

Recommended Practice for Analysis, Design, Installation, and Testing of Safety Systems for Subsea Applications

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Introduction

This recommended practice (RP) presents a systematization of proven practices for providing a basic safety system for subsea applications. Proper application of these practices, along with good design, maintenance, and operation of the entire production facility can provide an operationally safe system.

Recommended Practice for Analysis, Design, Installation, and Testing of Safety Systems for Subsea Applications

1 Scope

1.1 General

This recommended practice (RP) presents recommendations for designing, installing, and testing a process safety system for subsea applications. The basic concepts of subsea safety systems are discussed and protection methods and requirements of the system are outlined.

For the purposes of this RP, 'subsea system' includes all process components from the wellhead (and surface controlled subsurface safety valve [SCSSV]) to upstream of the boarding shutdown valve. For gas injection, water injection, and gas lift systems, the shutdown valve is within the scope of API 17V. This also includes the chemical injection system. Refer to Figure 1.

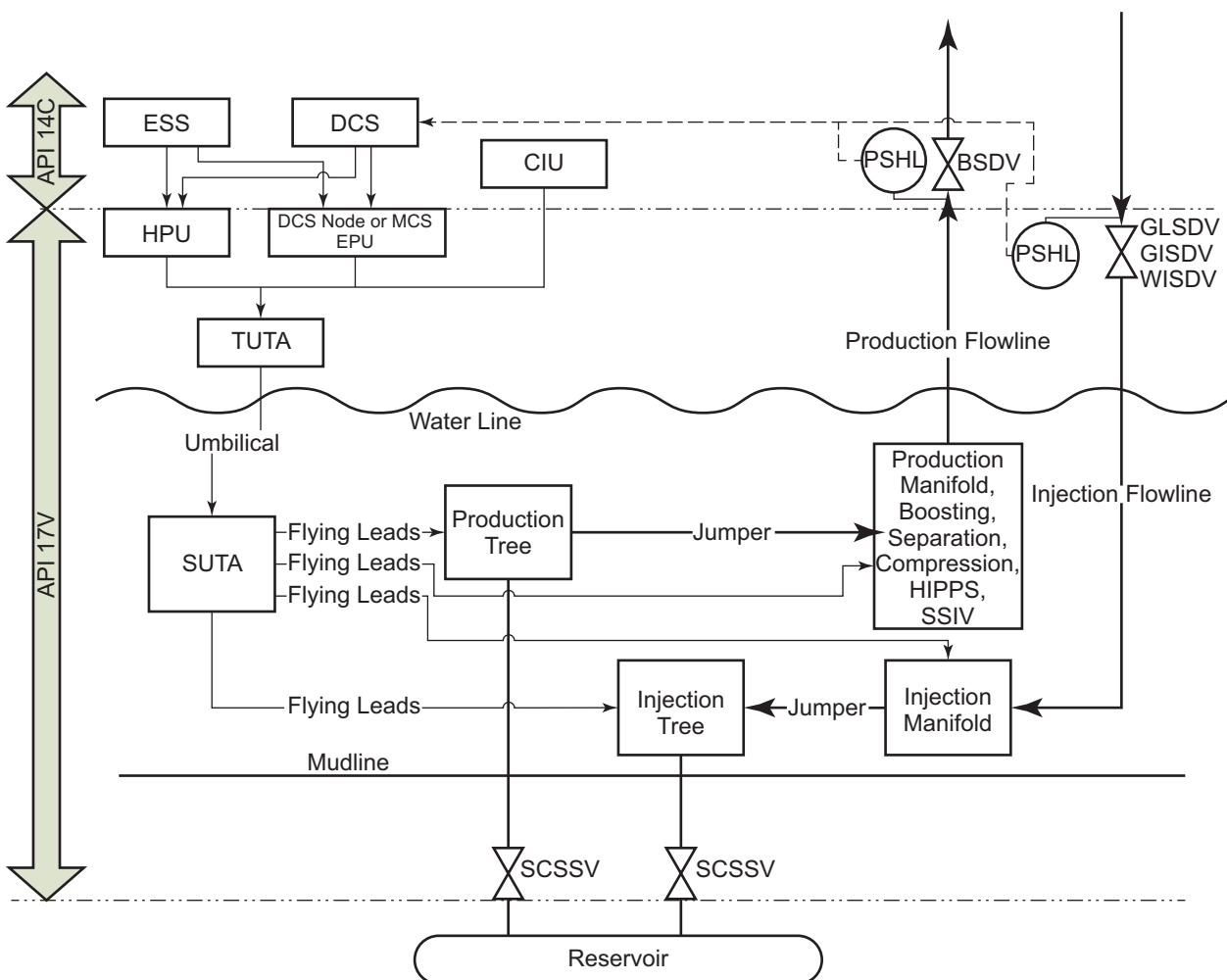


Figure 1—API RP 17V Scope

This document is a companion document to API 14C, which provides guidance for topsides safety systems on offshore production facilities. Some sections of this document refer to API 14C for safety system methodology and processes. This RP illustrates how system analysis methods can be used to determine safety requirements to protect any process component. Actual analyses of the principal components are developed in such a manner that the requirements determined will be applicable whenever the component is used in the process. The safety requirements of the individual process components may then be integrated into a complete subsea safety system. The analysis procedures include a method to document and verify system integrity. The uniform method of identifying and symbolizing safety devices is presented in API 14C and adopted in this RP.

Subsea systems within the scope of this document include:

- subsea trees (production and injection), flowlines, and SCSSVs;
- chemical injection lines;
- manifolds;
- subsea separation;
- subsea boosting;
- subsea compression;
- flowlines;
- gas lift;
- high integrity pressure protection system (HIPPS);
- subsea isolation valves;
- risers;
- hydraulic power unit.

The safety system includes valves and flow control devices in the production system. The safety system also includes sensors installed in the production system to detect abnormal conditions and allow corrective action to be taken (whether manual or automatic).

