

Standard for Subsea High Integrity Pressure Protection Systems (HIPPS)

API STANDARD 17O
SECOND EDITION, JULY 2014

REAFFIRMED, FEBRUARY 2019



AMERICAN PETROLEUM INSTITUTE

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Standard for Subsea High Integrity Pressure Protection Systems (HIPPS)

1 Scope

This standard addresses the requirements for the use of high integrity pressure protection systems (HIPPS) for subsea applications. API 14C, IEC 61508, and IEC 61511 specify the requirements for onshore, topsides, and subsea safety instrumented systems (SIS) and are applicable to HIPPS, which are designed to autonomously isolate downstream facilities from overpressure situations. This document integrates these requirements in order to address the specific needs of subsea production. These requirements cover the HIPPS pressure sensors, logic solver, shutdown valves, and ancillary devices including testing, communications, and monitoring subsystems.

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 Recommended Practice 6HT, *Heat Treatment and Testing of Large Cross Section and Critical Section Components*

API Recommended Practice 17A, *Design and Operation of Subsea Production Systems—General Requirements and Recommendations*

API Specification 17D, *Subsea Wellhead and Christmas Tree Equipment*

API Specification 17E, *Specification for Subsea Umbilicals*

API Standard 17F, *Standard for Subsea Production Control Systems*

API Recommended Practice 17H, *Remotely Operated Tools and Interfaces on Subsea Production Systems*

API Recommended Practice 17P, *Recommended Practice for Design and Operation of Subsea Production Systems—Subsea Structures and Manifolds*

ANSI/ASME B31.3 ^{1, 2}, *Process Piping*

ANSI/ASME B31.8, *Gas Transmission and Distribution Piping Systems*

AWS D1.1 ³, *Structural Welding Code—Steel*

IEC 61508, Parts 1 to 4 ⁴, *Functional safety of electrical/electronic/programmable electronic safety-related systems*

IEC 61511, Part 1, *Functional safety—Safety instrumented systems for the process industry sector*

¹ American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, New York 10036, www.ansi.org.

² ASME International, 2 Park Avenue, New York, New York 10016-5990, www.asme.org.

³ American Welding Society, 8669 NW 36 Street, #130, Miami, Florida 33166-6672, www.aws.org.

⁴ International Electrotechnical Commission, 3, rue de Varembé, P.O. Box 131, CH-1211, Geneva 20, Switzerland, www.iec.ch.

NACE MR 0175, *Petroleum and natural gas industries—Materials for use in H₂S-containing environments in oil and gas production*

ANSI/SAE J343 ⁵, *Test and Test Procedures for SAE 100R Series Hydraulic Hose and Hose Assemblies*

ANSI/SAE J517, *Hydraulic Hose*

SAE AS 4059, *Aerospace Fluid Power—Cleanliness Classification for Hydraulic Fluids*

3 Terms, Definitions, and Acronyms

3.1 Terms and Definitions

For the purposes of this document, the following definitions apply. Where applicable, these definitions are aligned with those found in the latest edition of IEC 61508-4.

3.1.1

alternative pressure source

Injection fluid used for a valve seal test that does not exceed the RWP of the HIPPS at its depth rating.

NOTE Injection fluid can be any fluid that can be introduced into the system not only for testing but also for flushing or preventing hydrates from forming.

3.1.2

beta factor (β)

Factor used to represent the proportion of the dangerous failure rate of a nonredundant subsystem that would occur due to common cause hardware failures, if a redundant configuration is adopted.

3.1.3

commissioning

Functional verification of equipment and facilities prior to initiating operations.

3.1.4

dangerous failure

Failure of an element and/or subsystem and/or system that plays a part in implementing the safety function that:

- a) prevents a safety function from operating when required (demand mode) or causes a safety function to fail (continuous mode) such that the EUC is put into a hazardous or potentially hazardous state; or
- b) decreases the probability that the safety function operates correctly when required.

3.1.5

final element

Part of a SIS which implements the physical action necessary to achieve a safe state.

NOTE The final element includes HIPPS closure devices (isolation valves), control valves (used to apply or relieve hydraulic control fluid pressure which actuates the HIPPS closure device), and quick exhaust valves.

3.1.6

fortified section

Piping and equipment with an intermediate pressure rating somewhere between the SIP (high) and MAWP (low) ratings.

⁵ SAE International (formerly the Society of Automotive Engineers), 400 Commonwealth Drive, Warrendale, Pennsylvania 15096-0001, www.sae.org.

