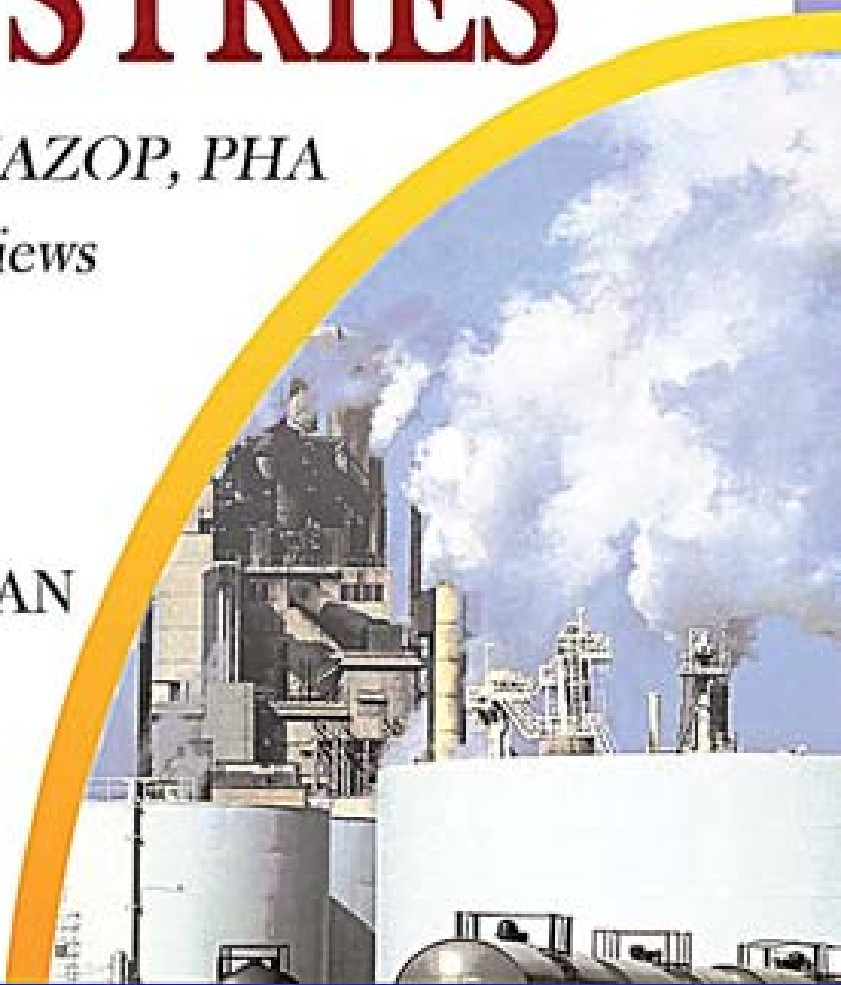
SAFETY AND SECURITY REVIEW FOR THE PROCESS INDUSTRIES

Application of HAZOP, PHA and What-If Reviews

2nd Edition

DENNIS P. NOLAN



William Andrew

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William Andrew
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Preface

This book is intended as a typical guideline and reference for application at industrial facilities and commercial processes and systems. It is suggested that it be used as a practical reference to prepare the safety review requirements for a process safety or security management system. The first edition of this book was entitled *Application of HAZOP and What-If Safety Reviews to the Petroleum, Petrochemical and Chemical Industries* and was issued in 1994. Since that time, the use of Process Hazard Analyses (PHAs) has become more prevalent and the threat to industrial and commercial facilities from security incidents has also become more relevant. Numerous other industrial and trade organizations have also since published similar guidance documents for PHAs and Security Vulnerability Analyses. It was therefore felt prudent to update the first edition to include these aspects and also incorporate additional technical updates and features. I have been involved in numerous safety and security reviews previous to and after writing this book, and have captured many hints and shortcuts to improve upon the formal classical method of these reviews and to improve their scope, economics, and timing. These aspects are vitally important for the management of major project designs and existing facilities. The outcome of these studies also reduces the potential incidents from existing unknown hazards or security threats.

Acknowledgments: Figure 8.1, provided by Issam Karkoutli of INOVx Solutions, EAM Plant Solutions, Irvine, California, is reprinted with permission. Figures 9.1–9.4, provided by Steve Metzler of Primatech, Inc., Columbus, Ohio, are reprinted with permission.

Dennis P. Nolan
Abqaiq, Saudi Arabia
March 2008

1 Purpose

This publication is intended to provide guidance for qualitative hazard analyses conducted for industrial and commercial processes, specifically for Preliminary Hazard Analysis (PHA), What-If, and Hazard and Operability (HAZOP) review teams. It also highlights how the methodology and procedures used for these reviews can be adopted and applied to Security Vulnerability Analysis (SVA). This book describes the nature, responsibilities, methods, and documentation required for the performance of such reviews. This ensures that these reviews are conducted in a timely, effective, objective, and consistent manner as may be prescribed by a company's Process Safety Management (PSM) policy and security requirements. This book relies heavily on the common practices in the petroleum, chemical, and petrochemical industries since most of the major hazardous processes are located in these industries and these facilities are increasingly becoming a potential target for security incidents.

The safety and security of process facilities are an important part of a company's operations. Worldwide petrochemical safety regulations, international security threats, and a company's own PSM policies would require that a

hazard identification, process safety, and security analysis review of its existing and proposed operations be accomplished.

The limits for hazardous substances cited by both the U.S. Occupational Safety and Health Administration (OSHA) and the Environmental Protection Agency (EPA) regulations dictate the application of PSM elements at almost all of a petroleum or chemical company's facilities. These reviews are intended to reduce the probability and/or consequences of a major incident that would have a detrimental impact on the employees, the public's well-being, onsite or offsite properties, the environment, and most importantly on a company itself and its continued business operation and survival. It should also be noted that there may be a general adverse public reaction as a result of which a company's prestige may suffer. Hazard identification and process analysis reviews are not intended to identify the minor "slips, trips, or falls"; these are the responsibility of the company's general safety requirements that are well established and can be analyzed with other tools (e.g., Job Safety Analysis (JSA)).

In March 2003, the United States implemented Operation Liberty Shield to increase the readiness and security in the United States primarily due to international threats from non-government affiliated, self-motivated political and religious groups. One objective of this operation is to implement comprehensive process security management programs into existing OSHA, EPA, and FDA laws to address deliberate acts or threats of terrorism, sabotage, and vandalism. In April 2007, the Department of Homeland Security (DHS) issued the Chemical Facility Anti-Terrorism Standard (CFATS). DHS is to identify, assess, and ensure effective security at high-risk chemical facilities. Included in this standard is the requirement for facilities handling chemicals above a threshold amount to submit a SVA for DHS review and approval along with a site security plan (SSP). A potential fine of $25,000/day, an inspection and audit by DHS, or an order to cease operations is stated for non-compliance. The type and amount of chemicals handled that require submission of screening reviews and SVA submittals have been listed on the DHS website. Additionally, internal company security procedures, although confidential, would also require that an adequate security review be undertaken to identify and assess such risks. Since the methodology of conducting process security reviews are similar to existing process hazard analysis reviews, they can be adapted to fit within the parameters of existing procedures established for these analyses. Both the American Petroleum Institute (API) and the American Institute of Chemical Engineers (AIChE) have also issued their own guidelines to assist

companies undertaking process security reviews. A major process safety consultant recently stated that statistics show that the use of outside security experts for protective services consultations has increased by 200% in the last five years. This was due to escalating concerns over workplace and domestic violence, privacy and security practices, and terrorist threats. Process security reviews are not intended to identify minor thefts or mishaps as these are the responsibility of the company's general security requirements that are well established and can be examined with other financial auditing tools.

The purpose of the evaluations described in this book is to identify the major risks facing industry, which have the potential for severe impacts. It identifies simple processes and procedures to apply these reviews in an easy and practical manner.

PHA, What-If, and HAZOP reviews are the most common industrial qualitative methods used to conduct process hazard analyses, while SVAs are typically applied for process security analyses. It is qualitatively estimated that up to 80% of a company's hazard identification and process safety analyses may consist of PHA, What-If, and HAZOP reviews, with the remaining 20% comprising checklists, fault tree analysis, event tree analysis, failure mode and effects analysis, etc.

An experienced review team can use the analyses described above to generate possible deviations from design, construction, modification, and operating intent or from deliberate actions that define potential consequences. These consequences can then be prevented or mitigated by the application of the appropriate safeguards.

The reader is reminded that a PHA, What-If, HAZOP, or SVA report is a living document for a facility. As changes are made to a facility or its procedures, the applicable review should be updated to represent the current facility. Process hazard analysis reviews are also required to be updated and revalidated every five years as a minimum by U.S. regulations (OSHA and EPA). Also, since the terrorists' agenda has not subsided, threat assessment/vulnerability analysis needs to be continually re-evaluated.

A completed review report can be used to demonstrate to interested parties that a prudent analysis has been accomplished and all possible actions have been examined and/or implemented to eliminate major hazards or minimize the threat. It has been noted that the Chemical Safety and Hazard

Investigation Board (CSB) routinely examines hazard analyses that have been performed on processes that they are reviewing to ensure that the analyses were performed adequately.

This document can also be referred to by review team members. It will serve as a reminder of their duties and responsibilities in the performance of the required reviews and report development.

2 Scope

These guidelines should be considered for all of a company's facilities, domestic and international. They are intended to be applied at both permanent and temporary facilities, whether located onshore or offshore.

The typical review is usually intended to be a formal audit review of an "essentially" complete project design or modification, to ensure that the probabilities or consequences of major incidents have been eliminated or reduced to acceptable levels prior to being placed in service. Risk analyses should be continually conducted as a part of the project design to avoid the identification of major concerns in later reviews. In fact, documentation from a design risk analysis should supplement the formal PHA, What-If, HAZOP, or SVA review. Process safety and security reviews are not intended to replace or duplicate a project design review. Unusually complex or large projects may require several levels of a safety or security review during their design phase. These may be initiated at the conceptual design stage, preliminary design, detailed design, and at the final design. Such levels are usually encountered in multi-million dollar offshore facilities, refineries, or chemical processing plant projects, where major changes occurring later in the design would be severe in economic and schedule terms. These multi-level reviews start at a broad viewpoint and gradually narrow down to specifics just as the project design proceeds. Where operating procedures are not available during the design, a supplemental PHA, What-If, HAZOP, or SVA review may be considered for these documents. In fact, an initial review may recommend that subsequent final designs be evaluated again by a PHA, What-If, HAZOP, or SVA review as a follow-up. It is essential that these follow-up reviews should be completed, as incidents investigated by the CSB have identified the failure to perform a follow-up risk analysis as a contributing factor in some incidents.

During the period of initial implementation of process safety and security management policies, existing facilities may also be the subject of PHA, What-If, HAZOP, or SVA reviews.

Typically, most reviews will be concentrated toward processes that have the potential for major incidents (i.e., hydrocarbon or chemical processing equipment and operations). It should be remembered that where there are utility systems that could pose severe consequences to individuals or

the company (e.g., toxic vapor releases, exposed high voltage electrical components), a review of their system or components should also be considered.

The basic approach for these reviews is quite flexible. They can be used to analyze a variety of operations and processes such as oil- and gas-well drilling, product manufacturing, chemical production, factory processes, chemical processing, transportation, marketing, computer control logic, operating procedures, organizational changes, and security control and monitoring.

3 Objective and Description of PHA, What-If, and HAZOP Reviews

Most hazards that arise in a system are thought to be primarily due to defects in design, material, workmanship, or human error. There are many methods of safety analysis reviews that are available and can be applied to a facility or project design to examine and overcome human errors and the various failures of the process system. The methods may be either qualitative or quantitative in nature.

Typical Qualitative Methods	Typical Quantitative Methods
Checklists	Event trees
Preliminary Hazard Analysis	Fault trees
What-If reviews	Failure modes and effects analysis
Hazard and Operability reviews	

Quantitative methods are usually applied to obtain a more precise evaluation of an identified hazard. These are typically employed for design evaluations and resolution of recommendations when the identified risk is above normally acceptable industry levels and when major capital expenditures need additional justification. The reader is referred to other publications for guidance on quantitative methods.

Safety reviews are ultimately, primarily, looking for the possibilities of where human errors may occur. Human error is commonly thought of as occurring mainly during the operational phase of the facility or system, but it can also be the cause of defects in the design, material, or workmanship. Since most petroleum or chemical facilities are not mass produced for specific applications, but individually designed, there is a large potential for human errors to occur during design, procurement, and construction. The extended operation lives of most facilities balance the equation so that "operational" human failures are equally important.

Human error is considered when one of the following events occur (which may be applied equally to design or operation of a facility):

1. An individual fails to perform a task or some portion of a task.
2. The task (or portion) is performed incorrectly.
3. Some steps are introduced into the sequence which should not have been included.
4. A step is conducted out of sequence.
5. The task is not completed within an allocated time period.

Human errors can be committed by all personnel—designers, engineers, operators, and managers. Some theories attribute the majority of all incidents to human errors.

3.1 Definition

PHA, What-If, and HAZOP reviews are basically a communication exercise. Information is presented, discussed, analyzed, and recorded. Specifically, the safety aspects are identified, to determine if adequate design measures have been taken to prevent major incidents as perceived by the review team. Communication and evaluation are the prime facets of the procedures.

HAZOP reviews follow a definitive guideword approach, step by step. PHA and What-If analyses are usually combined with a checklist to provide a "road map" for the review.

3.2 Objectives

The primary objective of PHA, What-If, and HAZOP reviews is to assure that catastrophic incidents will be avoided during the lifetime of the facility from the processes under review. The objectives of these reviews should be thorough, impartial, and adequate.

3.3 Origins of Qualitative Safety Reviews

HAZOP reviews have been stated as arising from the chemical industry in U.K. during the 1960s. Imperial Chemical Industries, Ltd., developed a

standardized method of analyzing processing hazards based on the basic operation conditions and then changed individual parameters one at a time to see the subsequent consequences. This evolved into a standard practice within their company and soon found its way into the general chemical industry (although it was not universally or consistently applied).

Simultaneously, most petroleum and chemical companies had also brainstormed a safety review which asks "What-If" questions of the process (e.g., SOHIO, circa 1967). This was common practice in the industry and during the design phases of a facility but was usually verbal and less formal in its application. Therefore, not as much historical documentation is available on it as compared to the HAZOP method.

3.4 Limitations or Disadvantages

PHA, What-If, and HAZOP methods all have limitations and advantages. Listed below is a brief description of these.

3.4.1 Limitations

3.4.1.1 Preliminary Hazard Analysis

1. *It is based on experience.* Usually, these reviews cannot be relied upon for identifying unrecognized hazards. A review team may fail to delve deep enough into the process or the process control with which they have become superficially familiar. Unless the right questions are asked by the review team, hazards may go unidentified.
2. *It is not systematic*. These reviews are typically considered a brainstorming session. Personnel familiar with the facility discuss aspects in a random fashion (i.e., whatever comes to mind). Therefore, most PHA or What-If reviews refer to a checklist to overcome this handicap.
3. *It is usually applied when limited information is available or may change*. A PHA is usually conducted early in a project's life cycle, usually in the initial conceptual stages or early design phase. Some information about the project may not be fully defined for an adequate review or the project scope or conceptual design may change significantly during this period.

3.4.1.2 What-If Reviews

1. *It is based on experience*. Usually, these reviews cannot be relied upon for identifying unrecognized hazards. A review team may fail to delve deep enough into the process or the process control with which they have become superficially familiar. This may be true for older team members where new technological control systems have made the application of 25–30 years of experience in older process control methods less relevant (e.g., PLCs versus relays, analog versus digital). However, experience and insight together will allow the identification of hazard scenarios that are not readily apparent. Unless the right questions are asked by the review team, hazards may go unidentified.
2. *It is not systematic*. These reviews are typically considered a brainstorming session. Personnel familiar with the facility discuss aspects in a random fashion (i.e., whatever comes to mind). Therefore, most PHA or What-If reviews refer to a checklist to overcome this handicap.

3.4.1.3 HAZOP Reviews

1. *It needs a moderate level of skill to implement*. The review is a thorough and systematic process that has to be conducted in a proper fashion and accurately recorded. In order to perform a HAZOP review, a specialized team leader is assigned to guide the review team during the process. The team leader is usually someone who has had specialized training and experience in the conduction of HAZOP reviews.
2. *It may be slower to implement than other methods*. In order to perform a HAZOP review, a specialized team leader is assigned to guide the review team throughout the process. The team leader follows a standard format with special guidewords and deviations that need to be addressed. Because a standardized listing is used for all systems, some unnecessary and unimportant issues may be addressed in some portions of the system under review.

3.4.2 Advantages

3.4.2.1 Preliminary Hazard Analysis

1. *It can identify concerns early in the project*. Since a PHA is usually conducted early in a project's life cycle, it can identify concerns early in the project's conceptual stage and avoid costly changes later.
2. *It is generally economical*. The conceptual project stage usually has a limited information base, so the time/man-hours needed to perform the review will not be extensive.

3.4.2.2 What-If Reviews

1. *It can be accomplished with a relatively low skill level*. The typical What-If review is a basic brainstorming session—all sorts of topics may be randomly addressed as they come to mind. Combined with a checklist format, the review may become simple questions to answer.
2. *It is fast to implement compared to other qualitative techniques*. Since the What-If review is a direct question method, possibly from a standardized checklist, the questions can be easily and usually rapidly addressed.
3. *It can analyze a combination of failures*. The option of addressing continuing sequential failures can be investigated to the final outcome.
4. *It is flexible*. It is readily adaptable to any type of process flow or facility. Questions can focus on specific potential failures.

3.4.2.3 HAZOP Reviews

1. *It uses a systematic and logical approach*. It has a specific guideword listing and the process under review is subdivided into smaller sections for analysis.
2. *It can analyze a combination of failures*. The option of addressing continuing sequential failures can be investigated to the final outcome.

3. *It provides an insight into operability features*. Operation control methods are fully investigated for potential varying conditions in the entire process flow. From this review, an operator can readily deduct what hazards may be present at the facility.

Table 3.1 Comparison of PHA, What-If, and HAZOP Methods

	PHA	What-If	HAZOP
Experience based	Yes	Yes	No
Systematic	Partially	Partially	Yes
Skill	Low	Moderate–low	Moderate
Speed	Fast	Fast–moderate	Slow
Level of detail	General	Medium–specific	Very specific
Relative cost	Moderate–low	Moderate–low	High–moderate
Flexible	Yes	Yes	Yes

4 Adaptation to Security Vulnerability Analysis (SVA)

An SVA is quite similar to a process hazard analysis (PHA); both perform a risk assessment and evaluate the results. An SVA evaluates risk from deliberate acts that could result in major incidents. It is performed in a systematic and methodical manner by a multi-disciplined team coached by a leader. It analyses potential threats and evaluates these threats against plant vulnerabilities. From this analysis, it determines possible consequences and whether safeguards to prevent or mitigate their occurrence are recommended. This procedure and documentation is similar in manner to existing PHA methodologies, so it can be easily adapted into existing programs efficiently and effectively. Sections in this book that describe PHA procedures have been expanded to also include SVA steps. Some consulting companies that offer PHAs have added SVAs to their capabilities due to the similar nature and overlapping objectives. They have easily adapted PHA software into SVAs in order to conduct these reviews. The DHS primarily relies on the methodology of AIChE and Sandia VAM, but accepts equivalent methodologies developed in the industry. Current equivalent methodologies specifically identified as acceptable by the DHS are listed below.

- Air Products and Chemicals SVA
- API/NPRA (only for petroleum sites)
- Asmark SVA (only for silver chemicals distribution)
- Bayer SVA
- BASF SVA
- ExxonMobil SSQRA
- FMC SVA
- Georgia Pacific SHA
- Marathon Ashland Petroleum
- National Paint and Coatings Association (only for paint and coating formulators)
- PPG SVA
- SOCMA (manual method use only)
- SRM (chemical extended version, Straec)
- SVA-Pro by Dyadem

4.1 Comparison to Process Hazard Analysis Reviews

All of the methodologies utilize what is frequently termed as "threat analysis" to identify the "deviations" against protective measures, similar to PHA/What-If questions and guidewords in a HAZOP. These are then applied through a vulnerability assessment (i.e., variation on process intention similar to the PHA). Subsequently, the consequences are determined and the effectiveness of the protective measures is evaluated. Where these are considered inadequate, recommendations are recorded to prevent or mitigate the event, similar to PHA reviews. Communication and evaluation are the prime facets of both methodologies.

4.2 Overall Procedure for SVA

The general steps in the process are:

1. Undertake a threat analysis (identifying sources, types, and likelihood of threats).
2. Divide facility into areas and also identify global concerns (to be addressed for the overall facility).
3. Evaluate each credible threat within the process area.
4. Identify vulnerabilities against each threat (brainstorming/checklist approach).
5. Determine the possible consequences.
6. List safeguards against threat scenarios and evaluate if protective measures are adequate.
7. Determine if recommendations are required (ranking of risk can be used to determine necessity).

These steps are easily followed and can be applied at a variety of facilities and operations at varying degree of detail as necessary.

4.3 Major Differences between SVA and Process Hazard Analyses

Although SVAs are similar to PHAs, there are some notable differences that should be realized. The following is listing of the major differences:

- A PHA typically evaluates equipment and operator failures, while SVAs evaluate scenarios that originate from deliberate actions.

- An SVA has to identify sources, types, and likelihood of threats, while a PHA has to determine what hazards are to be considered.
- SVAs have to accommodate various threat levels based on current cultural perceptions.
- SVAs rely on or usually involve law enforcement.
- SVAs have to determine if threats are credible, while a PHA has to determine if a failure is credible.
- Safeguards for PHAs may not be applicable for SVAs.
- Likelihood definitions for SVAs (threat analyses) are different from likelihood (probabilities) for PHAs.

4.4 Necessity of Threat Analysis

Since exact guidewords or a definitive checklist is not available to cover the complete threat possibilities that may evolve as in a process hazard analysis, a threat analysis is performed as one of the first steps in the SVA. Different methodologies may identify this process by other names (e.g., consequence and target attractiveness), but they all have the same intention. A threat analysis is a continuing process of collecting and reviewing all available information concerning potential adversaries that may target an organization or facility. The main information will be related to the factors responsible for an adversary's existence, its capabilities, intentions, history, targeting, and the security environment of the target. The technique utilizes a team brainstorming/checklist approach to identify the threats to be examined and may qualitatively rank the findings to assist in identifying highly credible threats.

5 Team Members, Qualifications, and Responsibilities

Review team members or consultants retained to support a review should be chosen such that they are intimately familiar with the industrial or commercial processes under examination. For example, a crude separation operator should not be chosen to support a review of a refinery gas plant; however, he could serve as a reviewer for another crude separation unit. The typical review team should also have a balanced number of individuals from different organizations such as company employees, consultants, equipment fabricators. Hopefully one group's self-interest should not be able to outweigh and unduly sway the entire group's outlook.