The intention is to design subsea safety systems to meet the requirements of IEC 61511; this document supplements these requirements.

Procedures for testing common safety devices are presented with recommendations for test data, test frequency, and acceptable test tolerances.

Instrumentation logic circuits are not discussed since these should be left to the discretion of the designer as long as the recommended safety functions are accomplished. Rotating machinery is considered in this RP as a unitized process component as it interfaces with the subsea safety system. When rotating machinery (such as a pump or compressor) is installed as a unit consisting of several process components, each component may be analyzed as prescribed in this RP.

1.2 Organization of Technical Content

The technical content of this RP is arranged as follows:

Section 2: Provides a listing of the normative references relating to this RP.

Section 3: A compilation of terms, definitions, acronyms, and symbols used throughout this document, including recommended standard symbols and abbreviations for safety device and process component identification.

Section 4: The general purpose, functional requirements, and basic premises of subsea safety system analysis and design.

Section 5: A detailed discussion of recommended safety analysis techniques, the concepts of protection from which they were developed, and a step-by-step procedure for analyzing and establishing design criteria for a subsea safety system.

Annex A: A safety analysis for each process component commonly used in a production process, including a checklist of additional criteria that should be considered when the component is used in a specific process configuration.

Annex B: A discussion of supporting systems that perform specific safety functions common to the entire facility.

Annex C: Testing procedures and reporting methods for the accumulation of safety system test data that can be used for operational analysis and reports that may be required by regulatory agencies.

1.3 Government Codes, Rules, and Regulations

Regulatory agencies have established certain requirements for the design, installation, and operation of offshore production facilities. In addition to federal regulations, certain state and local regulations may be applicable.

In addition to the regulations listed in API 14C, the following federal documents pertain to offshore oil and gas producing operations and should be used when applicable:

- 30 *Code of Federal Regulations* Part 250, Subpart H (*Oil and Gas Sulphur Operations in the OCS*) and Subpart J (*Pipelines and Pipeline Right-of-Ways*);
- 40 *Code of Federal Regulations* Part 112, Chapter I, Subchapter D (*Oil Pollution Prevention*).

