will be evaluated on the basis of their effects on process hazards. Most of the time these systems will be considered safeguards.

The study will assume steady state operation. Start up and shut down lines as well as vents and drain lines will only be addressed as possible routes for unintended flow.

Scope

The scope of this study will be limited to Abqaiq plant 106 (UA Spheroids). The battery limits of the plant will be used as points of initiation for establishing the HAZOP nodes.

The formal team effort will be limited to the two week period which has been scheduled for the study.

Utility systems will not be considered outside the scope of their direct impact on the process related hazards.

The following pieces of equipment will be reviewed in order of priority:

- Spheroids
- Incoming Lines
- P-Lines
- Spheroid Suction/Discharge Lines
- Over Head Gas Lines

The process will be studied as it is utilized currently. The idled equipment will be studied as it relates to the present steady state operations.

2.2 TEAM COMPOSITION

HAZOP studies are carried out by multi-disciplinary teams. Team members play two basic roles, the primary one being that of providing a technical contribution. Members are also needed for supporting and structuring roles. Members of the team should be selected for their ability and experience to contribute to either or both of these roles. In addition, team members should also possess local process and operating knowledge from the facility under study.

The makeup of the team depends on the type of process being studied. The team should contain sufficient expertise to provide the necessary technical input. The HAZOP technique requires the team to have detailed knowledge of the way the process is designed and operated. It is also advisable to have people with sufficient knowledge and experience to answer the majority of questions without having to check elsewhere for information. A typical team composition is shown in Figure 6.

Figure 6

Typical Team Members

Typical Team Members

- Inspection
- Instrumentation/Electrical
- Loss Prevention/Fire Prevention
- Maintenance
- Operations
- Operations/Process Engineering
- Other Specialists as required

Because HAZOP working sessions are highly structured and systematic, it is necessary to have a person control the discussions. This chairman-type role is held by the person designated as the “team-leader”.

In addition to the team leader, it is desirable to have a further supporting member of the team to take notes of the study sessions. This person is known as the “scribe” or secretary. Experience indicates that a separate scribe and team leader are necessary for a successful study.

The team leader plays a critical role throughout the study. The team leader helps with the selection and training of the team. Additionally, he collects the necessary data for the study and converts this into a suitable form, if necessary. The most important aspect of the team leader’s role emerges during the working sessions. It is at this point that the team leader guides the systematic questioning process and must draw on his experience and training for this job.

The team leader should not be responsible for making a major technical contribution. It is not required that he has a detailed knowledge of the design and operation of the unit. If the team leader is too familiar with the subject of the study, there is a danger of developing “blind spots”.

The requirement for local participation in HAZOP studies needs to be stressed. It is recommended that as a minimum, an operations representative from the local facility be on any HAZOP team. Although he may not have any operating experience with the new unit being designed, he will be familiar with the overall operating environment into which the new unit will be placed. Next to the operations representative, a process engineer from the local facility is just as important.

2.3 ESTIMATING TIME REQUIREMENTS

Estimating the time for a HAZOP study is important for preparing a tentative meeting schedule. The first step is to estimate the total working hours required for the HAZOP team meetings. This time will then be broken down into working sessions. A tentative schedule can be established when the approximate number of sessions is known.

There are two basic methods of estimating the time required for the HAZOP team meetings. The first is by allowing a certain amount of time for each major vessel. The second is by allowing a certain amount of time for each pipe into or out of a vessel. Saudi Aramco Loss Prevention has found the major vessel estimating method to be more accurate and will offer that method in this manual.

This method is only used for estimating the time required for the team meetings. Time is also required for preparing and documenting the study, including follow-up on various unresolved items. The time required for these ‘other’ activities is more variable, but could easily be twice or more of the study time. However, this additional time is generally only for a few team members, such as the team leader and scribe.

Estimating the study time begins with defining the major vessels to be considered. Once the major vessels are selected, the remaining equipment are grouped with the appropriate major vessels to be studied.

For example, it may be decided that the major vessels to be focused on are the drums and columns. All other equipment, such as pumps, compressors, exchangers, heaters, etc., would then be grouped with one of these major vessels. This grouping is primarily for the purpose of determining the study time required and does not constrain how or when the miscellaneous equipment is actually reviewed. In specific circumstances, there may be a need to establish a pump, compressor, exchanger, heater, etc., as an estimating group, but in general, it is more convenient to consider them as a “bump” in the line which has an effect on the pressure and/or temperature parameters of the line.

Having established a preliminary list of vessel groups, an estimate is made of the time to HAZOP each group. The time allowed for each vessel group is typically 2-4 hours. The time estimate for each group may depend upon a number of factors, including the complexity of the equipment within the group and the experience of the team leader.

Factors which may influence the estimate towards the high end (i.e. 4 hours) may be:

- vessel with many input and output lines;
- vessel with a number of other pieces of equipment assigned with it;
- a new, unique design vessel;
- several operating modes to be considered, and;
- “speed” of operation of the team leader.

Factors which may influence the estimate towards the low end (i.e. 2 hours) may be:

- simple vessel with few inputs and outputs;
- “standardized” design; typical of others, and;
- “speed” of operation of the team leader.

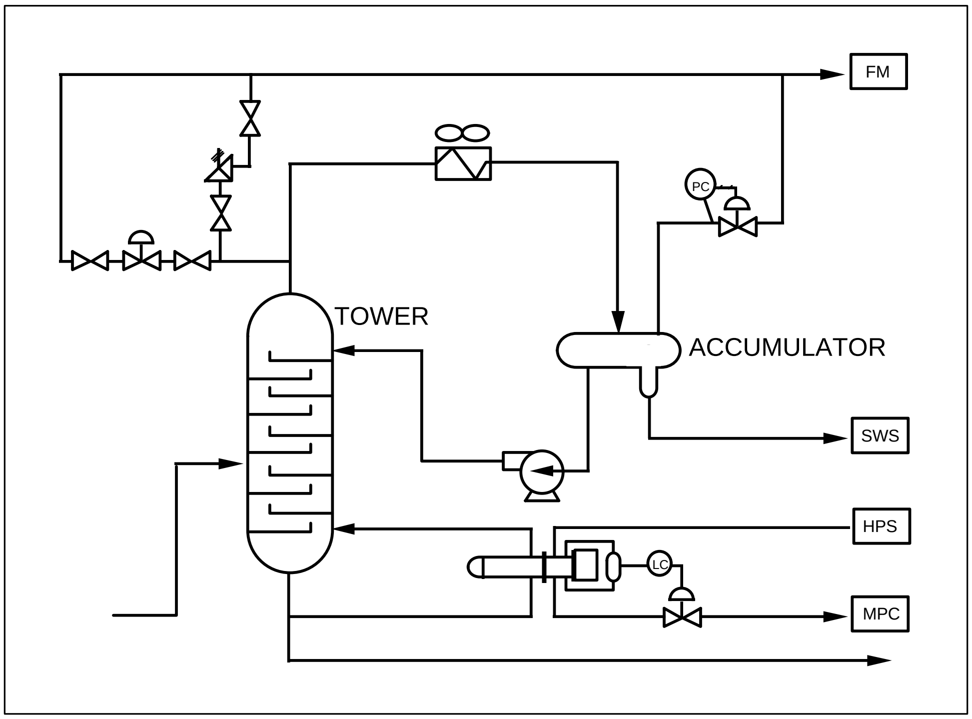
If a group appears to require more than 4 hours, it may be easier to analyze if it is split into smaller groups.

Once total team hours have been estimated, the length of each team session should be decided on. The number of sessions will be determined by dividing the total hours required by the hours per session. At this point scheduling of study team working sessions may begin.

The following example (Figure 7) illustrates how time estimates are established for HAZOP studies.

Figure 7

Time Estimates



1. Number of equipment groups = 3
2. 3 equipment groups x (2-4) session hours/group @ 12 session hours maximum
3. 12 session hours maximum ÷ 4 hrs/session @ 3 sessions

2.4 PREPARATIVE WORK

Schedule

Once the total working session hours are estimated, the schedule for the working sessions can be established. This should not be viewed as a rigid schedule which must be adhered to, but is simply a planning guide. Establishing a preliminary schedule at the beginning of the study assists the team members in planning their personal work schedule. It also keeps management aware of the commitment required for the study. As the study progresses, the number of drawings completed and time taken can be compared to the original estimate. This allows tracking study progress and provides an indication of potential schedule problems. It also provides feedback (for future reference) on the accuracy of the original time estimate.

