Process Hazard Analysis  
Layer of Protection Analysis

<%Unit%>

<%Facility\_Owner%>

<%Facility%>

\_\_COMPANY\_\_

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
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# Executive Summary

<%Facility\_Owner%> is in the process of evaluating hazards of its <%Unit%> at its <%Facility%> in accordance with applicable standards, codes, industry recommended practices, and internal practices for hazard analysis. A Process Hazards Analysis (PHA) was required to identify and address hazards of the process using the Hazard and Operability (HAZOP) method. In addition, Layer of Protection Analysis (LOPA) was required to address select, high hazard scenarios and scenarios that address functional safety per industry norm ANSI/ISA 61511.

\_\_COMPANY\_\_ supported <%Facility\_Owner%> in conducting PHA and LOPA by performing the following tasks:

* Compiling and defining the study nodes
* Facilitating a HAZOP study
* Conducting LOPA for selected high hazard scenarios

The study was conducted at the \_\_STUDY/LOCATION\_\_ during the period of \_START/DATE\_\_ to \_\_END/DATE\_\_, and was completed with the assistance of personnel from the following organizations:

\_\_AFFILIATED/COMPANIES\_\_

HAZOP guidewords were used to identify deviations beyond safe operating limits, credible causes, the hazard and the potential consequence. Where a hazard was identified as a possible safety consequence, the scenario is qualitatively evaluated for hazard severity. The severity of the hazard was defined in terms of safety, environmental, and commercial impact.

Hazard severity ratings were selected according to <%Facility\_Owner%> policies and procedures for ranking risks. For each cause of a hazard, a list of safeguards that prevents the consequence was recorded. The team then determined the likelihood of the hazard with all the safeguards in place. The risk ranking was then selected from the risk matrix using the consequence level and the likelihood. Where the scenario represented a major process hazard, additional semi-quantitative hazard analysis using LOPA was conducted.

Recommendations to management were made by the PHA-LOPA team when the team determined that safeguards for a specific hazard were not adequate to reduce the risk. Recommendations were also made when compliance with codes/standards was identified as an issue, or in some cases, major operability issues arose. The intent of recommendations to reduce the likelihood and / or the severity of the hazard scenario identified by the team.

The study made ## recommendations, and these are listed in *Appendix D* (HAZOP) and *Appendix G* (LOPA). Based on the results of this analysis, \_\_COMPANY\_\_ recommends that all recommendations listed in *Appendix D* and *Appendix G* be addressed and resolved by <%Facility\_Owner%> management. Resolution should be documented with a rationale for determining whether the recommendation will be implemented, not implemented with justification, or alternative risk reduction means be implemented that substantially address the PHA-LOPA team’s concerns.

Major findings from the HAZOP:

Major findings from the LOPA:

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# Introduction

## Background

<%Facility\_Owner%> desired to evaluate hazards of its <%Unit%> at its <%Facility%> in accordance with applicable standards, codes, industry recommended practices, and internal practices for hazard analysis. A decision was made to conduct a Process Hazard Analysis (PHA) and Layer of Protection Analysis (LOPA) for the chlorine and VCM production process. The PHA was required to identify and address hazards of the process using the Hazard and Operability (HAZOP) method. It was determined that the HAZOP method would be most effective in identifying hazards for the <%Unit%> at its <%Facility%>.

This report documents the PHA-LOPA study conducted for the <%Unit%> at the <%Facility%> in <%Facility\_Location%>.

In addition, selected high hazard scenarios require semi-quantitative hazard analysis using LOPA technique. This is required per industry standards that address functional safety, including ANSI/ISA 61511. This report also describes the development of the design basis for SIS, which was developed in accordance with ANSI/ISA 61511 – *Functional Safety: Safety Instrumented Systems for the Process Industry Sector* and <%Facility\_Owner%> policies and procedures related to process risk management and SIS design and implementation. In accordance with this standard, the LOPA study determined of the risk reduction requirements for each of the instrumented safeguards identified in the HAZOP, also known as Safety Instrumented Functions (SIF). The SIF are utilized to reduce the risk of certain hazards to a tolerable level. The required risk reduction was assigned in terms of Safety Integrity Level (SIL), which are order-of-magnitude bands of average probability of failure on demand of a SIF, as defined in ANSI/ISA 61511 – *Functional Safety: Safety Instrumented Systems for the Process Industry Sector*. This assignment was based on an analysis of the risk of the hazard that the SIF is intended to protect against.