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Specification 6A, *Specification for Wellhead and Christmas Tree Equipment*

API Specification 6AV1, *Specification for Validation of Wellhead Surface Safety Valves and Underwater Safety Valves for Offshore Service*

API Specification 14A, *Specification for Subsurface Safety Valve Equipment*

API Recommended Practice 14B, *Design, Installation, Repair and Operation of Subsurface Safety Valve Systems*

API Recommended Practice 14C, *Analysis, Design, Installation, and Testing of Basic Surface Safety Systems for Offshore Production Platforms*

API Recommended Practice 14H, *Installation, Maintenance and Repair of Surface Safety Valves and Underwater Safety Valves Offshore*

API Recommended Practice 14J, *Design and Hazards Analysis for Offshore Production Facilities*

API Specification 17D, *Design and Operation of Subsea Production Systems—Subsea Wellhead and Tree Equipment*

API Recommended Practice 17O, *Recommended Practice for Subsea High Integrity Pressure Protection System (HIPPS)*

API Technical Report 6AF, *Technical Report on Capabilities of API Flanges under Combinations of Load*

IEC 61511¹, *Functional Safety—Safety Instrumented Systems for the Process Industry Sector*

3 Terms, Definitions, Acronyms, and Abbreviations

For the purposes of this document, the following definitions apply.

3.1 Safety Device Symbols and Identification

A standard method for identifying, abbreviating, and symbolizing individual safety devices is necessary to promote uniformity when describing or referring to safety systems. This method can be used to illustrate safety devices on flow diagrams and other drawings, and to identify an individual safety device for any purpose. Refer to API 14C for functional device identification, symbols, component identification, and identification examples.

3.2 Terms and Definitions

For the purposes of this document, the following definitions apply.

3.2.1

abnormal operating condition

Condition that occurs in a process component when an operating variable ranges outside of its normal operating limits.

3.2.2

abnormal temperature

Temperature in a process component above or below the allowable temperature.

3.2.3

backflow

Fluid flow in a process component opposite to the normal flow direction.

3.2.4

barrier

Element forming part of a pressure-containing envelope that is designed to prevent unintentional flow of production/injected fluids, particularly to the external environment.

NOTE For more detail, refer to API 17A.

¹ International Electrotechnical Commission, 3, rue de Varembé, P.O. Box 131, CH-1211, Geneva 20, Switzerland, www.iec.ch.

3.2.5**choke**

Device that controls pressure and flow rate by a fixed or adjustable amount.

NOTE 1 Chokes are not considered a safety device.

NOTE 2 For the purpose of this document, figures may show chokes for clarity.

3.2.6**detectable abnormal condition**

An abnormal operating condition that can be automatically detected.

3.2.7**emergency shutdown (ESD) system**

System of manual stations that, when activated, initiates facility shutdown.

NOTE Activation of the emergency shutdown (ESD) system may also be initiated automatically by fire detection devices and other safety devices.

3.2.8**fail closed valve**

A valve that will shift to the closed position upon loss of the power medium.

3.2.9**fail open valve**

A valve that will shift to the open position upon loss of the power medium.

3.2.10**failure**

Improper performance or operation of a device or equipment item that prevents completion of its design function or intent.

3.2.11**final element**

Part of a safety instrumented system that implements the physical action necessary to achieve a safe state.

3.2.12**flowline**

Piping that directs the well fluids from the wellhead to an offshore or onshore facility.

3.2.13**flow safety valve**

A check valve installed in the system to minimize back flow.

3.2.14**flowline segment**

Any portion of a flowline that has an operating pressure different from another portion of the same flowline.

3.2.15**fully rated**

The design pressure of the system is greater than or equal to the maximum allowable working pressure.

3.2.16**gas blowby**

The discharge of gas from a process component through a liquid outlet.

3.2.17**high liquid level**

Liquid level in a process component above the highest operating level.

3.2.18**high pressure**

Pressure in a process component in excess of the maximum operating pressure, but less than the maximum allowable working pressure (MAWP) (for flowlines, maximum allowable operating pressure).

3.2.19**high temperature**

Temperature in a process component in excess of the design operating temperature.