The working sessions should preferably be held in the morning when the team members are at their peak performance for the day. The sessions should not last more than 3-4 hours. When estimating the number of sessions, it may be better to use 3 hours as a rule of thumb and schedule the sessions for 4 hours. This will allow some cushion in the time estimate. Divide the required total working session hours by 3 to get the number of sessions required. This should be considered as the minimum. Some additional time should be allowed for review sessions. These sessions are used to update open items that have been assigned for follow up to various team members. Approximately one follow-up session should be allowed for each 5 working sessions. The follow-up session can be handled as a scheduled session when no further HAZOPing is necessary. It can also be handled by spending a short time at the beginning of each working session to review any follow-up items that team members want to discuss.

When possible, schedule the working sessions to minimize conflicts with other commitments of the team members. It is possible to schedule HAZOP sessions 5 mornings a week. However, 3 meetings per week may be a preferred schedule to avoid burnout of the team, allow time for follow up activities, and have time for regular work duties.

Reference Material

The HAZOP technique asks many questions. There are 3 basic answers to these questions:

1. there is no problem;
2. there is a problem, and;
3. more information is needed to determine whether there is a problem.

To keep the HAZOP study moving, adequate up-to-date references should be available to answer most routine questions which arise. *Up-to-date Piping & Instrumentation Diagrams (P&IDs) are of primary importance*. An effort should be made to have the adequacy of the P&IDs reviewed prior to the HAZOP start date and updated as necessary. This may simply involve having an operator mark up a set of existing drawings to show the present field conditions. The importance of having updated P&IDs cannot be over-stressed. A HAZOP study cannot be done without up-to-date P&IDs. Process Flow Diagrams (PFDs) and plot plans, particularly for new projects, are also important in helping team members visualize overall flow patterns in a plant.

A basic amount of the reference material should be available in the meeting room for each session. The P&IDs and PFDs should be available for each session. Other reference material may include the design basis scoping paper, equipment data sheets, pressure relief valve data sheets including calculations sheets, if available, and operating/maintenance/ emergency manuals. The basic objective in having reference material available is to minimize the number of open items at the end of the study.

In addition to ensuring that the reference data is available, the data must be in a usable form. One of the basic preparatory steps is to ensure the accuracy and completeness of the data.

Additional preparatory work may be important where a batch process is HAZOPed. This preparation may involve preparing block diagrams, or similar, to show the different equipment arrangements for various operating modes. Typical operating modes, for which the equipment configuration and valving may be different, include regeneration, startup, and shutdown. These diagrams do not need to be professionally done. Hand sketches of the various alternatives can greatly improve the efficiency of the study.

Meeting Room

The room chosen for conducting HAZOP working sessions can greatly contribute to the success of the study. The room must have sufficient space for the entire team to sit comfortably. There should be sufficient table space for drawings to be spread out (generally 1 set for each 2 or 3 team members), and room for meeting attendees to take notes. It is convenient to have wall space to hang a set, or most of a set, of full size drawings of the plant being studied. Hanging several drawings permits following lines from one drawing to another while keeping the drawing being studied open on the table. A flip chart and/or white board is useful for preparing quick sketches, diagrams, calculations, or summarizing points.

Location of the room is also an important factor. A meeting room that is remote from the team members' normal work location is preferred. This will prevent the team members from wandering off during breaks, getting busy on something else, getting interrupted by co-workers, etc. Be sure to provide coffee and other refreshments during breaks.

Computer Aid

A personal computer software package can facilitate the performance of the HAZOP study by providing a series of worksheets (see figure 8) for recording and documenting hazard causes, deviations, consequences, etc. A HAZOP can be performed without the use of such a program. In this case the worksheets will have to be prepared beforehand and completed manually throughout the sessions.

A computer is needed in the meeting room if a HAZOP program is to be used. A printer is required to facilitate printing the daily reports. Also, when using the computer, a data projection pad is of great value. This allows the entire team to see what is entered into the worksheet in real time. This virtually eliminates the need for the team members to review the worksheets later, thereby speeding up the generation of reports. If a data projection pad is going to be used, an overhead projector and screen will also be needed.

Adequate table space should be available to locate the computer and an overhead projector. Ideally, the room lighting should allow split control of the lights so that those lights near the screen can be dimmed to improve the projection view, while other lights may be on to allow the team to view the drawings. Other details to check out ahead of time include the location and number of electrical outlets, the need for extension cords, and spare bulb for the overhead projector.

2.5 STUDY IN PRACTICE

Study Sessions

HAZOP study working sessions can be divided into the following steps:

Select a vessel or line (i.e. node) on the drawing being studied

Have a process engineer or operations person describe the purpose and design of the particular node. This is the time to be specific about what are important criteria for the node. From the description of the node purpose or intention, determine what are the relevant parameters to be reviewed for this node.

Apply the guide words

Apply one at a time to the relevant parameters to develop meaningful deviations.

Determine whether there are realistic causes for the deviation

If the team determines that the deviation is credible (i.e. there is a cause), proceed to review the consequences.

Determine the consequences

Evaluate the effects of the deviation and review whether the consequences vary depending upon the causes. Also note any safeguards that exist and will prevent the failure scenario from occurring or will mitigate the consequences if it occurs.

Record the results

Document the findings and any recommendations on the HAZOP worksheet. The recommendations may be obvious solutions to identified problems, which will remain as part of the study report. The recommendations may also define needs for additional information, which must be addressed before a determination can be made whether or not a problem exists. These recommendations should be assigned to a member of the HAZOP team for follow-up as soon as possible, preferably before the study is completed.

Team Interaction

One of the team leader's key responsibility is to deal with group dynamics. In this context, some points that need to be addressed include:

Prompt input from the team

Some members may not speak out, particularly if other members tend to dominate the conversation. Quiet members should be encouraged to provide relevant comments.

Ensure all comments are considered

An element of the brainstorming process is to allow the free flow of comments without judgment as to their acceptability or relevance. No one should make negative remarks about someone's input. This is a quick way to discourage and kill input from other members. As previously stated, it is the team leader's responsibility to promote healthy communication and relevant input from all the team members.

Avoid conflicts between team members

Often different departments have ongoing disagreements that tend to be aired during a HAZOP session. Personality clashes can also occur. Try to avoid competition between team members.

It is important to keep the team focussed on the basic objective of the HAZOP study—problem identification. Allowing the team to drift into problem solving will slow down the study and may result in failing to complete the study in the prescribed time. Where a potential solution to a recognized hazard is obvious, document it as a recommendation.

However, do not let discussions regarding possible solutions continue for more than a short time or the discussion will detract from the study objectives.

Keep the team energy level high

There are several ways of doing this. Show enthusiasm, encourage other members, and take breaks often. As a rule of thumb, try taking a five minute break every hour.

Summarize often

This will help to ensure that everyone understands and agrees on a point and will help the leader know what should be documented.

The pace of the sessions needs to be controlled in two directions

Going too fast may mean that points are brushed over and important items missed. Too fast a pace will also result in the scribe missing important details. Too slow a pace is also undesirable. There are two primary reasons for a slow pace. One is having lengthy discussions on points where insufficient information is available. The other is trying to engineer a solution during the HAZOP session. If there isn’t sufficient information to decide whether a hazard exists, then document it for further investigation and research, assign it to one of the team members to follow up, and move on. If a hazard has been identified and the discussion is how to resolve the issue, document that the hazard exists and record apparent solutions, if possible, before moving on.

2.6 RISK RANKING

The traditional HAZOP method does not include any formal ranking of the hazards identified. Sometimes this makes it difficult to prioritize the recommendations for implementation. Therefore, it is beneficial to use a risk ranking scheme to rank failure scenarios according to their estimated severity and likelihood. A five point scheme for hazard severity and likelihood levels, and the corresponding risk grid are given on the following pages.