5.1 Team Members

Three types of individuals are needed to support a process hazard or vulnerability analysis: (1) a leader, (2) a recorder/scribe, and (3) the experts. The experts are commonly (1) the project manager or engineer who has designed the facility, (2) a person knowledgeable in how the facility will be operated, and (3) a person knowledgeable in loss or security risk aspects associated with the industry under examination.

5.1.1 Minimum Team Members

Using this philosophy, the following five personnel are considered to be the minimum required individuals needed to accomplish a successful review:

1. Team leader
2. Scribe
3. Project manager (project, process, or facility engineer)
4. Operations or manufacturing representative
5. Loss prevention/safety representative
6. Security officer (for SVA)

The project manager (project, process, or facility engineer) is the individual responsible for the accomplishment of the process hazard analysis. The process hazard analysis review should be considered part of a project just as an ordinary design review is. The project manager is essentially the manager of the review and all other participants support his requests.

An operations representative should be included for existing as well as new designs. Although most engineers design a facility with the best intentions of how it will be operated, personnel may operate the facility in their own fashion. For a new design, either the designated future operators should be included or operators with experience in the type of facility being designed should be seconded to the review.

If a required team member is not available, the project manager shall determine with the concurrence of the project safety representative, if the review can be adequately accomplished without the designated member. In such cases, a substitute individual from the supplemental member list below should usually be provided in his place. A review should not be undertaken if an operations representative or his delegate is unavailable.

In some instances, the duties of a team leader or the scribe may be performed simultaneously by the other team members. This may be considered acceptable; however, it may lead to a less objective and productive session than may have otherwise been accomplished. The dual role of some of the team members may also cause the review to last longer than expected, as the review must stop to record the discussions, than if a real-time scribe was available to take notes. For short reviews, this may be acceptable; however, for longer reviews it can soon be realized that the additional man-hours for the entire team are not as cost-effective when the interruptions are totaled.

5.1.2 Supplemental Members

The review team may be supplemented with additional personnel to augment the review process. Preferably, supplemental personnel should only be considered when a particular complicated aspect of the project needs further in-depth review. Supplemental members may only be required for part-time review support. Suggested supplemental personnel are selected from the following individuals:

- PSM coordinator
- Maintenance representative
- Corrosion representative
- Health, safety, and environmental (HSE) representative
- Security representative
- Process, manufacturing, facility, or construction engineers
- Drilling engineers
- Project designers (electrical, instrumentation, piping, etc.)
- Operation technicians or supervisors
- Specialized consultants
- Equipment fabricators or vendors
- Security consultants or vendors

Typically, most review teams will consist of five individuals. Teams of eight or more individuals are discouraged unless the extra members are strictly observers who would not participate in the review. It should also be noted that with teams of more than eight members or less than four, the review progress will be slower. If the team composition can be kept close to five personnel, knowledgeability, efficiency, and cost benefits will be realized.

Where facilities employ operators in multiple shifts (process plants and manufacturing facilities) or have rotational leave personnel (such as offshore or at remote foreign locations), it may be prudent to include an operator from each shift or work period in the review process. It may be realized that the separate shifts or work periods may have different methods to achieve similar operational objectives.

The same individuals should attend all safety review meetings for a particular facility. Substitution of other individuals for a designated position during a review impairs the continuity and quality of the review. If a convenient process or facility review break, which does not impact continuity, occurs during the study, a replacement individual may be considered. This

is especially important if further staff training or experience in the review cycle is helpful.

5.2 Qualifications of Team Members

As a minimum, about 20 total years of experience in the respective industry being examined should collectively be available from the technical team members (i.e., excluding the scribe). Ideally, 40–50 years of industrial experience is preferred.

5.2.1 Team Leader

The team leader should possess an engineering degree or equivalent. The leader should have a minimum of five years of related industry experience and be trained or experienced in conducting PHA, What-If, HAZOP, or SVA reviews. A leader will typically have had three to five days of classroom training and have actually trained as a leader for one or two actual review sessions. A leader should possess a congenial personality and yet still be authoritative to the other review team members. Typically, the team leader and most of the review team are not directly involved in the facility design. This allows them to offer an independent assessment aspect to the review process.

5.2.2 Scribe

The scribe should be able to type a minimum of 45 words per minute, be computer literate, and have a general understanding of petrochemical technical terminology. A minimum of six months of secretarial or clerical duties involving personal computer word processing or spreadsheet applications is preferred. Previous experience in a safety review is not necessary.

5.2.3 Project Manager (Project, Process, Manufacturing, or Facility Engineer)

For the purposes of this guidance, the project manager may be the project, process, manufacturing, or facility engineer. The manager should possess an engineering degree and have a minimum of five years of industry

experience. Preferably, individuals should have responsibility and knowledge of the design or operation of the facility, with some authority to make changes. The project manager should be a direct company employee.

5.2.4 Operations Representative

The operations representative should have a minimum of five years of experience in the operation or maintenance of the type of facility being studied. The operator should have intimate knowledge about the specific process or the type of facility being evaluated.

5.2.5 Loss Prevention or Safety Representative

A loss prevention or safety representative should have a minimum of five years experience (engineering, operations, inspections, etc.) in loss prevention practices in the specific industry being examined.

5.2.6 Security Officer or Representative (for SVA)

A security officer or representative should have a minimum of five years experience (operations, consulting, etc.) in security practices in the specific industry being examined and be aware of the latest security threats facing the industry.

5.2.7 Supplemental Team Member

Supplemental team members should have a minimum of three years experience in the industry being examined, in the discipline the individual represents.

5.3 Team Responsibilities

It is project manager's responsibility to see that a process hazard analysis review has been performed for a project. In this respect, the other team members provide support and assistance. The manager or engineer directs and controls the other members as he would for any other aspect of the project or facility management. For the purposes of this guidance, a project or facility manager may be a project, process, manufacturing, or facility engineer.

5.3.1 Team Leader

1. Prepare a proposed study schedule and obtain its approval from the project manager. At the request of the project manager, prepare a cost estimate of the proposed review.
2. Organize the meeting locations, dates, times, and refreshments (conference room reservation, lunch, etc.).
3. Identify, obtain, copy, and organize the necessary drawings and documents for the review, for each team member (drawings and documents to be obtained from the project manager).
4. Organize the necessary computer hardware and software, real-time computer overhead projection screen, etc.
5. Select and identify nodes or areas for the review(s) with the project manager.
6. Lead and chair the review sessions in all matters except technical direction.
7. Ensure an adequate technical review while observing the proposed review schedule.
8. Recommend that sub-sessions or investigations are proposed to discuss specific points where this is more productive, from a technical or schedule standpoint, during the review meetings.
9. Prepare and issue preliminary, draft, and final copies of the review reports to the project manager. Incorporate comments from preliminary and draft reports in the final report.
10. Attend all review meetings.
11. Check review worksheet(s) for technical accuracy at the end of each day's review meeting(s).
12. Direct the work of the scribe during and outside the review meetings.
13. Provide expertise in the conduction and review of HAZOP, PHA, What-If, or threat/vulnerability analysis meetings.
14. Assist the project manager in the preparation and the issue of an addendum report on the review for recommendations and resolutions or closeouts.
15. Ensure consistency in the reviews to the company's approach and philosophy of risk and protection methods.

5.3.2 Scribe

1. Prepare the review meeting node listings and worksheets before each review session.

2. Transcribe review discussion notes onto a spreadsheet format.
3. Attend all review meetings.
4. Assist the team leader in the preparation of the preliminary, draft, and final copies of the review reports.
5. Verify spelling, wording, listed equipment tag numbers, fluid compositions, units of measurement, etc., of each report, especially the recommendations.
6. Order and arrange lunch and refreshments.

5.3.3 Project Manager (Project, Process, Manufacturing, or Facility Engineer)

1. Organize the applicable reviews (obtain required support, funding, select and notify team members, etc.). Project reviews should normally include the cost of these reviews as part of the project design cost (i.e., the project corporate budget request) or existing facility operating costs.
2. Select team personnel and ensure their attendance at all review meetings.
3. Supply required accurate/up-to-date drawings and documents to the team leader.
4. Attend all review meetings.
5. Provide project knowledge, process system or facility design expertise, and the company's policy and preferences to the review meetings. During the actual review, provide the design intent of node and process conditions and limitations. For the review report, a process description should be provided.
6. Take immediate corrective action of any items that have been found to be an immediate serious threat to life during the review meetings by using the company's management of change (MOC) procedures.
7. Let the management know of review activities and results, as required by normal company policies and practices.
8. Review, comment, and approve the preliminary, draft, and final copies of the review reports.
9. Define distribution of review reports with management.
10. Issue and distribute copies of the preliminary, draft, and final copies of the review reports.
11. Follow through on action items identified as part of the study review. Obtain resolution or closeout of the recom-

mendations. Prepare and issue any addendum reports documenting recommendation resolutions or closeouts.

5.3.4 Operations Representative

1. Attend all review meetings.
2. Provide operations knowledge, policies, procedures, and facility practices to the review meeting.
3. Respond to discussions of facility operations during the review meetings.
4. Identify any field changes to the facilities that have not been shown on the design drawings.
5. Identify maintenance concerns and requirements.
6. Verify equipment tag numbers as requested.
7. Review and comment on preliminary and draft reports as required.

5.3.5 Loss Prevention or Safety Representative

1. Attend all safety review meetings.
2. Provide loss prevention knowledge and the company's loss prevention and environmental policies and practices to the review meetings.
3. Confirm the company's philosophy to risk acceptance and protection methodology.
4. Respond to discussions of loss prevention during the review meetings.
5. Provide knowledge of recent loss incidents applicable to the facility as necessary to discuss.
6. Advise on PSM goals, to ensure they are being addressed.
7. Review and comment on preliminary and draft reports as required.

5.3.6 Security Officer or Representative (for SVA)

1. Attend all threat/vulnerability analysis review meetings.
2. Provide security protection knowledge and advice on the company's security policies and practices to the review meetings.

3. Provide information on threats—source, type, and likelihood. Liaison with outside security agencies as required.
4. Respond to discussions of vulnerability analysis during the review meetings.
5. Provide knowledge of recent security incidents applicable to the facility as necessary to discuss.
6. Advise on latest practical security measures that can be adopted.
7. Review and comment on preliminary and draft reports as required.

5.3.7 Supplemental Team Member(s)

1. Attend review meetings as requested by the project manager.
2. Provide knowledge of policies and facility practices with respect to the position the individual represents.
3. Respond to discussions during the review meetings.
4. Review and comment on preliminary and draft reports as required.

5.4 Team Dynamics

The review process is centered on a group of personnel reviewing information. It is therefore obvious that successful interaction and direction of the group or team is maintained. If poor team interaction or direction exists, the review will suffer accordingly.

5.4.1 Leadership Influences

The following practices will enhance the team leadership during the review:

- Look at things from the other person's perspective.
- Offer genuine appreciation and praise.
- Harness the power of enthusiasm.
- Respect the dignity of others.
- Don't be overly critical.
- Give people a good reputation to live up to.
- Keep a sense of fun and balance.

Table 5.1 Possible Lines of Team Communication (Assuming that Only the Team Leader Communicates to the Scribe)

Number of Team Members	Possible Lines of Communication (Two Way)
2	1
3	2
4	4
5	7
6	11
7	16
8	22
9	29

5.4.2 Lines of Communication

The possible lines of communication for review teams of up to nine members are shown in Table 5.1. There are 7 possible lines of communication for a 5-member team, while for comparison, for teams that are composed of 9 members, there are 29 possible lines of communication.

The number of conversations (for teams with more than six members) that may occur are difficult to maintain or take into account. This increases the amount of discussion (and confusion) that may develop and is significant in that it may impact progress of the review and therefore increases costs without added benefits.

5.4.3 Efficiency Factors

Several factors have been known to influence the speed and accuracy of the review process.

1. *The number of nodes or areas in the review*. If the time to review a design continues more than a week, the review process becomes more laborious and unfortunately maybe boring to the team members. Personnel will become less interested in the actual review at hand and desire to "get back" to their normal activities and co-workers. This longing for the routine work activities will necessarily distract

from the contribution and therefore also affect the effectiveness of the review being conducted.

2. *The completeness of the design versus level of safety review desired*. If a final review is to be performed on a design that is, say, only 75% complete, the review team will necessarily have a lot to say about the unfinished portion of the design. The scheduled review method should be consistent with the level of design that is presented for review.
3. *The experience of the review team*. If most of the review team members have never participated in a safety review, they will necessarily be "lost" and only learning the process during the first day or so. The team leader will be striving to instruct the team members rather than have them contribute to the review.
4. *The effectiveness of the team leader*. The success of the review lies with the team leader, whose whole purpose is to lead the team throughout the review and bring out the concerns of the process. If the team leader is ineffective, the team will perceive this and not contribute effectively.
5. *The language background of the review team*. If several members of the team are conversing in a language that is not their primary language, they may have to "think" and possibly discuss among themselves, in their own language, the meaning of the discussions occurring. This will impart breaks or retard the process of the review, which normally would not have to account for such discussions. This is not to mean that such discussions are detrimental, in fact, quite the opposite may be true; however, the schedule of the review should account for such contingencies. Some overseas reviews may use a translator, who may also act as the scribe. The translator is especially useful when further in-depth discussion or explanations are needed by either the team leader or from the review team.
6. *The number of review team members*. As more personnel become involved in the review, the avenues of discussion become greater; however, they may not necessarily improve the quality (Table 5.1).
7. *The number of similar or duplicate process vessels or support equipment*. Where duplicate or similar process vessels occur at the facility, the review team can refer to the earlier episodes of the review. If they can confirm that the analysis

would be very similar, it could be essentially copied for the identical vessel.

5.5 Use of Consultants

The use of a consultant to lead a review should be considered whenever the project design team support is unfamiliar or inexperienced in the safety review process. Due to the close contact with the scribe, both the team leader and the scribe are frequently employed as consultants, although only the leader is primarily necessary.

5.5.1 Qualifications

- *Experience*: As the role of the consultant is to lead and guide the review process, it could be stated that he/she might not need to be particularly familiar with the types of facilities under review. This is not true since some knowledge of the basic hazards of the facility and substances involved are needed in order to provide adequate importance to points raised in the review. For example, mercury levels in produced gas streams for production systems may not be of concern, but in refining systems the high levels of mercury may cause extensive corrosion problems. Experienced leaders can expedite the review process by knowing important issues to highlight and vice versa. A consultant should be chosen such that he/she has the closest match of experience to the type of facility that is to be reviewed. The consultant's qualifications should be evaluated for the facility under study and the type of review, for example, (1) petroleum versus chemical industry experience; (2) upstream versus downstream operations experience; (3) domestic versus international security experience; (4) onshore versus offshore experience.
- *Training*: The consultant should have attended a recognized training class from a professional association sponsored course (e.g., AIChE) or from internationally recognized training consultants in the field of loss prevention or security analysis, applicable for the type of industry they will be involved with (e.g., the petroleum or chemical industries).
- *Pre-qualifications (technical)*: The consultant should usually have credentials that match his advertised expertise. The

credentials usually entail a recognized engineering degree, registration with the local government as a practicing engineer, membership in loss prevention or engineering societies, and/or publication of papers on loss prevention subjects. The consulting company should have a demonstrated clientele that is representative of the industry sector that the facility under review represents.

5.5.2 Advantages

- *Independent viewpoint*: The consultant offers an independent viewpoint. Since his role is detached from the project or the company, he can view the review with an open and unbiased opinion.
- *Process hazard review expertise*: A consultant can provide the means to expedite a review where an inexperienced team may become bogged down. Additionally, he offers his experience of solutions to similar problems.
- *Impartial*: On occasion, a discussion will require an objective and impartial mediator who would not favor either party but propose a resolution that is based on the most prudent and practical approach.
- *Security expertise*: Most individuals in industry are usually not familiar or aware of security issues and concerns. A security consultant for SVAs brings in a valuable asset to supplement the team's knowledge.

5.5.3 Disadvantages

- *Costs*: Consultants are essentially additional personnel costs to the company.
- *Unfamiliarity*: The consultant will not be familiar with company facilities and procedures. Although this is not necessary, it may require additional time during discussions for the consultant to fully comprehend the facility and its processes in order to adequately lead the team.
- *Confidentiality*: Many issues discussed in process safety and security would be considered confidential company information. The consultant would be required to maintain this

confidentiality through adequate legal controls. This is especially critical where financial litigation exposure may develop against the company.

5.6 Record of Employee Experience

It may be useful to maintain a record of training and experience of employees who have been involved in HAZOP, PHA, What-If, and SVA reviews. This may be useful when planning for participants in future reviews or to determine the areas where training is required. A suggested log sheet of personnel experience is indicated in Table 5.2.

Table 5.2 Suggested Employee Review Experience Record

	Training	Team Leader	Scribe	Participant			
				HAZOP	What-If	PHA	SVA
J. A. Doe	X	X		X	X		X
A. N. Other			X			X	
A. N. Other	X			X	X	X	X
A. N. Other	X			X		X	X
A. N. Other					X		

6 Management Support and Responsibilities

The ultimate responsibility for the safety and security of a facility lies with senior management. A company's senior and local management should therefore ensure that the appropriate process hazard or vulnerability analysis reviews are undertaken. Appendix A provides an example of a typical statement from a company's CEO.

It is also prudent that the general results of a process hazard security assessment are explained or are known to the management prior to its occurrence so that their expectations are consistent with those results. Management should fully realize that monetary commitments (manpower and financial expenditures) are required to initiate, perform, and follow-up the review.

Management should insist that reviews are conducted in a timely, efficient, and cost-effective manner. This may imply that the in-house personnel need to be familiarized and trained on these techniques. Review preparations, schedule, and cost estimates should be submitted by the project manager for senior management approval where appropriate. Team members should be committed to a review once it is scheduled. The team concept suffers if a member is removed for other duties while involved in the review. Where the use of a consultant, whose costs and services may be extensive, is contemplated, competitive proposals should be sought and the final selection should be approved by the management.

Management should acknowledge the risk results of the process hazard or vulnerability analysis reports. If the risks of the process hazards or security analysis are not acknowledged by the management, the review team members will feel that their efforts have been in vain and that recommendations do not have to be dealt with. Where management does not acknowledge their results, their importance will suffer and therefore the quality will degrade. Eventually, this could result in a situation that existed before the reviews were conducted (i.e., hazards and risks are not really known or fully understood).

There may also be legal obligations associated with the review results. A properly administered process safety and security management program

will help minimize legal exposures. All recommendations produced by the study should be circulated in draft form to all interested parties within the company. The report should be consistent with other hazard assessment or security reports, and there should be a follow-up procedure to manage recommendations in a timely and effective manner. All steps in the process should fully document the resolution path for each recommendation.

Resolution of some of the recommendations may require some level of risk acceptance by senior management (sometimes beyond that normally deemed acceptable by company policy). Management will have to sign-off on these acceptances.

Management will soon realize that the results of HAZOP, PHA, What-If, or vulnerability analyses will also provide an indication of how well engineering staff or contract design firms have been performing their functions. The level of thought for engineering effort for both process safety and security concerns will be demonstrated. There may be a case to eliminate some project design contractors from bid proposals where there has been a history of extensive recommendations from HAZOP, PHA, What-If, or vulnerability analyses as a result of their work products.

It should also be realized that these reports will highlight areas where a particular facility production may be vulnerable. This may be particularly important in situations where subversive or militant public or internal labor unrest may be suspected or ongoing, which is highlighted by the SVA. Since these reports may provide indications of key vulnerability points in the process, suitable controls on the distribution of the information of the report is necessary in these instances.

7 Review Applications for Typical Facilities

The bulk of process hazard analyses will be a HAZOP, What-If, or PHA review. Generally, in the upstream sector, 60%–80% of the safety reviews will be PHA or What-If reviews, while in the downstream sector, 60%–80% will be HAZOP reviews. SVAs will be applicable to all types of facilities.

PHA, HAZOP, What-If, and SVA reviews are generally organized and conducted in a similar fashion. The HAZOP review is more detailed and structured, while the PHA and What-If approach, which is also applied in SVAs, is typically broader and free flowing.

It has been found that the PHA or What-If style of analysis is generally a convenient method to use for a “simple” facility when conducting a process hazard review. For simple facilities, the detailed HAZOP approach has been found to be tedious and just as productive as a PHA or What-If method. The PHA and What-If approach stimulates generation of new ideas and discussion to cover issues associated with the items under review as well as addressing generic issues. The specific HAZOP review is not necessary when the process is simple and well understood by the

reviewing team. The team can readily review the major items of concern by asking What-If questions, such as what happens when a pump fails, without relying on itemized and detailed variations of a process condition as required by the HAZOP method, such as high level, low pressure.

Processes that contain unusual, complicated, or extremely hazardous materials should be reviewed by the detailed HAZOP method to ensure that major possible events, which may not be familiar to the team, have been accounted for. This may also be true when a high employee or public population may be exposed to potential hazards (such as may be the case with some offshore oil production facilities).

The level of a project design may also dictate the method of the process hazard review that is chosen. During conceptual or course designs only general information is available. Therefore, in the strict sense, a detailed HAZOP study cannot be performed. In these circumstances, a course HAZOP is applied, which is more a What-If review or checklist type of undertaking. Table 7.2 provides a guide in selecting the appropriate method during a facility design.

In the conceptual stages of a project, when details of the design are not known, emphasis should be put on the several accidental scenarios with a potential of impacting the main safety functions.

Since What-If reviews are considered to be somewhat without direction, they are usually combined with a simple checklist to improve their efficiency.

If doubt exists as to what method to apply, the HAZOP method should be chosen over the PHA or What-If method. The PHA and What-If approach rely on the team leader to ferret out the real hazards associated with the process. The systematic HAZOP approach will examine each portion of the system to determine hazardous conditions.

7.1 PHA Review Applications

PHA reviews are similar to What-If reviews and therefore can cover the same basic “simple” facilities as identified in Section 7.2. Primarily, it is

an initial hazard identification and evaluation tool in capital project proposals prior to HAZOP or other quantitative reviews that are later detailed in design phases.

7.2 What-If Review Applications

The following basic facilities are considered likely candidates for a What-If review. These facilities contain basic fluid/gas transfer, storage, or separation systems:

- Wellheads*
- Tank batteries*
- Pipelines (gathering and trunk)*
- Production test facilities
- Subsea (template) production facilities
- Drilling operations
- Wireline and workover operations
- Pumping stations
- Multistage separation systems (gas/oil/water)
- Gas compression systems for sales
- Water injection systems
- Tank farms
- Liquid loading facilities (truck, rail, ship)
- Marketing terminals
- Unmanned offshore facilities

Of these facilities, the first three (marked by asterisks) may in fact be more suited to a checklist approach due to their usually identical features; alternatively, a one-time generic PHA or What-If approach may be employed that is representative of all the subject facilities (i.e., wellheads with similar gas–oil ratio (GOR), H_2S content, pressures, etc.).

