Safety Integrity Verification and Validation of a High Integrity Pressure Protection System (HIPPS) to IEC 61511

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Abstract

A key requirement in Safety Instrumented systems (SIS) design is risk reduction, all Safety Instrumented Functions (SIF) require a level of risk reduction to be defined (Risk Reduction Factor) and from that factor a Safety Integrity Level (SIL) specified that can be maintained throughout the operational life of the SIF. The design process must therefore address all of the safety lifecycle requirements to provide assurance that the target SIL is achieved and maintained.

This paper describes a methodology for assuring that the SIF has achieved the target SIL in this case study the target system is a High Integrity Pressure Protection System (HIPPS). The case study will model two hazardous event scenarios using fault tree analysis to assess if the proposed solution is viable with respect to the requirements of IEC 61511 [2] and to calculate the likely probability of failure on demand (PFD) of the proposed HIPPS.

1. Problem Statement

The design intent was to inject sour gas into existing wells which have a maximum allowable working pressure (MAWP) ranging from 385 to 450 barg which was below the delivery pressure of the new compression plant that supplied the sour gas at a nominal pressure of 550 barg into the flow lines connecting to the gas re injection wells. Each gas injection wellhead set comprises an injection pressure control valve, HP shutdown valve, choke valve, hydraulically operated wing valve, master valve and a sub surface safety valve. To eliminate the potential of well annulus casing damage in the event of tube failure, the maximum operating tubing head pressure must not exceed the rated pressure for the well and failure to protect the annulus casing against the over pressure situation would result in a significant hydrocarbon release to the environment and would represent a significant danger to personnel in the vicinity.

2. Introduction

The term HIPPS is applied to a SIF where the plant is not fully rated to the pressures to which it might be exposed in a fault condition and the mechanical protective systems are present but by themselves may be inadequate to prevent loss of containment in certain reasonably foreseeable circumstances [9]. The HIPPS is implemented only after all other risk control measures are considered and discounted. In terms of the hierarchy of risk control measures we firstly look at inherently safe measures, then passive solutions and finally active protection layers [12]

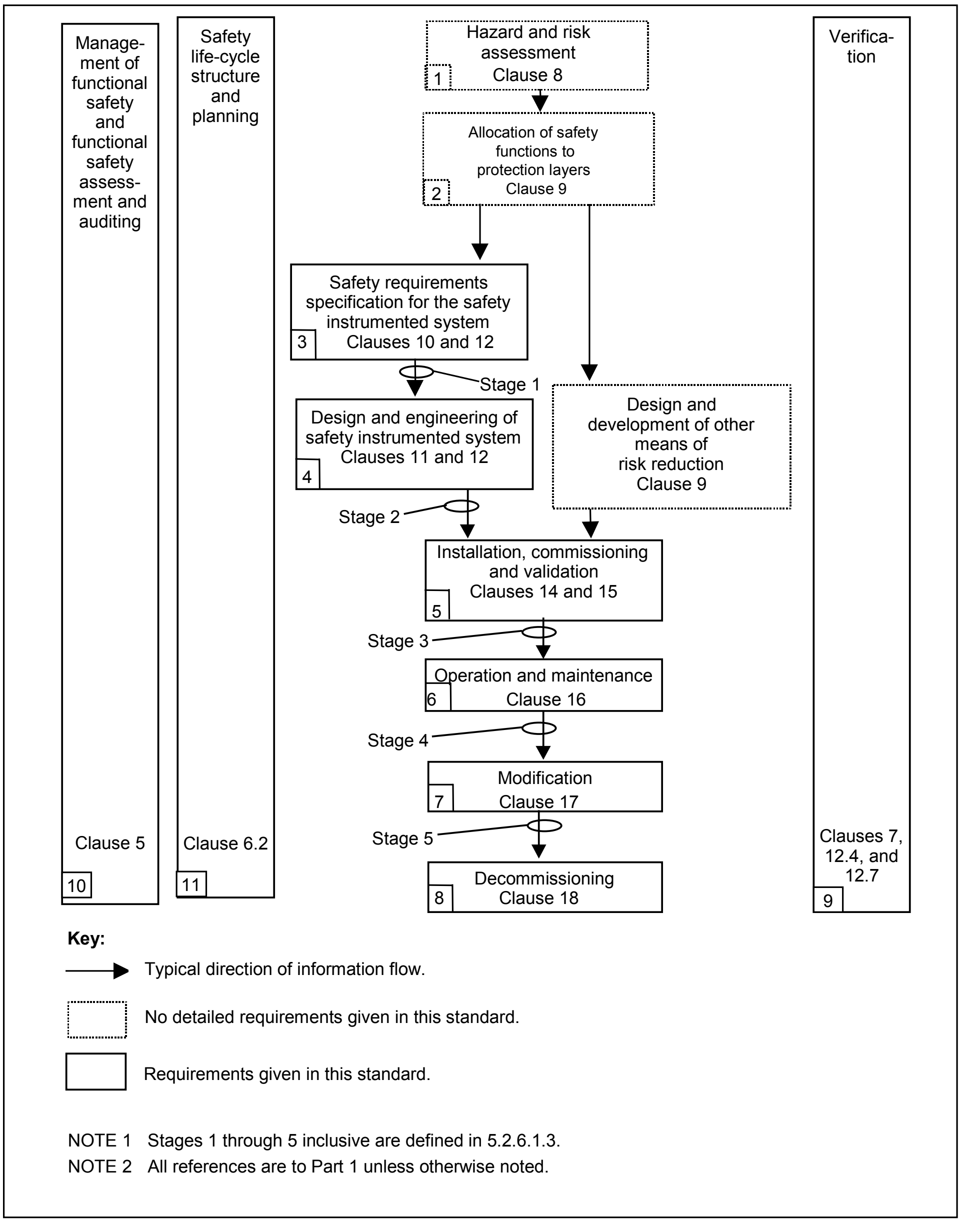
In the context of the protection provided by the HIPPS there are two scenarios considered:

1. HIPPS operates as a preventative layer of protection isolating the well – this scenario considered a downstream failure of the pressure control system and / or the compressor control system resulting in an over pressure of the tubing which due to existing deterioration mechanisms fails leading to a rupture of the casing annulus and a gas release. Target SIL2
2. HIPPS operates as a mitigation layer reducing the escalation effects from the flow lines this scenario considered an upstream failure of the tubing due to existing deterioration mechanisms leading to a rupture of the casing annulus and a gas release. Target SIL1

3. IEC 61511 Lifecycle Phases 1 to 5

The application of a HIPPS within the Process Industries follows the requirements of IEC 61511 [2] and the 11-lifecycle phases (se figure 8 from IEC 61511 below). Applying the lifecycle framework will assist in addressing systematic failures generally introduced due to human error, such as mistakes made during specification or testing. Once it has been determined that a SIF will be required then a functional safety management plan is developed for the system. This plan covers all phases of the lifecycle and his handed over to the end user before the system is put into operation as a part of the final validation package.

All design documents, test procedures and records, inspection checklists, commissioning procedures, mechanical completion certificates etc are listed in the plan to provide assurance during final validation that evidence has been provided for each lifecycle phase. Before the system is put into service an Functional Safety Assessment is carried out so that a judgment can be made, by an experienced functional safety engineer / professional, as to the fitness for purpose of the system in respect to meeting the requirements of IEC 61511.


Manage-ment of functional safety and functional safety assess-ment and auditing
Clause 5
10
Safety life-cycle structure and planning
Clause 6.2
11
Hazard and risk assessment
1
Clause 8
Allocation of safety functions to protection layers
2
Clause 9
Safety requirements specification for the safety instrumented system
3
Clauses 10 and 12
Stage 1
Design and engineering of safety instrumented system
Clauses 11 and 12
4
Design and development of other means of risk reduction
Clause 9
Stage 2
Installation, commissioning and validation
Clauses 14 and 15
5
Stage 3
Operation and maintenance
6
Clause 16
Stage 4
Modification
7
Clause 17
Stage 5
Decommissioning
8
Clause 18
Verifica-tion
Clauses 7, 12.4, and 12.7
9
Key:
Typical direction of information flow.
No detailed requirements given in this standard.
Requirements given in this standard.
NOTE 1 Stages 1 through 5 inclusive are defined in 5.2.6.1.3.
NOTE 2 All references are to Part 1 unless otherwise noted.

IEC 3247/02

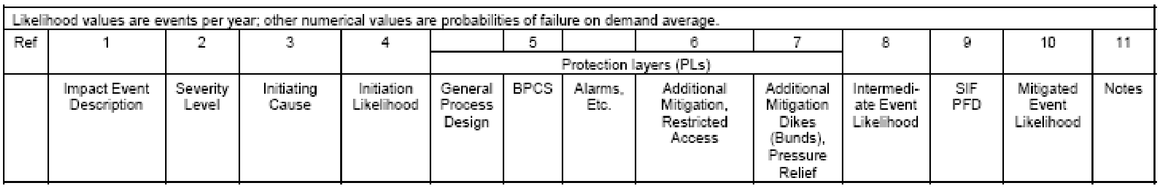
Figure 8 – SIS safety life-cycle phases and functional safety assessment stages

4. Process Hazard and Risk Assessment

Phase 1 requires that a process hazard and risk assessment be carried out to identify the potential hazard scenarios, including cause/consequence pairs, which will lead to a loss of containment. Due to the high significance of the risk of a potential release of sour gas the PHRA phase included a HAZOP Study followed by work from the Process Safety team in the form of a Quantified Risk Analysis, Transient Annulus Pressure Modelling and Dynamic Modelling of the Gas Re-injection System

5. **Allocation of Safety functions (LOPA) (Phase 2)**

The output from the PHR assessment is used to enable the integrity specification for the HIPPS to be determined. A typical format for this determination is the Layer of Protection Analysis technique [13] see below. Other safety systems are only considered so that their contribution can be taken into account when considering the performance requirements for the HIPPS.



