

Functional safety - Safety instrumented systems for the process industry sector - Part 3: Guidance for the determination of the required safety integrity levels

EESTI STANDARDI EESSÕNA

NATIONAL FOREWORD

See Eesti standard EVS-EN 61511-3:2017 sisaldab Euroopa standardi EN 61511-3:2017 ingliskeelset teksti.	This Estonian standard EVS-EN 61511-3:2017 consists of the English text of the European standard EN 61511-3:2017.
Standard on jõustunud sellekohase teate avaldamisega EVS Teatajas	This standard has been endorsed with a notification published in the official bulletin of the Estonian Centre for Standardisation.
Euroopa standardimisorganisatsioonid on teinud Euroopa standardi rahvuslikele liikmetele kättesaadavaks 21.04.2017.	Date of Availability of the European standard is 21.04.2017.
Standard on kättesaadav Eesti Standardikeskusest.	The standard is available from the Estonian Centre for Standardisation.

Tagasisidet standardi sisu kohta on võimalik edastada, kasutades EVS-i veebilehel asuvat tagasiside vormi või saates e-kirja meiliaadressile standardiosakond@evs.ee.

ICS 13.110, 25.040.01

Standardite reprodutseerimise ja levitamise õigus kuulub Eesti Standardikeskusele

Andmete paljundamine, taastekitamine, kopeerimine, salvestamine elektroonsesse süsteemi või edastamine ükskõik millises vormis või millisel teel ilma Eesti Standardikeskuse kirjaliku loata on keelatud.

Kui Teil on küsimusi standardite autorikaitse kohta, võtke palun ühendust Eesti Standardikeskusega:
Koduleht www.evs.ee; telefon 605 5050; e-post info@evs.ee

The right to reproduce and distribute standards belongs to the Estonian Centre for Standardisation

No part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying, without a written permission from the Estonian Centre for Standardisation.

If you have any questions about copyright, please contact Estonian Centre for Standardisation:

Homepage www.evs.ee; phone +372 605 5050; e-mail info@evs.ee

English Version

**Functional safety - Safety instrumented systems for the process
industry sector - Part 3: Guidance for the determination of the
required safety integrity levels
(IEC 61511-3:2016)**

Sécurité fonctionnelle - Systèmes instrumentés de sécurité
pour le secteur des industries de transformation - Partie 3:
Conseils pour la détermination des niveaux exigés
d'intégrité de sécurité
(IEC 61511-3:2016)

Funktionale Sicherheit - PLT-Sicherheitseinrichtungen für
die Prozessindustrie - Teil 3: Anleitung für die Bestimmung
der erforderlichen Sicherheits-Integritätslevel
(IEC 61511-3:2016)

This European Standard was approved by CENELEC on 2016-08-25. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.



European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

European foreword

The text of document 65A/779/FDIS, future edition 2 of IEC 61511-3, prepared by SC 65A "System aspects" of IEC/TC 65 "Industrial process measurement, control and automation" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 61511-3:2017.

The following dates are fixed:

- latest date by which the document has to be (dop) 2017-10-21
implemented at national level by
publication of an identical national
standard or by endorsement
- latest date by which the national (dow) 2020-04-21
standards conflicting with the
document have to be withdrawn

This document supersedes EN 61511-3:2004.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

Endorsement notice

The text of the International Standard IEC 61511-3:2016 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 61025:2006	NOTE	Harmonized as EN 61025:2007.
IEC 61165:2006	NOTE	Harmonized as EN 61165:2006.
IEC 61508-5:2010	NOTE	Harmonized as EN 61508-5:2010.
IEC 61508-6:2010	NOTE	Harmonized as EN 61508-6:2010.
IEC 62551:2012	NOTE	Harmonized as EN 62551:2012.
ISO/TR 12489:2013	NOTE	Harmonized as CEN ISO/TR 12489:2016.