7.3 HAZOP Review Applications

A HAZOP review method is suggested for the process when more complex facilities are under study. These facilities contain processes that are

typically complex in nature, have chemical processes containing volatile hydrocarbons/toxic chemicals, or have high employee concentrations.

- Facilities with toxic or highly corrosive fluids and vapors treating equipment (e.g., H_2S treating facilities, such as an amine unit).
- Gas injection systems
- Gas loading facilities (truck, rail, ship)
- Liquefied petroleum gas (LPG) processing plants
- Liquefied natural gas (LNG) processing plants
- Gas storage facilities
- Topping plants
- Manned offshore facilities (e.g., production and storage facilities)
- Refinery unit process
- Chemical plant unit process

Tables 7.1 and 7.2 summarize the suggested applications of HAZOP, PHA, and What-If reviews.

Table 7.1 Suggested Applications of PHA, What-If, and HAZOP Reviews in the Petroleum Industry (for Final Designs or Existing Facilities)

Facility	Checklist	What-If	PHA*	HAZOP
Wellhead	X			
Tank battery	X			
Pipeline	X			
Production test facility		X	X	
Subsea production facility		X	X	
Drilling operation		X	X	
Workover/wireline		X	X	
Pumping station		X	X	
Multistage separation facility		X	X	
Gas compressor (sales)		X	X	
Water injection facility		X	X	
Tank farm		X	X	
Liquid loading facility		X	X	
Marketing terminal		X	X	
Unmanned offshore facility		X	X	
Toxic vapor treating facility			X	X
Gas injection or loading system			X	X
LPG or LNG processing plant			X	X
Gas storage facility			X	X
Manned offshore facility			X	X
Refinery process unit			X	X
Chemical process unit			X	X

*Used for initial screening for hazard identification severity potentials.

7.4 SVA Review Applications

SVAs will generally be applicable to all types of facilities; however, there will be more concern to apply its review to highly visible, valuable, and important facilities or operations. Separately, the DHS requires that any facility that manufactured, used, stored, or distributed certain chemicals

Table 7.2 Suggested Safety Reviews during a Project Life

Level	Activity	Checklist	PHA or What-If	HAZOP	Available Information
1	Feasibility study	X	O	—	Basic outline
2	Budgetary request	X	O	—	General description
3	Conceptual design	O	X	O	General layout, PFDs
4	Intermediate drawings	O	X[1]	X[1]	Preliminary P & IDs
5	Vendor drawings	O	X[1]	X[1]	Preliminary P & IDs
6	Final design	—	X[1]	X[1]	Refer to Table 8.1
7	Operational or facility changes	*	*	*	*
8	Periodic evaluation	*	*	*	Refer to Table 8.1

O: optional; X: recommended; X[1]: as required by Table 7.1; PFDs: process flow diagrams; P & IDs: piping and instrumentation diagrams.

*Refer to management of change (MOC) procedures, level of safety review determined by magnitude of change to process (Section 7.5).

above a specified quantity (as identified on their website) must be identified, and must complete and submit a list through a web-based application "CSAT Top-Screen" to their office. These facilities are usually identified as critical and will be candidates for an SVA. The determination of criticality is usually based on the consequences that could be expected from an incident. Any other facilities identified through an initial screening process that the team conducts to determine asset value and importance or whether it could lead to major impacts onsite or offsite would also be candidates for an SVA.

An SVA can also be applied during the design of a facility. Since its threats (or "deviations") are normally not detailed variances, its methodology is flexible so that it can be utilized throughout the project design phases and various applications.

7.5 Application during Changes at a Facility

The magnitude of a change to the facility or its operation determines the level of safety review needed and whether an SVA is needed. A "like for like" replacement of pipe will typically not require a supplemental analysis. The substitution of a pipe of different material and routed to a new location may warrant a What-If review.

Since a multitude of different changes may occur at a facility, the company's MOC procedures should define the type of analysis required by the change and these requirements are beyond the scope of this guideline.

Once it is determined that a PHA, What-If, HAZOP, or SVA review is necessary for the change, reference should be made to these guidelines.

8 Review Procedures

8.1 Review Preparation and Setup

Three areas of preparation are needed for a review to take place—location, administrative support, and documentation.

8.1.1 Location

The location of where a review is to be held should be determined by where the most amount of information and personnel knowledgeable in the facility design and operation are located. Typically, new designs will have the data at the engineering contractor's offices and the reviews will be held there. For existing facilities, the review is usually held at the facility itself close to the process or area under examination, where additional operators will also be available and on-site verification/inspection can be performed if needed.

8.1.2 Administrative Support

A conference room should be used for the team members to gather and conduct the review. The room should have a table with ample space for each team member to review drawings and capability for overhead projection. Chairs should be comfortable for extended periods of sitting.

Adequate lighting for the viewing of engineering drawings is necessary. Several note pads, a sketch pad, or flip chart should be provided. It should be possible to leave material out overnight without being disturbed.

If the review is conducted overseas, two main issues may arise. First, the local language may be inconsistent with available specific safety review software or a consultant, if used, may not be available in the host country's language. A translator is sometimes used in these instances. Second, if a portable personal computer is used, its power requirements may be different both in voltages and plug connections. In these circumstances, it is best to plan ahead and bring power converters, adapters, and multiple outlet power strips.

Lunch and refreshments should be provided in the review meeting room to avoid disruption and maintain continuity of personnel attendance. Further discussion of issues may also be informally pursued over lunch and breaks.

Interruptions from messages, cell phones, or other enquiries should be kept to an absolute minimum during the review sessions as these will only distract the participants. If possible, the conference room should be posted with a "Conference In Session, Do Not Disturb" sign.

8.1.3 Facility Documentation

Table 8.1 provides an ideal listing of documentation needed for final process safety reviews, while Table 8.2 provides an ideal listing for SVAs. The documentation should be accurate and up to date. Up to date is meant to indicate that all changes which have occurred at the facility including field changes have been incorporated into the reference drawings. This is usually a difficult requirement for most plants to confirm. If no changes have occurred at a facility, then the original design drawings would be considered accurate and up to date. If a review is conducted on outdated or incomplete drawings, its accuracy cannot be assured and the results may be incorrect. A review should not be undertaken if the minimum data is questionable. During a project review, adequate time should be made available to update drawings if they are found to be outdated before the review occurs. For existing facilities, a spot field check can be performed at the facility to determine if the drawings are adequate. Computer software is now available that allows as-built 3D modeling of a facility from laser

Table 8.1 Ideal PHA, What-If, and HAZOP Review Reference Data (for Final Reviews)

1. Piping and instrumentation drawings (P & IDs) that are "as-built" verified for the existing processing facilities*
2. Plot plan or equipment and main piping layout and pertinent elevation drawings, including surface drainage arrangements*
3. Cause and effects charts (SAFE charts) with schedule of alarm and trip settings*
4. P & IDs for vendor packages*
5. System design philosophy and process description*
6. Fire and explosion protection system drawings or arrangements (fire and gas detection/alarm, protection—passive and active)*
7. Chemical and physical properties of commodities involved, especially hazardous materials (crude oil GOR, material safety data sheets (MSDS), etc.)*
8. Emergency response plans (ERPs) indicating responsibilities and duties of management*
9. Operating procedures (including start up or shutdown and emergency) and maintenance schedules**
10. Process flow diagrams (PFDs) and material and energy balances
11. Electrical hazardous area diagrams
12. Full description and system design calculations of emergency shutdown (ESD) isolation and depressing (blowdown) capabilities including headers, vents, and flares
13. Design duties and basis of calculation of all relief valves, rupture disks, etc.
14. Corrosion monitoring and prevention systems
15. Engineering design data sheets for all plant items including vendor items
16. Data sheets for instruments and control valves
17. Piping and material specifications (if not indicated elsewhere)
18. Flare, vent, and drainage header diagrams
19. Electrical single line diagrams
20. Instrumentation philosophy (local/remote control, hardwired/data highway, failure mode(s), analog/digital, emergency alarms, etc.)
21. Drawings showing interfaces to existing systems
22. Special studies or calculations (vapor dispersions, blast overpressure, etc.)
23. Environmental ambient data (temperature, weather, seismic, etc.)
24. Utilities specifications and reliability (power, water, sewer, etc.)
25. Design codes and standards employed (API, NFPA, ANSI, ASME, NACE, etc.)

(Continued)

Table 8.1 (Continued)

26. Manning levels, distribution of personnel, levels of supervision, and evacuation routes or plans
27. JSA for critical tasks
28. Ergonomic or human factors features (color coding, accessibility, practical use, languages, and instructions, etc.)
29. Loss histories of the existing or similar facilities, including near miss reports with trend analysis

*These items marked are considered to be the minimum data required for a HAZOP or What-If review to occur. This data basically contains the layout (plot plan) of the facility, the process design (P & ID and process description) and how it will be controlled during an emergency (SAFE chart and fire protection plant). With this information, the "experts" can understand the design and operating principles of the facility. Since the emergency isolation, depressurization, and fire protection features are provided, it can be readily deduced as to how the facility will fare during a catastrophic incident.

**For new designs the operational and maintenance procedures are usually yet to be written, as the review is conducted just after the design has just been finished. For existing facilities, the procedures should be made available.

scans of the site to ensure that all changes have been identified and recorded. These scans are highly accurate and allow a database of information to be linked directly to each item to verify its properties (material specifications, inspection records, incident reports, etc.). This is an ideal tool for a PHA, What-If, HAZOP, or SVA analysis which is reviewing plant areas for variances, efficiencies, and threats. Figure 8.1 provides an example of this type of tool that has been in use in the petroleum and chemical industries.

Preferably, copies of all drawings for the analysis should be provided to each team member, no larger than A3 size (i.e., approx. 11" × 17"). If reduced copies are unavailable, team members may share a larger print. Color markers (highlighters) should be available to highlight the drawings (nodes) as required.

Scale models of a facility may also assist and add further understanding to the review process. For existing facilities, photographs or, if time allows, a site visit are also extremely helpful.

The review reference data should be provided in the meeting room or be immediately accessible.

Table 8.2 Ideal SVA Reference Data

1. Plot plan and topographic drawings of the facility and surrounding area
2. Aerial photographs of the facility and surrounding area or access to an internet website showing overhead (satellite) plot views
3. Process description that includes inventories, identification of all materials, tanks, etc.
4. P & IDs that are "as-built" verified for the existing processing facilities
5. Chemical and physical properties of commodities involved, especially hazardous materials (crude oil GOR, MSDS, etc.)
6. Description and routing of all services—power, communication, fuel lines, sewage disposal
7. Layout of transportation network—roads, rail, airports, within facility and outside
8. Description and location of security policies and measures—ID issue, guards, patrols, fencing, monitoring, sensors, weapons, offsite assistance, computer protection, provisions for "outages" of security systems, etc.
9. Previous facility security incidents and data from similar industries
10. Threat information applicable to the facility, product, or management
11. Background checks for employees and long-term contractors
12. Types and number of visitors on a daily basis—vendors, service, consultants, tours, etc.
13. Personnel considered "important" or "vital" to the organization
14. ERPs indicating responsibilities and duties of management
15. Fire and explosion protection system drawings or arrangements (fire and gas detection/alarm, protection—passive and active)*
16. Full description and system design calculations of ESD isolation and depressing (blowdown) capabilities including headers, vents, and flares
17. Operating procedures (including start up or shut down and emergency) and maintenance schedules
18. Electrical hazardous area diagrams
19. Electrical single line diagrams.
20. Instrumentation philosophy (local/remote control, hardwired/data highway, failure mode(s), analog/digital, emergency alarms, etc.)
21. Manning levels, distribution of personnel, levels of supervision, and evacuation routes or plans
22. Special studies or calculations (vapor dispersions, blast overpressure, etc.)
23. Maintenance and testing of security systems and equipment

*See Table 8.1.

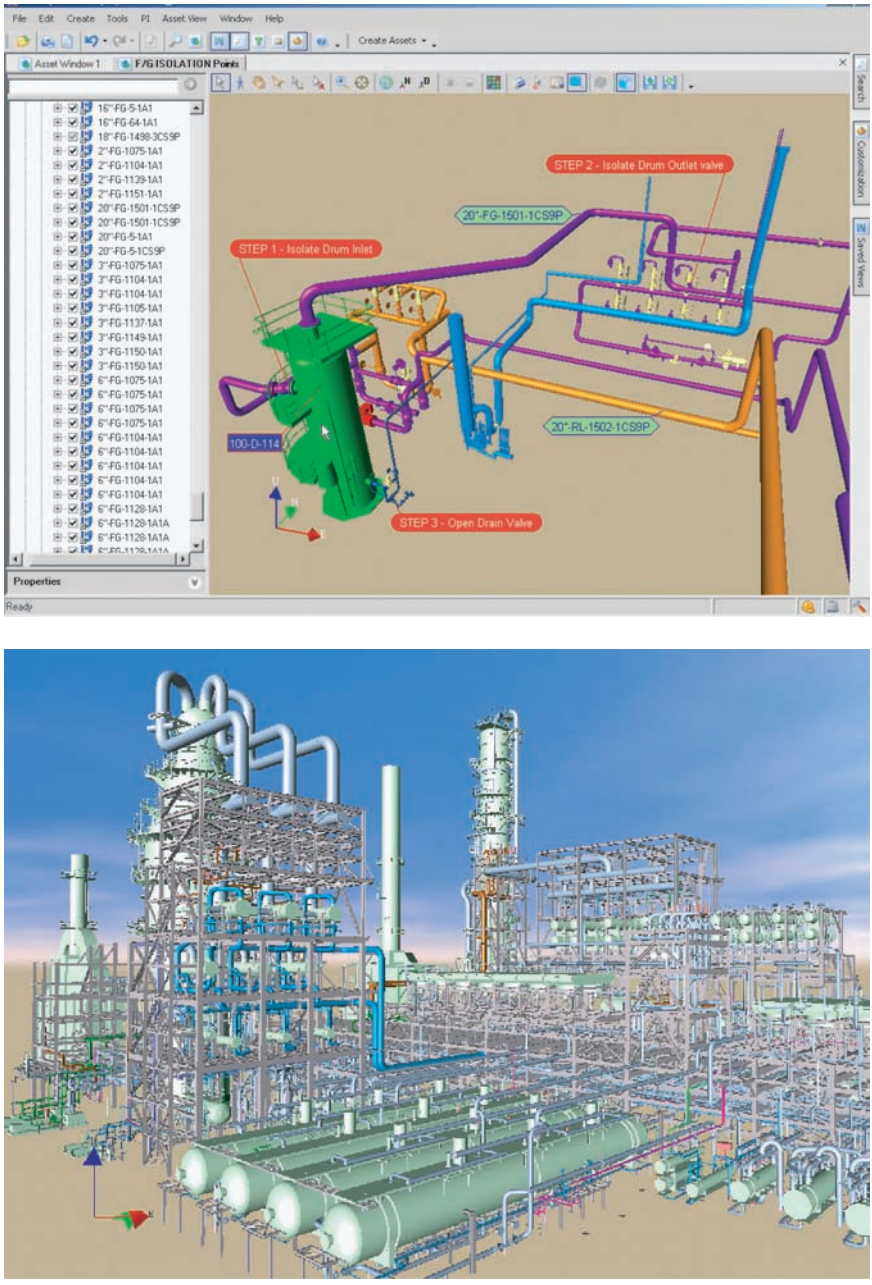


Figure 8.1 3D laser scan "as-built" software modeling (examples courtesy of INOVx Solutions, Irvine, California).

If the "supplemental" data is not available for the review, the review may recommend that the additional drawings and data be obtained for further clarification of the facility's protection features, or to facilitate resolution of possible recommendations.

For large projects, the information is usually available in several stages and therefore several levels of reviews are scheduled.

8.1.4 PHA Consequence and Likelihood Data Resources

The HSE, loss prevention, safety or insurance department of the company will maintain files on incidents within the company that can be reviewed for internal incidents. Various industry insurance companies also publish yearly listings of major incidents by industry. The accuracy of a review is dependent on its input data. Therefore, it is imperative to have failure data and loss histories that accurately represent or can be related to the environment and facilities that are being studied. Inaccurate presumptions will result otherwise. For example, if the environment of the Gulf Mexico is applied to an offshore facility located in southeast Asia, where the basic air and water temperatures are different. How personnel will react and equipment will perform in this comparison is not a direct application from one site to another. As long as assumptions are made and documented in the report, an understanding and acceptance of the review can be possible.

8.1.5 SVA Threat Analysis Data Resources

Information for the security review is available from a variety of sources. These typically include the following:

- Company loss history/security incident records
- Local police information
- State and national agencies (e.g., FBI, DHS, U.S. State Department)
- Industry associations and alerts
- Security consultants
- Subscribed information services

8.1.6 Computer Hardware and Software Support

All review sessions should be recorded using a personal computer (PC). Word processing software should be used for the report narrative write-up.

A computer software spreadsheet, prepared for process safety reviews, is normally used for all reviews in the industry. It facilitates speed, ease of use, and maintains exact consistency in format. Before the advent of PCs in the business office, pre-printed spreadsheet forms were used. Today, almost all reviews are conducted with the aid of a computer, as manual methods are highly inefficient and costly to perform. This is especially important when the man-hour rates of specialized consultants are utilized. Preliminary and final copies of the review reports may possibly be transmitted by electronic means to team members and pertinent company personnel where the infrastructure is available.

An overhead projection of the spreadsheet greatly eases viewing of the computer video output. The overhead projection of the computer screen allows all review team members to easily and simultaneously observe and comment on the recorded information as it is being recorded. A typical review involves at least five personnel, so the projection enables all participants to view the software worksheet as it is prepared. Access to a computer printer is needed to generate hard copies of the worksheets and word processor reports.

Some popular safety and security review software products that are commercially available are listed in Table 8.3.

Table 8.3 Commercially Available Safety and Security Review Software

Vendor	PHA	What-If	HAZOP	SVA
ABS Consulting	Hazard Review Leader™	—	Hazard Review Leader™	Security Review Leader™
Daydem	PHA-Pro®	PHA-Pro®	PHA-Pro®	SVA-Pro™
DNV	Safeti™ Hazard Analysis	—	Safeti™ Hazard Analysis	—
ioMosaic	HAZOP timizer™	HAZOP timizer™	HAZOP timizer™	—
PrimaTech	PHAWorks	PHAWorks	PHAWorks	PHAWorks
Relex	—	—	Relex FMEA/ FMECA	—

8.1.7 Node Identification

Before the review actually starts, the team leader and the scribe should identify, highlight, and list the nodes that will be selected for the review. The team leader should confirm the selection with the project manager before the review begins. These nodes may be modified during the review process, but a baseline and estimate for the review may be prepared from the listing. Preliminary node identification can be entered into the software worksheets by the scribe and also be used in the review reports. The level of resolution of the nodes depends on the level of safety review that is desired.

A facility or process is divided into systems and subsystems. The subsystems will usually contain one or two components called "nodes."

The guidelines for identifying and selecting nodes for safety reviews are as follows:

1. Divide the facility into process systems and subsystems.
2. Follow the process flow of the system under study.
3. Isolate subsystems into major components that achieve a single objective (i.e., increase pressure, remove water, separate gases, etc.).

Some typical nodes identified in the petroleum and chemical industries are:

- Free water knockout vessels
- Distillation column
- Multi-phase separator
- Reactor vessel
- Process tower
- Mixing vessel
- Pumping unit
- Gas cooler
- Heat exchanger
- Compressor
- Metering skid
- Storage tank
- Furnace or incinerator
- Flare
- Cooling tower
- Fire pump

8.1.8 SVA Area Identification

To identify and select the areas in a security process review, the following process is applied:

1. Critical processes or operations are identified.
2. The facility is divided into areas based on geographical separation or consideration of hazardous material present.
3. Systematically review the facility area by area for critical processes or operations.
4. Utilize a global entity to identify a vulnerability that would apply to all areas or processes.

Some typical critical areas identified in the petroleum and chemical industries are:

- Security gates and fencing
- Administration buildings
- Maintenance/repair shops
- Pipelines
- Process units
- Mixing units
- Tank farms
- Loading/unloading facilities
- Utility units (power, water, etc.)
- Transportation network
- Computer hardware and software
- Global

8.2 Review Methodology

The objective of the process hazard or SVA is to identify possible unusual occurrences in the individual systems of the facility or areas and to anticipate the possible consequences resulting from these occurrences. Where these occurrences are deemed to be inadequate, a recommendation for their improvement is provided.

A HAZOP study is undertaken by the application of a formal, systematic, and critical examination of the process and engineering intentions of the process design. The potential for hazards or operability problems are thus

assessed, and malfunction of individual items of equipment and associated consequences for the whole system are identified. This examination of the design is structured around a specific set of parameters and guidewords, which ensures complete coverage of all major possible problems.

The review meeting follows a structured format. The complete process to be studied is divided into discrete nodes or areas. For each node or area, a parameter or guideword deviation is considered. For each deviation, causes are identified. For each cause, consequences are identified. For each consequence, existing protection is identified. After considering existing protection, recommendation for action would be made, if the remaining level of risk is considered unacceptable. Clarifying remarks are included as appropriate. A PHA or What-If review, generally very similar in organization except PHA/What-If questions (usually referred to from a checklist), are substituted for guidewords and parameters, while the SVA utilizes concerns from a threat analysis to determine vulnerabilities (similar to causes or deviations).

The HAZOP, PHA, or What-If review has four primary aims:

- To identify the causes of all deviations or changes from the design intent.
- To determine all major hazards and operability problems associated with these deviations.
- To decide whether action is required to control the hazard or the operability problem.
- To ensure that the actions decided upon are implemented and documented.

For SVAs, the primary aims are similar:

- To identify threats from deliberate acts (source, type, likelihood).
- Perform a vulnerability analysis from the identified threats.
- To determine the consequences associated with these threats.
- Decide whether action is required to prevent or mitigate potential threats.
- To ensure that the actions decided upon are implemented and documented.

8.3 Review Procedure

8.3.1 Review Steps

All reviews follow a structured format. The sequence of steps used to conduct each review is listed below.