## Scope / Objectives

The objective of this study was to identify process hazard scenarios that are within the scope and application of the HAZOP method. Process hazards involve a release of a highly hazardous chemical with attendant affects associated with fire, explosion, acute toxic exposure, or other exposure to the hazards of the material. The study scope is limited to reviewing potential safety impacts to personnel, including onsite and offsite personnel.

The objective of this study was also to establish a design basis for the Safety Instrumented Functions (SIF) recommended for the process.

The scope of the study included / was limited to the following areas of the process:

* \_\_SCOPE/BULLETLIST\_\_

## Report Organization

This report is comprised of the following sections.

*Section 2* presents a description of the process, the process hazards, and methodology.

*Section 3* provides conclusions and a summary of recommendations from the study.

*Appendix A* lists the documents used and participants, and PHA study sessions.

*Appendix B* lists the study nodes.

*Appendix C* contains the HAZOP worksheets.

*Appendix D* lists HAZOP recommendations along with associated risk rankings.

*Appendix E* contains the LOPA worksheets.

*Appendix F* lists the LOPA recommendations.

*Appendix G* provides P&IDs with nodes highlighted

# Results

\_\_COMPANY\_\_ supported <%Facility\_Owner%> in analyzing process hazards for the <%Unit%> by performing the following tasks:

* Compiling and defining the study nodes
* Facilitating a HAZOP study
* Conducting Layer of Protection Analysis (LOPA) for selected high hazard scenarios

The study was conducted at the \_\_STUDY/LOCATION during the period of \_\_START/DATE\_\_ to \_\_END/DATE\_\_ and was completed with the assistance of personnel from the following organizations:

\_\_AFFILIATED/COMPANIES\_\_

## Process Description and Hazards

The project included review of the processes described below. This PHA encompasses equipment, process streams and utilities associated with piping and instrumentation diagrams (P&IDs) listed in *Appendix A*.

\_\_PROCESS/DESCRIPTION\_\_

The major hazards associated with the process under review are described below.

\_\_MAJOR/HAZARD/DESCRIPTION\_\_

## PHA Methodology

The PHA study was performed using the Hazards and Operability (HAZOP) method. HAZOP is a recognized, systematic approach designed to aid in identifying potential hazard and operability scenarios associated with the process. Safe operating limits are identified for the process, and a team of multidisciplinary experts postulates credible scenarios involving possible deviations from the safe operating limits. The team identifies the potential consequences associated with the event with the assumption that all protective safeguards can fail.

The team then identifies the levels of protection or safeguards that are in the design to help prevent the hazardous scenario from occurring or mitigate the consequence of the event. For each identified scenario, the team also identifies the frequency of the event based on the experience team.

### Team Composition

The PHA study was carried out by a multi-disciplinary team with expert knowledge in operations, engineering, and the PHA method being used. The team meetings were facilitated by the \_\_COMPANY\_\_ project facilitator. Participants are identified *Appendix A*.

### Node Definition

The process was subdivided into systems, or nodes. The purpose is to aid in application of the study technique to a smaller system where study guidewords can be properly applied. The nodes were defined by \_\_COMPANY\_\_ by grouping equipment with similar design intent, design limits, and operating conditions. A list of nodes is provided in *Appendix B* and is also provided graphically along with P&IDs in *Appendix H.* Safe Operating Limits are defined for each node. Operation of equipment within the Safe Operating Limits is defined to be a safe condition. The HAZOP method assumes that hazards can occur only when operating beyond the safe operating limits of equipment.

### Study Workflow

Each node is analyzed for possible deviations from the Safe Operating Limits that can cause hazards. Guidewords were used to help understand the possible deviations. A sample of those guidewords is listed in *Table 2.1*.

Table 2.1 Deviation Matrix for Continuous Process

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Parameters** | **Guideword** | | | | | | |
| More | Less | No | Reverse | Part of | As Well As | Other Than |
| Flow | More Flow | Less Flow | No Flow | Reverse Flow | Wrong Percentage | Contamination | Wrong Materials |
| Pressure | High Pressure | Low Pressure | Vacuum |  |  |  |  |
| Temperature | High Temperature | Low Temperature |  |  |  |  |  |
| Level | High Level | Low Level | No Level |  |  |  |  |
| Relief |  |  |  |  |  |  | Relief |
| Leak / Rupture |  |  |  |  |  |  | Leak/ Rupture |
| Abnormal Operation |  |  |  |  |  |  |  |
| Composition | Composition Change | Composition Change |  |  |  | Contamination | Composition Change |

Guidewords help identify deviations beyond safe operating limits, which are potentially caused by normal control equipment failures, human errors – i.e., mis-operation of equipment, and failures of pumps, compressors, motors, and shutdown valves. For each credible deviation from normal process control, credible causes and potential consequences of the deviation are recorded. Consequences are identified based on worst-case conditions assuming that there is a credible chance that all protective safeguards can fail. Once a hazard scenario is identified, the scenario is qualitatively evaluated for hazard severity. This is accomplished by the severity of the potential consequence using the <%Facility\_Owner%> risk-ranking matrix. The severity of the hazard is defined multiple times, once each for: safety to personnel, environmental impact, and commercial losses.