3.2.20**inherently safe design**

A design that avoids hazards instead of controlling them, particularly by reducing the amount of hazardous material and the number of hazardous operations.

3.2.21**interlock**

A function that prevents an action given a certain set of defined conditions are met.

3.2.22**leak**

The inability of a device (i.e. valve) to seal, referring to internal leakage within the process.

3.2.23**liquid overflow**

The discharge of liquids from a process component through a gas (vapor) outlet.

3.2.24**logic solver**

The portion of a safety system that performs one or more logic function(s).

3.2.25**loss of containment**

The escape of fluids from a process component to the environment; alternatively, the environment entering into the process in under pressured systems.

3.2.26**low flow**

Flow in a process component less than the minimum operating flow rate.

3.2.27**low liquid level**

Liquid level in a process component below the lowest operating level.

3.2.28**low pressure**

Pressure in a process component less than the minimum operating pressure.

3.2.29**low temperature**

Temperature in a process component less than the minimum operating temperature.

3.2.30**malfunction**

Any condition of a device or an equipment item that causes it to operate improperly, but does not prevent the performance of its design function.

3.2.31**maximum allowable working pressure****MAWP**

The highest operating pressure allowable at any point in any component other than a flowline during normal operation or static conditions.

3.2.32**nuisance trips**

Activation of the safety system due to an internal systems failure or human error.

NOTE Commonly known as a false or spurious systems failure.

3.2.33**overpressure**

Pressure in a process component in excess of the MAWP (for flowlines, maximum allowable operating pressure).

3.2.34**permissive**

A function that allows an action or state when all defined conditions are met.

3.2.35**process component**

A single functional piece of subsea production equipment and associated piping used, such as a separator, compressor, or pump.

3.2.36**process shutdown**

The isolation of a given subsea process by dual barriers to shut-in flow.

3.2.37**qualified person**

An individual with characteristics or abilities gained through training, experience, or both, as measured against established requirements, such as standards or tests, which enable the individual to perform a required function.

3.2.38**safety device**

An instrument or control device used within the safety system.

3.2.39**sensor**

A device used to sense or measure the condition of a process variable or condition of a piece of process equipment and provide input to the process control or safety system.

3.2.40**safety instrumented function****SIF**

A function implemented by a safety instrumented system (SIS) to achieve or maintain a safe state for the process in a specific hazardous event. Each SIF is designed and tested to meet its target safety integrity level (SIL).

3.2.41
safety instrumented system
SIS

A system of sensors, logic solvers, and actuators that take a process to a safe state when normal predetermined set points are exceeded or safe operating conditions are violated.

3.2.42
shutdown valve
SDV

An automatically operated, fail closed valve used for isolating equipment.

3.2.43
source

Any contained volume of hydrocarbons.

3.2.44
subsea isolation valve
SSIV

An emergency shutdown valve located in the flowline that is normally installed below the splash-zone, often on the seabed.

3.2.45
subsea safety system

An arrangement of safety devices and ESSs to effect the subsea system shutdown.

NOTE The system may consist of a number of individual process shutdowns and may be actuated by either manual controls or automatic devices sensing detectable abnormal conditions.

3.2.46
under pressure

Pressure in a process component less than the design collapse pressure.

3.2.47
underwater safety valve
USV

An automatic valve assembly (installed at an underwater wellhead location) that provides a tested barrier to the wellstream and is fail closed.

3.2.48
undesirable event

An adverse occurrence or situation in a process component or process station that poses a threat to safety, such as overpressure, under pressure, liquid overflow, etc.