Annex ZA (normative)

Normative references to international publications with their corresponding European publications

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

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 61511-1	2016	Functional safety - Safety instrumented systems for the process industry sector - Normative (uon) -- Part 1: Framework, definitions, system, hardware and software requirements	EN 61511-1	2016

CONTENTS

FOREWORD.....	7
INTRODUCTION.....	9
1 Scope.....	12
2 Normative references	13
3 Terms, definitions and abbreviations	13
Annex A (informative) Risk and safety integrity – general guidance	14
A.1 General.....	14
A.2 Necessary risk reduction	14
A.3 Role of safety instrumented systems.....	14
A.4 Risk and safety integrity	16
A.5 Allocation of safety requirements	17
A.6 Hazardous event, hazardous situation and harmful event	17
A.7 Safety integrity levels	18
A.8 Selection of the method for determining the required safety integrity level	18
Annex B (informative) Semi-quantitative method – event tree analysis	20
B.1 Overview	20
B.2 Compliance with IEC 61511-1:2016	20
B.3 Example	20
B.3.1 General	20
B.3.2 Process safety target	21
B.3.3 Hazard analysis	21
B.3.4 Semi-quantitative risk analysis technique.....	22
B.3.5 Risk analysis of existing process	23
B.3.6 Events that do not meet the process safety target.....	25
B.3.7 Risk reduction using other protection layers.....	26
B.3.8 Risk reduction using a safety instrumented function	26
Annex C (informative) The safety layer matrix method	28
C.1 Overview	28
C.2 Process safety target	29
C.3 Hazard analysis	29
C.4 Risk analysis technique	30
C.5 Safety layer matrix	31
C.6 General procedure	32
Annex D (informative) A semi-qualitative method: calibrated risk graph	34
D.1 Overview	34
D.2 Risk graph synthesis	34
D.3 Calibration	35
D.4 Membership and organization of the team undertaking the SIL assessment.....	36
D.5 Documentation of results of SIL determination	37
D.6 Example calibration based on typical criteria.....	37
D.7 Using risk graphs where the consequences are environmental damage	40
D.8 Using risk graphs where the consequences are asset loss	41
D.9 Determining the integrity level of instrument protection function where the consequences of failure involve more than one type of loss.....	41
Annex E (informative) A qualitative method: risk graph	42

E.1	General.....	42
E.2	Typical implementation of instrumented functions	42
E.3	Risk graph synthesis	43
E.4	Risk graph implementation: personnel protection	43
E.5	Relevant issues to be considered during application of risk graphs.....	45
Annex F	(informative) Layer of protection analysis (LOPA)	47
F.1	Overview	47
F.2	Impact event	48
F.3	Severity level	48
F.4	Initiating cause.....	49
F.5	Initiation likelihood	50
F.6	Protection layers	50
F.7	Additional mitigation.....	51
F.8	Independent protection layers (IPL)	51
F.9	Intermediate event likelihood	52
F.10	SIF integrity level	52
F.11	Mitigated event likelihood	52
F.12	Total risk.....	52
F.13	Example	53
F.13.1	General	53
F.13.2	Impact event and severity level	53
F.13.3	Initiating cause	53
F.13.4	Initiating likelihood	53
F.13.5	General process design.....	53
F.13.6	BPCS	53
F.13.7	Alarms	53
F.13.8	Additional mitigation.....	54
F.13.9	Independent protection layer(s) (IPL).....	54
F.13.10	Intermediate event likelihood.....	54
F.13.11	SIS	54
F.13.12	Next SIF	54
Annex G	(informative) Layer of protection analysis using a risk matrix	56
G.1	Overview	56
G.2	Procedure.....	58
G.2.1	General	58
G.2.2	Step 1: General Information and node definition	58
G.2.3	Step 2: Describe hazardous event	59
G.2.4	Step 3: Evaluate initiating event frequency	62
G.2.5	Step 4: Determine hazardous event consequence severity and risk reduction factor	63
G.2.6	Step 5: Identify independent protection layers and risk reduction factor.....	64
G.2.7	Step 6: Identify consequence mitigation systems and risk reduction factor.....	65
G.2.8	Step 7: Determine CMS risk gap.....	66
G.2.9	Step 8: Determine scenario risk gap	69
G.2.10	Step 9: Make recommendations when needed	69
Annex H	(informative) A qualitative approach for risk estimation & safety integrity level (SIL) assignment	71
H.1	Overview	71