Table 2.2 Consequence Severity Categories

<%Safety\_Consequence\_Categories%>

Severity ratings were selected according to the <%Facility\_Owner%> policies and procedures for ranking risks. For each cause, a list of safeguards that prevents the consequence is recorded. The team then determines the likelihood of the hazard with all the safeguards in place. The risk ranking is then selected from the risk matrix using the consequence level and the likelihood.

Table 2.3 Likelihood Categories

<%Likelihood\_Categories%>

Table 2.4 Risk Matrix for <%Facility\_Owner%>

<%Safety\_Risk\_Matrix%>

Where risks were found to be elevated, recommendations were developed by the team for consideration by management. Recommendations were generated when the team determined that safeguards for a specific hazard were inadequate to reduce the risk; alternatively, when compliance with codes/standards was identified as an issue, or in some cases, major operability issues arose. The intent of the recommendations is typically to reduce the likelihood and / or the severity of the hazard scenario identified by the team.

The PHA study Worksheets are provided in *Appendix C.* The worksheets describe each scenario that was developed by the team including the deviation, the cause, consequence, severity ratings, safeguards, and recommendations.

The PHA Study also included:

* A review of potential hazards associated with the Facilities Siting aspects of the process.
* A human factors analysis of working conditions that may impact the performance of operating personnel. Note: human factors are also addressed in the node-by-node HAZOP scenarios when operating errors (mis-operation) scenarios are identified that represents credible causes of process hazards that are related to human factors.
* A review of previous PHA study recommendations and Change Management logs since the previous PHA was conducted.

### Limitations

HAZOP is limited in scope and application. It is not intended to address every potential hazard in the plant. The following limitations are commonly recognized.

* HAZOP is not intended to address non-process hazards, such as occupational hazards not related to fires, explosion, toxic releases, or exposure to the hazards of a released material.
* HAZOP not suitable for examining the high-level issues such as the details of layout or the quantification of risks that would be performed with more detailed assessments such as a Quantitative Risk Assessment (QRA), a facility siting study, or a fire hazard analysis, vapor cloud explosion analysis, etc.
* HAZOP does not normally consider double jeopardy events (i.e., simultaneous failures of two or more self-revealing failures or normal means of process control) although closer scrutiny often finds that these events may not be truly independent
* HAZOP relies on expertise and knowledge of the team members involved, and therefore, is limited by knowledge of the members of the team.
* HAZOP quality is affected by the accuracy and completeness of information related to the technology of the process, the equipment of the process, and operating methods / procedures. Inaccurate or incomplete information results in additional time required and could lead the HAZOP team to incorrect conclusions.

## Assumptions

Based on documentation and client discussion, the following assumptions were made for the PHA study.

* Failures of inherently safe design features are not included as potential causes of process hazard scenarios.
* Basic Process Control System (BPCS) control loops can malfunction in a way that creates out of normal control process conditions. When a component of that loop is identified as a cause of deviation in the HAZOP worksheets, it is implicit that any component in the loop including the sensor, the logic solver, interposing equipment, and the final control element can result in the specified deviation from normal process control.
* The materials of construction of piping, vessels, gaskets, and valves have been correctly selected according to company design standards.
* Causes of deviations from normal process control that cannot result in operation beyond the safe operating limits (due to inherent limitations of the design) are not necessarily included / identified in the HAZOP study.
* The process is operated by trained operators and clear written operating instructions are followed.
* The equipment is inspected per the plant preventive maintenance standards, and maintenance is performed adequately.
* Piping and equipment are subject to a corrosion inspection program. Leaks due to corrosion of pipes and vessels are considered credible for piping and equipment included in such programs. However, total rupture of process equipment is not deemed a credible scenario unless otherwise specified in the HAZOP study worksheets.
* The car seal program is adequate to prevent the inadvertent, incorrect opening or closing of valves that are included in the program.
* Steam and electric tracing are adequate and properly maintained where it is installed.
* The electrical classification for all equipment is as per the specified electrical area classification.
* Blind flanges do not leak process fluids from higher pressure side of the blind flange to the lower pressure side of the blind flange.
* Sampling points and bleeders accidentally left open were not considered a cause of deviation.
* Blinds accidentally left in a line were not considered as a credible cause of a process deviation.
* Relief valves and relief valve discharge are properly designed to relieve credible overpressure scenarios for which they have been designed. Furthermore, relief valves are maintained in good working order.
* Deviations resulting from two or more independent events occurring at the same time were not considered unless one of the events had a high probability of occurrence or there was a history of the two events occurring simultaneously (i.e., no double jeopardy scenarios).