3.3 Acronyms and Abbreviations

The following acronyms and abbreviations are used in this specification:

AMV	annulus master valve
ANSI	American National Standards Institute
AWV	annulus wing valve
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
BSDV	boarding shutdown valve

CIU	chemical injection utilities
CIV	chemical injection valve
DCS	distributed control system
EPU	electrical power unit
ESD	emergency shutdown
ESS	emergency support system
FSV	flow safety valve
GISDV	gas injection shutdown valve
GLIV	gas lift isolation valve
GLSDV	gas lift shutdown valve
HAZOP	hazard and operability study
HIPPS	high integrity pressure protection system
HPU	hydraulic power unit
ISA	International Society of Automation
LAH	level alarm high
LAHH	level alarm high high
LAL	level alarm low
LALL	level alarm low low
LSH	level safety high
LSL	level safety low
MAWP	maximum allowable working pressure
MCS	master control station
NACE	National Association of Corrosion Engineers
OCS	outer continental shelf
PMV	production master valve
PSH	pressure safety high
PSHL	pressure safety high/low
PSL	pressure safety low
PSV	pressure safety valve
PT	pressure transmitter
ROV	remotely operated vehicle
RP	recommended practice
SAC	safety analysis checklist
SAFE	safety analysis function evaluation
SAT	safety analysis table
SCSSV	surface controlled subsurface safety valve
SDV	shutdown valve
SIF	safety instrumented function
SIL	safety integrity level
SIS	safety instrumented system

SITP	shut-in tubing pressure
SSIV	subsea isolation valve
SSV	surface safety valve
SUTA	subsea umbilical termination assembly
TR	technical report
TSH	temperature safety high
TSHL	temperature safety high/low
TSL	temperature safety low
TUTA	topsides umbilical termination assembly
USV	underwater safety valve
WISDV	water injection shutdown valve
XOV	crossover valve

4 Introduction to Safety Analysis and System Design

4.1 Purpose and Objectives

Subsea safety systems protect personnel, the environment, and the facility from production process threats. A safety analysis identifies undesirable events that might pose a threat to safety and/or environment, and defines reliable protective measures that will prevent such events or minimize their effects if they occur.

Potential threats to safety and/or the environment are identified through proven system analyses that have been adapted to the production process. These analyses include hazard identification (HAZID), hazard and operability study (HAZOP), layer of protection analysis (LOPA), and failure modes, effects, and criticality analysis (FMECA), among others. Recommended protective measures are common industry practices that are proven through experience. System analyses and protective measures have been combined into safety analyses for subsea production systems.

The subsea safety system shall meet the requirements of IEC 61511.

The content of this RP establishes a firm basis for designing and documenting a safety system for subsea components, systems, and processes.

Moreover, it establishes guidelines for analyzing components or systems that are new or significantly different from those covered in this document. However, it is incumbent on the user to apply appropriate additional hazardous analysis methodologies to ensure that hazards are identified and mitigated.

Before a production subsea safety system is placed in operation, procedures should be established to assure continued system integrity. Annex C may be used for this purpose.

4.2 Safety Flow Chart

The safety flow chart in Figure 2 depicts the manner in which undesirable events could result in personnel injury, pollution, or facility damage. It also shows where safety devices or procedures should be used to prevent the propagation of undesirable events. As shown on the chart, the release of hydrocarbons is a factor in virtually all threats to safety. Thus, the major objective of the safety system should be to prevent the release of hydrocarbons from the process and to minimize the adverse effects of such releases if they occur.

a) Referring to Figure 2, the overall objectives may be enumerated as follows:

- 1) prevent undesirable events that could lead to a release of hydrocarbons;
 - 2) shut-in the process or affected part of the process to stop the flow of hydrocarbons to a leak or overflow if it occurs.
- b) Accidents caused by events external to the subsea system are not self-propagating unless they affect the process or start a fire. If they affect the process, the safety system should shut down the process or affected part of the process. If they result in fire, the safety system should shut down all subsea activity. Such accidents may be caused by natural phenomenon, dropped objects, failure of tools and machinery, or mistakes by personnel. These types of accidents may be prevented or minimized through safe design of tools and machinery, safe operating procedures for personnel and equipment, and personnel training. Figure 2 indicates the manner in which external accidents may affect the process.

4.3 Safety System Operation

The safety system provides protection in the following ways:

- a) automatic monitoring and automatic protective action if an abnormal condition indicating an undesirable event can be detected by a sensor;
- b) protective action manually actuated by personnel who observe or are alerted to an unsafe condition by an alarm;
- c) continuous protection by support systems that minimize the effects of escaping hydrocarbons.