8.3.1.1 PHA and What-If Review Steps

1. Define the assumptions about the facility to be accepted during the review process.
2. Define the boundaries and operational modes of the facility under review.
3. Select and confirm the scope of a node.
4. Explain the general design intentions and operating conditions of the node.
5. Specify the node's process parameters.
6. Select or formulate a PHA concern or What-If question.
7. Identify all hazard scenarios (causes) from the PHA concern or What-If question.
8. Identify all major consequences associated with each hazard scenario, without consideration of safeguards.
9. Specify predominate safeguards against each consequence.
10. Determine the probability and severity of each consequence, and document if desired. (For determining probability and severity levels the user is referred to the company's PSM documents and Appendix C.)
11. Make recommendations to mitigate the consequences if the severity and/or probability are unacceptable, according to the company's risk acceptance levels.
12. Reiterate above steps for other PHA concerns or What-If questions.
13. Reiterate above steps for all other nodes in the review.
14. The review team should rank all produced recommendations based on the priority of assigned risk for schedule of implementation. Ranking of recommendations assists senior management in allocating resources.
15. Prepare summary and listing of recommendations in order of priority (ranking).

Question ⇨ Cause ⇨ Hazard/consequence ⇨ Safeguard ⇨ Recommendations

Global questions should also be considered in the PHA or What-If review. Global PHA or What-If questions are generally considered the effects that would simultaneously affect the entire process or facility. These are, but not limited to, equipment layout, seismic activity, flooding, sandstorm, extreme weather conditions, loss of power, human factors, etc.

8.3.1.2 HAZOP Review Steps

1. Define the assumptions about the facility to be accepted during the review process.
2. Define the boundaries and operational modes of the facility under review.
3. Select and confirm the scope of a node.
4. Explain the general design intentions and operating conditions of the node.
5. Specify the node's process parameters.
6. Select a process parameter (flow, pressure, etc.) and specify the design intention relating to this parameter.
7. Apply a deviation (more, less, etc.) to the parameter and develop a meaningful scenario (causes/hazards) from the intention.
8. Identify all scenarios (causes/hazards) of the deviation from the intention.
9. Identify all major consequences associated with each cause, without consideration of safeguards.
10. Specify predominate safeguards against each consequence.
11. Determine the probability and severity of each consequence, and document if desired. (For determining probability and severity levels the user is referred to the company's PSM documents and Appendix C.)
12. Make recommendations to mitigate the consequences if the severity and/or probability are unacceptable, according to the company's risk acceptance levels.
13. Reiterate above steps for other guidewords.
14. Reiterate above steps for other process parameters.
15. Reiterate above steps for all other nodes in the review.
16. The review team should rank all produced recommendations based on the priority of assigned risk for schedule of implementation. Ranking of recommendations assists senior management in allocating resources.

17. Prepare summary and listing of recommendations in order of priority (ranking).

Guideword ⇨ Cause ⇨ Hazard/consequence ⇨ Safeguard ⇨ Recommendations

Global deviations should sometimes be considered in a HAZOP review. Global deviations are generally considered the effects that would simultaneously affect the entire process or facility. These are, but not limited to, equipment layout, seismic activity, flooding, sandstorm, extreme weather conditions, loss of power, human factors, etc.

8.3.1.3 SVA Review Steps

1. Define the assumptions about the facility to be evaluated during the review process.
2. Define the boundaries and operational modes of the areas under review through an initial screening to determine "critical" processes or facilities (use CSAT Top-Screen input).
3. Perform a threat analysis (see Section 8.3.1.4).
4. Select area for review.
5. Apply each threat identified to the area under review and determine if it is vulnerable to an incident.
6. Identify all major consequences associated with each vulnerability, without consideration of safeguards.
7. Specify predominate safeguards against each consequence.
8. Determine the probability and severity of each consequence, and document if desired.
9. Make recommendations to mitigate the consequences if the severity and/or probability are unacceptable, according to the company's risk acceptance levels.
10. Reiterate above steps for other areas identified for the facility.
11. Reiterate above steps for all global applications in the review.
12. The review team should rank all produced recommendations based on the priority of assigned risk for schedule of implementation. Ranking of recommendations assists senior management in allocating resources.
13. Prepare summary and listing of recommendations in order of priority (ranking).

Threat ⇨ Vulnerability ⇨ Hazard/consequence ⇨ Safeguard ⇨ Recommendations

Global deviations should also be considered in the SVA review. Global deviations are generally considered the effects that would simultaneously affect the entire process or facility. These are, but not limited to, power, toxic vapor exposures, etc.

8.3.1.4 Threat Analysis

In order to ensure that a comprehensive evaluation is undertaken for the vulnerability analysis portion of the SVA, a broad range of exposures are considered under a threat analysis (or a consequence and target attractiveness—a two-stage screening tool). Through this analysis, the review becomes focused to target those threats that are deemed most applicable to the facility and to the locations that are likely targets. The threat analysis reviews and identifies the (1) source of threats, (2) potential goal/objectives of the adversaries, and (3) an assessment of the likelihood of the threat, taking into account their motivations and capabilities and the target's attractiveness. Some methodologies or consultants assign relative qualitative weightings to each of these factors in order to perform a relative comparison or establish a further need of evaluation for the SVA. A brainstorming qualitative approach using these factors is commonly used with experienced and knowledgeable experts in security with team members knowledgeable in the target's vulnerabilities. These brainstorming sessions may be supplemented with internal review checklists, leading security questions, or standardized security forms. As a result of these reviews, the facilities to be evaluated can be further screened out and a comprehensive list of specific threats can be identified.

The source of the threats can be external to the company or internal, and are listed in the table below.

Threat objectives are motivated by root cause ideas and these are typically categorized as outlined in Table 8.4.

The likelihood assessment is usually composed of three factors: (1) the asset's attractiveness to the adversary, (2) the degree of threat posed by the adversary, and (3) the vulnerability of the asset. The asset's attractiveness is usually defined by two sub-factors: first, the potential for causing maximum casualties, damage, and economic loss to the company, region, or national infrastructure; second, by the type of target. These include usefulness of process material as a weapon, proximity to a national landmark or asset,

Table 8.4 Threat Analysis Root Cause Motivation and Objectives

Root Cause Motivation	Objective	Potential Target
Political	Change governmental laws, policies, or leadership	Governments/military Vital industries, infrastructure or commodities High life impact locations
Ethnic/racial	Eradication of a minority population	Specific ethnic or racial population/dwellings
Social/cultural	Change customs, behavior, or beliefs	General population/ leaders Religious groups
Religious	Conversion, elimination, or eradication of evil	Religious affiliated governments Religious organizations, sects, groups, or populations Religious leaders
Ideological	Change beliefs, thoughts, and understanding	General population, educational institutions, religious groups, individuals
Economical	Financial distribution change, financial impact, or improper gain	Industry, infrastructure, or commodities Governments
Cause or issue	Perceived concern	Government Industry
Vengeance/revenge	Retribution for perceived injustice	Government (national or local) Industry Individuals

ease of attack, widely known company or product, a symbolic or iconic object, and precursor chemical for chemical or biological weapons. The degree of threat is defined by the adversary's intent, motivation, capabilities, and patterns of operation. Vulnerability is any weakness in the target

that can be utilized by the adversary to enter a facility and interrupt, damage, or harm the operation.

8.4 Credible Scenarios and Causes

The objective of performing a review is to identify and develop credible process upsets or security scenarios that could adversely impact safety, health, environment, quality, productivity, or the public's perception of the company. Obviously, a multitude of events both common (line rupture) and very far fetched (meteor striking the facility) could be identified. The aim is to identify events that have a very real possibility of occurring at the facility. Although all such far-fetched events may be listed, it is generally not practical or necessary to do so. Tables 8.5 and 8.6 present typical scenarios that are generally considered to be credible and non-credible.

The possible causes for process hazard analyses can be categorized by the following:

1. *Equipment failures* (e.g., spurious valve operation, pressure regulator failure, software bugs, leakage, ruptures, excessive wear, wrong material of construction, material defect)
2. *Operational errors* (e.g., opening or closing wrong valve, valve left open or closed, bad mounting).
3. *External events* (e.g., fire in the area, external corrosion, dropped objects, utility failure).

Table 8.5 Credible Scenarios

Credible Scenarios	Examples
A single human error with or without established operating instructions	Incorrect sequencing of events, improper valve positioning, prolonged or excessive cycles, materials transferred too quickly or to the wrong vessel
Two simultaneous human errors with or without established operating instructions	Same as above
A single instrument or mechanical failure	Pump failure, loss of flow, instrument malfunction, line rupture or leak, loss of cooling
A single human error, coupled with a single instrument or mechanical failure	Same as above

Table 8.6 Non-credible Scenarios

Non-credible scenarios	Examples
Simultaneous failure of two independent instruments or mechanical systems	Malfunction or redundant temperature or pressure shutdowns, loss of cooling, and failure of both TSH and PSV
Failure of both the primary and secondary relief device to operate as designed	PSH fails and PSV does not release at the set pressure or is blocked
Immediate change of process fluid characteristics	Increase of produced gas H_2S content from 5 ppm to 500 ppm within one day
Massive impact from foreign event	Plane crash into facility (unless facility sited next to airport)

PSH: Pressure Switch High; PSV: Pressure Safety Valve; TSH: Temperature Switch High.

4. *Product deviations* (e.g., change in GOR, basic sediment and water (BS & W), pressure, sand production, non-conforming products).

(Appendices D and E provide further typical in-depth listings of potential causes when using HAZOP or What-If/PHA methods.)

Causes for SVAs are identified through the threat analysis.

8.5 Safeguards

The primary safeguards for any facility is usually considered human observation, either physically at the plant or from instrumentation in a control room. API RP 14C provides typical process hardware safeguards (instrumentation, alarms, and shutdowns) usually employed in the petroleum and chemical industries.

Security prevention usually involves layered protective measures to make it more difficult for an event to occur and be successful. They can be generally categorized into the following:

- Background checks and IDs—employees, vendors, and visitors
- Layered barriers—entrances, gates, and fencing, including utility entrances/exits
- Manned security surveillance (onsite and offsite)
- Vehicle access (automotive, train, aircraft)—control and search
- Surveillance and alarms (CCTVs, sensors, communications, lighting, etc.)
- Hardening of buildings and structures (blast resistance, windowless, etc.)
- Inventory obscuration, relocation, or reduction
- Portable property control (IDs, vaults/safes, audits, accountability)
- Document control (controlled files, classification, etc.)
- Software integrity (firewalls, encryption, etc.)
- Vital personnel protection (executives and directors)

8.6 Likelihood (Probabilities)

Refer to Appendix C. Likelihood should be relevant to the loss history of the facility itself.

8.7 Consequences

Table C.1 in Appendix C contains typical generic consequence descriptions. Since it is not fully known that a consequence would occur, most consequences are written to state "possible" or "potential" prior to the action of the consequence itself.

8.8 Notetaking

Except for the scribe, no team member is expected to make notes during the review. Their obligation is to discuss the unusual circumstances the design or facility may be subjected to. A team member may desire to take some personal notes during the discussion, which is allowable.

The scribe should transcribe all the "official" discussions onto the worksheet as directed by the team leader. No other team member should direct the scribe. When other team members are allowed to direct the scribe, confusion and misdirection may result losing valuable time for review.

The review team should not be concerned with minor spelling errors that occur during the transcribing of the discussion notes, unless these would lead to an incorrect interpretation of the transcribed notes pursuant to later review of the report. The scribe can correct these later when editing the report or when a period in the session allows time for real-time editing (i.e., when the team is discussing a particular issue).

For the final version of the review report, complete sentences or phrases should be used and abbreviations and non-standard words should be avoided. For example, do not abbreviate "personnel," "pressure," "possible," or "atmosphere." To speed up the actual review process sessions, use a shortened version of these words and then use a "replace" function in the software to insert the complete words during the edit sessions. One abbreviation which will be accepted is "Temp" for temperature.

Avoid hyphenating words in order to split them across two lines within a column. If the replace function is used during editing, the spacing will then be changed and the hyphens may need to be removed. Entries in the worksheet columns should be followed by a period. The only exception will be lists of instrument numbers in the safeguard column. Use all capitals when naming specific instrumentation (PSV, Level Alarm High (LAH), etc.). The review team members should try at all times to use the complete

identification number assigned to the equipment (e.g., 12PSV251 or 23LAH561). If the tag numbers are unavailable during the actual review session (as may occur during project designs), these may be added later, but will have to be provided and verified by the design engineers or equipment operators. Adequate alternative descriptions of the equipment being discussed will need to be provided when this is the case. Avoid the use of slang terminology. Use accepted industrial equipment descriptions and nomenclature whenever possible, as typically described in industry publications (e.g., API RP 14C). Ensure that the personnel listing is updated when there is a change in the review team personnel. Beware of "cutting" and "pasting" columns. It is easy to lose focus and overlook items. Back up all computer hard drive worksheet data on a disk each day. If an automatic "worksheet save" is available, it is usually set at every five minutes.

If the software in use has prepared "pop-up" menus for prompting, these should be used as much as possible for consistency and efficiency. The pop-up menus should not be modified without the review of the PSM coordinator or loss prevention manager. They may be supplemented during the actual review undertaken for a project, when the team has identified a consistent feature which would be useful to refer to in other nodes.

List applicable drawing numbers in the report for each node or area identified in the review. Include pertinent information in the "intention" or "description" at the top of the worksheet. When multiple vessels are included in a single node, correlate the information in the intention or description spaces.

8.9 Helpful Review Suggestions

The following suggestions are offered to aid in the review process:

- Until team confidence is gained, the leader should begin with simple nodes or areas.
- The review should try to follow the process flow, beginning at the fluid inlet and continuing to the outlet (sales). In the case of SVAs similar principles apply—start at the front of the facility and work in a consistent manner inwards or around.
- The leader should always strive for team consensus before proceeding.
- Generally, all the major causes of a particular deviation or What-If question should be listed before moving onto consequences, this alleviates confusion later.

- Ensure that each suggested cause is not a restatement of the deviation, question, or a consequence.
- Think through the complete chain of consequences to the final outcome and record this.
- Note any significant supporting facts in the comment or remark columns of the worksheet.
- Team members should be encouraged to ask "dumb" questions.
- If the team becomes unusually less responsive to the ongoing discussion, a short break should be considered, to rejuvenate the team members.
- Reviews are typically considered boring and laborious. It is advantageous to the team leader if he can keep the momentum of discussions continuing without undue breaks in the process. Once an upset in the review occurs, team members' attention will begin to drift.
- The most costly portion of the review process is the time spent by the review members to attend the sessions. It is imperative that the team leader strives to maintain the estimated review schedule without becoming enlisted in deep discussions during the review cycle.

8.10 Helpful Technical Suggestions

8.10.1 General

- Always check the design rating versus operating conditions for each piece of equipment. Consider whether the deviations may cause the specified design ratings to be exceeded.
- Identify scenarios where equipment could be used in more than one service (i.e., common spare pumps) or where there are alternative methods of operation.
- Check the means of pressure relief for each piece of equipment. Verify that a PSV cannot be isolated from the equipment it is intended to protect.
- Consider common unit upsets or equipment failures.
- For existing facilities, verify that equipment and PSV numbers are consistent between the P & IDs, the equipment data plates, tags in the field, equipment lists, and PSV lists. If there are discrepancies, the equipment numbers in the operating procedures should also be checked.

- For existing facilities, verify that out-of service equipment and lines are properly blinded or isolated.
- Verify that eyewash or safety shower stations are located in the process units where required by company policy.
- Verify that liquid and vapor sample stations meet appropriate company specifications.
- Review acid gas lines for check valves where appropriate.
- If the system contains anhydrous ammonia or other highly hazardous materials, verify that product lines are in compliance with the appropriate industry standards.
- Review heaters for adequate alarms in the event of loss of process flow (consider tube skin temperature alarms).

8.10.2 HAZOP Suggestions

- *No flow*: Identify and list all lines that "normally" flow as part of the intended process. These lines should be listed in the deviation column underneath "no flow." Identify cause for "no flow" for each line identified. Identify consequences, list safeguards, recommendations, etc. for each "no flow" cause.
- *More flow*:
  1. Copy all "no flow" lines identified above to the deviation column underneath "more flow." First, identify cause for all "more flow" lines, then list consequences, safeguards, and recommendations, etc.
  2. Identify lines that are not part of the "intended process flow" that if flowing result in more flow of the intended process. Identify causes, consequences, etc., for these lines.
- *Less flow*:
  1. The first item in "less flow" is usually "see no flow above." This implies that all lines covered in "no flow" may also have similar cause, consequence, etc., as "less flow." For example, a block valve closed in "no flow" is analogous to a block valve partially closed in "less flow" and generally causes, consequences, etc., will be the same or less severe. Discuss if there are other consequences.
  2. Identify lines that are not part of the "intended process flow" that if flowing result in less flow of the intended process. Identify causes, consequences, etc., for these lines.
  3. Include "PSV lift or leaks by" in "less flow," if applicable.

- *Reverse flow*:
  1. Include in "cause" the circumstance that will cause reverse flow (i.e., pump suction block valve open while fill line from tank open, etc.).
  2. List "N/A" (not applicable) when no cause can be identified.
  3. List check valves in "comments" as an optional reference.
- *Temperature*:
  1. Reference items from the flow parameter where "no/less/more flow" results in high or low temperature as well.
  2. Identify streams in the deviation column if node includes an exchanger.
  3. List N/A for low temperature if there are no significant consequences.
  4. Review node operating and design temperatures. If operating temperature can exceed design temperature, list as consequence "Operating temperature may exceed design temperature." Establish recommendation as appropriate.
- *Pressure*:
  1. Reference items from the flow parameter where "no/less/more flow" results in high or low pressure as well.
  2. On modes that include cooling water exchanger, verify PSV on cooling water side for thermal relief. Cause for high pressure cooling water side—"Block valve closed on cooling water inlet/outlets to exchanger."
  3. The following items should be evaluated in "low pressure": (i) tube leak or rupture; (ii) line or equipment rupture; (iii) drain or bleed valve open; (iv) PSV lifts or leaks by.
- *Level*: Reference items from the flow parameter where "no/less/more flow" results in high or low level as well. Also review pressure and temperature parameters for references.

8.10.3 General PHA, What-If, HAZOP, and SVA Review Suggestions

- List both operating and design information in the "intention" for each parameter, first list operating and then design.
- Identify control loops and equipment by number.
- If cause originates from adjacent node or area, identify specific examples of the cause if possible (i.e., "Block valve closed on upstream node").

- Strive to be as specific as possible on identification of process upsets (i.e., "Process upset resulting in loss of reaction," etc.).
- Try to match one consequence with one cause, as much as possible. If necessary, list consequences as long sequence of events (i.e., "this and that resulting in this and possible that").
- Safeguards that are located on other nodes can be referenced. Generally, it is not necessary to be specific when using "alarms on other nodes" as a safeguard. However, be sure to verify it before applying it. If the consequences are severe, a specific reference of the alarm should be made.
- The consequences of control valves failing to open or close should be evaluated, regardless of the specified failure position of the valve.
- Do not use an indicator or an alarm that derives its signal from a control loop as a safeguard if that control loop is the cause of the deviation.
- Avoid duplicating recommendations for similar equipment or occurrences. The ordinal recommendation should be numbered; subsequent recommendation should be referenced to the original recommendation. For example, Original recommendation: (GCU-101) Consider installing compressor shutdown on high level in 12V-201. Subsequent recommendation: Consider installing a compressor shutdown on high level in 12V-201 (Refer to GCU-101, Node #3, High Level, Item #2). Subsequent repeating of identical recommendations should be assigned a priority in relation to the original recommendation.
- When recommending to verify alarms, list recommendation number of ordinal recommendation for all subsequent recommendations. Reference to the ordinal recommendation is not required. For example, Original recommendation: (GCU-101) Consider verifying alarm: 12PC250 (Pressure Alarm High (PAH)). Subsequent recommendation: (GCU-101) Consider verifying alarm: 12LC260 (LAH). Also, review set point while reviewing alarms. If set point needs adjustment, list suggested value in remarks.
- Typically a fire protection system or response is not used as a safeguard.
- Generally, take no credit for safeguards when developing consequences, that is, even when a high level alarm would activate a downstream equipment shutdown, consequences should be

liquid carryover and damage to downstream equipment. The high level alarm should then be listed as a safeguard.

- All safeguards shall be listed individually. Do not "reference" safeguards.
- Separate listing of the indication and alarm function of a control loop safeguard is not necessary. Listing a control loop as a safeguard implies that all control, indication, and alarms that are part of the control loop apply. Note that a recommendation to verify alarms may be required.

8.11 Assumptions for the Review Process

A common mistake in many safety reviews is to delve into the analysis without a basic understanding or agreement of how the facility was designed or intended to be operated. Prior to a discussion of the hazards and consequences, the team should identify and agree to the design philosophy of the facility under review. Sometimes, some features of a facility are assumed, but never documented.

Typical examples are as follows:

1. The facility is manned (operated) with adequate staff as intended by the design philosophy.
2. The failures of process equipment, instrumentation, and safety devices occur randomly.
3. The failure rates and demand rates of safety devices are considered low.
4. Facility maintenance and operational testing is considered accomplished accurately and timely.
5. Security patrols and observations are conducted as required by company guidelines.
6. The time to repair equipment or perform maintenance is considered negligible.
7. Production flows are of a constant volume.
8. Production flows are generally of an identical composition.
9. The facility is designed, operated, and maintained to good management and engineering standards.
10. Security measures are in place for the perceived threats faced by the company.
11. Management is concerned with safety and security.

Typical periods when these assumptions may not be true are during start-up or shutdown, turnarounds, maintenance activities, unusual environments, process upsets, labor disputes, national political instability, etc.

8.12 Providing Recommendations

Recommendations produced by the reviews are the most important item of interest from the report. Therefore, they require special attention. The team leader is not responsible to produce any recommendations. The team leader has to guide the team during the review to arrive at a consensus of what is the required level of protection desired for the facility. In this respect, the team leader can suggest methods of protection for safety or security commonly employed by the company's philosophy of protection or applied in the industry. All recommendations should be arrived at through a consensus of the team review members.

Team members should primarily consider the technical merit of the recommendations and should not be intimidated by their cost or project schedule impact; however, the practicability of all suggestions should be kept in mind. It must also be realized that an infinite amount of money would be required to eliminate "all" hazards that an employee, the public, or the company could be exposed to. The final decision on any major recommendation should be evaluated in its absolute terms, that is, its cost to implement by performing a value analysis (cost versus benefit).

Recommendations should be as precise as possible and include specific equipment references (e.g., the facility equipment tag numbers) when appropriate. Later interpretation by management and design engineers trying to resolve the recommendation may be confusing if the exact nature of the recommendation is not understood. Where further clarifications are needed, the "comments" and "remarks" columns of the worksheet should be used.

The team members should not feel obligated to make recommendations that completely resolve the concern. An engineering or operations group will evaluate a recommendation after the review to determine the best course of action. In many cases, a recommendation may be made to evaluate, study, or perform a cost-benefit analysis, rather than insist that a particular feature be added to the process or facility. Experience has shown that many reviews waste valuable time trying to determine the exact nature of an item to recommend. Future in-depth evaluations of the recommendation

may entirely alter the suggested solution. If the review team recommended a study or evaluation of the problem, they could immediately continue to other areas of the review and save valuable man-hours. A review may uncover "common" minor safety hazards that are of the nature of slips, trips, and falls. These may be noted and appropriate recommendations made; however, the team should strive to avoid undue concentration on these events, as the objective of these reviews are to identify potential major process hazards or security concerns.