FIVE POINT SCHEME FOR HAZARD SEVERITY LEVLES

LEVEL	SEVERITY
1. VERY HIGH	• Multiple employee fatalities • Public fatalities and injuries • Extensive property damage • Major environmental impact • Major adverse public reaction
2. HIGH	• Employee fatalities • Public injuries • Significant property damage • Significant environmental impact • Adverse public reaction
3. MEDIUM	• Employee injuries • Minor public injuries • Moderate property damage • Moderate environmental impact • Moderately adverse public reaction
4. LOW	• Minor employee injuries • No public injuries • Minor property damage • Minor environmental impact • No adverse public reaction

5. INSIGNIFICANT
   - Operational upset
   - No employee injuries
   - No public injuries
   - No property damage
   - No environmental impact
   - No adverse public reaction

FIVE POINT SCHEME FOR HAZARD LIKELIHOOD LEVELS

LEVEL	**LIKELIHOOD**
1. Very High	• greater than 1E-2
2. High	• 1E-2 to 1E-3
3. Medium	• 1E-3 to 1E-4
4. Low	• 1E-4 to 1E-6
5. Very Low	• less than 1E-6

RISK GRIND FOR COMBINATIONS OF SEVERITY AND LIKELIHOOD LEVELS

		Likelihood Level				
		1	2	3	4	5
Severity Level	1	1	2	3	4	5
	2	2	4	6	7	8
	3	3	6	7	8	9
	4	4	7	8	9	10
	5	5	8	9	10	10

2.7 RECORDING AND REPORTING

Documenting the HAZOP study is an important task. There are a number of objectives in documenting the study; these include:

- reporting the results of the study;
- documenting what was included and what was not included in the study;
- facilitating follow up activities by team members, and;
- conveying the need for action to management or others who may follow up items after the study is essentially completed.

Daily Documentation

The daily documentation typically consists of the HAZOP session worksheets, action item reports and Corrective Action and Recommendation Forms (CARF). The drawings used for the study are also important and the particular drawing numbers and revisions should be documented.

The worksheet helps to record what is done at each session. It is filled out by the scribe under the direction of the team leader during the working sessions. It is recommended that it be included in the report as an appendix item.

If a computer is available, then a HAZOP software program can be utilized to document the study. A typical worksheet from a HAZOP software program is shown in Figure 8. The use of the computer program will reduce the time required to produce the standard reports. When combined with the use of a data projection device, the savings in time is even greater by reducing the time required for post-editing and review of the worksheets.

A basic question to be resolved is “How much to document?” One school of thought is to only record something if a hazard exists. This will minimize the volume of documentation. The

Figure 8

HAZOP Session Worksheet

HAZOP-PC 2.02 **Worksheet**

Company:
Facility:
Page:

Session:
Node:
Parameter:

Revision: Dwg#:

Intention:

GW	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	REMARKS	BY	P

other option is to document whatever is considered, whether a hazard exists or not. This will document for later reference what was considered and avoid guessing by the reviewers. The argument against full documentation is that it slows down the study.

The recommendation for Saudi Aramco HAZOPs is that it is better to document more than less. It is better to document too much, and be able to address questions which arise, rather than document too little, and possibly need to have parts or all of the study redone.

At the end of each day's session, the worksheets for the study nodes discussed that day should be printed. The session identification data should also be printed as it serves as an attendance list for that session.

A Personal Action Items Report as shown in Figure 9 is a standard report option in a HAZOP software program. This report sorts all recommendations by the individual assigned and prints out separate reports for each individual. These serve as reminders of the items assigned to specific individuals.

A typical HAZOP study generates a number of items for follow-up. Obtaining the necessary information to resolve these items will allow a decision by the team as to whether a situation is acceptable or a recommendation is necessary. It is important to try to follow-up on as many of these items as possible and to resolve them before the study is completed.

At the beginning of each HAZOP team meeting, team members should be asked if anyone has any information to report on the items they are following. The team can then decide how to resolve these items.

In an effort to better track the progress of items identified during the HAZOP, the Corrective Action & Recommendation Form (CARF) has been developed (Figure 10). Each item to be included as a recommendation in the final report should be documented on a CARF. Space is provided on the CARF to indicate the background of the problem, the resolution, date of completion and sign off by appropriate individuals.

Figure 9

Personal Action Items Report

Personal Action Items Report **HAZOP-PC 2.02**

Company:

Process:

Node:

Page:

Deviation	Item	Follow-up review comments

Figure 10

Corrective Action & Recommendation Form

HAZOP Study
Corrective Action & Recommendation Form

Project Name:
HAZOP Study: Project No:
Recommendation/Action #:

Problem Statement:

Recommendation/Action:

Assigned To: Date:

- ❑ HAZOP Team
- ❑ PMT Management
- ❑ Proponent
- ❑ Engineering
- ❑ Other ______________

Resolution:

Work Completed:

By: Approved:

Date: Date:

Final Report

At the conclusion of the study, a report is presented to management. A typical report format is shown in Figure 11. As shown in this format, the HAZOP worksheets and copies of the drawings used in the study are included as appendices to the report. With this report format, management can be given a concise report which will provide the results of the study, as well as detailed worksheets available for review.

Figure 11

HAZOP Study Reports

HAZOP Study Reports

Standard Cover Page
Cover Page with Team Members & Study Data
Executive Summary

Table of Contents

I. Introduction, Scope and Objectives
II. Process Description
III. Study Procedure
IV. HAZOP Study Nodes
V. Recommendations and Conclusions

Appendix A - Corrective Action and Recommendation Forms
Appendix B - Worksheet Summary and Individual Worksheets
Appendix C - Drawings Used in Study

As stated in previous sections, drawings are one of the important documents of a study. For all HAZOP studies, include a copy of the study session drawings in the report. A listing of the drawings, including the revision number, should also be somewhere in the report. Additionally, it is recommended that a retrievable copy of the drawings used, either as a hard copy or microfilm copy, be retained for later reference.

To summarize, the following are guidelines for documenting a HAZOP study:

Daily (after each session)

- ❑ Produce a copy of the worksheets, including session identification page, for the nodes discussed during that session. The session identification page should reflect that particular day's team attendance and any relevant comments.

- ❑ Produce a personal action items report and distribute to the appropriate individuals.

- ❑ Prepare a CARF for any recommendation identified which will be included in the final report. This will minimize a crunch at the end of the study to prepare all the necessary CARFs.

Completion of study

- ❑ A draft report should be prepared and distributed to the study team members and appropriate management personnel for comments.

- ❑ A final report should be prepared after review and comments by the team members and appropriate management personnel.

- ❑ A copy of the study drawings marked during working sessions should be retained for future reference.

3.0
Scheduling of HAZOP Studies

3.1 EARLY CHECKING FOR MAJOR HAZARDS

The intention of the preliminary hazard analysis (PHA) is to identify all “large scale” potential hazards in the project very early in the design stage and to evaluate the severity of these hazards. This analysis should be undertaken when there is sufficient time to make major and fundamental modifications in the design concept. If the review is properly conducted, only relatively minor hazards and/or operability problems should be identified when more rigorous HAZOP study is carried out later in the design.

Potential hazards identified during this preliminary review can have a significant impact on the project as a whole. In fact, in some instances a decision to abandon the project at this stage may be made based on the severe consequences of the identified hazards. For example, an initial hazard review may identify or underscore concerns regarding the toxicity and/or environmental sensitivity of a by-product of a new process, which could pose significant handling and disposal problems.

A hazard review during the conceptual stage of a project typically results in a more inherently safe design. This may be accomplished by reducing inventories of hazardous materials in the process, finding/utilizing a less hazardous raw or intermediate material, using an alternate process requiring lower pressures and/or temperatures, or choosing an alternate site location which provides a larger buffer zone to third parties. If a management decision is made to omit the preliminary hazard review and rely solely on the detailed HAZOP study, recommendations addressing the hazards identified by the HAZOP team could involve addition of costly protective equipment (e.g., emergency isolation valves, leak detectors, additional instrumentation and interlocks, etc.).

The preliminary hazard review, which is a variation of the HAZOP technique, is accomplished by listing the hazards associated with the project at the conceptual design stage. In order to identify these hazards, various general parameters should first be established.