The emergency shutdown (ESD) system is required for all offshore facilities. These ESD systems are required for those facilities that are not continuously occupied, because many accidents and failures are caused by human error and may occur on normally unoccupied facilities during those times when personnel are aboard and conducting maintenance or other activities. Thus, personnel may be available to actuate the system.

4.4 Premises for Basic Analysis and Design

The recommended analysis and design procedures for a subsea safety system are based on the following premises.

- a) The subsea facility will be designed for safe operation in accordance with good engineering practices.
- b) The principles of inherently safe design are followed.
- c) The safety system should provide two levels of protection to prevent or minimize the effects of an equipment failure within the process.
- d) The two levels of protection should be the highest order (primary) and then the next highest order (secondary) available. Judgment is required to determine these two highest orders for a given situation. As an example, two levels of protection from a rupture due to overpressure might be provided by a pressure safety high (PSH) or pressure safety valve (PSV). The PSH prevents the rupture by shutting in affected equipment before pressure becomes excessive, and the PSL shuts in affected equipment after the rupture occurs. However, a PSV is selected in lieu of the PSL, because it prevents the rupture by relieving excess volumes to a safe location. Moreover, its fast response could prevent a rupture in situations where the PSH might not effect corrective action fast enough.
- e) The use of proven systems analysis techniques, adapted to the production process, determine the minimum safety requirements for a process component. If such an analysis is applied to the component as an independent unit, assuming worst case conditions of input and output, the analysis will be valid for that component in any process configuration.