If a review consistently indicates considerable design faults, the quality of the design or its completeness may be in question. When this occurs, an evaluation of the project design team's qualifications or timing and level of the review should be carried out.

Overall recommendations for safety reviews usually can be categorized into any of the following:

- Modify the design.
- Add an indicator or sensor.
- Add an alarm.
- Add an interlock.
- Develop or change a procedure.
- Develop a preventive maintenance procedure.
- Conduct a more detailed safety or security review.
- Review the design.
- Provide a means to isolate.
- Improve fire or explosion protection.
- Improve incident emergency response.

For SVA reviews, recommendations typically can be categorized into the following:

- Employee hiring screening.
- Contractor screening.
- Behavior observation program.
- Perimeter security procedures.
- Improvement to physical perimeter systems (fencing, lighting, roads, sensors, CCTVs).
- Controls on documentation.
- Coordination with local agencies.
- Obscuring facilities or changing their appearance.

- Inventory reduction or relocation.
- Preplanning with emergency response agencies.

8.12.1 Examples of Inadequate versus Adequate Recommendations

All the recommendations produced by the team should be easily understood by future readers of the report. It is therefore imperative that the recommendations be clear, concise, unambiguous, and relevant. They should also be given a ranking based on reducing risk at the facility.

Examples of inadequate versus adequate recommendations are illustrated in Table 8.7.

8.12.2 How to Rank Recommendations

Recommendations that are associated with the highest risk should have the highest priority. Those with the least risks would therefore be assigned the lowest priority. Usually, most of the low-priority items are of low costs and therefore can be easily implemented. They may be completed before most of the highest priority items have been resolved or implemented. This is natural since the low-priority, low-cost items are less complex and time consuming than the high-priority issues. The priority indirectly indicates that more man-hours may be necessary for its resolution and/or implementation.

Items that are more threatening to life safety should always be ranked first. Next would be protection of the environment and last protection of the company's property, continued business operations, and prestige.

Usually, the probability and consequence levels can be determined separately and then combined to formulate a risk level. The risk level develops a ranking of the recommendation.

8.13 Quality Audit

With the increasing emphasis on quality in all facets of a facility operation, a quality assurance (QA) audit checklist should be completed as an essential final step in the review meeting. This helps to ensure that an adequate review occurs and that project quality objectives are being met. A suggested

Table 8.7 Examples of Recommendation Quality

Inadequate Quality	Adequate Quality
Add a pressure indicator (PI)	Add a local PI on the north side of vessel V-101 for operator surveillance
Verify sizing of the relief valve	Verify relief valve PSV-11 on V-102 is sized for fire conditions as per API RP 520
Increase security patrols	Increase the security patrols at Tank Farm #2 from every four hours to every hour
Study the problem of surge	Conduct a calculation of surge pressure in line 6-3W-1243 from start-up of pump P-201 within the next two months
Check the level of the overflow tank	Add in operating procedure X-123 to verify daily if overflow tank T-105 is within 25% of its capacity
Increase maintenance on the unit	Revise maintenance schedule Q-50 for engines QM-350 A & B; revise bi-monthly change of lube oil filters to monthly
Determine depressurization needs	Evaluate vessel V-501 for depressurizing needs from spill fires, weakening its steel in accordance with API Standard 521/ISO 23251
Check that valve fails closed	Field verify if ESD valve V-5 closes when power is removed from its actuator

checklist is provided as part of this publication in Appendix B. The team leader should review and verify the checklist with all members of the review team as a final assurance that significant and pertinent items have been considered and accomplished.

Any exceptions to the checklists should be explained on the form. Both the team leader and the project manager (or project, facility, process, or manufacturing engineer) should sign-off the audit checklist. The checklist is added to review report as a quality verification of the review process.

9 Review Worksheets

A worksheet (database spreadsheet) form is used to collect and collate the process hazard analysis review data. A computer software generated spreadsheet is typically used. For a complete description of commercially available software, the user should refer to the manufacturer's software user instructions. Although pre-printed forms may be used, they are highly inefficient and should be maintained only as a backup in case of computer hardware or software failures.

The worksheet is organized with identification data at the top of the page, followed by columns for the review discussions and notes. The columns are usually organized from left to right in the sequence of the review information that is gathered and analyzed. In this respect, the deviations are written on the left, causes and consequences in the middle, and safeguards, possible recommendations and comments and remarks on the right. Examples of suggested worksheets are given in Tables 9.1–9.4.

9.1 PHA Worksheet

For a typical PHA worksheet the columns are identified by the following titles and a description of their contents is given below.

What If: PHA concern that prompts process hazard analysis concerns.

Hazard: Characteristic, (physical or other) that has the potential for causing harm to people, property, the environment, or continued business operation.

Consequences: The effects of a deviation resulting from various cases.

Safeguards: Measures taken to prevent or mitigate the risks of accidents.

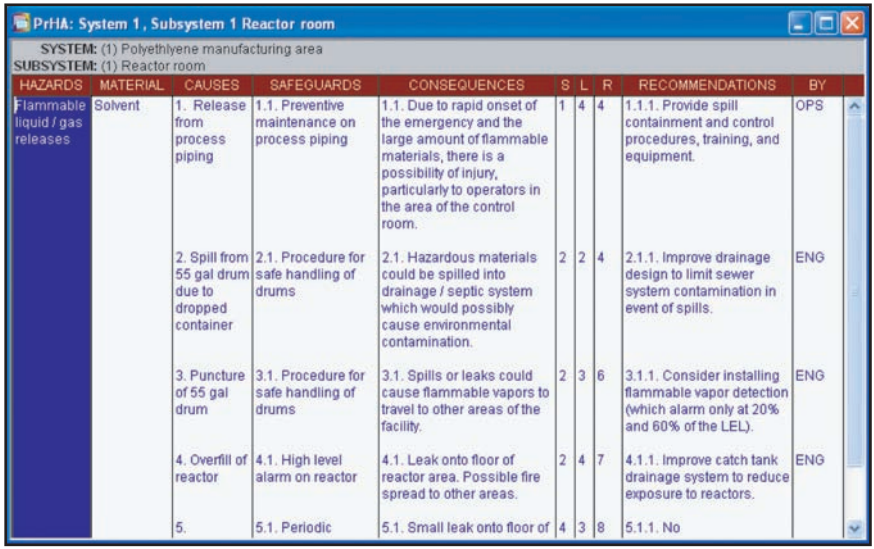
Severity (S): The magnitude of physical or intangible loss consequences.

Likelihood (L): A measure of the expected frequency of an event's occurrence.

Ranking (R): The qualitative estimation of risk from severity and likelihood levels in order to provide a prioritization of risk based on its magnitude.

Table 9.1 Suggested PHA Worksheet Arrangement

PHA Concern	Hazard	Consequences	Safeguards	S	L	R	Recs.	Comments


PrHA: System 1, Subsystem 1 Reactor room

SYSTEM: (1) Polyethlyene manufacturing area
SUBSYSTEM: (1) Reactor room

HAZARDS	MATERIAL	CAUSES	SAFEGUARDS	CONSEQUENCES	S	L	R	RECOMMENDATIONS	BY
Flammable liquid / gas releases	Solvent	1. Release from process piping	1.1. Preventive maintenance on process piping	1.1. Due to rapid onset of the emergency and the large amount of flammable materials, there is a possibility of injury, particularly to operators in the area of the control room.	1	4	4	1.1.1. Provide spill containment and control procedures, training, and equipment.	OPS
		2. Spill from 55 gal drum due to dropped container	2.1. Procedure for safe handling of drums	2.1. Hazardous materials could be spilled into drainage / septic system which would possibly cause environmental contamination.	2	2	4	2.1.1. Improve drainage design to limit sewer system contamination in event of spills.	ENG
		3. Puncture of 55 gal drum	3.1. Procedure for safe handling of drums	3.1. Spills or leaks could cause flammable vapors to travel to other areas of the facility.	2	3	6	3.1.1. Consider installing flammable vapor detection (which alarm only at 20% and 60% of the LEL).	ENG
		4. Overfill of reactor	4.1. High level alarm on reactor	4.1. Leak onto floor of reactor area. Possible fire spread to other areas.	2	4	7	4.1.1. Improve catch tank drainage system to reduce exposure to reactors.	ENG
		5.	5.1. Periodic	5.1. Small leak onto floor of	4	3	8	5.1.1. No	

Figure 9.1 Sample PHA worksheet (figure reprinted with permission from Primatech, Inc., Columbus, Ohio).

Recommendations: Activities identified that may reduce a risk through the lowering of a probability or consequence level.

Comments: Technical notes of the facility, system, or process under study.

9.2 What-If Worksheet

For a typical What-If worksheet the columns are identified by the following titles and a description of their contents is given below.

What If: "What-If" question scenarios that prompt process hazard analysis concerns.

Hazard: Characteristic (physical or other) that has the potential for causing harm to people, property, the environment, or continued business operation.

Consequences: The effects of a deviation resulting from various cases.

Safeguards: Measures taken to prevent or mitigate the risks of accidents.

Severity (S): The magnitude of physical or intangible loss consequences.

Likelihood (L): A measure of the expected frequency of an event's occurrence.

Ranking (R): The qualitative estimation of risk from severity and likelihood levels in order to provide a prioritization of risk based on its magnitude.

Recommendations: Activities identified that may reduce a risk through the lowering of a probability or consequence level.

Comments: Technical notes of the facility, system, or process under study, if necessary.

Table 9.2 Suggested What-If Worksheet Arrangement

What-If	Hazard	Consequences	Safeguards	S	L	R	Recs.	Comments

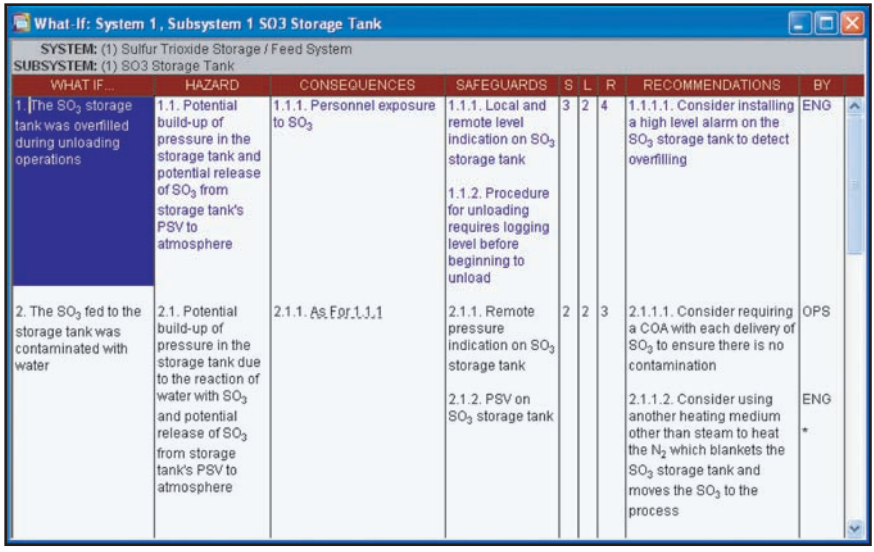


Figure 9.2 Sample What-If worksheet (figure reprinted with permission from Primatech, Inc., Columbus, Ohio).

9.3 HAZOP Worksheet

For a typical HAZOP worksheet the columns are identified by the following titles and a description of their contents is given below.

Guideword (GW): A simple word or phrase used to generate deviations by application on a system or process activities (pressure, level, temperature, etc.).

Deviation: A departure from the design and operating intention (high, low, more, less, etc.).

Causes: Reasons because of which deviations occur (failures, wrong operation, etc.).

Consequences: The effects of a deviation resulting from various causes (fire, explosion, process upset, etc.).

Safeguards: Measures taken to prevent or mitigate the risk of accidents (operator surveillance, instrumentation, ESD, blowdown, etc.).

Severity (S): The magnitude of physical or intangible loss consequences (qualitative measure of consequences compared to industry experience).

Likelihood (L): A measure of the expected frequency of an event's occurrence (qualitative measure of probability based on historical data or theoretical estimate).

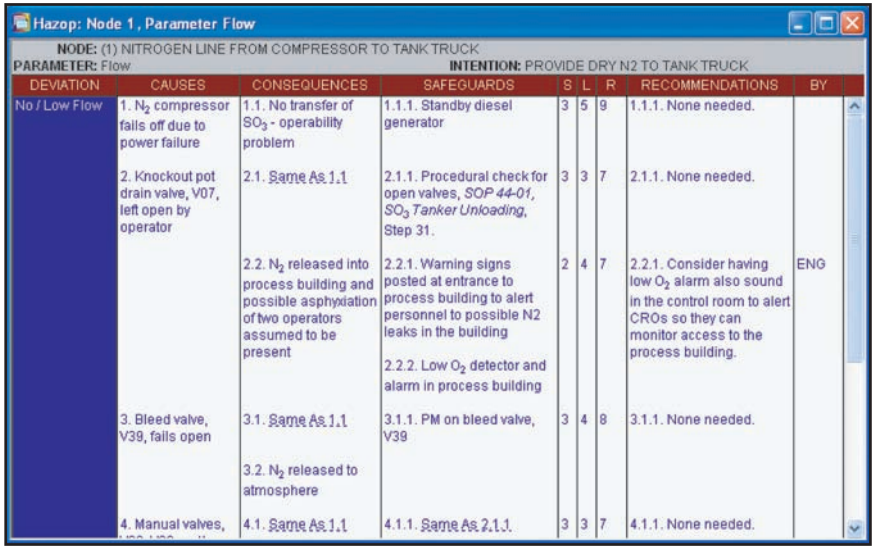
Ranking (R): The qualitative estimation of risk from severity and likelihood levels in order to provide a prioritization of risk based on its magnitude (refer to corporate risk matrix for ranking based on severity and likelihood levels).

Recommendations: Activities identified that may reduce a risk through the lowering of a probability or consequence level (suggested safety improvement to a process to reduce risk level).

Comments: Technical notes of the facility, system, or process under study (supplemental information about the issue being discussed), if necessary.

Table 9.3 Suggested HAZOP Worksheet Arrangement

GW	Deviations	Causes	Consequences	Safeguards	S	L	R	Recs.	Comments



Hazop: Node 1 , Parameter Flow

NODE: (1) NITROGEN LINE FROM COMPRESSOR TO TANK TRUCK
PARAMETER: Flow INTENTION: PROVIDE DRY N2 TO TANK TRUCK

DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	S	L	R	RECOMMENDATIONS	BY
No / Low Flow	1. N_2 compressor fails off due to power failure	1.1. No transfer of SO_3 - operability problem	1.1.1. Standby diesel generator	3	5	9	1.1.1. None needed.	
	2. Knockout pot drain valve, V07, left open by operator	2.1. Same As 1.1	2.1.1. Procedural check for open valves, *SOP 44-01, SO_3 Tanker Unloading*, Step 31.	3	3	7	2.1.1. None needed.	
		2.2. N_2 released into process building and possible asphyxiation of two operators assumed to be present	2.2.1. Warning signs posted at entrance to process building to alert personnel to possible N2 leaks in the building 2.2.2. Low O_2 detector and alarm in process building	2	4	7	2.2.1. Consider having low O_2 alarm also sound in the control room to alert CROs so they can monitor access to the process building.	ENG
	3. Bleed valve, V39, fails open	3.1. Same As 1.1 3.2. N_2 released to atmosphere	3.1.1. PM on bleed valve, V39	3	4	8	3.1.1. None needed.	
	4. Manual valves,	4.1. Same As 1.1	4.1.1. Same As 2.1.1.	3	3	7	4.1.1. None needed.	

Figure 9.3 Sample HAZOP worksheet (figure reprinted with permission from Primatech, Inc., Columbus, Ohio).

9.4 SVA Worksheet

For a typical SVA worksheet the columns are identified by the following titles and a description of their contents is given below.

Threat: Description of the threat identified in the threat analysis and under review.

Vulnerability: Characteristic (physical or other) that has the potential for causing harm to people, property, the environment, or continued business operation.

Consequences: The effects of a threat occurring.

Safeguards: Measures taken to prevent or mitigate the risks of a threat.

Severity (S): The magnitude of physical or intangible loss consequences.

Likelihood (L): A measure of the expected frequency of an event's occurrence.

Ranking (R): The qualitative estimation of risk from severity and likelihood levels in order to provide a prioritization of risk based on its magnitude.

Recommendations: Activities identified that may reduce a risk through the lowering of a probability or consequence level.

Comments: Technical notes of the facility, system, or process under study, if necessary.

Table 9.4 SVA Worksheet Arrangement

Threat	Vulnerabilities	Consequences	Safeguards	S	L	R	Recs.	Comments

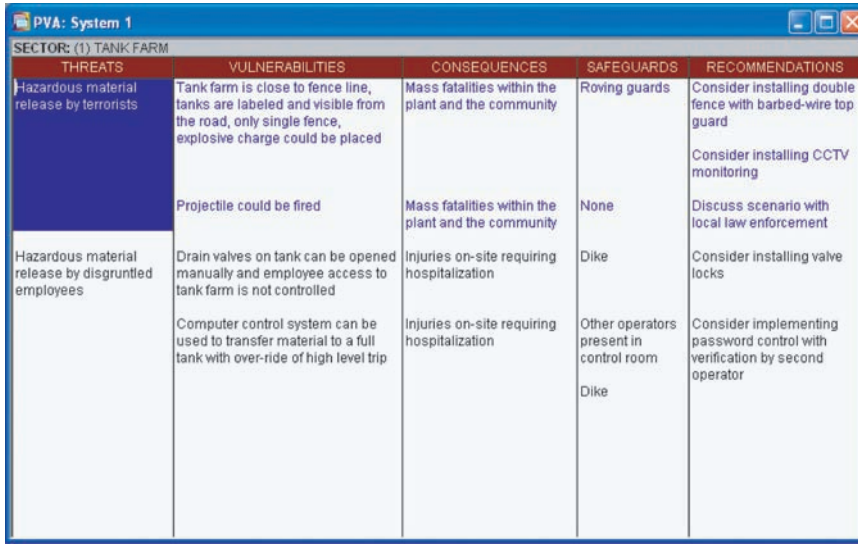


Figure 9.4 Sample SVA worksheet (figure reprinted with permission from Primatech, Inc., Columbus, Ohio).

9.5 Worksheet Identification

Every worksheet should be provided with identification and a means to correlate it to the node and design conditions it was evaluated against. Locations for date, location, drawing reference, node identification or description, and design parameters should be noted on each worksheet.

10 Report Preparation and Distribution

10.1 Report Stages and Purpose

Typically, four stages of the study report are provided—preliminary, draft, final, and addendum. The purpose of each individual level of the report is described below.

Preliminary report: A rough draft of the report provided to the project manager. It is used to give a good immediate approximation of the content of the final report that will be issued including any recommendations that will be made. This report is usually produced immediately after the last review session, from the unedited computer worksheets, and does not include copies of drawings.

Draft report: A report that has been reviewed and edited by the team leader and the scribe to ensure proper organization and correct transcription of notes. This report is issued to interested parties to provide comments on its format, accuracy, and completeness.

Final report: The finished review meeting report that has evaluated and incorporated pertinent comments from the draft report and forms part of the project design file.

Addendum report: A report that resolves any recommendations concluded from the HAZOP or What-If review final report. This report is issued before start-up of the facility and added to the final report as an addendum.

10.2 Report Preparation and Organization

Recent practice is to issue electronic reports (e-copies) for ease and speed of distribution and for reduction of hardcopy files, with scanned or e-copies of drawings/attachments included. Electronic document review software is available (e.g., Doc Review) to route the e-copies to individuals, which allows for comment insertion at the applicable location. Hardcopies are usually issued for the final version. Final reports should be provided on A4 (i.e., approximately 8 1/2" × 11") paper size, preferably in three ring

binders (or equivalent) with individual labeled sectional tabs. Ideally, included drawings should be neatly folded to A4 size of reduced prints on A3 (i.e., approximately 11" × 17") paper size.

Drawings that highlight the nodes (piping and equipment outlines) or areas (for SVAs) should be included by:

- bubble outlining and identifying the nodes/areas on the P & IDs/plot plan,
- color coding (highlighting) the nodes/areas on the P & IDs/ plot plan, or
- preparing separate "node" P & ID/plot plan drawings.

Inclusion of node drawings should be provided immediately after the respective node worksheet. This eases supplemental understanding of the review process during later audits or reviews of the document.

Final reports should be clearly organized. The suggested contents of a report are identified in Table 10.1.

The final report does not have to physically include all of the supplemental project or facility design data that was used in the review. This data can be referenced, as long as the referenced location is adequately described and the information is maintained.

10.3 Report Distribution

Copies of the report are to be prepared by the team leader and delivered to the project manager. The project manager is responsible for formally distributing copies of the reports. Information stored on computer software disks may be considered original copies.

As with most of a company's information where proprietary data, trade secrets, or a facility's security may be involved, process hazard analysis reports may be considered confidential information. Release outside the company should be discussed with the legal staff or by the contractor agreements made with outside personnel participating in the study. A suitable distinction should be applied to the cover of any review-produced documents whenever confidentiality is required.

Table 10.1 Suggested Contents of a Typical Report

Item	Subject
A	Title or cover page (company name, facility location, date, report number, revision, confidentially statement)
B	Table of contents
C	Procedure description
D	Methodology
E	List of team members and qualifications (names, titles, degrees, years of experience, licenses, etc.)
F	Meeting location, date, and duration of study sessions
G	Facility/process description (process flow, mechanical description, vessel instrumentation and controls, ESD and process shutdown philosophy, normal operating parameters, and design codes used)
H	Critical areas or facilities (for SVA reports)
I	Threat analysis summary or statement (for SVA reports)
J	List of assumptions made prior to or during the review
K	Node listing and descriptions (for PHA, What-If, or HAZOPs)
L	Node or area worksheets (date, node description, drawing number parameters, process intention, guidewords/What-If questions, deviation, cause, consequence, safeguard, recommendations, comments, and node P & IDs)
M	Other drawings (PFD, plot plan, cause and effects chart), with an overall drawing index to be included
O	Separate summary of recommendations in a suggested ranking order for implementation
P	Quality assurance (QA) audit checklist
Q	Software disks containing master copy of report spreadsheets (for file copy)

The following is a listing of the typical distribution of reports. Internal company policies may require additional copies of reports for senior management review. A document distribution matrix is typically employed in project designs that indicate what documentation is to be provided to the company's personnel for review. A suggested document distribution matrix is provided in Table 10.2. This distribution matrix may supplement the facility or project drawing distribution matrix.