For example:

- Raw materials, intermediates/finished products and by-product/ effluent materials
- General process or unit operations (i.e., mixing, reacting, distillation, drying, etc.) and major equipment items
- General layout/spacing within each unit and between units and adjacent facilities
- Operating environment
- General safety/protective equipment or systems

By applying various "hazard guide words" to these general parameters, potential hazards are identified. An example of a hazard guide word list is as follows:

- Fire
- Explosion
- Toxicity
- Corrosion
- Erosion
- Vibration
- Noise
- Mechanical failure
- Asphyxiant
- Electrocution
- Radiation
- Reactivity

The following example will illustrate the procedure. Consider a new, multi-step reaction process which generates chemical intermediate "X". A meaningful combination of "intermediate X" and "toxicity" may reveal a lack of knowledge and/or available information regarding the toxicity of the subject material. This would necessitate further laboratory and/or literature reviews. On the other hand, if the above combination reveals that the intermediate material is extremely toxic and will be present in sufficient quantities to significantly expose plant personnel and/or third parties, the review team may recommend an alternative design, a better site location, a preliminary consequence (dispersion) analysis or an emergency disposal system, etc.

Utilizing past experience from as many different sources as possible aids in assessing the consequences/severity of each event. These sources could include hazard studies of similar processes and equipment items, operating experience from similar facilities and various hazard check-lists.

As each hazard is identified, the potential causes, consequences and severity are listed, along with all recommended corrective and/or preventive measures.

3.2 STUDIES AT DESIGN FREEZE STAGE

At the “design freeze” stage in the project, P&IDs are reasonably accurate and the design concept is very well defined. It is at this stage that a detailed HAZOP study is most effective as sufficient detail is available to satisfactorily answer many of the questions generated during the rigorous hazard review. Further, if the HAZOP study calls for a modification in the project design, it is much more cost effective to incorporate these changes at the design freeze stage rather than later on in the project.

In the case of large projects, it may be more efficient to carry out the HAZOP study first for only those sections of the plant which have well established designs. However, to ensure a through review, the interactions of these sections with the rest of the plant should be evaluated at the appropriate time. This may be especially useful when the project consists of both new and modified units or is a plant modification project only. There are instances where a segment of the unit is bought “off the shelf.” The vendors normally do not supply sufficient details about the package to efficiently HAZOP the unit. If these units have a substantial risk then an effort should be made to HAZOP these units with the contractors. Asking to see the results of the contractor/manufacturer’s study is advisable. Accepting the contractors’ HAZOP results without review is insufficient. It may be possible to prompt the vendor to conduct his own HAZOP and then review the results. If successful, this can also be a very time saving technique. However, this may result in an increase in the cost of the packaged unit.

When trying to deal with unit modifications it’s generally preferable to HAZOP the entire unit, however, it may be difficult to encourage a project manager to study portions of the unit that are not within his scope. A possible compromise may be to go 1 or 2 nodes inside the existing unit where tie-ins are to be made.

A HAZOP study on a large project may take several months to complete, even with multiple teams working in parallel on different sections of the plant. Since a typical project manager would rarely agree to hold up the detailed design and construction of a project until the HAZOP is completed, the possibility exists of having to modify the project design once the results of the HAZOP study are available. Interim status reports, which t a minimum highlight areas of major concerns, should be generated and transmitted to appropriate project management personnel during the course of the study.

This issue highlights the challenge of waiting until absolutely perfect P&IDs are available. The difficulty with this approach is that the project schedule may not allow sufficient time for the delay inherent in conducting the HAZOP study and subsequent implementation of the study findings. However, if the findings are significant then implementing them during design is more efficient than affecting a field change once construction has commenced. Ideally the project should have the HAZOP study and implementation of results factored into the schedule. Another important element regarding this issue is coordination of multiple HAZOP's for various units all associated with the same project. As mentioned above, if multiple HAZOP's are to be conducted then responsibility should be assigned to a particular individual to ensure consistent and timely resolution of results.

3.3 STUDIES AT PRE-START UP

The type of study required at the pre-start up stage depends on the extent of hazard analyses conducted earlier in the project.

A detailed HAZOP should be completed at the pre-start up stage if such study was not performed earlier. However, since construction will be nearly complete at this stage, it should be recognized that it may be difficult and/or costly to implement major changes recommended by the study team.

If the study was conducted at the “design freeze” stage, it is generally not necessary to carry out an additional HAZOP study at this stage. However, if any modifications in the design have been implemented since the detailed study, then the original HAZOP team should be reconvened to review all changes made. In addition, the study team should review all start up lines if they were excluded from the original study. All documentation from this follow-up study should be filed with the information from the original study sessions.

It is generally at the pre-start up phase that operating procedures are finalized. Prior to the plant commissioning, a detailed review of the operating procedures (i.e., normal, start up, shut down and emergency) must be completed. Many companies have found the HAZOP technique to be a useful tool in accomplishing this task. A description of how the HAZOP procedure should be applied to operating procedures is included in later sections of this manual.

It is also essential that a review of all outstanding HAZOP action items and/or follow-up items be made and that all “critical” recommendations be implemented or otherwise resolved before the unit/plant start up.

During the pre-start up stage, a detailed field check should be made to ensure that the P&IDs which were the basis for the extensive HAZOP study of the plant, accurately reflect “as built” conditions.

3.4 STUDIES ON EXISTING PLANTS

Although the HAZOP procedure is most well known for its application on new plants, the use of the technique on existing facilities is rapidly increasing. This is primarily attributed to a greater industry awareness of the benefits and utilization of the technique and increasing legislation requiring hazard analyses of existing plants.

The hazard potential of an existing plant may change dramatically over a period of years due to various modifications and debottlenecking. Particularly with older facilities, many of these modifications may not have been subjected to a rigorous hazard analysis. Consequently, the changes made could have compromised the safety of the original plant design. A HAZOP study for such plants is highly recommended.

The preparative work associated with a HAZOP study on an existing plant is usually found to be substantial since operating instructions and P&IDs often need updating. Attempting to perform a HAZOP on incomplete or outdated information is not practical. Hence, when making a commitment to HAZOP an existing facility, management must be willing to allocate resources necessary to prepare and/or update the necessary drawings and documents, if needed.

To minimize the duration of a study on an existing plant and to avoid redundancy, care is required at the study definition phase. The study team may generate numerous recommendations, some of which may involve significant capital expenditure. A well defined scope and objectives for each HAZOP study helps to ensure that the study results will be acceptable to all parties concerned. The general objectives for a study are normally set by the individual responsible for the project or for the plant (e.g. project manager, project engineer or plant manager). Assistance in defining the scope and objectives is usually provided by the study team leader.

It is also important to be clear as to who will be responsible for pursuing each action item which results from the study. An effective follow-up system should be implemented.

3.5 STUDIES PRIOR TO PLANT MODIFICATIONS

To remain competitive in today's petroleum industry, a processing facility must remain dynamic. To accomplish this, plant modifications from time to time are essential. These modifications may entail simple additions of vessels or pumps, changes in venting schemes to reduce pollution potentials, or process changes to improve yields, conserve energy or reduce costs.

Although the benefit and use of the HAZOP technique is growing at a rapid pace, many facilities still consider this method inappropriate for all but "major" plant modifications. While it would be difficult, and not very cost effective, to convene a HAZOP meeting for every proposed change, it should be noted that many accidents in the petroleum industry have occurred because "small" modifications had unforeseen consequences. The following incidents exemplify this concern:

- To treat a solvent which was found to be out-of-spec due to high acidity, the solvent stream was routed through a small neutralizer filled with flake caustic soda. A stabilizer in the solvent formed a detonatable material which caused the neutralizer to explode, leaving a hole 3 feet deep and 7 feet in diameter.
- A new filter was installed in a liquid chlorine line at a chemical facility. As the equipment was placed back on-line, a fire occurred at the filter due to spontaneous reaction between tin in the filter and the liquid chlorine stream.