H.2	Risk estimation and SIL assignment	73
H.2.1	General	73
H.2.2	Hazard identification/indication	73
H.2.3	Risk estimation	73
H.2.4	Consequence parameter selection (C) (Table H.2)	74
H.2.5	Probability of occurrence of that harm	75
H.2.6	Estimating probability of harm	77
H.2.7	SIL assignment	77
Annex I (informative)	Designing & calibrating a risk graph	80
I.1	Overview	80
I.2	Steps involved in risk graph design and calibration	80
I.3	Risk graph development	80
I.4	The risk graph parameters	81
I.4.1	Choosing parameters	81
I.4.2	Number of parameters	81
I.4.3	Parameter value	81
I.4.4	Parameter definition	81
I.4.5	Risk graph	82
I.4.6	Tolerable event frequencies (Tef) for each consequence	82
I.4.7	Calibration	83
I.4.8	Completion of the risk graph	84
Annex J (informative)	Multiple safety systems	85
J.1	Overview	85
J.2	Notion of systemic dependencies	85
J.3	Semi-quantitative approaches	88
J.4	Boolean approaches	89
J.5	State-transition approach	92
Annex K (informative)	As low as reasonably practicable (ALARP) and tolerable risk concepts	96
K.1	General	96
K.2	ALARP model	96
K.2.1	Overview	96
K.2.2	Tolerable risk target	97
Bibliography	99
Figure 1	Overall framework of the IEC 61511 series	11
Figure 2	Typical protection layers and risk reduction means	13
Figure A.1	Risk reduction: general concepts	16
Figure A.2	Risk and safety integrity concepts	17
Figure A.3	Harmful event progression	18
Figure A.4	Allocation of safety requirements to the non-SIS protection layers and other protection layers	19
Figure B.1	Pressurized vessel with existing safety systems	21
Figure B.2	Fault tree for overpressure of the vessel	24
Figure B.3	Hazardous events with existing safety systems	25
Figure B.4	Hazardous events with SIL 2 safety instrumented function	27
Figure C.1	Protection layers	28

Figure C.2 – Example of safety layer matrix.....	32
Figure D.1 – Risk graph: general scheme	38
Figure D.2 – Risk graph: environmental loss.....	41
Figure E.1 – VDI/VDE 2180 Risk graph – personnel protection and relationship to SILs.....	44
Figure F.1 – Layer of protection analysis (LOPA) report.....	49
Figure G.1 – Layer of protection graphic highlighting proactive and reactive IPL.....	56
Figure G.2 – Work process used for Annex G	58
Figure G.3 – Example process node boundary for selected scenario	59
Figure G.4 – Acceptable secondary consequence risk	67
Figure G.5 – Unacceptable secondary consequence risk	67
Figure G.6 – Managed secondary consequence risk	69
Figure H.1 – Workflow of SIL assignment process	72
Figure H.2 – Parameters used in risk estimation.....	74
Figure I.1 – Risk graph parameters to consider.....	81
Figure I.2 – Illustration of a risk graph with parameters from Figure I.1.....	82
Figure J.1 – Conventional calculations	85
Figure J.2 – Accurate calculations.....	86
Figure J.3 – Redundant SIS	88
Figure J.4 – Corrective coefficients for hazardous event frequency calculations when the proof tests are performed at the same time.....	89
Figure J.5 – Expansion of the simple example.....	89
Figure J.6 – Fault tree modelling of the multi SIS presented in Figure J.5.....	90
Figure J.7 – Modelling CCF between SIS ₁ and SIS ₂	91
Figure J.8 – Effect of tests staggering	91
Figure J.9 – Effect of partial stroking.....	92
Figure J.10 – Modelling of repair resource mobilisation.....	93
Figure J.11 – Example of output from Monte Carlo simulation.....	94
Figure J.12 – Impact of repairs due to shared repair resources	95
Figure K.1 – Tolerable risk and ALARP	97
Table B.1 – HAZOP study results	22
Table C.1 – Frequency of hazardous event likelihood (without considering PLs).....	31
Table C.2 – Criteria for rating the severity of impact of hazardous events.....	31
Table D.1 – Descriptions of process industry risk graph parameters.....	35
Table D.2 – Example calibration of the general purpose risk graph	39
Table D.3 – General environmental consequences	40
Table E.1 – Data relating to risk graph (see Figure E.1).....	45
Table F.1 – HAZOP developed data for LOPA	48
Table F.2 – Impact event severity levels.....	49
Table F.3 – Initiation likelihood.....	50
Table F.4 – Typical protection layers (prevention and mitigation) PFD _{avg}	51
Table G.1 – Selected scenario from HAZOP worksheet.....	59
Table G.2 – Selected scenario from LOPA worksheet	61