Table 10.2 Suggested Document Distribution Matrix

	Preliminary	Draft	Final	Addendum
Team leader	X	X	X	
Scribe	O			
Project manager*	X	X	X	X
Operations representative	O	X	X	
Safety representative	O	X	X	
Supplemental member	O	X	X	
Project file		O	X	X
Facility file			X	X
Risk engineer**		O	O	O
Environmental engineer**		O	O	O
Engineering manager		X	X	X
Operations manager		X	X	X
Loss prevention manager		X	X	X
Security manager (for SVAs)	O	X	X	X
Legal		O	O	O
Senior management			S	S

X: recommended; O: optional; S: optional summary report.

*Project, process, facility, drilling engineer, or security representative (for SVAs).

**May be same copy as provided to the loss prevention manager.

10.3.1 Preliminary Reports

A preliminary report is usually provided by the team leader to the project manager. These are usually issued immediately after the study sessions but not later than two working days after the conclusion of the review meetings. The report should be labeled “preliminary’ and is considered a level “A” revision. The project manager usually distributes copies of the preliminary reports to the review team members. Additional copies may be distributed by the project manager at his/her discretion.

10.3.2 Draft reports

A draft report is to be provided by the team leader to the project manager. It should be provided within five working days of the conclusion of the review meetings. The report should be labeled “draft” and is considered a level “0” revision.

The project manager distributes copies of the draft report as follows:

All team members (except scribe)	Loss prevention manager
PSM coordinator	Security manager (for SVAs)
Fire protection or risk engineer	Operations manager
Environmental engineer	Engineering manager
Project file (original worksheet/software copies)	Facility office file

In some cases, a review by the company’s legal staff and senior management may be necessary.

It may be beneficial, where it is deemed cost-effective and efficient for the completion of a project, for the project manager to distribute copies of the draft report to the appropriate project engineering and design personnel. This may allow these individuals to resolve recommendations as soon as possible and prior to the finalization of the report. This avoids costly changes in the design later in the process.

10.3.3 Final Reports

The final report is to be provided by the team leader to the project manager. It should be issued within ten working days of receiving all comments on the draft report. The report should be labeled “final” and is considered a level “1” revision.

The project manger distributes copies of the final reports as follows.

All team members (except scribe)	Loss prevention manager
PSM coordinator	Security manager (for SVAs)
Fire protection or risk engineer	Operations manager
Environmental engineer	Engineering manager
Project file (original worksheet/software copies)	Facility office file

10.3.4 Addendum Reports

The addendum report should be prepared by the project manager with the help of the team leader. This report is prepared and issued before start-up or operation of the facility or system. For existing facilities, this is determined as a reasonable period (as determined by local management) for the recommendations to be resolved by management and action taken.

Some recommendations may require that an extensive action plan be developed for resolution. The action plan should identify a time frame to address the item, resources necessary, and frequencies of status reports.

The project manager distributes copies of the addendum report as follows.

Project engineer	Loss prevention manager
PSM coordinator	Security manager (for SVAs)
Fire protection or risk engineer	Operations manager
Project file (original worksheet/software copies)	Engineering manager
Facility office file	

In some instances, legal and senior management should be provided with a copy of the addendum report.

11 Handling and Resolution of Recommendations

It is important to realize that a review is not actually complete until all recommendations have been resolved and a closeout "addendum" report is produced. All recommendations should be decided upon in a sound, rational, and technical manner when all alternatives have been identified and studied. If such documentation is not prepared, future possible accident investigations may query the effectiveness of the review and possible legal implications may arise.

The project manager should be responsible for handling and resolving recommendations. He/she may designate a person to handle the day-to-day activities for this function. Typically, a risk engineering or loss prevention engineer is nominated for this task. Once the project manager has a suggested course of action for each recommendation, these should be submitted to the appropriate higher-level management for their concurrence.

11.1 Ranking and Classifying Recommendations

There are several possible actions for each recommendation listed in the addendum report.

- Implement the recommendation as stated in the report.
- Implement a viable alternative to the recommendation.
- Document reasons why the recommendation is not to be implemented. A strong argument for not implementing the recommendation should be made (e.g., not cost-effective, technically infeasible, not an accepted design as per applicable codes, the recommendation would create additional hazards).

Changing the design of an existing facility or an advanced design is usually the least cost-effective option. Often, some control logic change is more easily implemented and incorporated.

The project manager should first confirm the risk ranking of the recommendations received from the review report. The most important recommendations should receive the most attention. Hazards that pose an

immediate life, health, environmental, or security hazard should have their recommendations immediately implemented; in fact, if found during the review itself, corrective action should be taken at once, before completion of the entire review. Likewise, for any recommendation which indicates that national or local regulation may not have been accommodated.

Recommendations that have a minimal cost should be readily accepted, since their cost to review and evaluate would probably be more than to immediately implement the recommendation. For example, if the cost to evaluate the usefulness of a recommendation is more than the apparent cost to implement it, the value to the company is wasted and inadvertently lost. The project manager should be able to readily evaluate recommendations that are useful and of minimal cost to implement them without further expert evaluation. Usually, for most large companies, if the evaluation is less than on the order of several days of technical work and, say, of several thousand dollars of materials, it is considered negligible and should be readily implemented. The project manager may then desire to indicate which recommendations should be accepted, rejected, or studied for further evaluation.

The recommendations should then be divided into various specialized disciplines (safety, operational, engineering, etc.) for evaluation, verification, and concurrence on the project manager's decision. Experts in these disciplines should first reconfirm the circumstances that the team has postulated to arrive at the need for a recommendation. If these are reaffirmed, the suggested recommendation should then be evaluated.

Recommendations should be analyzed by first:

1. ensuring that the recommendation follows the safety philosophy applied to the facility;
2. those that remove the cause of the hazard or operability problem or what-if question; and
3. those actions that reduce the consequences (either by lessening the probabilities or consequences themselves by protective measures).

Usually, it is better and more effective to remove the hazard and make the facility more intuitively safe and secure. If there is no practical method to remove the hazard, the likelihood (probability) for reducing the event consequences should be considered next. Finally, if the probabilities cannot be

reduced, the consequences should be evaluated with additional protective measures.

For acceptable recommendations, prepare cost estimates. For unacceptable recommendations, request expert justification for rejection. Validate the cost to implement the subject recommendation. If it is not a cost-effective measure or approach, include risk acceptance as an option with insurance alternatives.

Track the status of recommendations until resolution is obtained. Obtain management approval for the resolution of the recommendations (prepare and obtain budgets and engineering designs).

11.1.1 Recommendation Resolution Summary

1. Implement immediate hazard or regulatory recommendations as soon as possible.
2. Accept recommendations that are minor or easy to implement.
3. List remaining recommendations in order of importance.
4. Categorize the remaining recommendations (i.e., safety, operability, environmental).
5. Submit proposed recommendations to recognized expertise for evaluation and if in agreement, a cost estimation for implementation should be carried out.
6. If recommendation is not acceptable, prepare alternative or justification for rejection.
7. Determine if the cost to implement provides an acceptable value to the company (i.e., lowering of risk (consequences or probabilities)).
8. Submit formal listing of recommendations with suggested actions to management for approval.
9. Implement and track closing of recommendations as required.

11.2 Objectives of a Safe and Secure Facility Design

The general project design philosophy is defined as follows (in order of importance):

1. Prevent the immediate exposure to the health and safety of individuals, impact on the environment, or undue exposure of the company to a security risk.

2. Meet the requirements of national and local governmental regulations for HSE and security protection.
3. Are designed to be inherently safe and secure.
4. Achieve a level of risk that is acceptable to the government, the company, the industry, and the public.
5. Protect the economic interests and reputation of the company (from both onsite and offsite damages).
6. Comply with corporate policies and guidelines.
7. Consider the interests of joint venture partners.
8. Achieve a cost-effective and practical approach.
9. Minimize space (and weight, if offshore) implications.
10. Respond to operational needs and capabilities.
11. Are consistent with industry practices (i.e., AIChE, API, ASME, ANSI, NACE, NFPA).

11.3 Recommendation Action Plans

An action plan for each recommendation should be made and tracked until the recommendation is closed out. Typically, a recommendation action plan summary is prepared in tabular format for ease of use where multiple recommendations may exist. An example is shown in Table 11.1. Additionally, most companies use proprietary corporate data software for capturing and managing their internal records electronically (e.g., SAP, Oracle). These programs can be easily tailored to input and track the progress of safety and security recommendations until closure.

The project manager should maintain and issue an action plan summary until all items are closed out. The addendum report is usually prepared from the action plan summaries. Items that are not closed out prior to the facility or project start-up should be addressed as part of the Pre-Startup-Safety-Review (PSSR). A copy of the action plan should be made available to operating, maintenance, and other employees whose work assignments are in the process and who may be affected by the recommendations or actions.

The action section of the recommendation action plan summary is the most important and should provide a brief description of the action to be taken and an estimated completion date.

Table 11.1 Recommendation Action Plan Summary

Recommendation Number	Description	Assignment	Action	Last Update

11.4 Risk Assessment Studies

Identified hazards do not need to be analyzed in detail when it is known, from company or similar experiences or studies of similar systems, that their probability of occurrence is well below the acceptance criteria for risk or that the resulting consequences do not have the potential to impair the main safety functions. Where such information is unavailable, a specialized risk assessment study should be undertaken to address such issues. In such instances, a risk assessment consultant is usually retained.

11.5 Risk Acceptance Criteria

In order to fully assess the risk of a hazard, it must be judged against a set of standards that are recognized for risk acceptance levels. A typical example of risk acceptance levels is provided in Appendix C.

11.6 Cost-Benefit Analysis

Recommendations that are strictly for the protection of the fixed property and business interruption can be easily evaluated against the potential economic loss that will be incurred. Since it is already assumed that the probability of the risk is high, as a recommendation has been made, it is simply a matter to determine whether the cost to implement the recommendation would exceed the cost to rebuild and economic loss of sales. This value may be further reduced if insurance coverage would alleviate some of the burden of the projected loss. If the cost to implement the recommendation approaches the rebuild and business interruption loss, it cannot be justified and is therefore impractical.

Recommendations that involve the protection of individuals and the environment are less easily evaluated. Typically, the ethical questions of the

value of human life and company reputation or prestige are involved. Some insight can be obtained by the legal and financial issues that would arise in such cases.

For the sake of analysis, the worst-case conditions are usually analyzed for cost-benefit decisions. In cases where the cost for any proposed recommendation is close to or exceeds the potential remediation costs after the potential incident, the risk may be termed as low as reasonably practical (ALARP).

12 Schedule and Cost Estimates

The most frequently asked questions when a process hazard analysis or SVA is proposed are “How long will it take?” and “What will it cost?” A review of the influencing factors on both these concerns has been made and a method to determine their impact has been formulated.

12.1 Schedule

A process hazard analysis or SVA can be effectively used at several stages during the life cycle of a facility. They are most commonly used as a final design audit at the stage when the project’s detailed P & IDs and plot plans are essentially complete. It may also be employed in several points in a large project design (see Table 7.2). General industry experience also substantiates that conducting a process hazards analysis or SVA review in the design phases requires less changes and is more productive than if the reviews were applied later in the life of the project or facility.

The safety or security impact of design and construction changes to a project performed after the final HAZOP, PHA, What-If, or SVA reviews and prior to commissioning are identified as part of the facility PSSR and MOC procedures.

The time required to complete a review is dependent on several factors, namely:

1. type of facility (e.g., pump station versus refinery),
2. number and complexity of individual equipment (number of nodes),
3. number of team members,
4. participation of personnel,
5. type of review method chosen, and
6. level of the facility design.

Typically, it takes an experienced team about two hours to thoroughly complete a HAZOP review for a single node and one hour for a PHA/What-If node or SVA area review. A P & ID sheet with two nodes is estimated to require four hours to review by a HAZOP approach and two

hours by a PHA/What-If approach. It can readily be seen that a What-If review typically requires one-half of the time to accomplish a HAZOP review. A formula to estimate the man-hours to accomplish a review has been formulated based on historical observations. Personnel hours expended to accomplish a review can be easily estimated by multiplying the estimate for the time needed for a review by the number of persons in the review team.

12.1.1 Formula to Estimate Review Scheduling

The estimated time of review, T_e, is given by

$$T_e = (N_d \times C_1 \times C_2 \times L \times F)/(E)$$

where

N_d = Number of nodes*

C_1 = Factor for complexity of nodes
For 1 component per node, use 1.0
For 2–4 components per node, use 2.5
For 5 or more components per node, use 5
For SVAs, use 1.0 for each area

C_2 = Factor for complexity of component**
For simple facilities (i.e., separation, pumping), use 1.0
For moderately complex (i.e., gas plant), use 1.5
For complex facilities (i.e., refineries), use 2.0
For SVAs, use 1.0

L = Level of design
Final review, $L = 1.0$
Course review, $L = 0.5$

F = Typical time period to review a node/area, make recommendations, short break (with PC and software support)
HAZOP method typically $F = 2.2$ (average)
PHA/What-If method typically $F = 1.2$ (average)
For SVAs use 1.5 (average, includes time to account for threat analysis)

E = Efficiency of review process (range 0.5–1.0)

$= E_1 \times E_2 \times E_3 \times E_4 \times E_5 \times E_6 \times E_7$
If $N_d > 25$, $E_1 < 0.9$, otherwise $E_1 = 1.0$
If design is incomplete, $E_2 < 0.75$, otherwise $E_2 = 1.0$
If team is inexperienced, $E_3 < 0.75$, otherwise $E_3 = 1.0$
If team leader is ineffective, $E_4 < 0.75$, otherwise $E_4 = 1.0$
If English is a second language for the team, $E_5 < 0.75$, otherwise $E_5 = 1.0$

N_o = Number of review team members
(Engineers = 1.0, scribe = 0.5, others = 0.75).
If $N_o < 4$ or > 8, $E_6 < 0.9$, otherwise, $E_6 = 1.0$
If some duplicate process equipment exists***, $E_7 = 1.1$, otherwise $E_7 = 1.0$

*An extrapolation of the number of nodes may be made based on a project's number of P & ID sheets. Currently produced P & IDs will normally have one or two nodes. For estimation purposes, use two nodes per sheet. Older existing facility P & IDs and vendor drawings may have four or more nodes on a single P & ID sheet.

**Certain facilities have more complex components and equipment than others. For example, a refinery column may have several inlet and outlet lines with a chemical reaction occurring.

***In some instances where identical or almost similar pieces of equipment exist at a facility, the outcome of the first may be generally copied or reviewed against the second item. This aids the review process for both units and speeds the review on the second unit.

Short ten minute breaks in the review session are recommended after one to two hours or after completion of a P & ID sheet. Studies may be conducted for eight hours per day when the overall review is expected to be less than five working days. If a review continues for more than an entire week, sessions should be limited to five hours per day. Team member exhaustion increases and productivity decreases during longer reviews.

12.1.2 Time Bar Scheduling and Integration with Project Schedule

An overall time bar of the review session and documentation preparation can be made as part of a project master plan. An example of a review schedule is presented in Figure 12.1. Based on the estimated schedule, an integrated schedule with the project design highlighting project milestones can be prepared if desired.

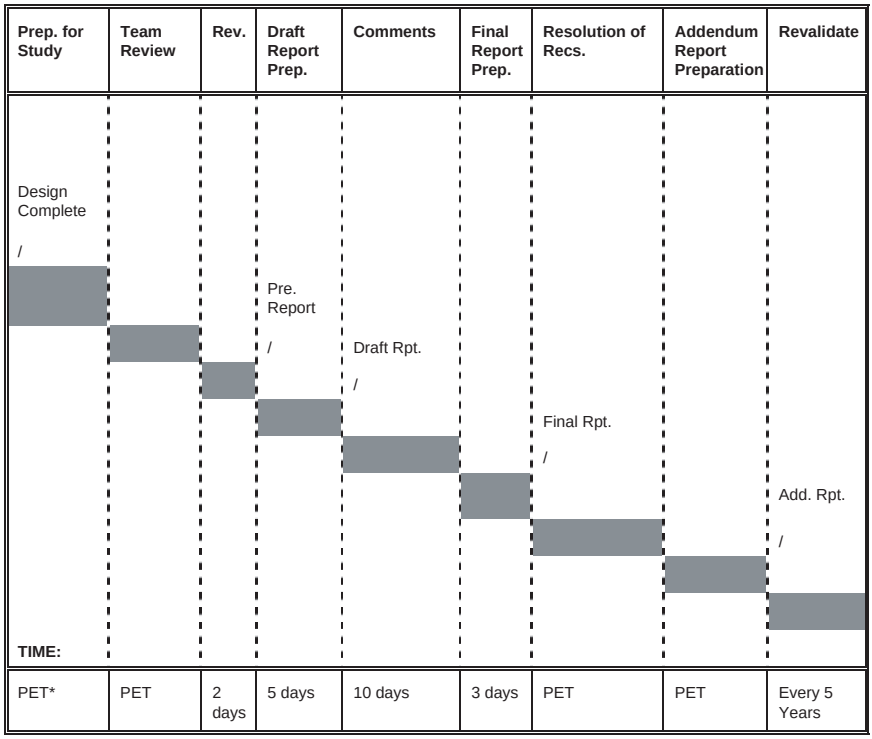


Figure 12.1 Overall review schedule (PET: project estimated time).

12.2 Cost Estimate

The cost associated with a review can be broken into three parts—the preparation to conduct the review, the review itself, and time and materials for the review documentation. A formula to estimate the costs has been prepared from the experiences of conducting many reviews for several types of facilities. This formula may be used to estimate different levels of reviews (i.e., conceptual, detailed, and final), by varying the number of nodes and complexity factors. It may also be used to calculate the entire team cost or a portion thereof (where a consultant's services may be utilized). The cost estimating formula does not account for the cost to analyze recommendations or issue an addendum report. Since the outcome of recommendations can vary tremendously, these costs cannot be estimated until the recommendations are produced. All costs are calculated using a PC with standard software support. Conducting a review without similar support will lengthen its period. The review sessions comprise the predominant cost of the process hazard analysis due to the number of personnel involved.

12.3 Estimating Formula

A formula to estimate the expense in performing a review is provided below. The cost of review can be broken into three parts—the cost of preparation, the review itself, and the cost of documentation preparation.

The overall estimated cost of review, C_e, is given by

$$C_e = (C_s + C_{pr}) \times C_t$$

where

C_s = Cost estimate for sessions

C_{pr} = Cost preparing for review and cost of reviewing and preparing documentation.

= $C_p + C_r$
C_p = Cost of preparation of review
C_r = Cost of documentation (preparation and issue)

C_t = Contingency factor (typically use 20% contingency)

= 1.2

12.3.1 Cost of Preparation

$$C_p = a + b + c$$

where

a = Documentation organization and copying, meeting set-up

= $(4 \times R) + (0.5 \times R \times 8) = 8 \times R$
(4 hours of team leader support and 8 hours of scribe support)

b = Node or area identification and labeling

= $[(5/60) \times R \times N_d] + [(10/60) \times 0.5 \times R \times N_d]$
(5 minutes of team leader support per node/area and 10 minutes of scribe support per node/area)

c = Project engineering support for coordination, document retrieval, notifications, etc.

= $8 \times R$

12.3.2 Cost of Review Sessions

The cost of the review session can be estimated by calculating the man-hours expended during the sessions by an average engineering rate.

The cost estimate for sessions, C_s, is given by

$$C_s = (N_o \times T_e) \times R$$

where

N_o = Number of team members
(Engineers = 1.0, scribe = 0.5, others = 0.75)

T_e = Estimate time of review (from schedule estimation section)

R = Engineering rate (average)

12.3.3 Cost of Report Preparation and Review

The cost of report preparation, review, and comments, C_r, is given by

$$C_r = d + e + f$$

where

d = Incorporate comments, issue reports, make clarifications

= $[((20/60) \times N_d \times 0.5 \times R) + (6 \times R)] + [((10/60) \times N_d \times R) + (2 \times R)]$
(Scribe and team leader review of reports)

e = Review and comment on reports

= $N_i \times R \times N_d \times (2/60)$
N_i = number of reports issued for review

f = Project engineer coordination of review reports and comments

= $8 \times R$

12.3.4 Documentation Costs

Usually process hazard analysis documentation costs are included as part of the project management administrative costs. A qualitative estimate of

material and reproduction costs can be made based on overall costs. Usually 5%–10% of labor costs can be estimated for the material and reproduction costs of review. Smaller reviews have a 5% charge while larger reviews (>50 nodes/areas) have a 10% charge.

12.3.5 Hardware, Software, and Incidental Costs

Personal computers, printers, overhead projector, meeting room use are administrative overhead costs, unless provided by a specialized consultant. Standard spreadsheets and word processing software are typically available on business computers. Customized review spreadsheet software is available from several manufacturers and is obtained either by corporate overhead purchase or by specific location purchase.

12.4 Example Calculation for Schedule and Cost

How long will it take and how much will it cost to use a consultant to lead and a scribe to conduct a process hazard analysis review on a finished design for a new two-train, crude production separation facility?

The following is assumed:

1. Five experienced personnel will support the review (inclusive of the leader and scribe).
2. PC support and software is available.
3. There are 20 P & ID sheets (i.e., about 40 nodes).
4. The average labor rate is $100/hour.
5. A What-If analysis will be used.
6. Team consists of scribe, leader, project engineer, operations and safety Representative.
7. The two process trains have duplicate vessels.

Using the equation for estimating time, the *time estimate* is calculated as follows:

$$
\begin{aligned}
T_e &= [(N_d \times C_1 \times C_2 \times L \times F)/(E)] \\
&= [(40 \times 1.0 \times 1.0 \times 1.0 \times 1.2)/(0.9 \times 1.0 \times 1.0 \times 1.0 \\
&\quad \times 1.0 \times 1.1)] \\
&= 48 \text{ hours are needed to conduct the review sessions}
\end{aligned}
$$

(Note: If a HAZOP analysis is used, about 89 hours will be needed.)

The *cost estimate (for leader and scribe only)* is calculated as follows:

$$
\begin{aligned}
C_e &= [(T_e \times N_o \times R) + C_{pr}] \times C_t \\
&= [(48 \times 1.5 \times \$100) + \$3058] \times 1.2 \\
&= \$12{,}400 \\
&= \$12{,}400 \times 1.05 \text{ (including documentation costs)} \\
&= \$12{,}925
\end{aligned}
$$

(If a HAZOP analysis is used, the estimated cost is approximately $20,674—a 59% increase in cost.)

The example would require approximately 10 days (at 5 hours/day) and about $13,000 for a leader and scribe support from a consultant to perform a What-If analysis.