To manage plant modifications, it is extremely important to have a mechanism in place such that all proposed changes (hardware or procedural) are adequately evaluated. This mechanism should include a "focal point" where an experienced individual, usually in the maintenance planning group, is required to review each proposed change and, through the use of past experience and checklists, to determine the necessary level of engineering review. If the changes are sufficiently complex to warrant a HAZOP study, the "control of modifications" system should be structured such that the actual field changes cannot commence until plant management confirms that the study has been completed and all appropriate recommendations have been implemented.

3.6 STUDIES PRIOR TO T & I

When a plant or process unit is scheduled to undergo a T & I, it is essential that a thorough hazard analysis be conducted prior to the unit shutdown. A detailed hazard analysis, such as a HAZOP study, will aid in the identification of potential hazards which may not typically be present during normal plant operation.

Although many companies have “preparing for maintenance” procedures in place and utilize check lists for isolating equipment and minimizing personnel exposures, these “tools” may not be sufficient, particularly with large and/or complex process units.

There are two main objectives of a HAZOP study conducted on an existing plant or process unit just before a major overhaul. These are:

- to aid in the identification of new/unforeseen hazards (e.g., freezing of stagnant lines, flammable atmospheres in idle vessels and towers, etc.)
- to aid in the preparation for maintenance, particularly if adjacent process equipment is to remain in service (e.g., equipment isolation)

Since the operating conditions assumed in such a review frequently involve “no flow”, “ambient temperature”, “atmospheric pressure”, etc., the study can usually be completed in a relatively short period of time. However, care should be taken to ensure that all new “node intentions” are properly defined. For example, the normal design intention of a distillation column may be to maintain a certain overhead pressure and column temperature gradient such that the tower operates with a non-flammable (i.e., over rich) atmosphere. Depending on the required maintenance activity, the new “pressure intention” may be to sustain an inert (e.g., nitrogen) purge or blanket in the tower.

Once the plant is shutdown and the majority of process alarms/safeguards placed on by-pass, a much greater dependence is placed on operator surveillance. This necessitates a general understanding and acceptance by the study group of the current level of operator experience in the plant/unit and the adequacy of operator training programs and operating procedures during a T & I.

As with a study involving a new capital project, the HAZOP examination is accomplished via a multi-disciplinary team in a series of “brainstorming” sessions. Each of the guide words is applied to the appropriate design intention and corresponding deviations/hazards are evaluated.

Although a HAZOP on an idle plant or unit is generally easier than a study under normal operating conditions, the environment during a T & I usually requires a greater level of creative thinking.

3.7 STUDIES ON RESEARCH FACILITIES/LABORATORIES

Considering the frequent use of new chemicals and hazardous reactions in Research and Development (R&D) facilities, laboratory personnel and expensive analytical hardware are exposed to a hazardous environment.

To evaluate these hazards, which in a typical R&D facility are changing constantly, various hazard examination techniques need to be employed. These techniques range from a simple flammability analysis of a new or unfamiliar material to a detailed HAZOP study. The decision of which hazard analysis method to use depends on the amount of information already available regarding a new chemical and/or reaction and on the complexity of the particular operation.

In the laboratory environment, a HAZOP study is best suited for more permanent and large scale applications such as bulk systems supplying toxic and/or flammable gases and liquids (e.g., hydrogen sulfide, hydrogen, gasoline, solvents, etc.). The inventories of these systems and the routing of the supply piping within the laboratory building (i.e., through utility corridors) generally warrant a more detailed hazard review.

On the other hand, to perform a HAZOP study on each operation carried out in a hood or on a laboratory bench would not only be impractical and unnecessary, but would also be cost prohibitive. These type of operations are better analyzed utilizing a variety of screening methods (e.g., flammability, reactivity and shock sensitivity analyses) and thermochemical techniques (e.g., differential thermal analysis, differential scanning calorimetry, accelerating rate calorimetry, adiabatic studies, etc.). Periodic site safety inspections are also required to supplement these analytical reviews.

If a reaction is to be scaled up from the laboratory bench to a pilot plant operation, it is imperative that additional hazard analyses, including HAZOP reviews, first be conducted. Because of the relatively large inventories, the use of multi-purpose equipment and the possibility of unanticipated reaction runaways and/or side reactions, pilot plants present unique hazards which must be thoroughly examined.

4.0
HAZOP Studies in Saudi Aramco

4.1 INITIATION OF HAZOP STUDIES

Existing Facilities

For existing plants HAZOPs can be indicated as the result of a compliance review, an insurance survey recommendation, or by local plant management request. If the department is unfamiliar with the HAZOP technique, proponent management may contact the Loss Prevention Department to request an explanation of the HAZOP technique and to explain what portion of the facility they wish to have studied. At the meeting Loss Prevention can provide a brief explanation of the HAZOP procedure and also describe the manpower support and resources that will be required from the plant and other departments.

After the initial meeting if plant management wishes to proceed with the study, they should develop a formal letter requesting Loss Prevention assistance in supporting the study. While every effort will be made to assist, Loss Prevention may not always be able to provide team leaders or to provide assistance in the required time frame. Accordingly, departments may need to consider utilization of contractor personnel for time critical projects, or development of their own personnel in the HAZOP procedure.

After gaining experience with the HAZOP technique, departments may decide to initiate and conduct HAZOP studies internally. In such cases, it is recommended that the guidelines in this manual be utilized, and in particular, the team leader role is filled by a person with appropriate qualifications as discussed in section 2.0.

New Projects

For new or upgrade projects involving the production, processing, transportation, or storage of flammable, explosive or toxic substances, it is recommended that preliminary hazard analyses (PHAs) be conducted to assess “large scale” hazards in each project. When PHAs are complete a decision can then be made to conduct HAZOP studies where appropriate. This decision should be made jointly by Project Management and Loss Prevention in conjunction with input from proponent organizations and other appropriate technical organizations such as Process & Control Systems Department and Consulting Services Department.

Typically, both PHAs and HAZOPs for new projects should be part of the project scope, with appropriate provisions made for timely completion and funding. Project Management may consider in-house sources of expertise, where available, however it may be necessary to utilize contractor personnel to lead and conduct such efforts. Loss Prevention will support such studies with available resources.

Where required, Loss Prevention can arrange to provide Project Management departments with a brief explanation of the HAZOP technique and describe the support that is required for HAZOP studies.

4.2 TRAINING

Training can be divided into three sections:

- Team Leader
- Scribe (Secretary)
- Team Members

Team Leader

The team leader should have received training in the HAZOP technique and team leadership prior to conducting a HAZOP study. This is due to the critical role that the team leader plays in the HAZOP study.

The team leader helps with the selection and training of the team and advises on the assembly of the necessary data. The most important aspect of the team leader's role emerges during the working sessions when he guides the systematic questioning process and must draw on his experience and training for this job. The study leader should not be responsible for making a major technical contribution; he does not need to have detailed knowledge of the design and operation of the unit being studied. His role and his training should be focused on his knowledge of the HAZOP technique to control the team discussion and prepare reports at the end of the study.

Team leader's training consists of a number of aspects. The first is formal class room training. This would typically be an intense multi-day seminar that provides instruction in the basis of the HAZOP technique as well as simulated working sessions. The simulation provides an opportunity for the team leader to experience the efficient application of the HAZOP technique. It also demonstrates the challenges involved with managing group dynamics in a technical environment. Appreciation of the scribe’s role in the overall effort is also part of this class room exercise.

Either following or in conjunction with class room training, instruction is provided in how to most effectively utilize the HAZOP software programs. This includes software as well as hardware requirements. The team leader will need to be familiar with the program and it’s required support. Experience has shown that if a problem develops when computer support is unavailable such as in a remote area, the team leader will need to be equipped to handle such issues.

Scribe

The scribe should be someone who has good typing skills, and is relatively computer literate, and has a good command of the English language. If possible, practice with the scribe by performing a short HAZOP simulation. If the scribe does not posses the necessary attributes, then discuss with management the possibility of getting a new scribe. This is important since a scribe who does not know how to use the program and/or computer can seriously detract from the study.

Where scribes generally are fluent in the team’s language, it is recommended that the team leader spend a day with the scribe in a training mode. However, if conditions are unfavorable or a suitable scribe is not available it may be advisable for the team leader to scribe himself. Thus, knowledge of the program can be a critical factor in the HAZOP study progress and ultimate timely completion. This can be especially true if the team leader has brought his own computer and is familiar with that particular keyboard. If the scribe is to use a computer keyboard that is unfamiliar then ample time must be available for the scribe to become familiar with the new equipment.