Likelihood values are events per year; other numerical values are probabilities of failure on demand average.													
Ref	1	2	3	4		5		6	7	8	9	10	11
					Protection layers (PLs)								
	Impact Event Description	Severity Level	Initiating Cause	Initiation Likelihood	General Process Design	BPCS	Alarms, Etc.	Additional Mitigation, Restricted Access	Additional Mitigation Dikes (Bunds), Pressure Relief	Intermedi-ate Event Likelihood	SIF PFD	Mitigated Event Likelihood	Notes

To apply the LOPA approach each hazard scenario identified during PHRA is considered in detail following the process detailed below.

The first 4 columns in the figure above describe the hazard scenario and one or more initiating causes:

Column 1: Impact Event or consequence description – Loss of containment of sour gas

Column 2: Severity level (consequence) this will determine the “mitigated event likelihood” entered into column 10 that will be derived from a companies tolerability criterion or government guidelines [14]

Column 3: Initiating causes are listed, such as valve open when required closed etc

Column 4: Expected frequency of occurrence for each cause, these occurrences are generally taken from failure data or company historical data such as references 4 to 8

Columns 5, 6 and 7: Existing (non-SIS) risk reduction measures are considered and the probability of failure of each are entered this could include the probability of the tube not failing catastrophically. Credit may only be claimed for protection layers that are independent from other protection layers where credit has already been taken, and from the initiating cause event.

Column 8: By multiplying the values in columns 4, 5, 6 and 7 the intermediate frequency (without any additional SIS risk reduction) associated with this cause is determined. Adding the intermediate event frequencies for each cause of the hazard will determine the likely frequency of the harmful event associated with the hazard scenario.

Column 9: The ratio between the intermediate frequency (column 8) and the mitigated event likelihood (column 10), where the intermediate frequency is higher than the tolerable frequency, is a measure of the risk reduction factor (RRF) required from the HIPPS.

From the RRF the required probability of failure on demand and safety integrity level for the HIPPS is determined. If the intermediate frequency is lower than the mitigated event likelihood then no further risk reduction is required. Full details of the approach is described in CCPS guidance see reference 14.

6. **Safety Requirements Specification (SRS) - Phase 3**

Following on from a PHRA and LOPA it was determined that a SIL2 capable dedicated High Integrity Pressure Protection System (HIPPS) should be designed utilising if possible the existing high pressure shutdown valve, hydraulically operated wing valve and master valve to address the discrepancy between the re-injection pressure in the tubing and the MAWP of the casing

The full SRS was developed to meet IEC 61511-1 Clause 10.3 requirements with key areas of concern being: response time to safe state; test intervals, testing methodology; requirements for high pressure let down / bypass after trip and actions on fault detection

It is important to note that the HIPPS SIL capability includes all components and subsystems necessary to carry out the safety instrumented function from sensor(s) to final element(s).

7. Design and Engineering- Phase 4

The HIPPS design consists of:

- Pressure Transmitters (1A/B/C) in a 2oo3 architecture (Prevention Function)
- Pressure Transmitter (2A/B/C) in a 2oo3 architecture (Mitigation Function)
- One HIPPS Logic Solver (Configured 2oo3 degrading to 1oo2)
- Solenoid Valves in a 1oo2 architecture
- Slam Shut Hydraulically operated Gate Valve

Note: failures associated with the hydraulic accumulator (e.g. leaking, fail to refill) are not included assuming that the spring will drive the valve closed on demand in the required process safety time.

7.1 Safety Integrity Level Target

The HIPPS System 1 was been determined to require a target SIL of 2. The upper bound average probability of failure on demand (PFDavg) for a SIL 2 system is taken to be 1E-2 and System 2 required a target SIL of 1, the upper bound PFDavg being taken as 1E-1.

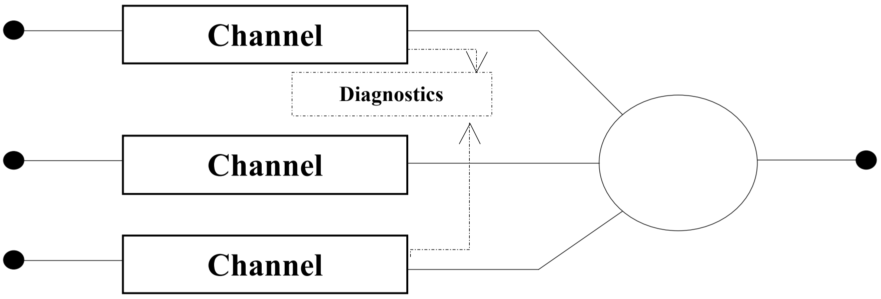
7.2 Human Error

No operator or maintenance activities (systematic failures) are explicitly numerically quantified within this report, as it has been assumed that the operator cannot remotely access the system and that maintenance will return the system to its fully working condition.