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Appendix A Typical Company Policy Statement

A to Z Company

Policy Statement on Environmental Protection, Health and Safety, and Security

Date: January 1, 2008

To: All Managers and Employees

From: Chairman, President and CEO of A to Z Company

Subject: Process Safety & Security Reviews—Corporate Policy

Recent U.S. and Worldwide Legislation and our own company policies recognize that process safety and security reviews are to be undertaken at our facilities. These reviews ensure that health, safety, and environmental protection are an integral part of our operations and that the security of our facilities is maintained. Implementation of these policies will not only improve our process safety and security but also lead to improved efficiencies and economics for the company that will directly benefit our employees.

I am advising all employees that the company's PSM and security polices receive my full support. All employees are responsible to support these policies accordingly.

Signed

_____

Chairman, President & CEO

Appendix B Quality Assurance Audit Checklist

Facility or System _____ Date(s) of Review _____

Yes or No

____ 1. Adequate team member support, qualifications, and continuity were provided.

____ 2. Adequate drawing resources, including accurate P & IDs, plot plans, and cause and effects (SAFE) charts, etc. were provided.

____ 3. Hazardous fluid characteristics have been identified, GOR or chemical substances in particular.

____ 4. Assumptions have been identified.

____ 5. All nodes/areas have been identified and examined.

____ 6. Equipment is properly identified and documented.

____ 7. Facility operation/instrumentation control philosophy stated and documented, especially for emergency shutdowns.

____ 8. A consensus was reached for any recommendations made.

____ 9. Verification items have been resolved.

____ 10. All team members feel an adequate review was accomplished.

For any exceptions provide explanations:

Verified _____ Date _____ Verified _____ Date _____
Team Leader **Project Manager**

Appendix C Probability, Severity, Risk, and Risk Acceptance Tables

Table C.1 Typical Likelihood Levels and Descriptions

Level	Likelihood (Probability) Descriptions
1	*Frequency:* 0.0 to 1×10^{-6} (never to 1 in 1,000,000 years). *Scenario:* Should not occur in the life of the process and there is no historical industry experience to suggest it will occur. *Layers of protection:* Four or more independent highly reliable safeguards are in place; failure of three safeguards would not initiate an unwanted event.
2	*Frequency:* 1×10^{-6} to 1×10^{-4} (1 in 1,000,000 years to 1 in 10,000 years). *Scenario:* Similar events are unlikely to occur, but have historically occurred in this type of process somewhere within the industry. *Layers of protection:* Three independent highly reliable safeguards are in place; failure of two safeguards would not initiate an unwanted event.
3	*Frequency:* 1×10^{-4} to 1×10^{-3} (1 in 10,000 years to 1 in 1,000 years). *Scenario:* This particular scenario is likely to occur somewhere in the industry during the life of this general type of process. *Layers of protection:* Two independent highly reliable safeguards are in place; failure of one safeguard would not initiate an unwanted event.
4	*Frequency:* 1×10^{-3} to 1×10^{-2} (1 in 1,000 years to 1 in 100 years). *Scenario:* This particular scenario will almost certainly occur somewhere in the industry during the life of this specific type of process (but not necessarily at this location). *Layers of protection:* Single layer of safeguard and operator interface are in place to prevent unwanted events.
5	*Frequency:* 1.0 to 1×10^{-2} (always to 1 in 100 years). *Scenario:* This particular scenario has occurred somewhere in the industry in this specific process or is likely to occur at this location during the life of this facility. *Layers of protection:* Procedures or operator interface relied upon to prevent unwanted events.

Table C.2 Typical Severity (Consequence) Levels and Descriptions

Level	Severity (Consequence) Descriptions
1	• Minor onsite injuries (first aid and non-disabling, reportable injuries) • Property damage less than base level amount* • Minor environmental impact (no remediation) • Loss of production less than base level amount* • No offsite impact or damage; no public concern or media interest
2	• Serious onsite injuries (temporary disabling worker injuries) • Property damage 1–20 times base level • Moderate environmental impact (cleanup or remediation in less than one week and no lasting impact on food chain, terrestrial life, or aquatic life) • Loss of production 1–20 times base level • Minor offsite impact (public nuisance-noise, smoke, odor, traffic) • Potential adverse public reaction; some media awareness
3	• Permanent disabling onsite injuries or possible fatality • Property damage 20–50 times base level • Significant environmental impact (cleanup or remediation in less than one month and minor impact on food chain, terrestrial life, or aquatic life) • Loss of production 20–50 times base level • Moderate offsite impact limited to property damage, minor health effects to the public or first aid injuries • Adverse public reaction; local media concern
4	• Onsite fatality or less than four permanent disabling worker injuries • Property damage 50–200 times base level • Serious environmental impact (cleanup or remediation requires three to six months and moderate impact on food chain, terrestrial life, or aquatic life) • Loss of production 50–200 times base level • Significant offsite impact, property damage, short-term health effects to the public, or temporary disabling injuries • Significant public concern or reaction; national media concern
5	• Multiple onsite fatalities or four or more permanent disabling onsite injuries • Property damage greater than 200 times base level • Extensive environmental impact (cleanup or remediation exceeding six months, significant loss of terrestrial and aquatic life, or damage to food chain uncertain) • Loss of production greater than 200 times base level

(Continued)

Table C.2 (Continued)

Level	Severity (Consequence) Descriptions
	• Severe offsite impact, property damage, offsite fatality, long-term health effects, or disabling injuries • Severe adverse public reaction threatening facility's continued operations; international media concern

*Base level amount determined by insurance coverage and financial impact acceptable to senior management.
Note: Levels of severity may especially differ at foreign locations, based on the society or cultural acceptance of hazards.

Table C.3 Suggested Risk Matrix

Probability	1	2	3	4	5
5	C	C	D	E	E
4	B	C	C	D	E
3	B	B	C	D	D
2	A	B	C	C	D
1	A	A	B	C	D

Consequence

Table C.4 Suggested Risk Response Actions and Responsibilities

	Risk Response
A	No further action or safety studies required. Individual personal judgment required for operation to occur.
B	Document process safety and security studies, hazards, and risk reducing measures. Consider feasibility and cost/benefit of additional risk reducing measures. Supervision approval required for operation.
C	Document process safety studies, evaluate feasibility of additional risk reducing features, and implement if worker and offsite exposure can be reduced to a lower level. Operating group approval is required for operation.

(Continued)

Table C.4 (Continued)

	Risk Response
D	Document process safety studies, hazards, and risk reducing measures. Identify additional risk reducing measures and implement if worker and offsite exposure can be reduced to a lower level. A quantitative risk analysis is required to assess hazards. Divisional management (Company*) approval is required for operation.
E	Additional process safety studies and risk reducing measures are mandatory to achieve lower risk. Corporate (Parent Company*) senior management approval is required for operation.

*Large multinational companies usually create "in country" companies for financial and legal reasons.

In this particular risk ranking matrix, the risk level is not inversely equal (i.e., C4 and P1 do not carry the same risk as P4 and C1). Generally, it is considered that the risk is higher when the consequences are more severe rather than when the frequency is greater.

Appendix D PHA and What-If Checklist Questions

A compilation of typical What-If questions used in a process facility has been made to facilitate a What-If checklist for typical petroleum, petrochemical, or chemical facilities. This listing is by no means exhaustive and should be supplemented and tailored to suit the particular facility under review.

- Part 1: Piping
- Part 2: Valves
- Part 3: Vessels
- Part 4: Tanks
- Part 5: Pumps
- Part 6: Compressors
- Part 7: Heat Exchanger
- Part 8: Reactors
- Part 9: Columns and Towers
- Part 10: Flares
- Part 11: Electrical Equipment
- Part 12: Cooling Tower
- Part 13: Utility Systems
- Part 14: Human Factors
- Part 15: Global Events

Part 1: Piping What-If Checklist

- What if piping leaks?
- What if high pressure flammable, corrosive or toxic gases leak into a liquid pipeline?
- What if piping is fractured?
- What if piping plugs?
- What if piping becomes fouled?
- What if moisture remains in piping?
- What if piping is corroded internally?
- What if piping is corroded externally?
- What if piping is eroded?
- What if piping becomes embrittled?

- What if piping loses its heat tracing?
- What if piping supports fail?
- What if piping is subject to external impact?
- What if piping is subject to internal impact?
- What if piping is subject to backflow?
- What if piping is subject to flow or pressure surges?
- What if piping is subject to liquid hammer?
- What if piping is subject to vibration?
- What if piping welds are insufficient?
- What if gaskets, seals, or flanges leak?
- What if pressure relief is not provided?
- What if pressure relief fails (open or closed)?
- What if sight glass breaks?
- What if flame arrestor fails?

Part 2: Valves What-If Checklist

- What if valve fails mechanically?
- What if valve actuator fails?
- What if valve is inadvertently operated or mis-operated?
- What if valve is locked, opened, or closed?
- What if valve leaks?
- What if seals fail?
- What if valve becomes fouled or corroded?
- What if valve electric or pneumatic controls fail?
- What if valve is subjected to flow or pressure surges?
- What if valve is subject to liquid hammer?
- What if valve is impacted externally?
- What if valve is impacted internally?
- What if valve is subjected to abrasive or particulate matter?
- What if valve is subjected to backflow?
- What if valve handles multi-phase substances?
- What if valve is not fire rated?

Part 3: Processing Vessels What-If Checklist

Feed

- What if vessel feed is increased?
- What if vessel feed is decreased?

- What if vessel feed is stopped?
- What if vessel feed temperature increases?
- What if vessel feed temperature decreases?
- What if vessel feed composition changes (e.g., more or less oil, gas, or water)?
- What if excessive solids are entrained in feed?

Vessel

- What if vessel pressure increases?
- What if vessel pressure decreases?
- What if vessel level increases?
- What if vessel level decreases?
- What if vessel LAH (Level Alarm High) fails?
- What if vessel LAL (Level Alarm Low) fails?
- What if vessel PAH (Pressure Alarm High) fails?
- What if vessel PAL (Pressure Alarm Low) fails?
- What if vessel TAH (Temperature Alarm High) fails?
- What if vessel TAL (Temperature Alarm Low) fails?
- What if vessel solid/sand removal system fails?
- What if vessel interface transmitter fails?
- What if vessel high-interface alarm fails?
- What if vessel low-interface alarm fails?
- What if vessel internals plug?
- What if vessel internals collapse?
- What if vessel relief valve lifts or leaks?
- What if vessel ruptures due to internal corrosion, defective materials, or poor workmanship?

Vessel Piping

- What if vessel oil outlet block valve is closed?
- What if vessel water outlet block valve is closed?
- What if vessel gas outlet block valve is closed?
- What if vessel oil outlet control loop fails open or closed?
- What if vessel water outlet control loop fails open or closed?
- What if vessel gas outlet control loop fails open or closed?
- What if oil outlet plugs?
- What if water outlet plugs?
- What if solids form (possible hydrates) in gas outlet line?

- What if vessel drain valve is open or leaking?
- What if pipe ruptures due to internal corrosion, defective materials, or poor workmanship?

Fired Vessels

- What if vessel temperature control loop fails to open or close?
- What if fuel supply is cut off?
- What if flame fails?
- What if air damper fails to open or close?
- What if blower or motor fails?
- What if fuel supply pressure decreases?
- What if fuel supply pressure increases?
- What if water is entrained in fuel supply?
- What if fuel supply regulator fails to open or close?
- What if fuel main/pilot shut-off valves fail to open or close as required?
- What if fuel supply PAH fails?
- What if fuel supply PAL fails?
- What if vessel TAH fails?
- What if vessel TAL fails?
- What if fuel oil heater fails?
- What if fuel oil pump fails?
- What if fuel oil contains excessive solids?
- What if atomizing steam flow rate increases?
- What if atomizing steam flow is cut off?
- What if burner tube skin temperature increases?
- What if burner tube skin temperature decreases?
- What if stack temperature decreases?
- What if stack temperature increases?
- What if burner tube ruptures?
- What if burner tube supports fail?
- What if solids or coke build-up on tube external surface?
- What if solids build-up on tube internal surface?

Vessel External Factors

- What if the instrument air supply is cut off?
- What if there is an electrical power failure?
- What if vessel or piping is damaged by a motor vehicle collision?

- What if the ambient temperature is low?
- What if the ambient temperature is high?
- What if there is a severe earthquake?
- What if there is a wind/sand storm?
- What if the instrument or electrical component has an electrical fault?
- What if the vessel is struck by lightning?
- What if there is excessive rainfall?

Part 4: Tanks What-If Checklist

Feed

- What if tank feed is increased?
- What if tank feed is decreased?
- What if tank feed is stopped?
- What if tank feed temperature increases?
- What if tank feed temperature decreases?
- What if tank feed composition changes (e.g., more or less oil, gas, vapor pressure, chemical proportions, water, etc.)?
- What if excessive solids are entrained in feed?

Tank

- What if the tank pressure increases?
- What if the tank pressure decreases?
- What if the tank level increases?
- What if the tank level decreases?
- What if the tank LAH fails?
- What if the tank LAL fails?
- What if the TAH fails?
- What if the TAL fails?
- What if the tank solid or sand removal system fails?
- What if the tank interface transmitter fails?
- What if the tank high-interface alarm fails?
- What if the tank low-interface alarm fails?
- What if the tank internals plug?
- What if the tank internals collapse?
- What if the tank relief valve lifts or leaks?
- What if the tank ruptures due to internal corrosion, defective materials, or poor workmanship?

Tank Piping

- What if the tank gross outlet block valve is closed?
- What if the tank oil outlet block valve is closed?
- What if the tank water outlet block valve is closed?
- What if the tank gas outlet block valve is closed?
- What if the tank gross outlet control loop fails to open or close?
- What if the tank oil outlet control loop fails to open or close?
- What if the tank water outlet control loop fails to open or close?
- What if the tank gas outlet control loop fails to open or close?
- What if the tank oil outlet plugs?
- What if the tank gross outlet plugs?
- What if the tank water outlet plugs?
- What if tank solids form (possible hydrates) in gas outlet line?
- What if the tank drain valve is open or leaking?
- What if a pipe ruptures due to internal corrosion, defective materials, or poor workmanship?

Tank External Factors

- What if instrument air supply is cut off?
- What if there is an electrical power failure?
- What if the tank or piping is damaged by a motor vehicle collision?
- What if the ambient temperature is low?
- What if the ambient temperature is high?
- What if there is a severe earthquake?
- What if there is a wind or sand storm?
- What if the instrument or electrical component has electrical fault?
- What if the tank is struck by lightning?
- What if there is excessive rainfall?

Part 5: Pumps What-If Checklist

- What if the pump fails to start or stop on demand?
- What if the pump is started with the discharge valve closed?
- What if the pump is started with the suction side valve closed?

- What if the pump inlet piping is blocked?
- What if the pump relief valve fails to open/close?
- What if the pump loses suction or has too low a NPSH (Net Positive Suction Head)?
- What if the pump becomes vapor locked or cavitates?
- What if the pump packing gland or seal leaks?
- What if the pump is subjected to fire?
- What if the pump is subjected to freezing?
- What if the pump is submerged under water?
- What if the pump overspeeds?
- What if the pump underspeeds?
- What if the pump is not maintained?
- What if the pump breaks a shaft?
- What if the pump loses lubrication?
- What if the pump is out of balance?
- What if the pump handles substances containing abrasive or particulate matter?
- What if the pump's power supply fails?

Part 6: Compressors What-If Checklist

- What if a compressor is started with the suction valve closed?
- What if a compressor is started with the discharge valve closed?
- What if a compressor overheats?
- What if a compressor is subjected to freezing conditions?
- What if a compressor underspeeds?
- What if a compressor overspeeds?
- What if a compressor's power fails?
- What if a compressor's coupling to driver fails?
- What if a compressor's suction liquid knock-out drum overflows?
- What if air enters the compressor?
- What if a compressor's feed line fails or has too low a pressure?
- What if a compressor's feed pressure increases?
- What if a compressor's relief valve fails closed?
- What if a compressor's relief valve opens inadvertently?
- What if a compressor's seals, valves, or piston rings leak?
- What if a compressor's tail rod breaks?
- What if a compressor is subjected to excessive vibration?

- What if a compressor instrumentation fails?
- What if a compressor is not cleaned or maintained?
- What if a compressor handles substances containing contaminants or particulate matter?
- What if toxic or corrosive gases are introduced to the compressor inlet stream?
- What if a compressor is submerged underwater?
- What if a compressor is exposed to a fire?

Part 7: Heat Exchangers What-If Checklist

Exchanger Feed

- What if an exchanger tube/shell flow rate is increased?
- What if an exchanger tube/shell flow rate is decreased?
- What if an exchanger tube/shell flow is stopped?
- What if the tube/shell feed temperature increases?
- What if the tube/shell feed temperature decreases?
- What if the tube/shell feed composition changes (e.g., more or less oil, gas, or water)?
- What if excessive solids are entrained in a tube/shell feed?

Exchanger

- What if an exchanger pressure increases?
- What if an exchanger pressure decreases?
- What if an exchanger tube ruptures?
- What if an exchanger experiences excessive fouling?
- What if an exchanger handles abrasive/erosive substances?
- What if an exchanger loses insulation?
- What if an exchanger internals plug?
- What if an exchanger internals collapse?
- What if an exchanger relief valve lifts or leaks?
- What if an exchanger shell ruptures due to internal corrosion, defective materials, or poor workmanship?

Exchanger Piping

- What if an exchanger tube/shell outlet block valve is closed?
- What if an exchanger drain or vent valve is open or leaking?

- What if a pipe ruptures due to internal corrosion, defective materials, or poor workmanship?

Exchanger External Factors

- What if an exchanger or piping is damaged by a motor vehicle collision?
- What if the ambient temperature is low?
- What if the ambient temperature is high?
- What if there is a severe earthquake?
- What if there is a wind or sand storm?
- What if an instrument or electrical component has an electrical fault?
- What if an exchanger is struck by lightning?
- What if there is excessive rainfall?

Part 8: Reactors What-If Checklist

- What if a reactor leaks?
- What if a reactor ruptures?
- What if a reactor experiences corrosion internally or externally?
- What if a reactor experiences erosion?
- What if a reactor loses agitation or agitates too little?
- What if agitates too much?
- What if a reactor loses cooling?
- What if a reactor cools too much?
- What if a reactor losses heating?
- What if a reactor's heating rate is increased or decreased?
- What if a reactor is charged too fast?
- What if a reactor is charged too slowly?
- What if a reactor is overfilled?
- What if a reactor is underfilled?
- What if a reactor is charged with an improper reactant ratio?
- What if a reactor loses a reactant feed?
- What if a reactor is charged with a wrong material?
- What if a reactor is charged in the wrong sequence of reactants?
- What if a reactor is charged with no or too little catalyst?
- What if a reactor vent line plugs?

- What if a reactor's pressure is too high?
- What if a reactor's pressure is too low?
- What if a reactor's relief valve opens inadvertently?
- What if a reactor's relief valve fails to close?
- What if a reactor's controls fail?
- What if reactor's instrumentation fails?
- What if a reactor's discharge line plugs?
- What if a reactor's discharge valve opens too soon?
- What if a reactor loses inerting?
- What if a reactor's lining fails?
- What if a reactor's coolant leaks into reactants?
- What if a reactor contents spontaneously ignite?
- What if a reactor produces hazardous by-products?
- What if a reactor's side reactions predominate?
- What if a reactor becomes contaminated?
- What if a reactor is not cleaned or maintained?

Part 9: Columns (Towers) What-If Checklist

- What if a column leaks?
- What if a column ruptures?
- What if a column experiences corrosion internally or externally?
- What if a column loses reflux or cooling?
- What if a column loses heating?
- What if a column loses feed?
- What if a column's feed is increased?
- What if a column's feed is too hot?
- What if a column's feed is too cold?
- What if a column's feed composition changes?
- What if a column loses liquid level?
- What if a column's discharge valve opens too wide?
- What if a column's discharge valve is blocked?
- What if a column's pressure is too high?
- What if a column's pressure is too low?
- What if a column is blocked in but heat remains on?
- What if a column under vacuum leaks air in?
- What if a column is subjected to fire conditions?
- What if a column's relief valve fails to open?
- What if a column's relief valve opens inadvertently?

- What if a column's instrumentation fails?
- What if a column experiences internal blockages to inlet diffusers or trays?
- What if a column experiences gas or liquid entrainment?
- What if a column loses packing?
- What if a column has tray damage?

Part 10: Flares What-If Checklist

- What if the flare flow rate is greater than design flow rate?
- What if the flare experiences a flameout?
- What if the flare is fed an inadequate amount of combustion air?
- What if the flare is fed excessive combustion air?
- What if the flare is fouled with solids?
- What if liquids carryover from upstream knock-out vessel to flare?
- What if the flare creates excessive radiant heat levels?
- What if the flare cannot be lighted?
- What if the flare blower or motor fails?
- What if there is an electrical power failure?
- What if the instrument air supply is lost?
- What if the fuel gas supply is lost?
- What if the flare control panel malfunctions?
- What if the fuel supply pressure decreases?
- What if the fuel supply pressure increases?
- What if water is entrained in fuel supply?
- What if solids or coke build-up on stack or nozzles?

Flare Piping

- What if the flare inlet block valve is closed?
- What if the fuel gas supply block valve is closed?
- What if the fuel gas regulator fails to open or close?
- What if the fuel shut-off valve fails to open or close as required?
- What if solids form (possible hydrates) in relief outlet line?
- What if a pipe ruptures due to internal corrosion, defective materials, or poor workmanship?

External Factors

- What if stack or piping is damaged by a motor vehicle collision?
- What if the ambient temperature is low?
- What if the ambient temperature is high?
- What if there is a severe earthquake?
- What if there is a wind/sand storm?
- What if the instrument or electrical component has an electrical fault?
- What if the relief stack is struck by lightning?
- What if there is excessive rainfall?
- What if excessive vegetation is allowed to grow at base of flare?

Part 11: Electrical Equipment What-If Checklist

Generators

- What if the *lead* generator fails?
- What if the *standby* generator fails?
- What if the *emergency* generator fails?
- What if the generator alarms or shutdowns fail?
- What if the generator space heaters fail to operate?
- What if the generator becomes overloaded?
- What if the fuel supply becomes contaminated?
- What if the engine cooling equipment becomes fouled?
- What if the voltage regulator fails high or low?
- What if an exciter fails open?

Motors

- What if a motor overheats?
- What if a motor fault occurs?
- What if a motor bearing fails?
- What if a motor turns in the reverse direction?
- What if the motor grounding cable is not connected?

Motor Control Center

- What if a main breaker trips?
- What if voltage is high or low?

- What if an internal fault occurs?
- What if a starter fails to open or close?
- What if a motor overload fails to operate?
- What if a motor circuit protector opens?
- What if a control transformer fuses open?
- What if the motor control center is not grounded?