3.1.7**hardware fault tolerance****HFT**

Ability of a functional unit to continue to perform a required function in the presence of faults or errors.

NOTE In determining the HFT, no account is taken of other measures that may control the effects of faults such as diagnostics, and where one fault directly leads to the occurrence of one or more subsequent faults; these are considered as a single fault.

3.1.8**high integrity pressure protection system****HIPPS**

Mechanical and electrical-hydraulic SIS used to protect production assets from high-pressure upsets.

3.1.9**logic solver**

In relation to a HIPPS, a Logic Solver is defined as the portion of an SIS that performs one or more logic function(s) related to the safety function(s).

3.1.10**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.

3.1.11**operating pressure**

Pressure in the equipment when the plant operates at steady state condition, subject to normal variation in operating parameters.

3.1.12**overpressure source**

One or a combination of sources which can create a pressure buildup beyond the RWP of hardware downstream.

NOTE Examples include the reservoir, pressure or boosting equipment (i.e. pump/compressor), manifolds, or other fluid injection sources.

3.1.13**pipeline**

Piping, risers, and appurtenances installed for transporting oil, gas, sulfur, and produced waters.

3.1.14**process hazard**

Process upset that could result in loss of life, injury to personnel, pollution, or damage to production assets such as overpressure and the subsequent rupture or failure of the process equipment.

3.1.15**process safety time**

The time period between a failure occurring in the process or the basic process control system (with the potential to give rise to a hazardous event) and the occurrence of the hazardous event if the safety instrumented function is not performed.

3.1.16**rated working pressure****RWP**

Maximum internal pressure that the equipment is designed to contain and/or control.

3.1.17**reliability**

Likelihood of a given piece of safety-related equipment to remain in operation for the expected duration.

3.1.18**risk analysis**

Determination of the frequency of the event (e.g. overpressure) and the ability of safeguards (e.g. HIPPS) to reduce the frequency or the consequence such that the event becomes tolerable, either by being very rare (unlikely) or by lessening the impact.

3.1.19**safe failure**

Failure of an element and/or subsystem and/or system that plays a part in implementing the safety function that:

- a) results in the spurious operation of the safety function to put the EUC (or part thereof) into a safe state or maintain a safe state; or
- b) increases the probability of the spurious operation of the safety function to put the EUC (or part thereof) into a safe state or maintain a safe state.

3.1.20**safe failure fraction****SFF**

Property of a safety related element that is defined by the ratio of the average failure rates of safe plus dangerous detected failures and safe plus dangerous failures.

NOTE Refer to the latest edition of IEC 61508 for additional information.

3.1.21**safety instrumented function****SIF**

Safety function with a specified SIL which is necessary to achieve functional safety and which can be either a safety instrumented protection function or a safety instrumented control function.

3.1.22**safety instrumented system****SIS**

Instrumented system used to implement one or more safety instrumented functions. An SIS is composed of any combination of sensor(s), logic solver(s), and final element(s) (for example, refer to Figure 1).

NOTE This can include either safety instrumented control functions or safety instrumented protection functions or both.

3.1.23**safety integrity level****SIL**

Discrete level (one out of four) for specifying the safety integrity requirements of the SIFs to be allocated to the SIS.

NOTE SIL 4 has the highest level of safety integrity; SIL 1 has the lowest level.

3.1.24**shut-in pressure****SIP**

Full internal product process pressure that is contained by the HIPPS at the seabed when the high-pressure source is abruptly isolated to protect lower pressure hardware downstream of the spec break.

3.1.25**specification (spec) break**

Point at which equipment pressure rating changes from one RWP rating to a lower one (or vice versa) downstream.

NOTE These locations are defined by the normal operating conditions of a flow stream that allows the use of lower design pressure equipment.

3.1.26**subsea tieback**

An offshore field developed with one or more wells completed on the seafloor, using subsea trees.

NOTE The wells are connected by flowlines and umbilicals (the pathways for electrical and hydraulic signals) to a production facility in another area.

3.1.27**systems integration test****SIT**

A process conducted on land to verify the fit, form, and function between interfaces of all subsea equipment and associated running tools prior to offshore installation.

3.1.28**systematic failure**

Failure related in a deterministic way to a certain cause, which can only be eliminated by a modification of the design or of the manufacturing process, operational procedures, documentation, or other relevant factors.

3.1.29**validation**

Validation within this document has the meaning of “type approval” and is the process of proving a design by testing to demonstrate conformity of the product to design requirements.