There has to be a balance between the team leader's supervisory role of the HAZOP team versus the additional responsibility or distraction in record keeping. If the scribe has inadequate computer or typing skills or does not understand the language very well, the team leader may spend as much time directing the scribe as he would if he had scribed himself. If scribe problems develop, the team leader must either make alternate arrangements or scribe for himself.

Team Members

Training for these individuals is basically provided by the team leader. This training includes review of distributed material prior to the HAZOP orientation session. Experience has shown that in some cases team members do not have sufficient time to review this material in advance and the orientation session is their first exposure to the HAZOP process. Also, the first few study sessions are effectively training sessions as the team comes up on the learning curve with the HAZOP technique. The team members basically 'learn by doing".

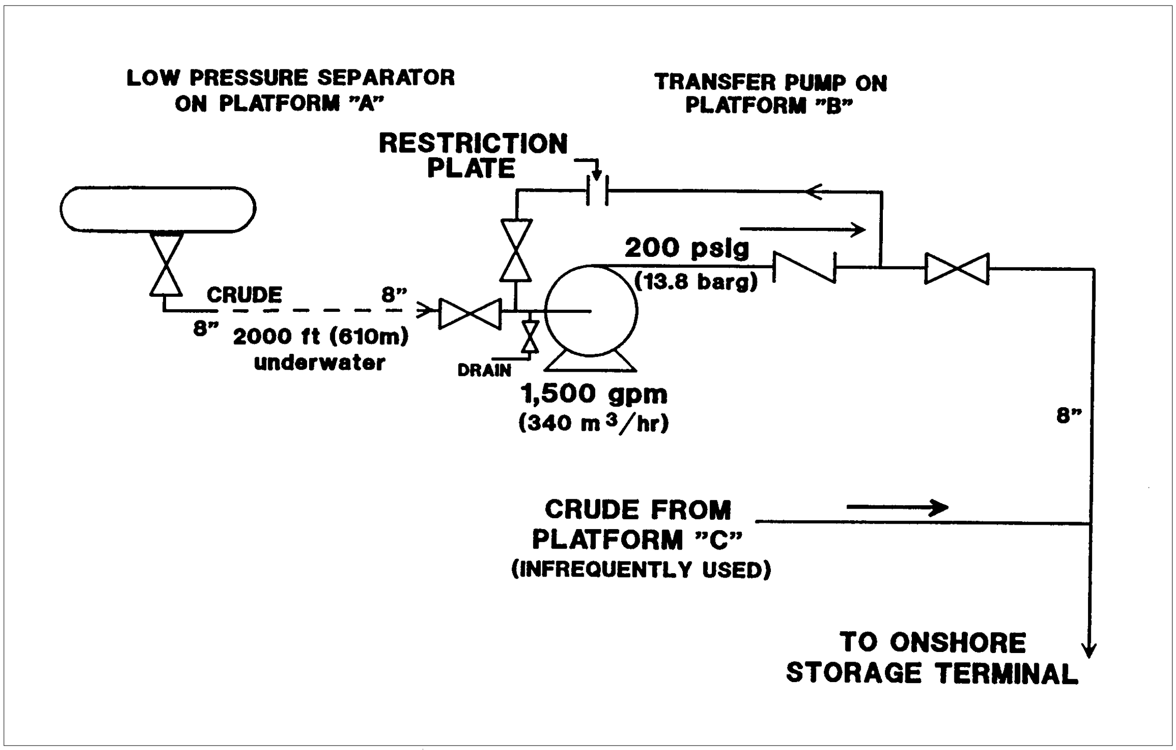
5.0

Examples of HAZOP Studies

5.1 APPLICATION TO A CONTINUOUS PLANT

Since the development of the HAZOP study method, the technique has been applied most frequently to continuous processes.

To illustrate the use of the technique on a continuous operation, consider the following example in which crude oil is transferred from the low pressure separator on Platform “A” to a transfer pump on Platform “B”. From Platform “B”, the oil is sent to an onshore storage terminal through approximately 5,000 ft. (1,525 m) of 8 inch pipe.



The node to be analyzed is defined as the crude line from the low pressure separator to the battery limits of the onshore terminal. As discussed earlier, the study proceeds with the application of the guide words to the design intention in order to identify credible deviations.

A summary of the HAZOP study results of this operation could be as follows:

Deviation:	No or Less Flow
Causes:	Pump malfunction; partially/completely closed valve; loss of level in LP Separator
Consequences:	Reduced throughput; pump cavitation and possible damage
Recommendations:	Evaluate need for an on-line spare pump and automatic level control on the LP Separator

Deviation:	More Flow
Causes:	Pump on Platform "C" is turned on
Consequences:	Unexpected increased flow at on-shore terminal, possibly resulting in a tank overflow
Recommendations:	Evaluate need for high level tank alarms at the terminal and re-evaluate procedures for bringing Platform "C" on line

Deviation:	Reverse Flow
Causes:	Platform "B" pump failure while Platform "C" is in service
Consequences:	Reverse flow through kick-back line to LP Separator
Recommendations:	Relocate check valve on the discharge side of the Platform "B" pump downstream of the kick-back line. Also, further evaluate the consequences on Platform "A".

Deviation:	As Well As Flow
Causes:	Leaking or inadvertently opened valve in crude line from Platform “C”
Consequences:	Crude flow to Platform “C”
Recommendations:	Evaluate need for a check valve in line from Platform “C” near tie-in to 8" line

Deviation:	Part of Flow
Causes:	Leaking or opened drain line valve near Platform “B” pump
Consequences:	Fire and/or environmental impact
Recommendations:	Equip drain line with a “bull” plug or provide an additional block valve

Deviation:	More Corrosion
Causes:	High H_2S concentration in crude
Consequences:	Line leakage or failure
Recommendations:	Determine maximum anticipated H_2S concentrations, ensure proper materials of construction will be utilized, evaluate need for a remote operated valve on LP Separator liquid outlet line and initiate a consequence analysis to further define the environmental impact

Deviation:	More Pressure
Causes:	Isolation valve fails
Consequences:	Possible system pressure exceeding equipment design ratings
Recommendations:	Lock/car-seal open isolation valve in kick-back line; ensure piping/flange ratings are adequate for worst case condition

Deviation:	Less Temperature
Causes:	Low ambient temperature
Consequences:	Freezing of water in dead legs (e.g., drain line)
Recommendations:	Insulate/heat trace all dead legs

5.2 APPLICATION TO A BATCH PLANT

The main differences between continuous and batch operations which significantly effect how a HAZOP study should be accomplished are:

- The operators in a batch plant often are physically involved in some of the process activities, such as charging bags of a dry raw material to a reactor.
- The various components of a batch operation frequently operate independently of each other and in a cyclic manner. Consequently, a line diagram alone gives a very incomplete picture.
- A batch plant often produces a variety of similar products in multi-purpose equipment, which typically results in a large number of inter-connections (active and idle) between system components.

The preparative work associated with a batch plant HAZOP is usually more extensive than with a continuous plant. In addition to drawings which describe the plant itself, it is necessary to know the sequence of plant operations. This can be in a variety of forms including, “recipe” cards or running instructions, logic diagrams and instrument sequence charts. With some complex batch operations, it may also be necessary to prepare a display indicating the status of each vessel on a time basis.