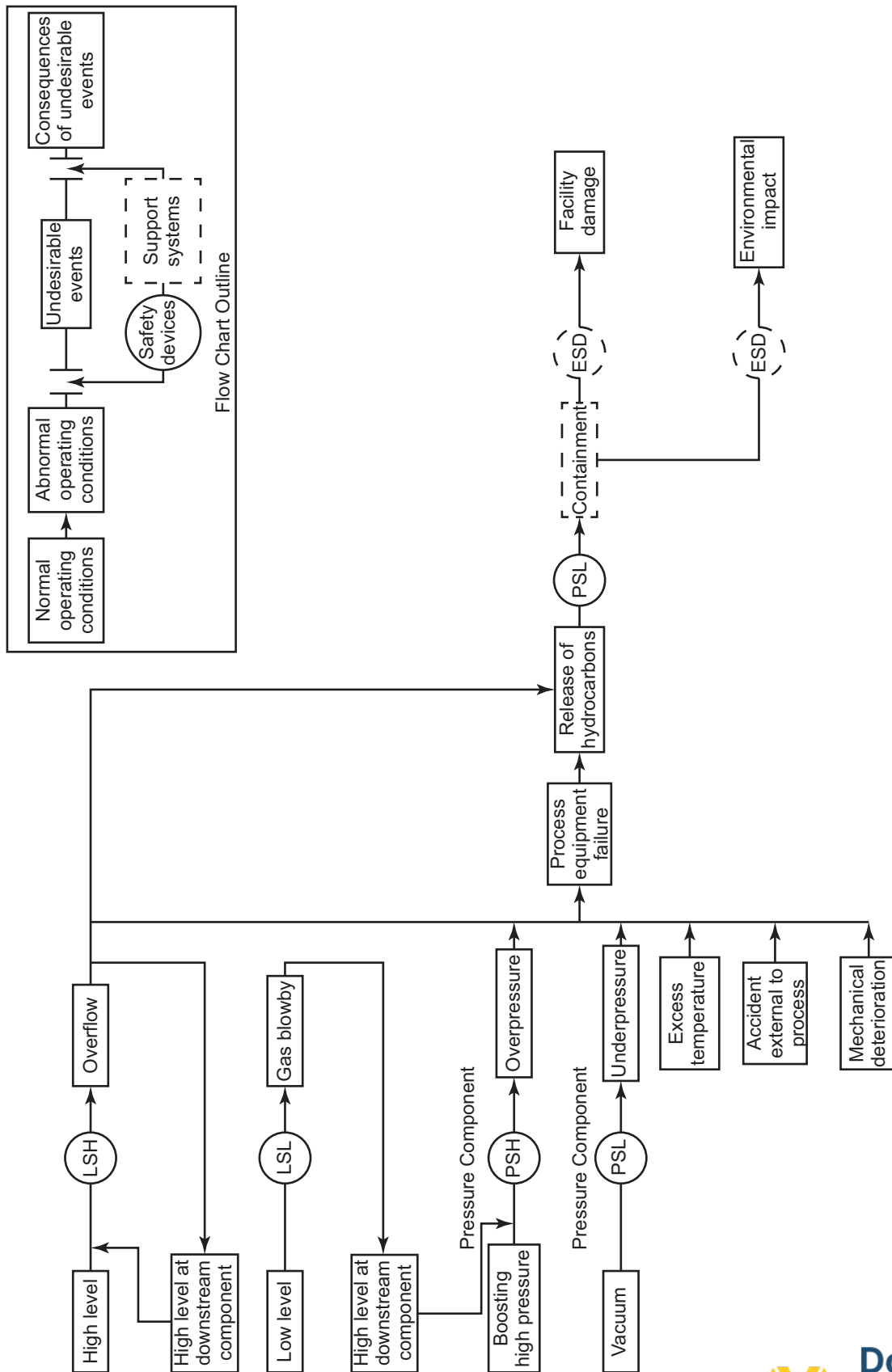


Figure 2—Safety Flow Chart—Subsea Production Facility

- f) All the components from the wellhead (and SCSSV) to upstream of the boarding shutdown valve comprise the subsea system. This also includes the chemical injection system.
- g) When fully protected process components are combined into a system, no additional threats to safety are created. Therefore, if all process component safety devices are logically integrated into a safety system, the entire facility will be protected. It is incumbent on the user to apply appropriate additional hazard analysis methodologies to ensure that hazards are identified and mitigated.
- h) The subsea production control system is not considered a safety system; however, it contributes to the overall safety system.
- i) The analysis procedure should provide a standard method to develop a safety system and provide supporting documentation.

5 Protection Concepts and Safety Analysis

5.1 Introduction

The analysis and design of a subsea safety system should focus on personnel safety, preventing releases of hydrocarbons, stopping the flow of hydrocarbons resulting from a loss of containment if it occurs, as well as preventing and mitigating the ingress of seawater resulting from a loss of containment in an under pressure system scenario.

Section 5.2 explains the basic concepts of protection used in the analysis. These concepts are repeated in Annex A, as applicable to individual component analysis.

Section 5.3 discusses methods of analyzing the process and establishing design criteria for an integrated safety system covering the entire subsea process.

Section 5.4 is a step-by-step summary for performing a safety analysis in accordance with this document. It is indicated that this method initially considers each component independently from the rest of the process and may recommend safety devices that are not required after larger segments of the process are considered. For example, many safety devices initially considered on manifolds are not normally required because their safety function is performed by devices on other components.

5.2 Protection Concepts

5.2.1 General

As defined in 1.1 and Figure 1, the boarding valve acts as a barrier between the subsea and topsides systems. The integrity of the boarding valve serves as the foundation of the protection concepts. It protects the topsides facility if an event occurs in the subsea system. Subsea systems are designed to be fully rated to shut-in tubing pressure (SITP). If the system is not fully rated (e.g. introduction of a HIPPS system), additional protection concepts are required as described herein.

Two barriers shall always be in place between a hydrocarbon source and the environment during normal production operations. However, it is acceptable practice to shut-in production and remove a pressure barrier (e.g. pressure cap) during temporary activities, such as well tie-in operations and remotely operated vehicle (ROV) sampling. For further definition of barrier philosophy, refer to API 17A.

5.2.2 Undesirable Events

5.2.2.1 General

An undesirable event is an adverse occurrence in a process component that poses a threat to system integrity. The undesirable events discussed in this section can develop in a process component under worst-case conditions of input and output. An undesirable event may be indicated by one or more process variables ranging out of operating limits. These abnormal operating conditions can be detected by sensors that initiate shut down action to protect the process component.