3.1.30**verification**

All activities necessary to confirm that the installed and mechanically completed HIPPS and its associated instrumented functions, meets the requirements stated in the SRS.

3.2 Acronyms, Abbreviations, and Symbols

β	beta factor
χ^2	uncertainty of the reliability estimate
λ	failure rate
λ_D	dangerous failures
λ_{DD}	dangerous detected failures
λ_{du}	dangerous undetectable failures
λ_{TOT}	total failure rate
AA	AA trim
ANSI	American National Standards Institute
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
ASNT	American Society for Nondestructive Testing
AWS	American Welding Society

BSDV	boarding shutdown valve
CFR	Code of Federal Regulations
DC	diagnostic coverage
DCS	distributed control system
DCV	directional control valve
DNV	Det Norsk Veritas
DOT	Department of Transportation
EPU	electrical power unit
ESD	emergency shutdown
EUC	equipment under control
FAT	factory acceptance test
FIV	flowline isolation valve
FMECA	failure mode effects and criticality analysis
GOR	gas-oil-ratio
HBN	Brinell hardness
HFT	hardware fault tolerance
HH	HH trim
HIPPS	high integrity pressure protection system
HPU	hydraulic power unit
HSCM	HIPPS subsea control module
IEC	International Electrical Commission
ISA	International Society of Automation
LOPA	layer of protection analysis
MAWP	maximum allowable working pressure
MCS	master control station
MOC	management of change
MTBF	mean time between failure
MTTF	mean time to failure
MTTR	mean time to repair
MWP	maximum working pressure
NACE	National Association of Corrosion Engineers
NDE	normally de-energized
NE	normally energized
OLF	recommended guidelines for the application of IEC 61508 and IEC 61511 in the petroleum activities of the Norwegian Continental Shelf
PCS	production control system
PE	programmable electronics
PES	programmable electronic system

PFD	probability of failure on demand
PLEM	pipeline end manifold
PLET	pipeline end termination
PR	performance requirement
PSD	production shutdown
PSH	pressure switch high
PSL	product specification level
PST	partial stroke testing
PSV	process safety valve
PT	pressure transmitter
QEV	quick exhaust valve
QRA	quantitative risk analysis
QTC	qualification test coupon
ROT	remotely operated tool
ROV	remotely operated vehicle
RP	recommended practice
RWP	rated working pressure
SAE	Society of Automotive Engineers
SAFE	safety analysis function evaluation
SCM	subsea control module
SCSSV	surface controlled subsurface safety valve
SDV	shutdown valve (isolation valve)
SEM	subsea electronics module
SFF	safe failure fraction
SIF	safety instrumented function
SIL	safety integrity level
SIP	shut-in pressure
SIS	safety instrumented system
SIT	systems integration test
SOV	solenoid valve
SRS	safety requirement specification
SWL	safe working load
UPS	uninterruptible power supply
USV	underwater safety valve
XZV	trip valve

4 System Considerations

4.1 Introduction and Overview

This section covers system elements that shall be considered when designing a HIPPS. HIPPS is an SIS used to protect downstream facilities and personnel, and prevent environmental release by containing high-pressure excursions.

The design and performance of the HIPPS, including all lifecycle activities, should be based on IEC 61511. Hazard and risk assessments shall be conducted to determine requirements for risk reductions, allocate safety integrity level (SIL) of the HIPPS, and demonstrate that the risk of overpressure has been adequately mitigated. Appropriate regulatory agencies should be consulted for additional design and operating requirements.

A typical HIPPS is shown in Figure 1.