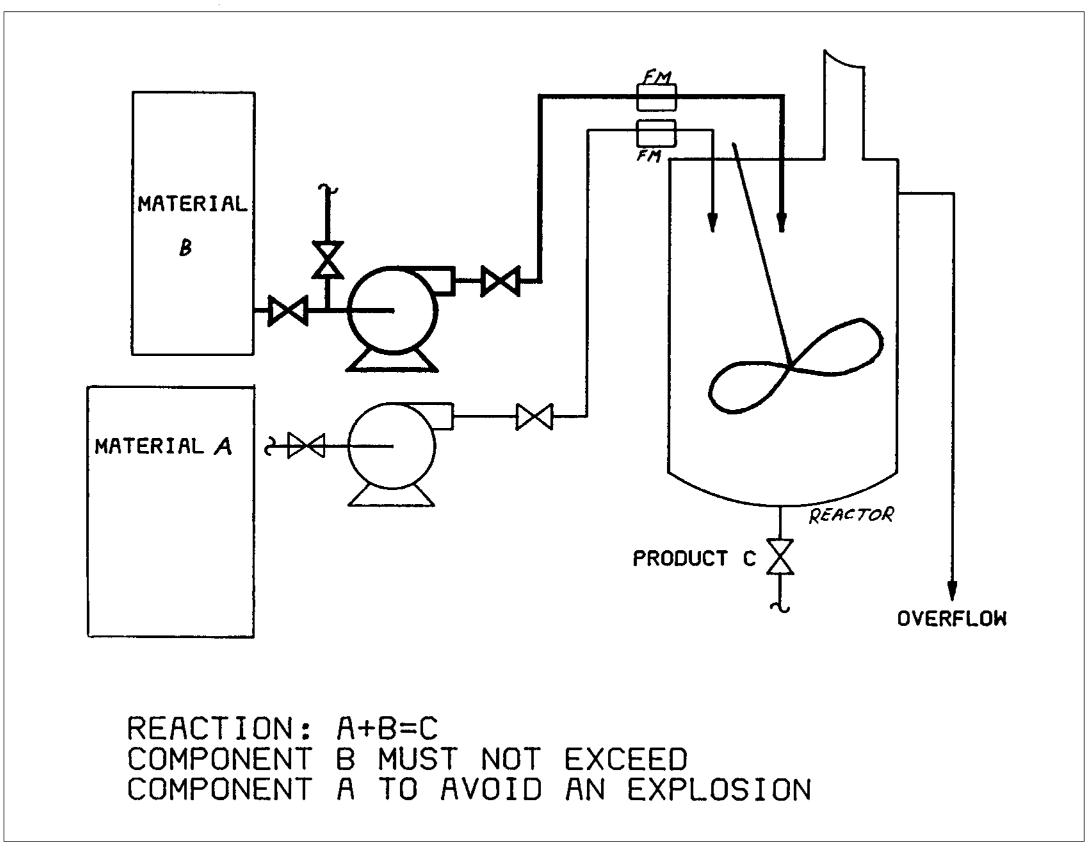
At a minimum, the following information should be available prior to the HAZOP study:

- Up to date running instructions depicting the state of various equipment items at each operating step (e.g., valve “A” open, agitator on, etc.)
- All interlocks designed to operate during each step must be known (particularly if P&IDs are not available)
- All conditions which must be satisfied before moving to the next operating step need to be known (e.g., reaction or retention time, temperature set point, etc.)

In studying a batch plant, the seven generally used HAZOP guide words mentioned in earlier sections must be applied to the instructions (whether written or on a computer display) as well as to specific equipment items (i.e., mix tank, feed lines, batch reactor, centrifuge, dryer, etc.).

To illustrate the application of the HAZOP technique to a batch operation, consider a simple process in which chemicals “A” and “B” are manually charged to a vessel where they react to form product “C”. Further, assume that previous industry experience reveals that the chemistry of the process is such that the concentration of raw material “B” must never exceed that of “A”, otherwise an explosion may occur.

For the purposes of this example, let us also assume that various preparation steps (e.g., purging, activating cooling systems, etc.) and the addition of raw material “A” have already been completed. Utilizing the operating instructions for manufacturing product “C” and the P&ID shown below, the next step in the “recipe” calls for the addition of 500 gallons of raw material “B” to the reactor via a pre-set meter.



To help provide insight as to exactly how this instruction would be carried out, a member of the team is asked to further define the intention. The first deviation, which is derived from the guide word MORE, is evaluated against the operating instructions and the P&ID to establish causes which might produce a greater flow of material "B" to the reactor. The causes established by the team might include:

- The operator erroneously sets the meter in the transfer line
- The meter malfunctions during the transfer and fails to shut-off

The most obvious consequence of these credible causes would be an excessive concentration of "B" over "A" in the reaction vessel, which could lead to an explosion. The results of the study are documented along with appropriate recommendations and the study continues.

In a similar fashion, the study team would apply the remaining guide words to the current operating instruction and evaluate the corresponding causes and consequences, such as:

- The operator fails to charge any "B"
- Less than 500 gallons of "B" is charged
- Another material is charged in addition to (as well as) "B", or "B" is charged to another reactor in addition to the correct vessel
- Only part of "B" is charged (if "B" is a mixture)
- Something other than "B" is charged
- Reverse flow occurs between the "B" supply tank and the reactor

The study leader would then mark that particular operating step as having been examined and the study would continue with the next instruction. Once all operating instructions associated with that particular section of the process have been analyzed, the guide words would then be applied to the specific equipment items. For example, in studying the reactor, the consequences of NO or LESS agitation would be evaluated.

5.3 APPLICATION TO A PROPRIETARY ITEM OF EQUIPMENT

In many HAZOP studies, particularly at the "design freeze" stage, specific equipment items may only be reviewed insofar as they impact the unit as a whole. For example, equipment such as compressors, heaters, dryers and centrifuges will most likely be treated as sources of more or less pressure, flow, temperature, drying, separation, etc. A detailed analysis of each piece of equipment, (e.g., compressor lube oil, seal oil and shutdown systems), cannot often be accomplished due to the lack of vender specifications/drawings or if equipment design specifications have not yet been finalized.

Once the specific equipment design details become available, a HAZOP review of the hardware and associated operator interactions should be performed. Generally, if multiple pieces of identical equipment (in similar service) or employed in a process, only one rigorous HAZOP is required. These studies should be accomplished before or during the pre-start up stage.

In many cases, a technical representative from the equipment vender will be asked to act as a part-time team member, particularly, if the equipment is of a unique and/or propriety design. The team leader should ensure that deviations identified during the study are evaluated not only as they impact the particular equipment under review, but also as to their effects on the overall unit/plant.

The following example depicts how the HAZOP technique is applied to a proprietary item of equipment.

In a recent HAZOP study of a naphtha reformer process unit, the gas fired reactor charge heater was defined by the study team as part of the node feeding the reactors and was analyzed only as far as its effect (e.g., temperature, pressure, flow, etc.) on the main process stream. Since sufficient details regarding the furnace combustion controls were not available at the time of the study, the furnace itself was examined in a subsequent HAZOP review. Also, since the designs of the reformer reactor charge heater and the pre-treater reactor charge heater were exactly the same, only the “representative” furnace was reviewed in the HAZOP study.

The results of the first node analyzed, which is defined as the main burner line from the knock-out pot to the furnace fire-box, are summarized below:

Deviation:	No or Less Flow
Causes:	Plugging of filter MM-8502
Consequences:	Possible loss of burner flames and accumulation of unburned fuel gas in heater fire-box, which could eventually lead to an explosion
Recommendations:	Provide a PDI with PDAH across filter MM-8502 and arrange to alarm in the control room

Deviation:	No or Less Flow
Causes:	Failure of vent valve XV-050 (fails open)
Consequences:	Release of fuel gas to atmosphere with possible ignition
Recommendations:	Provide a valve position switch with discrepancy alarm on valve XV-050

Deviation: More Flow

Causes: Inadvertent opening of the rotating disc valve in the bypass line around PV-019 or malfunction of PIC-019

Consequences: Possible burner flame-out resulting in unburned gas admission into fire-box with subsequent explosion

Recommendations:

A. Review heater design and ensure that burner flame-out cannot occur at high pressure

B. Provide a PAH on PIC-019 and arrange to alarm in the control room

C. Ensure new operating procedures address appropriate operator response to a high pressure condition when all burners are <u>not</u> in operation

Deviation: As Well As Flow

Causes: Failure to drain knock-out pot D-8533 causing hydrocarbon liquid to carry-over to the main and pilot fuel gas lines

Consequences: Uncontrolled burning in the heater fire-box possibly resulting in equipment damage and down-time

Recommendations: Provide heat tracing on the fuel gas piping from the upstream side of KO pot D-8533 to the burners, or provide a level switch with LAH on D-8533