Table G.3 – Example initiating causes and associated frequency	63
Table G.4 – Consequence severity decision table	64
Table G.5 – Risk reduction factor matrix	64
Table G.6 – Examples of independent protection layers (IPL) with associated risk reduction factors (RRF) and probability of failure on demand (PFD)	66
Table G.7 – Examples of consequence mitigation system (CMS) with associated risk reduction factors (RRF) and probability of failure on demand (PFD)	66
Table G.8 – Step 7 LOPA worksheet (1 of 2)	68
Table G.9 – Step 8 LOPA worksheet (1 of 2)	70
Table H.1 – List of SIFs and hazardous events to be assessed	73
Table H.2 – Consequence parameter/severity level	74
Table H.3 – Occupancy parameter/Exposure probability (F)	75
Table H.4 – Avoidance parameter/avoidance probability	76
Table H.5 – Demand rate parameter (W)	77
Table H.6 – Risk graph matrix (SIL assignment form for safety instrumented functions)	78
Table H.7 – Example of consequence categories	78
Table K.1 – Example of risk classification of incidents	98
Table K.2 – Interpretation of risk classes	98

preview generated by EVS

INTRODUCTION

Safety instrumented systems (SIS) have been used for many years to perform safety instrumented functions (SIF) in the process industries. If instrumentation is to be effectively used for SIF, it is essential that this instrumentation achieves certain minimum standards and performance levels.

The IEC 61511 series addresses the application of SIS for the process industries. A process hazard and risk assessment is carried out to enable the specification for SIS to be derived. Other safety systems are only considered so that their contribution can be taken into account when considering the performance requirements for the SIS. The SIS includes all devices and subsystems necessary to carry out the SIF from sensor(s) to final element(s).

The IEC 61511 series has two concepts which are fundamental to its application; SIS safety life-cycle and safety integrity levels (SIL).

The IEC 61511 series addresses SIS which are based on the use of Electrical (E)/Electronic (E)/Programmable Electronic (PE) technology. Where other technologies are used for logic solvers, the basic principles of the IEC 61511 series should be applied. The IEC 61511 series also addresses the SIS sensors and final elements regardless of the technology used. The IEC 61511 series is process industry specific within the framework of IEC 61508:2010.

The IEC 61511 series sets out an approach for SIS safety life-cycle activities to achieve these minimum standards. This approach has been adopted in order that a rational and consistent technical policy is used.

In most situations, safety is best achieved by an inherently safe process design. If necessary, this may be combined with a protective system or systems to address any residual identified risk. Protective systems can rely on different technologies (chemical, mechanical, hydraulic, pneumatic, electrical, electronic, and programmable electronic). Any safety strategy should consider each individual SIS in the context of the other protective systems. To facilitate this approach, the IEC 61511 series covers:

- a hazard and risk assessment is carried out to identify the overall safety requirements;
- an allocation of the safety requirements to the SIS is carried out;
- works within a framework which is applicable to all instrumented means of achieving functional safety;
- details the use of certain activities, such as safety management, which may be applicable to all methods of achieving functional safety;
- addressing all SIS safety life-cycle phases from initial concept, design, implementation, operation and maintenance through to decommissioning;
- enabling existing or new country specific process industry standards to be harmonized with the IEC 61511 series.