Switchgear

- What if an incoming voltage is too high or low?
- What if an incoming voltage frequency is too high or low?
- What if a main breaker trips?
- What if an internal fault occurs?
- What if a breaker control voltage fails?
- What if the breaker interlocks are bypassed?
- What if a grounding resistor is disconnected?

Part 12: Cooling Towers What-If Checklist

- What if a cooling tower has excessive fouling of internals?
- What if a cooling tower has power loss to pumps or fans?
- What if a cooling tower has containments in water?
- What if a cooling tower has excessive fan vibration?
- What if a cooling tower has flammable mixtures in the water?
- What if the cooling tower motor overheats?
- What if a cooling tower catches on fire?
- What if the cooling tower structure is deteriorated?
- What if the cooling tower motor is not grounded?

Part 13: Utility Systems What-If Checklist

- What if the facility air system fails?
- What if the instrument or utility air system fails?
- What if the breathing air system fails?
- What if the cooling water system fails?
- What if the cooling ammonia system fails?

- What if the cooling Freon system fails?
- What if the cooling steam system fails?
- What if the cooling nitrogen system fails?
- What if the electrical system fails?
- What if the fuel gas system fails?
- What if the natural gas system fails?
- What if the propane fuel system fails?
- What if the bunker C fuel system fails?
- What if the heating oil fuel system fails?
- What if the kerosene fuel system fails?
- What if the helicopter refueling system fails?
- What if the diesel fuel system fails?
- What if the steam heating system fails?
- What if the electric heating system fails?
- What if the transfer oil heating system fails?
- What if the inert gas blanketing system fails?
- What if the flush oil system fails?
- What if the seal oil system fails?
- What if the mineral oil system fails?
- What if the heat transfer oil system fails?
- What if the purge gas system fails?
- What if the NDT (Non-Destructive Testing) radioactivity system fails?
- What if the sanitary sewer system fails?
- What if the storm sewer system fails?
- What if the oil water drains system fails (open or closed system)?
- What if the steam system fails?
- What if the facility water system fails?
- What if the city water system fails?
- What if the well water system fails
- What if the fire water system fails?
- What if the water storage system is empty?
- What if the chilled water system fails?
- What if the zeolite water system fails?
- What if the demineralized water system fails?
- What if the communications network fails?
- What if the plant alarm system fails?
- What if the security system fails?
- What if the backup utility systems fails?

Part 14: Human Factors What-If Checklist

General

- What if an improper or unfinished design is issued?
- What if unqualified personnel prepared the engineering design?
- What if an error in engineering calculations was performed?
- What if incorrect materials are ordered or used?
- What if construction is performed improperly?
- What if quality assurance procedures are not available or followed?
- What if improper or inadequate startup procedures are written?
- What if improper or inadequate startup procedures are used?
- What if improper or inadequate operating procedures are written?
- What if improper or inadequate operating procedures are used?
- What if instructions for modifications are not provided?
- What if improper maintenance is performed?
- What if improper inspection is performed?
- What if improper decommissioning procedures are used?
- What if improper demolition procedures are used?
- What if management is inadequate or unsatisfactory?
- What if regulations have not been complied with?

Operators

- What if an operator does not perform an action?
- What if an operator performs the wrong action(s)?
- What if an operator performs an action at the wrong place?
- What if an operator performs an action in the wrong sequence?
- What if an operator performs an action at the wrong time?
- What if an operator makes and incorrect reading?
- What if operators work long hours?
- What if operators are not provided with supervision?
- What if operators are not trained?

- What if operators do not understand or know the hazards of the process?
- What if an operator is inundated with instrumentation readings or alarms?

Equipment

- What if access to equipment is not possible?
- What if a valve is too "frozen" to operate?
- What if a valve is not marked for identification?
- What if an electrical switch does not indicate its function?
- What if an emergency egress route is not marked?
- What if an emergency egress route is blocked?
- What if equipment operation is opposite to normal convention?
- What if color coding is not used (wiring, piping, signs, safety tools, etc.)?
- What if adequate lighting is not available?
- What if instructions are not provided in indigenous languages?
- What if indicator lights are not working?
- What if indictor light lenses are the wrong color?
- What if air breathing masks do not fit personnel?
- What if oil spill boom is too heavy to move?
- What if an emergency alarm does not operate?
- What if an emergency alarm cannot be heard?
- What if an emergency alarm is confused with other instructional tones?
- What if no communication devices are available?

Part 15: Global Events What-If Checklist

Maintenance

- What if maintenance is not performed regularly?
- What if maintenance is not performed accurately?
- What if maintenance is performed at the wrong time?
- What if maintenance is performed with the wrong materials or parts?
- What if maintenance does not restore the component to working conditions?
- What if maintenance inadvertently initiates a future hazardous condition?

Sampling

- What if sampling is performed irregularly?
- What if sampling is performed improperly or with improper containers?
- What if sampling is performed from the wrong system?
- What if sampling contaminates samples?
- What if sampling is not properly coordinated with others or with prudent controls?

Testing

- What if testing is performed improperly?
- What if testing is not performed thoroughly or realistically?
- What if testing is performed irregularly?

Weather

- What if a rapid change in barometric pressure occurs, such as hurricanes or severe storms?
- What if a drought occurs that impacts the availability of cooling water?
- What if a dust storm occurs?
- What if a sand storm occurs?
- What if the ambient temperature is extreme (low or high)?
- What if unexpectedly low temperatures occur (i.e., $< -50°F$)?
- What if a brush or forest fire occurs?
- What if flooding occurs?
- What if fog occurs?
- What if frost occurs?
- What if hail occurs?
- What if ice forms on structures during cold weather or from condensation on insulated lines?
- What if lighting occurs?
- What if a mud slide occurs?
- What if a heavy and prolonged rainstorm occurs?
- What if it snows?
- What if there is static electricity build up?
- What if there is a tornado?
- What if there are high winds?

Geological Events

- What if subsidence occurs?
- What if there is an avalanche?
- What if there is costal erosion?
- What if there is an earthquake?
- What if there is a landslide?
- What if there is a tsunami or tidal wave?
- What if there is volcanic activity?

Transportation

- What if there is an airplane accident?
- What if there is a helicopter accident?
- What if there is a marine accident?
- What if there is a railroad accident?
- What if there is a vehicle accident?
- What if there is a crane accident?
- What if there is a lifting device accident?
- What if there is a fork lift accident?

Human Induced

- What if there is an incident in an adjacent unit or facility?
- What if there is construction in the vicinity?
- What if there are dropped objects?
- What if there is a fire in an adjacent unit?
- What if there is leakage of hazardous or toxic chemicals in the area?
- What if there is a missile projection from compressed gas cylinders, rotating equipment, etc.?
- What if there is a problem from a nearby plant?
- What if there is problem from a pipeline incident?

Human/Civil

- What if someone sabotages the plant?
- What if someone vandalizes the plant?
- What if there is a terrorist act?
- What if there is civil or political unrest?

Appendix E HAZOP Parameters, Deviations, and Possible Causes

The following are typical guideword parameters, deviations, and possible causes that are used in HAZOP reviews. They are based on the standard HAZOP deviation matrix shown below.

	More	**Less**	**None**	**Reverse**	**Part of**	**As well as**	**Other**
Flow	High flow	Low flow	No flow	Back flow	Wrong concentration	Contaminants	Wrong material
Temp.	High temp.	Low temp.					
Pressure	High press.	Low press.					
Level	High level	Low level	No level				

This listing is by no means exhaustive and each review should be supplemented or tailored to meet the needs of a particular facility.

Flow

High

- Increased pumping capacity
- Increased suction pressure
- Reduced delivery head
- Greater fluid density
- Exchanger tube leaks
- Restriction orifice plates not installed
- Cross connection of systems
- Control faults
- Control valve trim changed
- Running multiple pumps

Less

- Restriction
- Wrong routing

- Filter blockage
- Defective pumps
- Fouling of vessels, valves, orifice plates
- Density or viscosity changes
- Cavitation
- Drain leaking
- Valve not fully open

None

- Wrong routing
- Blockage
- Incorrect slip plate
- One way (check) valve in backwards
- Pipe or vessel rupture
- Large leak
- Equipment failure
- Isolation in error
- Incorrect pressure differential
- Gas locking

Reverse

- Defective one way (check) valve
- Siphon effect
- Incorrect pressure differential
- Two way flow
- Emergency venting
- Incorrect operation
- In-line spare equipment
- Pump failure
- Pump reversed

Level

High

- Outlet isolated or blocked
- Inflow greater than outflow control failure
- Faulty level measurement

- Gravity liquid balancing
- Flooding
- Pressure surges
- Corrosion
- Sludge

Low

- Inlet flow stops
- Leak
- Outflow greater than inflow
- Control failure
- Faulty level measurement
- Draining of vessel
- Flooding
- Pressure surges
- Corrosion
- Sludge

Pressure

High

- Surge problems
- Connection to high pressure
- Gas (surge) breakthrough
- Inadequate volume of vents
- Incorrect vent set pressure for vents
- Relief valves isolated
- Thermal overpressure
- Positive displacement pumps
- Failed open PCV
- Boiling
- Freezing
- Chemical breakdown
- Scaling
- Foaming
- Condensation
- Sedimentation
- Gas release

- Priming
- Exploding
- Imploding
- External fire
- Weather conditions
- Hammer
- Changes in viscosity/density

Low

- Generation of vacuum conditions
- Condensation
- Gas dissolving in liquid
- Restricted pump/compressor line
- Undetected leakage
- Vessel drainage
- Blockage of blanket gas regulating valve
- Boiling
- Cavitation
- Freezing
- Chemical breakdown
- Flashing
- Sedimentation
- Scaling
- Foaming
- Gas Release
- Priming
- Exploding
- Imploding
- Fire conditions
- Weather conditions
- Changes in viscosity/density

Temperature

High

- Ambient conditions
- Fouled or failed exchanger tubes
- Fire situation

- Cooling water failure
- Defective control valve
- Heater control failure
- Internal fires
- Reaction control failures
- Heating medium leak into process
- Faulty instrumentation and control

Low

- Ambient conditions
- Reducing pressure
- Fouled or failed exchanger tubes
- Loss of heating
- Depressurization of liquefied gas—Joule–Thompson effect
- Faulty instrumentation and control

Part of

WRONG CONCENTRATION

- Leaking isolation valves
- Leaking exchanger tubes
- Phase change
- Incorrect feedstock specification
- Process control upset
- Reaction by-products
- Ingress of: water, steam, fuel, lubricants, corrosion products from high pressure system
- Gas entrainment

As well as

CONTAMINANTS

- Leaking exchanger tubes
- Leaking isolation valves
- Incorrect operation of system
- Interconnected systems
- Wrong additives
- Ingress of air: shutdown and start-up conditions

- Elevation changes, fluid velocities
- Ingress of: water, steam, fuel, lubricants, corrosion
- Products from high pressure system
- Gas entrainment
- Feed stream impurities (mercury, H_2S, CO_2, etc.)

Other

WRONG MATERIAL

- Incorrect or off specification feedstock
- Incorrect operation
- Wrong material delivered

Viscosity

More

- Incorrect material or composition
- Incorrect temperature
- High solids concentration
- Settling of slurries

Less

- Incorrect material or composition
- Incorrect temperature
- Solvent flushing

Relief System

- Relief philosophy (process/fire)
- Type of relief device and reliability
- Relief valve discharge location
- Pollution implications
- Two phase flow
- Low capacity (inlet and outlet)

Corrosion/Erosion

- Cathodic protection arrangements (internal and external)
- Coating applications
- Corrosion monitoring methods and frequencies
- Materials specification
- Zinc embrittlement
- Stress corrosion cracking
- Fluid velocities
- Sour service (H_2S, mercury, etc.)
- Riser splash zone

Service Failures

- Instrument air
- Steam
- Nitrogen
- Cooling water
- Hydraulic power
- Electric power
- Water supply
- Telecommunications
- PLCs/computers
- HVAC
- Fire protection (detection and suppression)

Abnormal Operation

- Purging
- Flushing
- Startup
- Normal shutdown
- Emergency shutdown
- Emergency operations
- Inspection of operating machines
- Guarding of machinery

Maintenance/Procedures

- Isolation philosophy
- Drainage
- Purging
- Cleaning
- Drying
- Access
- Rescue plan
- Training
- Pressure testing
- Work permit system
- Condition monitoring
- Lift and manual handling

Static

- Grounding arrangements
- Insulated vessels
- Low conductance fluids
- Splash filling of vessels
- Insulated strainers and valve components
- Dust generation
- Powder handling
- Electrical classification
- Flame arrestors
- Hot work
- Hot surfaces
- Auto-ignition or pyrophoric materials

Spare Equipment

- Installed/not installed
- Availability of spares
- Modified Specifications
- Storage of spares
- Catalog of spares

Sampling/Procedures

- Sampling procedure
- Time for analysis results
- Calibration of automatic samplers
- Reliability/accuracy of representative sample
- Diagnosis of results

Time

- Too long
- Too short
- Wrong time

Action

- Overkill
- Underestimated
- None
- Reverse
- Incomplete
- Knock-on
- Wrong action

Information

- Confusing
- Inadequate
- Missing
- Misinterpreted
- Partial
- Stress
- Wrong information

Sequence

- Operation too early
- Operation too late

- Operation left out
- Operation performed backwards
- Operation not completed
- Supplemental action taken
- Wrong action in operation

Safety Systems

- Fire and gas detection and alarms
- Emergency shutdown (ESD) arrangements
- Fire fighting response
- Emergency training
- TLVs of process materials and method of detection
- First aid/medical resources
- Vapor and effluent disposal
- Testing of safety equipment
- Compliance with local and national regulations

Global

- Layout and arrangement
- Weather (temperature, humidity, flooding, winds, sandstorm, blizzards, etc.)
- Geological or seismic
- Human factors (labeling, identification, access, instructions, training, qualifications, etc.)
- Fire and explosion
- Adjacent facility exposures

Glossary

Addendum Report: A supplement report issued after a final review report documenting the resolution of recommendations from the review.

ALARP (As Low As Reasonably Practical): The principle that no industrial activity is entirely free from risk and that it is never possible to be sure that every eventuality has been covered by safety precautions, but that there would be a gross disproportion between the cost (in terms of money, time, or trouble) of additional preventive or protective measures, and the reduction in risk in order to achieve such low risks.

Brainstorming: A group problem-solving technique that involves the spontaneous contribution of ideas from all members of the group primarily based on their knowledge and experience.

Cause: The reasons why deviations might occur.

Checklist: A detailed list of desired system attributes for a facility. Used to assess the acceptability of a facility compared to accepted norms.

Consequence: The direct undesirable result of an accident sequence usually involving a fire, explosion, release of toxic material. Consequence descriptions may include estimates of the effects of an accident in terms of factors such as health impacts, physical destruction, environmental damage, business interruption, and public reaction or company prestige.

Critical: Classification of a process, equipment, or process area with the potential to impact workers, adjacent community, the environment, and the company through business interruption or prestige, if it were to be effected from a security threat.

CSAT Top-Screen: A software application available from the DHS to perform a preliminary risk ranking of facilities that manufacture, use, store, or distribute certain chemicals in amounts as identified by the DHS. It is primarily used to determine if the facility needs to register with DHS, and if an SVA and SSP is required.

CSB: Acronym for Chemical Safety and Hazard Investigation Board. An agency of the U.S. Government charted to investigate chemical industry incidents, determine their root cause, and publish their findings to prevent similar incidents occurring.

Deviation: A departure from the design and operating intention.

Draft Report: A review report prepared after review meetings and thorough review by the team leader and scribe. Issued for comments by review team and appropriate company management.

EPA: Acronym for the Environmental Protection Agency, an agency of the U.S. Government for the protection of the environment.

Ergonomics: The study of the design requirements of work in relation to the physical and psychological capabilities and limitations of human beings.

Event Tree: A logic model that graphically portrays the combinations of events and circumstances in an accident sequence.

Facility: The process or system on which the HAZOP or What-If review is performed.

Failure Modes and Effects Analysis (FMEA): A systematic, tabular method for evaluating and documenting the causes and effects of known types of component failures.

Fault Tree: A logic model that graphically portrays the combinations of failures that can lead to a specific main failure or accident of interest.

Final Report: A review report prepared after consideration of comments from review team and appropriate company management.

GOR: Acronym for gas–oil ratio, the number of cubic feet of natural gas produced from a barrel of oil.

Guideword (GW): A simple word or phase used to generate deviations by operations on parameters.

Hazard: A chemical, activity, or physical condition that has the potential for causing harm to people, property, or the environment.

Hazcom: OSHA's Hazard Communication Standard (U.S. 29 CFR 1910.1200). Information on hazards is communicated by employers to employees.

HAZOP: Acronym for hazard and operability review. This is a formal, systematic, critical approach for identifying the qualitative potential of hazards and operating problems associated with an existing or new system or piece of equipment caused by deviations to the design intent and their resulting consequential effects. Recommendations for the mitigation of identified hazards are provided.

Human Factors: A discipline concerned with designing machines, operations, and work environments to match human capabilities and limitations.

Incident: An event or sequence of events that results in undesirable consequences.

Likelihood: The expected frequency (or probability) of an event's occurrence. *See also* Probability.

Node: A defined part (section or subsystem or item of equipment) of a process that has a design intention that is specific and distinct from the design intention of other process parts that allows the study team to analyze the specific equipment or system in an organized fashion.

OSHA: Acronym for the Occupational Health and Safety Administration, U.S. Department of Labor.

Parameter: A physical, chemical, or other variable associated with the activity or operation of a facility.

PFD: Acronym for process flow diagram. A facility engineering drawing depicting the process without showing instrumentation and minor isolation valves. Used to show flow quantities and conditions at various points in the process.

P & ID: Acronym for piping and instrumentation drawing. A facility engineering drawing depicting the process piping and equipment schematic arrangements and their associated control monitoring instrumentation devices.

Preliminary: Coming before and usually forming a necessary prelude to something. A PHA can be accomplished in a design or pre-operational phase; it can also be performed on a mature system.

Preliminary Hazard Analysis (PHA): An early or initial screening study for the identification, qualitative review, and ranking of process hazards, typically conducted during an initial evaluation of existing facilities or a project's conceptual design. Recommendations for the mitigation of identified hazards are provided. *See also* Process Hazard Analysis, which uses the same acronym.

Preliminary Hazard List (PHL): A line item inventory of system hazards, with no evaluation of probability, severity, or risk.

Preliminary Report: Review report prepared and provided to the project engineer at the immediate conclusion of the study review meetings.

Pre-Startup Safety Review (PSSR): Audit check performed prior to equipment operation to ensure adequate PSM activities have been performed. The check should verify that (1) construction and equipment is satisfactory, (2) procedures are available and adequate, (3) a PHA has been undertaken and recommendations resolved, and (4) the employees are trained.

Probability: The projected frequency of an event occurring usually based on statistical analysis (sometimes referred to as likelihood).

Process: Any activity or operation leading to a particular result.

Process Hazard Analysis: Generic term for the systematic, comprehensive, analytical study of a process utilizing a recognized method of analysis (e.g., PHAs, What-If analyses, and HAZOPs) to identify and evaluate process and operational hazards and their consequences. *See also* Preliminary Hazard Analysis (PHA), which uses the same acronym.

Process Safety Management (PSM): Comprehensive set of plans, policies, procedures, practices, and controls (administrative, engineering, and operating) designed to ensure that barriers to major incidents are in place, in use, and are effective.

Project Manager: Individual responsible for conducting the HAZOP or What-If review for an existing or new facility/system. May be the project engineer, facility engineer, drilling engineer, or a process engineer.

Qualitative: Relating to quality or kind.

Quantitative: To measure or determine precisely.

Review: Evaluation, examination, or study of information.

Risk: The combination of the expected likelihood/probability (events/year) and consequence/severity (effects/event) of an incident.

Sabotage: Deliberate acts of destruction or obstruction for political advantage, economical harm, or other disruptive action or impact.

Safeguard: A precautionary measure or stipulation. Usually equipment and/or procedures designed to interfere with incident propagation and/or prevent or reduce incident consequences.

Safety: Freedom from incidents that result in injury, damage, or harm.

Scribe: Secretarial or clerical support used to provide written (transcribed) notes of discussions or dictated wordings during a review meeting.

Security: Protection against threats.

Security Vulnerability Analysis (SVA): A security review method, by which identified threat analysis questions are asked by an experienced team of the facility under review where there are vulnerability concerns about possible undesired deliberate acts. Recommendations for the prevention or mitigation of identified hazards are provided.

Severity: The magnitude of physical or intangible loss consequences resulting from a particular cause or combination of deviations.

Systematic: A methodical procedure or plan (marked by thoroughness and regularity).

Target: Something having worth or value threatened by a hazard.

Team Leader: Individual who directs the Security or Safety review.

Terrorism: Threats or militant actions by unlawful and unethical individuals or groups against a country, its institutions, or population to intimidate or influence for political, religious, or ideological motives.

Threat: A potential for loss (injury, damage, or other hostile action) from a deliberate act.

Threat Analysis: An identification and review of potential threats to determine their source, motivation, and likelihood.

What-If Study: A PHA safety review method by which "what-if" investigative questions (brainstorming approach) are asked by an experienced team of the system or component under review where there are concerns about possible undesired events. Recommendations for the mitigation of identified hazards are provided.

Acronyms

AIChE	American Institute of Chemical Engineers
ALARP	as low as reasonably practical
ANSI	American National Standards Institute
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
BS & W	basic sediment and water
CCPS	Center for Chemical Process Safety
CFATS	Chemical Facility Anti-Terrorism Standard
CFR	Code of Federal Regulations
CO_2	carbon dioxide
CSAT	Chemical Security Assessment Tool
CSB	Chemical Safety and Hazard Investigation Board
DHS	Department of Homeland Security
EPA	Environmental Protection Agency
ERP	emergency response plan
ESD	emergency shutdown
FBI	Federal Bureau of Investigation
FDA	Food and Drug Administration
FMEA	Failure Modes and Effects Analysis
GW	guideword
HAZOP	hazard and operability
H_2S	hydrogen sulfide
HSE	health, safety, and environment
HVAC	heating, ventilation and air conditioning
JSA	Job Safety Analysis
MOC	management of change
MSDS	material safety data sheet
NACE	National Association of Corrosion Engineers
NFPA	National Fire Protection Association
OSHA	Occupational Safety and Health Administration
PC	personal computer
PCV	pressure control valve
PET	project estimated time
PFD	process flow diagram
PHA	Preliminary Hazard Analysis
PHL	preliminary hazard list
P & ID	piping and instrumentation diagram
PLC	programmable logic controller
PSM	Process Safety Management
PSSR	Pre-Startup Safety Review
PSV	pressure safety valve
SAFE	safety and failure effects
SSP	Site Security Plan
SVA	Security Vulnerability Analysis
TLV	threshold limit value

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