Deviation:	Higher Pressure
Causes:	Malfunction of upstream pressure controller
Consequences:	Possible equipment overpressure and damage
Recommendations:	Provide a pressure safety valve tied into the flare header on fuel gas mix drum D-8530

Excerpts of the HAZOP results for the pilot burner line are as follows:

Deviation:	No or Less Flow
Causes:	Failure of PCV-014 (fails closed)
Consequences:	Introduction of unburned gas into the combustion chamber during main burner lite-off, possibly resulting in a flame deflagration and heater damage
Recommendations:	Ensure set points of PAL and PALL on PT-016 are high enough to maintain combustible mixtures with all pilot burner valves open

Deviation:	Less Maintenance
Causes:	Inability to isolate the pilot gas line for preventive maintenance
Consequences:	Possible equipment failure
Recommendations:	Provide a ball valve in pilot fuel gas line FG85003-1.5"

Deviation: Less Safety

Causes: Inadequate combustion chamber purging prior to pilot lite-off

Consequences: Possible flame deflagration and heater damage

Recommendations:

A. Provide a damper position switch permissive interlock to ensure that the damper is fully open and that the purge timer is satisfied prior to the opening of XV-051 and XV-052

B. Evaluate the need for snuffing steam to provide adequate draft for purging. If steam is required, evaluate the need for a steam permissive interlock

5.4 APPLICATION TO OPERATING PROCEDURES

Start-up/Shutdown Procedures

The standard HAZOP technique may be used for analysis of stepwise procedures (startup, shutdown, emergency, batch, etc.) with relatively minor modifications. Normal operating procedures, however, are best treated as part of the P&ID HAZOP and are reviewed separately.

Nodes should be selected to represent the largest group of actions for which a single clear intention can be defined (e.g. “start the Acid Rerun System”). The study would then proceed as follows:

- Parameter : Step
- Guide Word : No
- Deviation : No Step (i.e., step is omitted)
- Causes
  - — Is the intention of the node unmistakable?
  - — Are all of the actions required stated in the procedure?
  - — Are the actions sufficiently explicit to ensure that all operators will execute them properly?
  - — Are checklists and other external documents complete and are they referenced as needed?
- Consequences: e.g. Loss of Containment
- Safeguards: e.g. Procedures & Training
- Recommendations may be general (e.g. Provide detailed procedures and checklists) or may list specific procedure changes.

The main steps in HAZOPing the start up/shutdown procedures are:

- ❑ List each action required to complete the step as a separate cause.
- ❑ Review the consequences if each action is not done, is done improperly, or is done out of order.
- ❑ Review safeguards (note disabled alarms and interlocks).
- ❑ Recommend appropriate warnings, procedure changes, or equipment modifications to help ensure that the action is done properly.

The following example demonstrates how the HAZOP technique is applied to the start-up procedures for a typical distillation column:

Deviation:	No Step
Causes:	Incomplete or inexplicit procedure
Consequences:	Possible hydrocarbon release
Recommendations:	Consider providing a detailed checklist and initials for all steps

Deviation:	No Step
Causes:	Batchwise steps not referenced
Consequences:	Possible pump damage and vessel overfill
Recommendations:	Consider providing an introductory step describing batch requirements and parallel operations (Note: start-up is essentially batchwise on each major unit and major units may be started-up in parallel)

Deviation:	No Step
Causes:	Reflux pump self-flush not lined up
Consequences:	Pump damage and possible hydrocarbon release
Recommendations:	Add a statement requiring the reflux pump self-flush to be lined up

Deviation:	Less Step
Causes:	Heat input to column not increased as needed
Consequences:	High level resulting in column flooding and aborted start-up
Recommendations:	Clarify procedure by referencing “steam flow” rather than “heat input”

Normal Operating Procedures

The basic steps involved in HAZOPing the normal operating procedures are:

- Identify the major hazards associated with the procedure.
- Describe the steps of a model or ideal procedure.
- Evaluate the existing procedure (if there is one) to determine whether it accommodates the hazards that were identified and listed, and if it follows the model.

The first step in reviewing a procedure, or “software” element, is to identify the major hazards associated with the process. These items will have been identified during the HAZOP of the “hardware” if a process HAZOP was previously done.

It is best to list the hazards associated with the process. This helps ensure the hazards are avoided when reviewing the procedures.

In addition to the obvious physical and chemical hazards, recognize that there may be ergonomic hazards. In other words, incompatibilities between what the procedure says to do and what the body can actually do.

The hazards may be those inherent in performing the procedure or hazards associated with the process that the procedure must avoid. For example, in using a torch to light off a furnace, an example of a physical hazard may be the potential for spilling and igniting the flammable liquid used to light the torch. An example of a chemical hazard might be the burning of a toxic waste material in the furnace. And an ergonomic hazard may be the improper positioning of the torch hole that requires the employee to get into an unsafe position to perform his duties.

The next step will be to list the major steps that would be required in the actual procedure. There may be decision criteria, such as minimums and maximums, that the employee should know and act upon in order to accomplish the tasks without an accident. These may be time, repetitions, pressure, temperature, etc. And this may be further complicated by an exact order in which the steps must be taken, such as in the case of certain regeneration processes. The model procedure must also be specific as to who will perform the steps and how they will be performed. The intent at this point in the procedure review process is not to write a procedure, but to quickly highlight those items the procedure should include, as well as any criteria or important variables.

The next step is to determine whether the actual procedure compensates for the hazards identified and how well the existing procedure compares with the ideal procedure that the team has prepared. If there are deficiencies in the existing procedure, they should be highlighted and corrected.

The following is an example of how the HAZOP technique can be used to evaluate existing normal operating procedures:

Deviation:	No Step
Causes:	Poor organization of procedure for chemical injection in overhead system
Consequences:	Possible confusion resulting in insufficient chemical addition and rapid downstream heat exchanger fouling
Recommendations:	Consider eliminating step 4 and incorporating information into steps 3, 45-47

Deviation:	Other Than Step
Causes:	Incomplete or inexplicit procedure
Consequences:	Possible HF acid or hydrocarbon release
Recommendations:	Consider adding operating condition targets to individual steps

Deviation:	Less step
Causes:	Depropanizer bottoms temperature not properly adjusted
Consequences:	Process upset and possible isostripper overpressure due to increased light ends concentration
Recommendations:	Add a warning note to the procedures regarding possible consequences to the isostripper due to low depropanizer bottoms temperature

Deviation:	More step
Causes:	Acid storage drum pressure increased above 140 psig
Consequences:	Possible HF release to ARN
Recommendations:	Add a high pressure alarm to the acid storage drum and arrange to alarm in the control room

Deviation:	As Well As step
Causes:	Normal butane storage tank lined up too early
Consequences:	Product contamination and process upset
Recommendations:	Clarify switching procedure and include specific time to make switch from isobutane to normal butane storage

Although the guide words used for the hardware review do not necessarily fit well when reviewing procedures, similar guide words may be helpful as a double check to insure the comprehensiveness of the review. A set of guide words, helpful in reviewing procedures is given in the table on the following page.

Guide Words for Procedure Reviews

Guide Word	Meaning
NO	Doesn’t perform the step. A step or important criteria, in the procedure is skipped.
LESS	Does less than is specified or required quantitative decrease (e.g., purges a vessel for 5 minutes when the procedure calls for 10 minutes)
MORE	Does more than is specified or required quantitative increase (e.g., opens a valve fully, when the procedure calls for “cracking” the valve)
PART OF	Performs part of the step (qualitative decrease (e.g., closes only one block valve when the procedure says to close a double block and open a bleed)
AS WELL AS	Does more than is specified (qualitative increase (e.g., opens the transfer valves to a number of tanks when only one is to be filled)
REVERSE	Does the opposite of what is specified (e.g., opens a valve when the procedure says that it is to be closed)
OTHER THAN	Complete substitution (e.g., opens valve A when the procedure says to open valve B)
HOW	How is the step to be accomplished? Are adequate facilities provided to allow the operator to perform the step as specified?
CHECK	How can it be checked, or verified that the step has been properly accomplished?
ORDER	Are the order of steps important and correct?
WHO	Is it clearly obvious, or stated, who is to perform each part of the procedure?
WHY	Why temperature set point is 300 °F?