The IEC 61511 series is intended to lead to a high level of consistency (for example, of underlying principles, terminology, information) within the process industries. This should have both safety and economic benefits.

In jurisdictions where the governing authorities (for example national, federal, state, province, county, city) have established process safety design, process safety management, or other regulations, these take precedence over the requirements defined in the IEC 61511-1.

The IEC 61511-3 deals with guidance in the area of determining the required SIL in hazards and risk assessment. The information herein is intended to provide a broad overview of the wide range of global methods used to implement hazards and risk assessment. The information provided is not of sufficient detail to implement any of these approaches.

Before proceeding, the concept and determination of SIL provided in IEC 61511-1:2016 should be reviewed. The informative annexes in the IEC 61511-3 address the following:

- Annex A provides information that is common to each of the hazard and risk assessment methods shown herein.
- Annex B provides an overview of a semi-quantitative method used to determine the required SIL.
- Annex C provides an overview of a safety matrix method to determine the required SIL.
- Annex D provides an overview of a method using a semi-qualitative risk graph approach to determine the required SIL.
- Annex E provides an overview of a method using a qualitative risk graph approach to determine the required SIL.
- Annex F provides an overview of a method using a layer of protection analysis (LOPA) approach to select the required SIL.
- Annex G provides a layer of protection analysis using a risk matrix.
- Annex H provides an overview of a qualitative approach for risk estimation & SIL assignment.
- Annex I provides an overview of the basic steps involved in designing and calibrating a risk graph.
- Annex J provides an overview of the impact of multiple safety systems on determining the required SIL.
- Annex K provides an overview of the concepts of tolerable risk and ALARP.

Figure 1 shows the overall framework for IEC 61511-1, IEC 61511-2 and IEC 61511-3 and indicates the role that the IEC 61511 series plays in the achievement of functional safety for SIS.