Each undesirable event that can affect a process component is discussed according to the following format:

- a) cause;
- b) effect and detectable abnormal condition;
- c) primary and secondary protection that should prevent or react to its occurrence.

5.2.2.2 Overpressure

5.2.2.2.1 General

Overpressure is pressure in a process component in excess of the maximum allowable working pressure (MAWP).

5.2.2.2.2 Cause

Overpressure can be caused by various scenarios that develop a pressure that is in excess of the MAWP of the component. Typical causes of overpressure include, but are not limited to, the following.

- a) An input source that will develop pressure in excess of a process component's MAWP if inflow exceeds outflow. Inflow may exceed outflow if an upstream flowrate control device fails, if there are restrictions or blockages in the component's outlets, or if overflow or gas blow-by from an upstream component occurs.
- b) Backflow occurs from a downstream source with a higher operating pressure than the MAWP of the component. Backflow could occur when forward flow is stopped, allowing reverse flow to the upstream components. Typical examples include centrifugal pumps and compressors where the suction side has a MAWP lower than the downstream operating pressure. Check valves should not be assumed to prevent such backflow as they are subject to leaking and failing open on demand. Careful consideration should also be given to side streams feeding into the system.
- c) Settle-out pressure resulting from compressor shutdown results in a pressure exceeding the MAWP of any component in the system. This scenario can occur when the MAWP of the suction side of a compressor is lower than the resulting settle out pressure.
- d) Misdirected flow resulting from a high-pressure source inadvertently routed to a component having a lower MAWP.

Causes of overpressure can vary and will depend upon the facility design and operating conditions.

5.2.2.2.3 Effect and Detectable Abnormal Condition

The effect of overpressure can be a sudden rupture and leak of hydrocarbons. High pressure is the detectable abnormal condition that indicates that overpressure may occur.

5.2.2.2.4 Primary Protection

For the purposes of this RP, a fully rated system considers the equipment as primary protection. If the system is not fully rated, HIPPS shall be required.

5.2.2.2.5 Secondary Protection

Secondary protection from overpressure in a pressure component should be provided by a PSH to shut off inflow.

5.2.2.2.6 Location of Safety Devices

In a process component with both a liquid and a gas section, the PSH should be installed to sense pressure from the gas or vapor section. The sensing connections for the safety devices should be located at the highest practical location on the component to minimize the chance of fouling by flow stream contaminants.

5.2.2.3 Loss of Containment

5.2.2.3.1 General

A loss of containment refers to the escape of fluids from a process component to the environment or alternatively, the environment entering into the process in under pressured systems.

5.2.2.3.2 Cause

A loss of containment can be caused by deterioration from corrosion, erosion, and mechanical failure or temperature effects; by rupture from overpressure or under pressure; or by accidental damage from external forces.

5.2.2.3.3 Effect and Detectable Abnormal Conditions

The effect of a loss of containment is the release of hydrocarbons to the environment. Low pressure and low level are the abnormal conditions that might be detectable to indicate that a loss of containment has occurred. For under pressured systems, a loss of containment may result in sea water ingress into the system. In this instance, higher than normal pressures may be detected, or the presence of sea water in a topside separator are the abnormal conditions that might be detectable to indicate that a loss of containment has occurred. Salinity detection in topsides components or a drop in normal operating temperature may indicate loss of containment.

5.2.2.3.4 Primary Protection

For the purposes of this RP, a fully rated system considers the equipment as primary protection.

In the case of a non-fully rated system where a HIPPS is installed, the system shall be fully rated for external pressure.

5.2.2.3.5 Secondary Protection

Secondary protection from loss of containment should be provided by a topside PSH/PSL.

5.2.2.3.6 Location of Safety Devices

In a process component with both a liquid and a gas section, the PSH/PSL should be connected to sense pressure from the gas or vapor section. The PSH/PSL should be installed at the highest practical location on the component to minimize the chances of fouling by flow stream contaminants. The level safety low (LSL) should be located a sufficient distance below the lowest operating liquid level to avoid nuisance trips, but with adequate volume between the LSL and liquid outlet to prevent gas blowby before shutdown is accomplished.