## Safety Instrumented Function (SIF) Compilation

SIF were identified during the HAZOP study. The current system has no dedicated safety instrumented system (SIS) and utilizes DCS control based interlocks. Potential SIF were identified when the HAZOP team identified DCS interlocks which were deemed to be safety critical, required additional independence from the DCS system, or new interlocks were recommended to further reduce the risk associated with HAZOP scenarios. In these cases, the scenario was imported to LOPA for further analysis.

## Safety Integrity Level Selection using Layer of Protection Analysis (LOPA)

A safety integrity level (SIL) was selected for each identified potential SIF. The SIL is a specification that defines the amount of risk reduction that the SIF is required to provide. SIL is defined in standards ANSI/ISA 61511 in terms of the average probability of failure on demand (PFDavg) of the SIF. The ranges of PFDavg that are associated with each SIL category and the corresponding risk reduction factors are shown in *Table 2.5* (for the low-demand mode of operation)*.*

**Table 2.5 SIL Categories**

|  |  |  |
| --- | --- | --- |
| **Safety Integrity Level (SIL)** | **Average Probability of Failure on Demand (PFDavg)** | **Risk Reduction Factor** |
| 4 | 10-4 to 10-5 | 10,000 to 100,000 |
| 3 | 10-3 to 10-4 | 1,000 to 10,000 |
| 2 | 10-2 to 10-3 | 100 to 1,000 |
| 1 | 10-1 to 10-2 | 10 to 100 |

Safety integrity level selection is an exercise in risk analysis. The consequence and likelihood of the hazard that the SIF is intended to prevent is estimated and then compared against guidelines that define the amount of risk reduction required to make the risk tolerable. This is usually accomplished through a qualitative analysis by a SIL Selection team comprised of individuals with expertise in process engineering, operations, control systems, and process safety management. The guidelines used for this project utilize a target mitigated event likelihood (TMEL) to define risk reduction requirements. The procedure and risk decision criteria used are provided in *Appendix I*.

The TMEL table process requires that the risk of a particular hazard be described as a **Consequence** - the magnitude of the injury that will result from the accident under analysis.

Once the process risk defining parameter is defined for a particular scenario, the risk reduction is selected. For this study, only safety was considered when determining the TMEL. The required risk reduction that is obtained from the TMEL does not consider the other layers of protection that have been installed in the process to reduce risk. The effectiveness of these non-SIS protection layers is evaluated by using an independent protection layer (IPL) analysis.

# 3 Conclusions and Recommendations

\_\_COMPANY\_\_ assisted <%Facility\_Owner%> in the evaluating hazards of its <%Unit%> at its <%Facility%>. A Process Hazard Analysis (PHA) was conducted in accordance with applicable standards, codes, industry recommended practices, and internal practices for hazard analysis.

Recommendations were generated to reduce the likelihood and severity of potential hazard scenarios, and these recommendations are listed in *Appendix D* (HAZOP) and *Appendix G* (LOPA). Based on the results of this analysis, \_\_COMPANY\_\_ recommends that all recommendations be resolved by <%Facility\_Owner%> management. Resolution should be documented with a rationale for determining whether the recommendation will be implemented, not implemented with justification, or alternative risk reduction means be implemented that substantially address the PHA-LOPA team’s concerns.

Major findings from the HAZOP:

Major findings from the LOPA:

# Appendix A – Study Basis

## A.1 Reference Documents

The following reference drawings were available to the PHA-LOPA team.

<%Documents%>

## A.2 Study Sessions

<%Sessions%>

## A.3 Participants / Attendance

<%Attendance%>

# Appendix B – Nodes

## B.1 List of Nodes

<%Nodes%>

# Appendix C – PHA Worksheets

## C.1 PHA Study Worksheets

<%Pha\_Worksheets%>

# Appendix D – PHA Recommendations

## D.1 PHA Recommendations

<%Pha\_Recommendations%>

# Appendix E – LOPA Worksheets

<%Lopa\_Worksheets%>

# Appendix F – LOPA Recommendations

<%Lopa\_Recommendations%>

# Appendix G – P&IDs