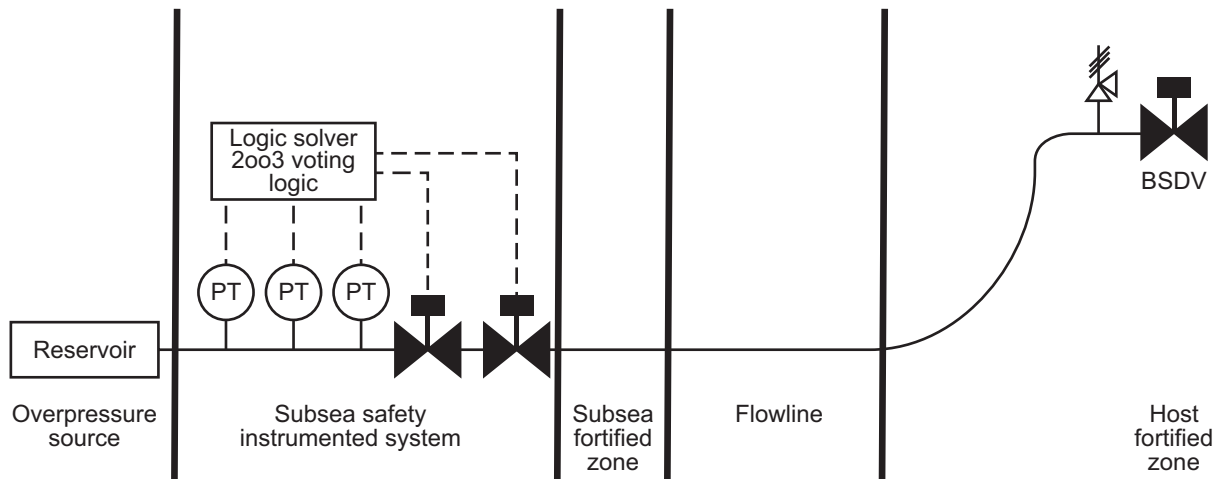


Figure 1—Typical Subsea Production HIPPS Valve Diagram

4.1.1 Pressure Source

The overpressure to be mitigated by the HIPPS could originate from a number of sources. Examples include, but are not limited to, high reservoir pressures, subsea booster pumps, connection to higher pressure pipelines, or a combination of these sources.

The source could be gas, liquid, or multiphase fluid, which have different system response requirements. The flow composition may change during the production life and may be dependent on topography. All of these aspects, and any uncertainties associated with them, need to be considered as part of a full HIPPS analysis. Before additional wells are tied into an existing system or any other change is made that could affect fluid properties, a new flow analysis shall be conducted to ensure that the system is designed to cover the new configuration.

4.1.2 HIPPS

HIPPS is an SIS, defined by this document, which provides pressure protection to downstream components.

4.1.3 Subsea Fortified Zone

A fortified section may be located downstream of the HIPPS isolation valves to allow time to respond to the system closure determined by the pressure transient calculations. The response time to system closure is dependent on the nature of the flow for the specific system and would include consideration of the gas-oil-ratio (GOR).

The pressure rating of the fortified section is project-specific and ranges from the maximum allowable working pressure (MAWP) of the flowline/pipeline, to the same as the full rating of the pressure source (e.g. subsea tree).

The length of the “fortified” section should be determined based on a transient flow analysis. The use of alternative flow assurance methods should not be included when determining the length of the fortified section. It is conceivable that this section may not be required, but this shall be proven based on flow analysis.

4.1.4 Unfortified Zone (Flowline)

The unfortified zone is downstream of the fortified zone and upstream of the host zone. The location of the unfortified zone shall be determined by the hydraulic analysis and be dependent on the impact of any eventual leakage risks to be mitigated. The hydraulic analysis should include all potential system transients (multiphase/slug flow, etc.). The unfortified zone shall be located to minimize risk of injury to people and damage to infrastructure and the environment. Design should also take into account the need for system testing.

The unfortified zone shall be proven to function by hydraulic analysis, design, and testing as appropriate.

4.1.5 Host Fortified Zone

The near-platform riser section shall be designed such that release of hydrocarbon or hazardous materials occurs away from the facility to protect personnel. Near-platform riser section refers to a region, which if breached by high-pressure excursions, could result in damage to the facility or threat to life.

4.1.6 Topsides

A process safety valve (PSV) upstream of the boarding shutdown valve (BSDV) can be used to relieve buildup of pressure due to valve leakage. Consideration needs to be given to safe venting of the PSV exhaust fluid.

4.2 Production Characteristics

Design of all product-containing systems shall consider the fluid and gas properties being transported and select materials and welding processes fully compatible with planned products.

For multiphase production systems, the full range of GOR, water production rates, sand, carbon dioxide, hydrogen sulfide, injected chemicals, and other products shall be fully investigated during analysis and design.

4.3 Flowline Rupture Considerations

Design of the flowline downstream of a HIPPS shall consider the possibility of failure of the HIPPS to correctly function. The design shall determine the likely consequences and design mitigations to minimize each consequence. Some of the key consequences of failure of the HIPPS and possible mitigations to consider include the following.