7.3 Calculation of Probability of Failure on Demand

The paper will demonstrate a detailed analysis for the sensor 2oo3 architecture, a similar analysis can be undertaken for the 1oo2 architecture and details of this can be found in IEC 61508 [1].

The sensor architecture consists of three channels connected in parallel with a majority voting arrangement for the output signals, such that the output state is not changed if only one channel gives a different result which disagrees with the two channels need to demand the safety function before it can take place. Thus there would have to be dangerous failure in two of the channels before a safety function failed on demand. It is assumed that any diagnostic testing would only report the faults found and would not change any output states or change the output voting.



2oo3 physical block diagram

$$PFD_{avg} = [((1-\beta) \text{ x } \lambda^{DU})^2 \text{x } TI^2] + [3(1-\beta) \text{ x } \lambda^{DU} \text{ x } \lambda^{DD} \text{ x MTTR x } TI] + [\beta \text{ x } \lambda^{DU} \text{ x } TI/2] + [\lambda^{D}{}_{F} \text{ x } TI/2]$$

For simplification, 1 – β is generally assumed to be one, which yields conservative results. Consequently, the equation reduces to:

$$PFD_{avg} = [(\lambda^{DU})^2 \text{ x } TI^2] + [3\lambda^{DU} \text{ x } \lambda^{DD} \text{ x MTTR x } TI] + [\beta \text{ x } \lambda^{DU} \text{ x } TI/2] + [\lambda^{D}{}_{F} \text{ x } TI/2]$$

Where:

β is the fraction of failures that impact more than one channel of a redundant system (CCF)

λ^{DU} is the dangerous undetected failure rate

λ^{DD} is the dangerous detected failure rate

TI is the proof test interval

MTTR is the mean time to repair

λ^{D}_{F} is the dangerous systematic failure

The 1st term represents the 2oo3 configuration

The 2nd term represents multiple failures during repair and is typically negligible for small MTTR

The third term is the common cause term - see section 8

The fourth term is the dangerous systematic error term these types of failures are not normally included in the model due to the difficulty in assessing the failure modes and effect and lack of verifiable data. Therefore they are normally addressed through the lifecycle management process.

The simplified equation used for the calculation is shown below

The base case test interval assumed is 1 per 3 months, with simultaneous testing of the HIPPS.

Voting System	Average Probability of Failure on Demand
1 out of 1	$(\lambda^{DU} * TI) / 2$
1 out of 2	$[(\lambda^{DU2} x TI^{2)}/3] + [\beta x \lambda^{DU} x TI/2]$
2 out of 3	$[\lambda^{DU2} x TI^{2}] + [\beta x \lambda^{DU} x TI/2]$

7.4 Common Cause Failure

A form of failure, that can occur in a redundant system is common cause failure (CCF) it occurs when the components are all from the same manufacturer, or are the same type, and are affected by common factors e.g. dirty environment, manufacturing fault, maintained incorrectly, miss-calibrated, etc. This can have a significant effect on the failure probability on demand.

A CCF can be viewed as a failure that can result in the co-incident loss of redundant items and such failures can often dominate the unreliability of redundant systems.

The reasons for CCFs typically include:

- **Separation:** The degree to which similar units can be affected by a single environmental effect. For example, a single failure may result in the loss of two power supplies.
- **Similarity:** The degree, to which equipment is similarly designed, manufactured, maintained or operated.

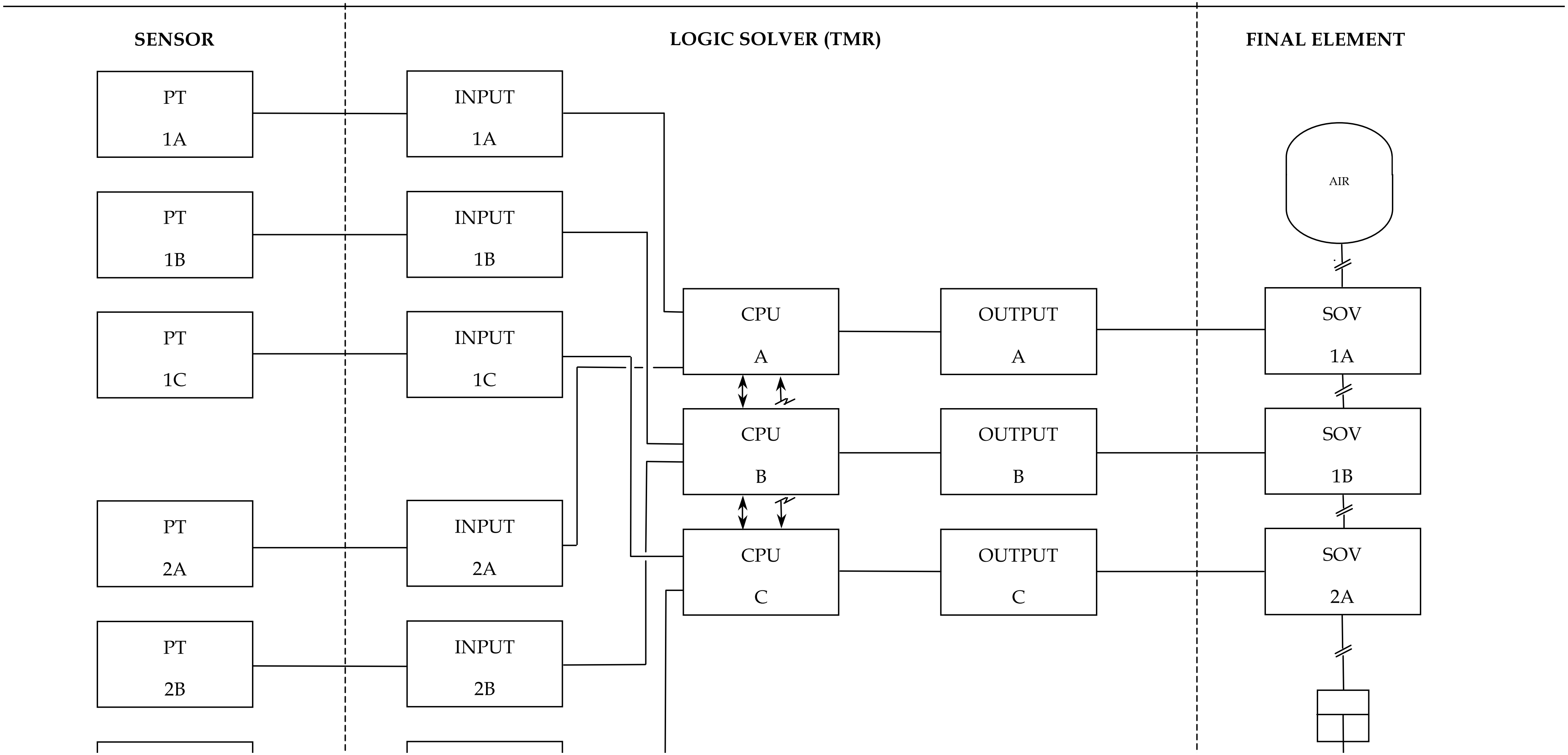
CCFs are often modeled using the beta-factor approach. This approach assumes that the CCF rate is a fixed proportion (i.e. beta-factor) of the individual item failure rate. The beta-factor is typically between 2% and 10% depending on competency, type of equipment, quality of installation and site conditions. CCFs have been included for:

- **Pressure Transmitters**: 2 out of 3 arrangements to obtain a trigger to the HIPPS
- **Solenoid Valves**: the activating solenoids are in a 1 out of 2 arrangement.

The logic solver calculation includes a Beta Factor modifier of 2%, factors for the Pressure Transmitters and Solenoid Valves were calculated using the Partial Beta model as detailed in Attachment 1. The components that are considered to be vulnerable to CCF are identified as:-

Reference in Attachment 1	Component	Beta Factor
PTBETA	1 off 2oo3 Pressure Transmitters	0.125
SOVBETA	1 off 1oo2 Solenoid Valves	0.177

SIL2 Capable HIPPS System Configuration



8. Data Verification

The failure data is collected either from third party reports such as TüV, manufacturer's own data, or generic data sources such as OREDA 2002. Equipment that includes software must be assessed for conformance against either IEC-61508 Part 3, existing field experience IEC 61508-7 B.5.4 Field experience or annex D software safety integrity for pre-developed software.

Section 8.1 presents an example of a typical data collection table of which one should be completed for each component to aid the verification and validation of the system.

8.1 Date Collection

8.1.1 Device Details

Manufacturer :	Invensys Process Systems
Model :	IDP / IAP / IGP

8.1.2 Vendor Data

Certification	2	SIL
Device Type (IEC 61508)	B	
Configuration	2oo3	
Hardware Fault Tolerance (KPO Configuration)	2	
PFDavg – Average Probability of Failure on Demand (Per Transmitter)	1.6	10^{-3}
λ - Overall Failure Rate	3680	FIT
λs - Safe Failure Rate	2150	FIT
λdd - Dangerous Detected Failure Rate	1160	FIT
λdu - Dangerous undetected Failure Rate	366	FIT
T - Proof Test interval	1	Year
SFF - Safe Failure Fraction	90.06 %	

9. HIPPS Probability of Failure on Demand (PFD) HIPPS Base Case

It is assumed that the HIPPS system is designed to prevent overpressures whatever the scenario causing the overpressure and the same PFD target applies to the HIPPS whatever the initiating scenario. Hence the mode of HIPPS operation in all scenarios is assumed to be:

Step 1: Pressure transmitters detect the overpressure.

Step 2: The logic solver initiates a trip following a high pressure signal.

Step 3: The gate valve close to a tight shut off state.

It is assumed that any through valve leakages will be sufficiently small that operator action can be taken to relieve any build-up in pressure downstream of the isolation. The minimum timescale for this action is assumed to be sufficiently long that appropriate operator actions can be completed well within the minimum pressure build-up time.

It has been assumed that a failure of the HIPPS system to complete step 1 or step 2 or step 3 will result in an overpressure of downstream pipework. The quantification of the common mode beta factors is undertaken in Attachment 1. The PFD has been calculated as per the example fault tree in Attachment 2 using the failure rate date collected as per Section 8.

Failure State	Probability of Failure on Demand (PFD)
HIPPS System -1 – ¼ year full functional test interval	9.32E-3 (Prevention Function)
HIPPS System -2 – ¼ year full functional test interval	9.66E-3 (Mitigation Function)

10. **Validation**

The verification shows that with respect to hardware integrity a 3 monthly test interval is adequate to meet the SIL 2 PFDavg target band of 1.0E-2 to 1.0E-03 and SIL 1 PFDavg target band of 1.0E-1 to 1.0E-02; use of a 3 month test interval is standard for HIPPS type systems. With respect to a spurious trip leading to a HIPPS valve closure this would occur once every eleven years.

For the prevention case (HIPPS System 1) the addition of a second gate valve in series with the existing gate valve may be considered which will give a PFD improvement of 33% (6.21E-03) that would set the PFDavg at approximately 50% of the SIL 2 PFD target band of 1.0E-2 to 1.0E-03.

With respect to the current design the single gate valve is the most significant factor in the failure path.

With respect to meeting systematic requirements for the system it is necessary, as stated in section 3, to address the human errors that can be introduced into the process. For components that are certified to IEC 61508 this is addressed by the certifying body such as TüV and the manufacturer following the guidance in the annexes of IEC 61508 parts 1, 2 and 3. For Phases 1, 2 and 3 of the lifecycle the errors are addressed by ensuring that only people recognised as competent [15] are allowed to facilitate or attend safety studies and develop the safety requirements specification. For Phase 4 activities in is also important that only people recognised as competent are allowed to design safety related systems, schemes such as the TüV Rheinland Functional safety program provide a route for eligible engineers, who have experience in the application of safety instrumented systems, to demonstrate competence.

11. References

[1] Functional safety of electrical/electronic/programmable safety-related systems, BS EN 61508-2010.

[2] Functional safety – Safety instrumented systems for the process industry sector, BS IEC 61511-2004.

[3] HSE Riser Emergency Shutdown Valve (ESDV) Leakage Assessment (SPC/TECH/OSD/26)

[4] Loss Prevention in the Process Industries Hazard Identification, Assessment and Control – ISBN 0 7506 1547 8

[5] Faradip.3 version 6.2 Reliability Data 2008 – ISBN 09516562 3 6

[6] OREDA 4th Edition – ISBN 82-14-02705-5

[7] Reliability Data for Safety Instrumented Systems (SINTEF September 2004)

[8] Process Equipment Reliability Data (AIChE CCPS) – ISBN 0-8169-0422-7

[9] HSE, HID Semi Permanent Circular, High Integrity Pressure Protection systems (HIPPS) for the Overpressure protection of Pipeline Risers, SPC/TECH/OSD/31

[10] HSE, HID Gas & Pipeline Units, Major Hazard Safety Performance Indictors in GB Onshore Gas and Pipelines Industry, Annual Report 2007/08

[11] BS EN 14161-2003: Petroleum and Natural Gas Industries: Pipeline Transportation Systems

[12] SI 1999/3242 The Management of Health and Safety at Work Regulations 1999

[13] Layers of Protection Analysis, Simplified Process Risk Assessment CCPS, Copyright 2001 American Institute of Chemical Engineers, ISBN 0 8169 0811 7, 2001

[14] Reducing Risks, Protecting People, HSE decision making process (R2P2) Crown copyright 2001 ISBN 0 7176 2151 0

[15] Managing Competence for Safety-related Systems, HSE 2007

ATTACHMENT-1

EXAMPLE BETA FACTOR CORRECTION (CCF)

PTBETA - Pressure Transmitters

SEPARATION/SEGREGATION (PES)

	Maximum		Input	Actual	
	A	B	%	A	B
Are all signal cables separated at all positions?	15	52	50	8	26
Are the programmable channels on separate printed circuit boards?	85	55	100	85	55
OR are they in separate units/racks?	90	60			
OR are they in separate rooms or buildings?	95	65			
Totals	110	117		93	81

DIVERSITY (PES)

	Maximum		Input	Actual	
	A	B	%	A	B
Do the channels employ diverse technologies?: 1 electronic + 1 mechanical/pneumatic	100	25	0	0	0
OR 1 electronic or CPU + 1 relay	90	25			
OR 1 CPU + 1 electronic hardwired	70	25			
Were the diverse channels developed from separate requirements from separate people with no communication between them?	20		0	0	
Were the 2 design specs. separately audited against known hazards by separate people and were separate test methods applied by separate people?	12	25	0	0	0
Totals	132	50		0	0

COMPLEXITY/DESIGN/APPLICATION/MATURITY (PES)

	Maximum		Input	Actual	
	A	B	%	A	B
Does cross-connection between CPUs preclude the exchange of any information other than the diagnostics?	30		0	0	
Is there > 5 years experience of the equipment in the particular environment?		10	0		0
Is the equipment simple, i.e. < 100 lines of code OR < 5 ladder logic rungs OR < 50 I/O and < 5 safety functions?		20	0		0
Is there protection from over-voltage and over-current (e.g. > 2:1)?	30		100	30	
Totals	60	30		30	0

ASSESSMENT/ANALYSIS and FEEDBACK OF DATA

	Maximum		Input	Actual	
	A	B	%	A	B
Has a combination of competent FMEA and design review attempted to establish multiple failure groups in the electronics?		140	100		140
Is there documentary evidence that field failures are fully analysed with feedback to design?		70	0		0
Totals		210		0	140

PROCEDURES/HUMAN INTERFACE

	Maximum		Input	Actual	
	A	B	%	A	B

Is there a written system of work on site to ensure that failures are investigated and checked in other channels (including degradation)?	30	20	0	0	0
Is maintenance of diverse/redundant channels staggered at intervals to ensure that proof-tests operate satisfactorily between the maintenance?	60		0	0	
Do written maintenance procedures ensure redundant separations (e.g. signal cables) are separated from each other and from power cables and cannot be re-routed?	15	25	0	0	0
Are mods. forbidden without full design analysis of CCF?		20	0		0
Do different staff maintain redundant equipment?	15	20	0	0	0
Totals	120	85		0	0

COMPETENCE/TRAINING/SAFETY CULTURE

	Maximum		Input	Actual	
	A	B	%	A	B
Have designers been trained to understand CCF?		100	100		100
Have installers been trained to understand CCF?		50	0		0
Have maintainers been trained to understand CCF?		60	0		0
Totals		210		0	100

ENVIRONMENTAL CONTROL

	Maximum		Input	Actual	
	A	B	%	A	B
Is there limited personnel access?	40	50	100	40	50
Is there appropriate environmental control? (eg temperature, humidity)	40	50	20	8	10
Totals	80	100		48	60

ENVIRONMENTAL TESTING

	Maximum		Input	Actual	
	A	B	%	A	B
Has full emc immunity or equivalent mechanical testing been conducted on proto-types and production units (using recognised standards)?		316	100		316
Totals		316		0	316

DIAGNOSTICS AND CROSS-COMMUNICATION (PES)

	Programmable Electronics - Interval				Input Value
	<1mins	1-5mins	5-10mins	>10mins	
Diagnostic Cover					
98%	3.0	2.5	2.0	1.0	
90%	2.5	2.0	1.5	1.0	
60%	2.0	1.5	1.0	1.0	
					2.5

"C" > 1 may only be scored if remedial action, initiated by the diagnostic, is timely enough to invalidate the effect of the second failure. (Note: In practice only a minority of programmable systems are configured in applications that allow a "C" score > 1).

Assessment of Beta value

```
                                                              A Score   B Score
Screen 1A - SEPARATION/SEGREGATION (PES)                         93        81
Screen 2A - DIVERSITY (PES)                                       0         0
Screen 3A - COMPLEXITY/DESIGN/APPLICATION/MATURITY (PES)         30         0
Screen 4  - ASSESSMENT/ANALYSIS and FEEDBACK OF DATA              0       140
Screen 5  - PROCEDURES/HUMAN INTERFACE                            0         0
Screen 6  - COMPETENCE/TRAINING/SAFETY CULTURE                    0       100
Screen 7  - ENVIRONMENTAL CONTROL                                48        60
Screen 8  - ENVIRONMENTAL TESTING                                 0       316

            Screens 1 to 8 Total                                171       697

                                                                   C Score
Screen 9A - DIAGNOSTICS AND CROSS-COMMUNICATION (PES)                2.5

                                                                 M out of N
Screen 10 - TYPE OF REDUNDANCY                                   2        3

            Beta (1 out of 2) = 5.24 %

            D factor =          2.40
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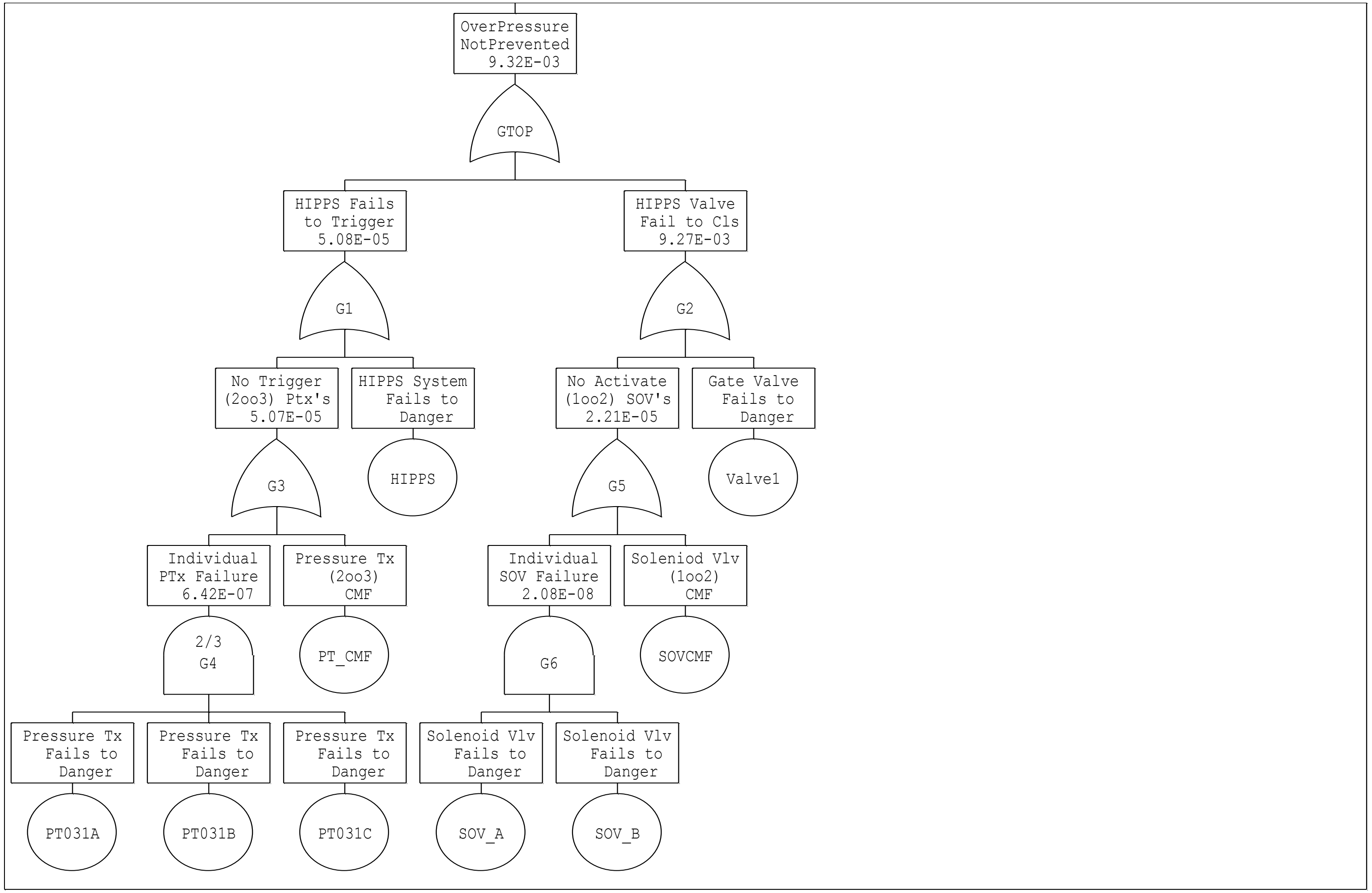
Beta (M out of N) = 12.6 %

ATTACHMENT -2

EXAMPLE - FAULT TREE – HIPPS VALVE FAILS TO CLOSE ON DEMAND


OverPressure NotPrevented 9.32E-03
GTOP
HIPPS Fails to Trigger 5.08E-05
HIPPS Valve Fail to Cls 9.27E-03
G1
G2
No Trigger (2oo3) Ptx's 5.07E-05
HIPPS System Fails to Danger
No Activate (1oo2) SOV's 2.21E-05
Gate Valve Fails to Danger
G3
HIPPS
G5
Valve1
Individual PTx Failure 6.42E-07
Pressure Tx (2oo3) CMF
Individual SOV Failure 2.08E-08
Soleniod Vlv (1oo2) CMF
2/3
G4
PT_CMF
G6
SOVCMF
Pressure Tx Fails to Danger
Pressure Tx Fails to Danger
Pressure Tx Fails to Danger
Solenoid Vlv Fails to Danger
Solenoid Vlv Fails to Danger
PT031A
PT031B
PT031C
SOV_A
SOV_B