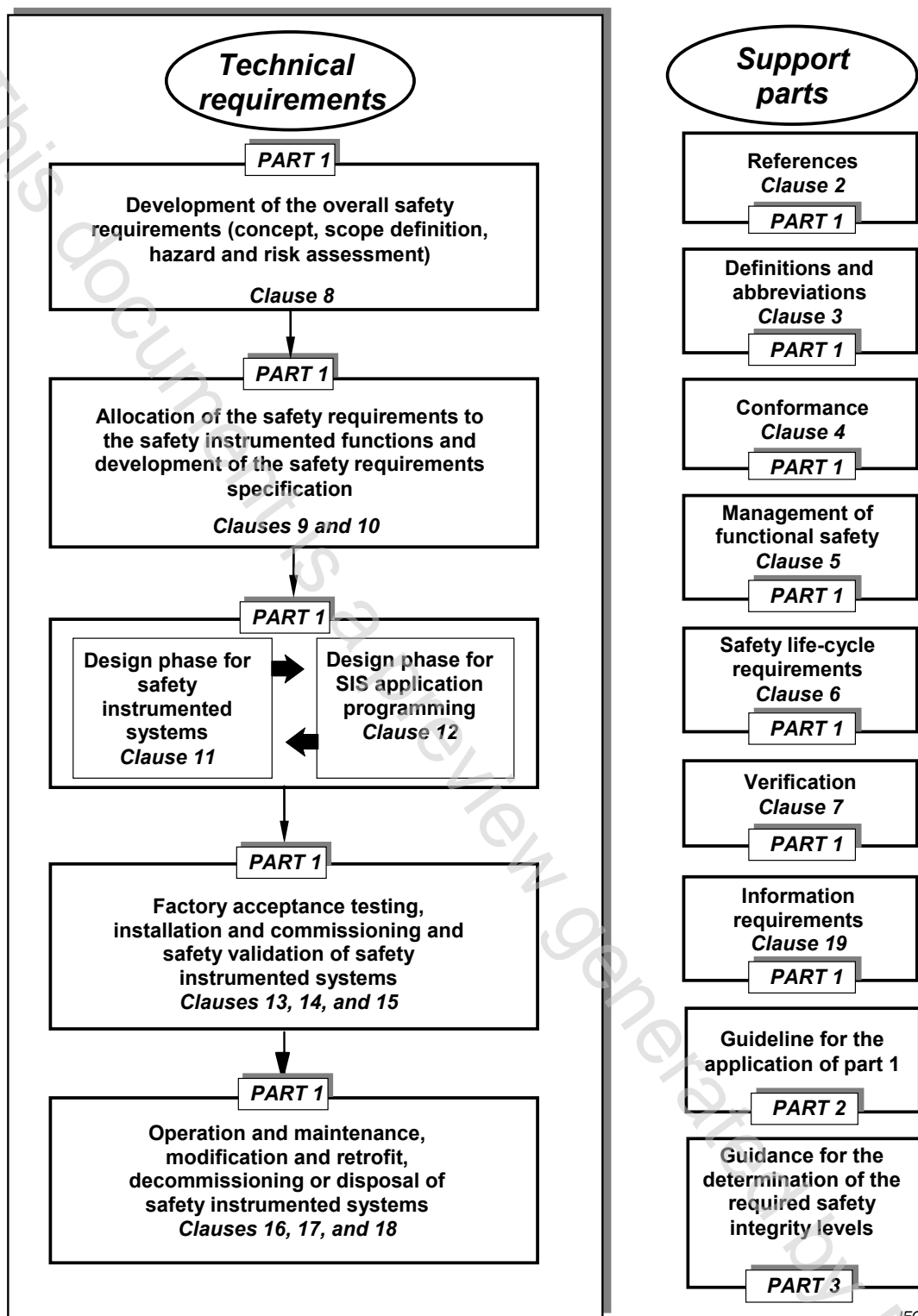


Figure 1 – Overall framework of the IEC 61511 series

FUNCTIONAL SAFETY – SAFETY INSTRUMENTED SYSTEMS FOR THE PROCESS INDUSTRY SECTOR –

Part 3: Guidance for the determination of the required safety integrity levels

1 Scope

This part of IEC 61511 provides information on:

- the underlying concepts of risk and the relationship of risk to safety integrity (see Clause A.4);
- the determination of tolerable risk (see Annex K);
- a number of different methods that enable the safety integrity level (SIL) for the safety instrumented functions (SIF) to be determined (see Annexes B through K);
- the impact of multiple safety systems on calculations determining the ability to achieve the desired risk reduction (see Annex J).

In particular, this part of IEC 61511:

- a) applies when functional safety is achieved using one or more SIF for the protection of either personnel, the general public, or the environment;
- b) may be applied in non-safety applications such as asset protection;
- c) illustrates typical hazard and risk assessment methods that may be carried out to define the safety functional requirements and SIL of each SIF;
- d) illustrates techniques/measures available for determining the required SIL;
- e) provides a framework for establishing SIL but does not specify the SIL required for specific applications;
- f) does not give examples of determining the requirements for other methods of risk reduction.

NOTE Examples given in the Annexes of this Standard are intended only as case specific examples of implementing IEC 61511 requirements in a specific instance, and the user should satisfy themselves that the chosen methods and techniques are appropriate to their situation.

Annexes B through K illustrate quantitative and qualitative approaches and have been simplified in order to illustrate the underlying principles. These annexes have been included to illustrate the general principles of a number of methods but do not provide a definitive account.

NOTE 1 Those intending to apply the methods indicated in these annexes can consult the source material referenced in each annex.

NOTE 2 The methods of SIL determination included in Part 3 may not be suitable for all applications. In particular, specific techniques or additional factors that are not illustrated may be required for high demand or continuous mode of operation.

NOTE 3 The methods as illustrated herein may result in non-conservative results when they are used beyond their underlying limits and when factors such as common cause, fault tolerance, holistic considerations of the application, lack of experience with the method being used, independence of the protection layers, etc., are not properly considered. See Annex J.

Figure 2 gives an overview of typical protection layers and risk reduction means.