- Uncontrolled—In this case, the flowline ruptures and inventory is released to the environment. The system shall be arranged so that any pipeline burst occurs within the protective segment. Protection of human life is the highest priority. An environmental remediation plan should be in place.
- Controlled but Uncontained—In this case, there is a pressure-relieving mechanism which minimizes the quantity of product released. An environmental remediation plan should be in place.
- Controlled and Contained—In this case, there is a pressure-relieving mechanism (preferably self-resetting) which contains the release. The capacity of the containment system shall be defined.

4.4 Process Hazard and Risk Analysis

The decision to utilize a HIPPS shall be based on a qualitative and quantitative risk analysis (QRA) carried out in accordance with industry standards. Risk analysis requires determining the frequency of the event (overpressure) and the ability of safeguards (HIPPS, etc.) to reduce the consequences, such that the probability of the event becomes tolerable.

A qualitative risk analysis such as process hazard analysis shall be conducted using a defined methodology. The process hazard is typically overpressure and the subsequent failure of downstream equipment, potentially resulting in a loss of hydrocarbon containment. The risk is the frequency, or possibility of, overpressuring the equipment and the resulting consequences of equipment failure.

Quantitative analysis shall be performed [e.g. layer of protection analysis (LOPA)] as defined in IEC 61511. Risk thresholds shall be those mandated by the regulatory agency or the owner, whichever is the most stringent.

4.5 Selection and Determination of SIL

SIL is a representation of the required safety unavailability [average probability of failure on demand (PFD)] of a safety instrumented function (SIF). The SIL is expressed as a Level 1 through Level 4, which corresponds with Table 1.

SILs are determined, either in a prescriptive manner where a preselected SIL may be used when the application meets the required criteria, or a quantitative manner where the required SIL is calculated based on the risk thresholds, initiating frequencies, and other layers of protection to determine the required SIL of the HIPPS.

Table 1—SILs

SIL	PFD	Risk Reduction Factor
SIL 1	0.1 to 0.01	10 to 100
SIL 2	0.01 to 0.001	100 to 1000
SIL 3	0.001 to 0.0001	1000 to 10,000
SIL 4 ^a	0.0001 to 0.00001	10,000 to 100,000
^a Not applicable in the process industry.		

Determination of the HIPPS SIL should consider additional safeguards that are installed:

- pressure switch high (PSH) at facility, upstream of BSDV;
- PSH at each individual pressure source, upstream of HIPPS;
- PSV at facility upstream of the BSDV sized for either leakage rate (partial protection) or full flow rate; and
- reinforced section at facility riser.

SIL analysis is primarily conducted for safety; however, additional consideration may be for environmental or economic impacts. Additional safeguards (levels of protection) compliant with API 14C should be specified by the end user, and reflected in the end user's LOPA allocation and SIL requirement. The consideration with the highest SIL requirement may be used as the design basis.

4.6 Safety Requirement Specification (SRS)

4.6.1 General

The SRS is the controlling document for design, verification, and validation of the HIPPS in accordance with the project requirements and specifications and the basis for HIPPS performance monitoring and follow-up during the operating lifetime. The safety requirements specification shall meet the requirements of IEC 61511.

The SRS shall be kept current through management of change (MOC) process from concept development until the HIPPS is decommissioned.

The SRS shall include the following information or make references thereto:

- process description (which includes pressure ratings for all flowline segments) and summary of the documented hazard scenarios generated from the hazard analysis process;
- descriptions of functions performed by the SIF (in relationship to the associated hazard scenario) stating the functional relationship between process inputs and outputs including logic, mathematical functions, and any required permissives;
- SIL and PFD for each SIF;
- HIPPS process measurements together with their normal operating ranges and applicable trip set point tolerance;
- safe state of the process for each identified SIF, the sources of demand, and the demand rate;
- response time requirements for the HIPPS to bring the process to safe state;
- requirements for resetting the HIPPS after a trip;
- requirements for de-energize to trip;
- requirements for overrides/inhibits/bypasses/manual shutdowns, including how they are to be cleared;
- considerations for process common cause failures such as corrosion, plugging, power supply, etc.;
- actions to be taken in event of diagnosed dangerous failures;
- requirements for special start-up and HIPPS restart considerations;
- interface to other safety and process control systems;
- requirements for proof testing;
- desired testing frequencies, PFD, and mean time to failure spurious (MTTF spurious); and
- any additional information as required by the specific design.

4.6.2 HIPPS SIS

The HIPPS SIS shall be an autonomous safety system with a local logic system controlling HIPPS operation and shall include the following elements: