

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Functional safety of electrical/electronic/programmable electronic
safety-related systems –
Part 6: Guidelines on the application of IEC 61508-2 and IEC 61508-3**

**Sécurité fonctionnelle des systèmes électriques/électroniques/électroniques
programmables relatifs à la sécurité –
Partie 6: Lignes directrices pour l'application de la CEI 61508-2 et de
la CEI 61508-3**

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Withdrawal

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**FUNCTIONAL SAFETY OF ELECTRICAL/ELECTRONIC/PROGRAMMABLE
ELECTRONIC SAFETY-RELATED SYSTEMS –**
**Part 6: Guidelines on the application of IEC 61508-2
and IEC 61508-3**

FOREWORD

- 1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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IEC 61508-6 has been prepared by subcommittee 65A: System aspects, of IEC technical committee 65: Industrial-process measurement and control.

The text of this standard is based on the following documents:

FDIS	Report on voting
65A/295/FDIS	65A/304/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 3.

Annexes A to E are for information only.

IEC 61508 consists of the following parts, under the general title *Functional safety of electrical/electronic/programmable electronic safety-related systems*:

- Part 1: General requirements
- Part 2: Requirements for electrical/electronic/programmable electronic safety-related systems

- Part 3: Software requirements
- Part 4: Definitions and abbreviations
- Part 5: Examples of methods for the determination of safety integrity levels
- Part 6: Guidelines on the application of IEC 61508-2 and IEC 61508-3
- Part 7: Overview of techniques and measures

The committee has decided that the contents of this publication will remain unchanged until 2005. At this date, the publication will be

- reconfirmed;
- withdrawn;
- replaced by a revised edition, or
- amended.

Withdrawn

INTRODUCTION

Systems comprised of electrical and/or electronic components have been used for many years to perform safety functions in most application sectors. Computer-based systems (generically referred to as programmable electronic systems (PESs)) are being used in all application sectors to perform non-safety functions and, increasingly, to perform safety functions. If computer system technology is to be effectively and safely exploited, it is essential that those responsible for making decisions have sufficient guidance on the safety aspects on which to make those decisions.

This International Standard sets out a generic approach for all safety lifecycle activities for systems comprised of electrical and/or electronic and/or programmable electronic components (electrical/ electronic/programmable electronic systems (E/E/PESs)) that are used to perform safety functions. This unified approach has been adopted in order that a rational and consistent technical policy be developed for all electrically based safety-related systems. A major objective is to facilitate the development of application sector standards.

In most situations, safety is achieved by a number of protective systems which rely on many technologies (for example mechanical, hydraulic, pneumatic, electrical, electronic, programmable electronic). Any safety strategy must therefore consider not only all the elements within an individual system (for example sensors, controlling devices and actuators) but also all the safety-related systems making up the total combination of safety-related systems. Therefore, while this International Standard is concerned with electrical/ electronic/programmable electronic (E/E/PE) safety-related systems, it may also provide a framework within which safety-related systems based on other technologies may be considered.

It is recognized that there is a great variety of E/E/PES applications in a variety of application sectors and covering a wide range of complexity, hazard and risk potentials. In any particular application, the exact prescription of safety measures is dependent on many factors specific to the application. This International Standard, by being generic, will enable such a prescription to be formulated in future application sector international standards.

This International Standard

- considers all relevant overall E/E/PES and software safety lifecycle phases (for example, from initial concept, through design, implementation, operation and maintenance to decommissioning) when E/E/PESs are used to perform safety functions;
- has been conceived with a rapidly developing technology in mind; the framework is sufficiently robust and comprehensive to cater for future developments;
- enables application sector international standards, dealing with safety-related E/E/PESs, to be developed; the development of application sector international standards, within the framework of this International Standard, should lead to a high level of consistency (for example, of underlying principles, terminology, etc.) both within application sectors and across application sectors; this will have both safety and economic benefits;
- provides a method for the development of the safety requirements specification necessary to achieve the required functional safety for E/E/PE safety-related systems;
- uses safety integrity levels for specifying the target level of safety integrity for the safety functions to be implemented by the E/E/PE safety-related systems;

- adopts a risk-based approach for the determination of the safety integrity level requirements;
- sets numerical target failure measures for E/E/PE safety-related systems which are linked to the safety integrity levels;
- sets a lower limit on the target failure measures, in a dangerous mode of failure, that can be claimed for a single E/E/PE safety-related system; for E/E/PE safety-related systems operating in
 - a low demand mode of operation, the lower limit is set at an average probability of failure of 10^{-5} to perform its design function on demand,
 - a high demand or continuous mode of operation, the lower limit is set at a probability of a dangerous failure of 10^{-9} per hour;

NOTE A single E/E/PE safety-related system does not necessarily mean a single-channel architecture.

- adopts a broad range of principles, techniques and measures to achieve functional safety for E/E/PE safety-related systems, but does not rely on the concept of fail-safe, which may be of value when the failure modes are well-defined and the level of complexity is relatively low – the concept of fail-safe was considered inappropriate because of the full range of complexity of E/E/PE safety-related systems that are within the scope of the standard.

Withdrawn

FUNCTIONAL SAFETY OF ELECTRICAL/ELECTRONIC/PROGRAMMABLE ELECTRONIC SAFETY-RELATED SYSTEMS –

Part 6: Guidelines on the application of IEC 61508-2 and IEC 61508-3

1 Scope

1.1 This part of IEC 61508 contains information and guidelines on IEC 61508-2 and IEC 61508-3.

- Annex A gives a brief overview of the requirements of IEC 61508-2 and IEC 61508-3 and sets out the functional steps in their application.
- Annex B gives an example technique for calculating the probabilities of hardware failure and should be read in conjunction with 7.4.3 and annex C of IEC 61508-2 and annex D.
- Annex C gives a worked example of calculating diagnostic coverage and should be read in conjunction with annex C of IEC 61508-2.
- Annex D gives a methodology for quantifying the effect of hardware-related common cause failures on the probability of failure.
- Annex E gives worked examples of the application of the software safety integrity tables specified in annex A of IEC 61508-3 for safety integrity levels 2 and 3.

1.2 IEC 61508-1, IEC 61508-2, IEC 61508-3 and IEC 61508-4 are basic safety publications, although this status does not apply in the context of low complexity E/E/PE safety-related systems (see 3.4.4 of IEC 61508-4). As basic safety publications, they are intended for use by technical committees in the preparation of standards in accordance with the principles contained in IEC Guide 104 and IEC/ISO Guide 51. IEC 61508 is also intended for use as a stand-alone standard.

1.3 One of the responsibilities of a technical committee is, wherever applicable, to make use of basic safety publications in the preparation of its publications. In this context, the requirements, test methods or test conditions of this basic safety publication do not apply unless specifically referred to or included in the publications prepared by those technical committees.

NOTE In the USA and Canada, until the proposed process sector implementation of IEC 61508 (i.e. IEC 61511) is published as an international standard, existing national process safety standards based on IEC 61508 (i.e. ANSI/ISA 884.01-1996) can be applied to the process sector instead of IEC 61508.

1.4 Figure 1 shows the overall framework for parts 1 to 7 of this standard and indicates the role that IEC 61508-6 plays in the achievement of functional safety for E/E/PE safety-related systems.

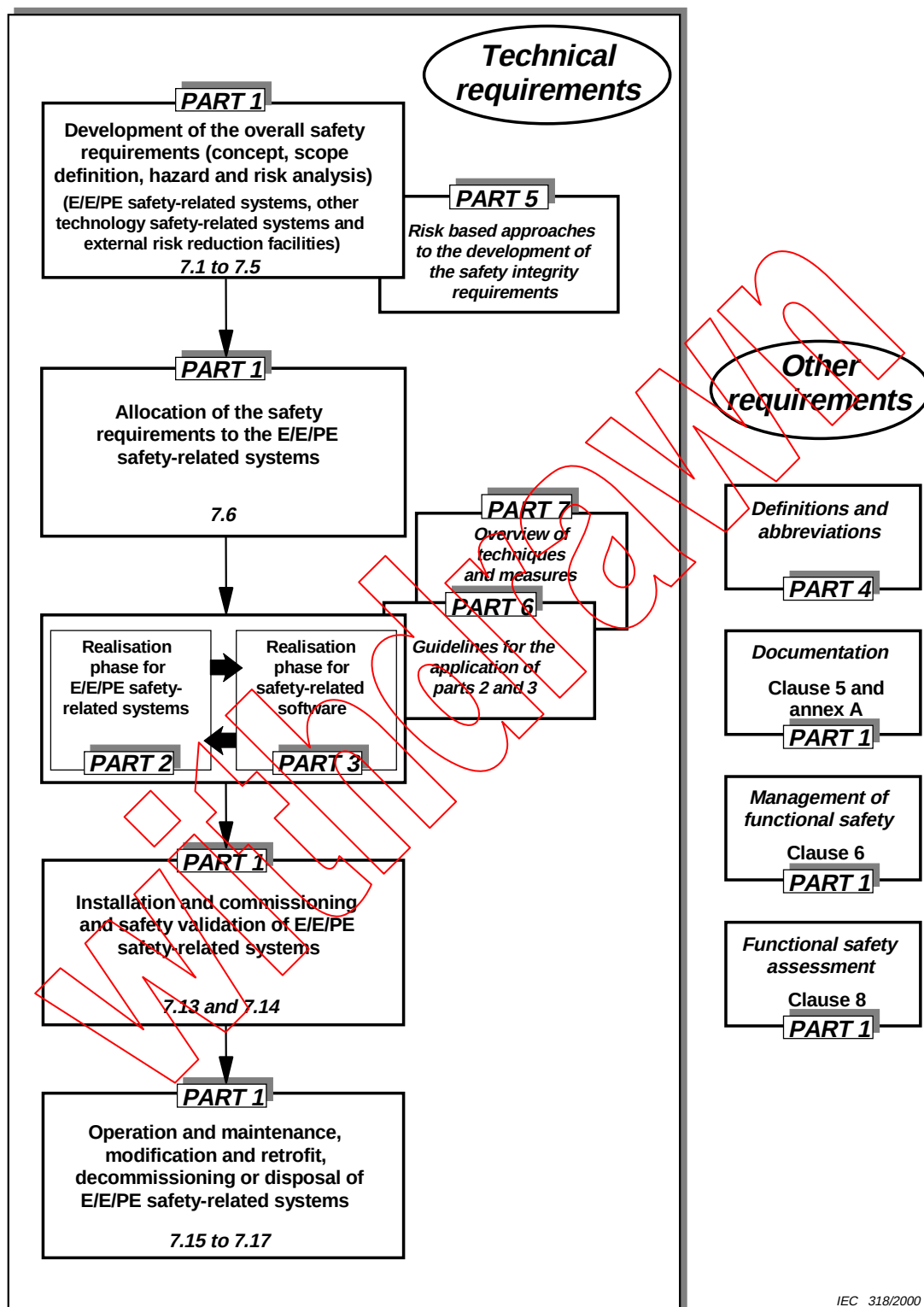


Figure 1 – Overall framework of IEC 61508

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 61508. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of IEC 61508 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

IEC 61508 (all parts), *Functional safety of electrical/electronic/programmable electronic safety-related systems*

IEC Guide 104:1997, *Guide to the drafting of safety standards and the rôle of committees with safety pilot functions and safety group functions*

IEC/ISO Guide 51:1990, *Guidelines for the inclusion of safety aspects in standards*

3 Definitions and abbreviations

For the purpose of this standard, the definitions and abbreviations given in IEC 61508-4 apply.

Withdrawn

Annex A (informative)

Application of IEC 61508-2 and of IEC 61508-3

A.1 General

Machinery, process plant and other equipment may, in the case of malfunction (for example by failures of electro-mechanical, electronic and/or programmable electronic devices), present risks to people and the environment from hazardous events such as fires, explosions, radiation overdoses, machinery traps, etc. Failures can arise from either physical faults in the device (for example causing random hardware failures), or from systematic faults (for example human errors made in the specification and design of a system cause systematic failure under some particular combination of inputs), or from some environmental condition.

IEC 61508-1 provides an overall framework based on a risk approach for the prevention and/or control of failures in electro-mechanical, electronic, or programmable electronic devices.

The overall goal is to ensure that plant and equipment can be safely automated. A key objective of this standard is to prevent

- failures of control systems triggering other events, which in turn could lead to danger (for example fire, release of toxic materials, repeat stroke of a machine, etc.); and
- undetected failures in protection systems (for example in an emergency shut-down system), making the systems unavailable when needed for a safety action.

IEC 61508-1 requires that a hazard and risk analysis at the process/machine level is carried out to determine the amount of risk reduction necessary to meet the risk criteria for the application. Risk is based on the assessment of both the consequence (or severity) and the frequency (or probability) of the hazardous event.

IEC 61508-1 further requires that the amount of risk reduction established by the risk analysis is used to determine if one or more safety-related systems ¹⁾ are required and what safety functions (each with a specified safety integrity ²⁾) they are needed for.

IEC 61508-2 and IEC 61508-3 take the safety functions and safety integrity requirements allocated to any system, *designated* as a E/E/PE safety-related system, by the application of IEC 61508-1 and establish requirements for safety lifecycle activities which

- are to be applied during the specification, design and modification of the hardware and software; and
- focus on means for preventing and/or controlling random hardware and systematic failures (the E/E/PE and software safety lifecycles ³⁾).

¹⁾ Systems necessary for functional safety and containing one or more electrical (electro-mechanical), electronic or programmable electronic (E/E/PE) devices are *designated* as E/E/PE safety-related systems and include all equipment necessary to carry out the required safety function (see 3.4.1 of IEC 61508-4).

²⁾ Safety integrity is specified as one of four discrete levels. Safety integrity level 4 is the highest and safety integrity level 1 the lowest (see 7.6.2.9 of IEC 61508-1).

³⁾ To enable the requirements of this standard to be clearly structured, a decision was made to order the requirements using a development process model in which each stage follows in a defined order with little iteration (sometimes referred to as a waterfall model). However, it is stressed that any lifecycle approach can be used provided a statement of equivalence is given in the safety plan for the project (see clause 6 of IEC 61508-1).

IEC 61508-2 and IEC 61508-3 do not give guidance on which level of safety integrity is appropriate for a given required tolerable risk. This decision depends upon many factors, including the nature of the application, the extent to which other systems carry out safety functions and social and economic factors (see IEC 61508-1 and IEC 61508-5).

The requirements of IEC 61508-2 and IEC 61508-3 include

- the application of measures and techniques ¹⁾, which are graded against the safety integrity level, for the avoidance of systematic failures ²⁾ by preventative methods; and
- the control of systematic failures (including software failures) and random hardware failures by design features such as fault detection, redundancy and architectural features (for example diversity).

In IEC 61508-2, assurance that the safety integrity target has been satisfied for dangerous random hardware failures is based on

- hardware fault tolerance requirements (see tables 2 and 3 of IEC 61508-2); and
- the diagnostic coverage and frequency of proof tests of subsystems and components, by carrying out a reliability analysis using appropriate data.

In both IEC 61508-2 and IEC 61508-3, assurance that the safety integrity target has been satisfied for systematic failures is gained by

- the correct application of safety management procedures;
- the use of competent staff;
- the application of the specified safety lifecycle activities, including the specified techniques and measures ³⁾; and
- an independent functional safety assessment ⁴⁾.

The overall goal is to ensure that remaining systematic faults, commensurate with the safety integrity level, do not cause a failure of the E/E/PE safety-related system.

IEC 61508-2 has been developed to provide requirements for achieving safety integrity in the hardware ⁵⁾ of the E/E/PE safety-related systems including sensors and final elements. Techniques and measures against both random hardware failures and systematic hardware failures are required. These involve an appropriate combination of fault avoidance and failure control measures as indicated above. Where manual action is needed for functional safety, requirements are given for the operator interface. Also diagnostic test techniques and measures, based on software and hardware (for example diversity), to detect random hardware failures are specified in IEC 61508-2.

1) The required techniques and measures for each safety integrity level are shown in the tables in annexes A and B of IEC 61508-2 and IEC 61508-3.

2) Systematic failures cannot usually be quantified. Causes include: specification and design faults in hardware and software; failure to take account of the environment (for example temperature); and operation-related faults (for example poor interface).

3) Alternative measures to those specified in the standard are acceptable provided justification is documented during safety planning (see clause 6 of IEC 61508-1).

4) Independent assessment does not always imply third party assessment (see clause 8 of IEC 61508-1).

5) Including fixed built-in software or software equivalents (also called firmware), such as application-specific integrated circuits.

IEC 61508-3 has been developed to provide requirements for achieving safety integrity for the software – both embedded (including diagnostic fault detection services) and application software. IEC 61508-3 requires a combination of fault avoidance (quality assurance) and fault tolerance approaches (software architecture), as there is no known way to prove the absence of faults in reasonably complex safety-related software, especially the absence of specification and design faults. IEC 61508-3 requires the adoption of such software engineering principles as: top down design; modularity; verification of each phase of the development lifecycle; verified software modules and software module libraries; and clear documentation to facilitate verification and validation. The different levels of software require different levels of assurance that these and related principles have been correctly applied.

The developer of the software may or may not be separate from the organization developing the whole E/E/PES. In either case, close cooperation is needed, particularly in developing the architecture of the programmable electronics where trade-offs between hardware and software architectures need to be considered for their safety impact (see figure 4 of IEC 61508-2).

A.2 Functional steps in the application of IEC 61508-2

The functional steps in the application of IEC 61508-2 are shown in figures A.1 and A.2. The functional steps in the application of IEC 61508-3 are shown in figure A.3.

Functional steps for IEC 61508-2 (see figures A.1 and A.2) are as follows.

- a) Obtain the allocation of safety requirements (see IEC 61508-1). Update the safety planning as appropriate during E/E/PES development.
- b) Determine the requirements for E/E/PES safety, including the safety integrity requirements, for each safety function (see 7.2 of IEC 61508-2). Allocate requirements to software and pass to software supplier and/or developer for the application of IEC 61508-3.

NOTE The possibility of coincident failures in the EUC control system and E/E/PE safety-related system(s) needs to be considered at this stage (see 7.5.2.4 of IEC 61508-1). These may result from failures of components having a common cause due to for example similar environmental influences. The existence of such failures could lead to a higher than expected residual risk unless properly addressed.

- c) Start the phase of planning for E/E/PES safety validation (see 7.3 of IEC 61508-2).
- d) Specify the architecture (configuration) for the E/E/PES logic subsystem, sensors and final elements. Review with the software supplier/developer the hardware and software architecture and the safety implications of the trade-offs between the hardware and software (see figure 4 of IEC 61508-2). Iterate if required.
- e) Develop a model for the hardware architecture for the E/E/PE safety-related system. Develop this model by examining each safety function separately and determine the subsystem (component) to be used to carry out this function.
- f) Establish the system parameters for each of the subsystems (components) used in the E/E/PE safety-related system. For each of the subsystems (components), determine the following:
 - the proof-test interval for failures which are not automatically revealed;
 - the mean time to restoration;
 - the diagnostic coverage (see annex C of IEC 61508-2);

- the probability of failure; and
 - the safe failure fraction (see annex C of IEC 61508-2).
- g) Determine the architectural constraints (see tables 2 and 3 of IEC 61508-2).
- h) Create a reliability model for each of the safety functions that the E/E/PE safety-related system is required to carry out.

NOTE A reliability model is a mathematical formula which shows the relationship between reliability and relevant parameters relating to equipment and conditions of use.

- i) Calculate a reliability prediction for each safety function using an appropriate technique. Compare the result with the target failure measure determined in b) above and the requirements of tables 2 and 3 of IEC 61508-2 (see 7.4.3.1 of IEC 61508-2). If the predicted reliability does not meet the target failure measure and/or does not meet the requirements of tables 2 and 3 of IEC 61508-2, then change
- where possible, one or more of the subsystem parameters (go back to f) above); and/or
 - the hardware architecture (go back to d) above).

NOTE A number of modelling methods are available and the analyst should choose which is the most appropriate (see 7.4.3.2.2 note 9 of IEC 61508-2 for a list of some methods that could be used).

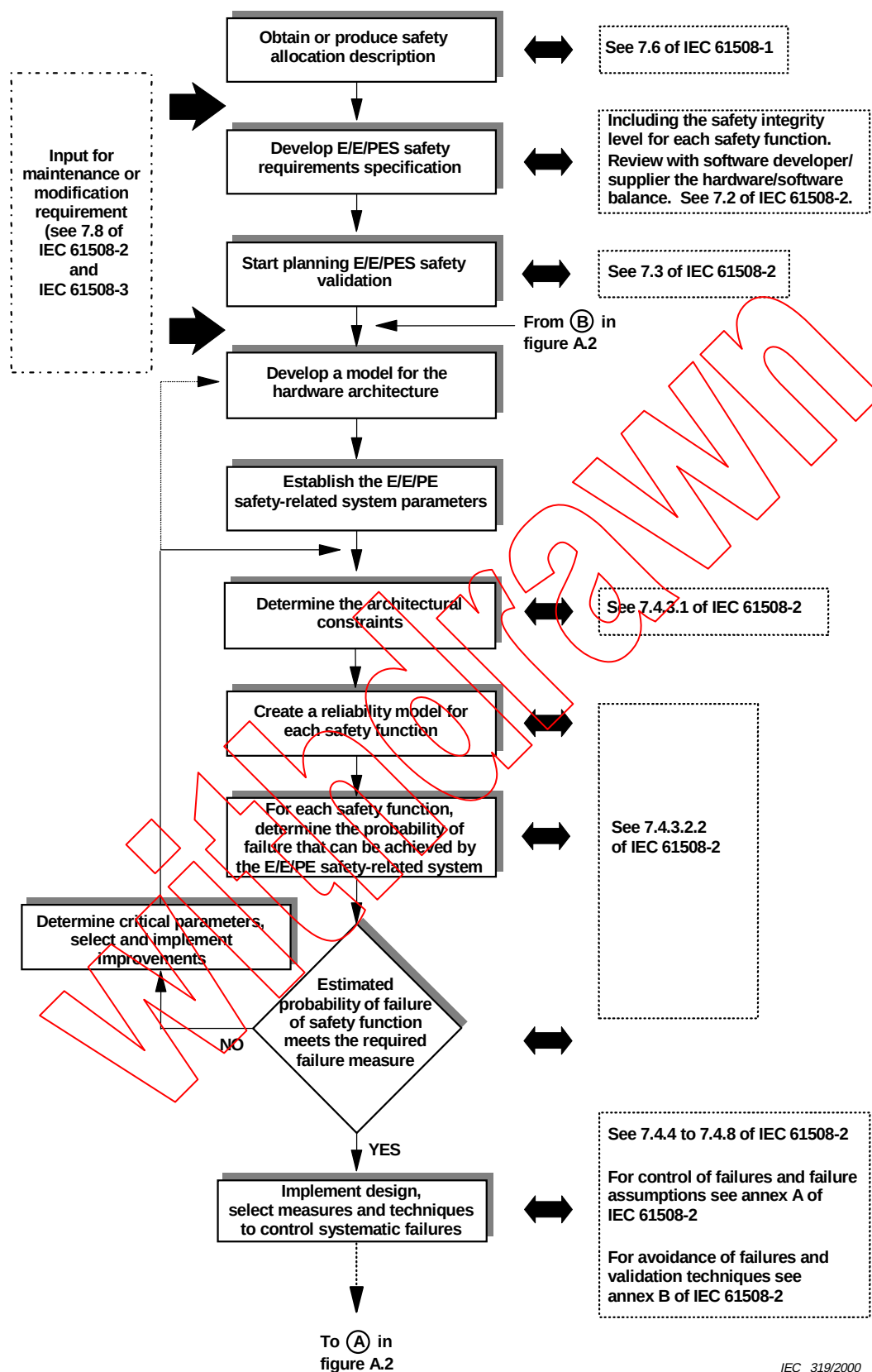
- j) Implement the design of the E/E/PE safety-related system. Select measures and techniques to control systematic hardware failures, failures caused by environmental influences and operational failures (see annex A of IEC 61508-2).
- k) Integrate the verified software (see IEC 61508-3) onto the target hardware (see 7.5 of IEC 61508-2 and annex B of IEC 61508-2) and, in parallel, develop the procedures for users and maintenance staff to follow when operating the system (see 7.6 of IEC 61508-2 and annex B of IEC 61508-2). Include software aspects (see A.3 f)).
- l) Together with the software developer (see 7.7 of IEC 61508-3), validate the E/E/PES (see 7.7 of IEC 61508-2 and annex B of IEC 61508-2).
- m) Hand over the hardware and results of the E/E/PES safety validation to the system engineers for further integration into the overall system.
- n) If maintenance/modification of the E/E/PES is required during operational life then re-activate IEC 61508-2 as appropriate (see 7.8 of IEC 61508-2).

A number of activities run across the E/E/PES safety lifecycle. These include verification (see 7.9 of IEC 61508-2) and functional safety assessment (see clause 8 of IEC 61508-1).

In applying the above steps the E/E/PES safety techniques and measures appropriate to the required safety integrity level are selected. To aid in this selection, tables have been formulated, ranking the various techniques/measures against the four safety integrity levels (see annex B of IEC 61508-2). Cross-referenced to the tables is an overview of each technique and measure with references to further sources of information (see annexes A and B of IEC 61508-7).

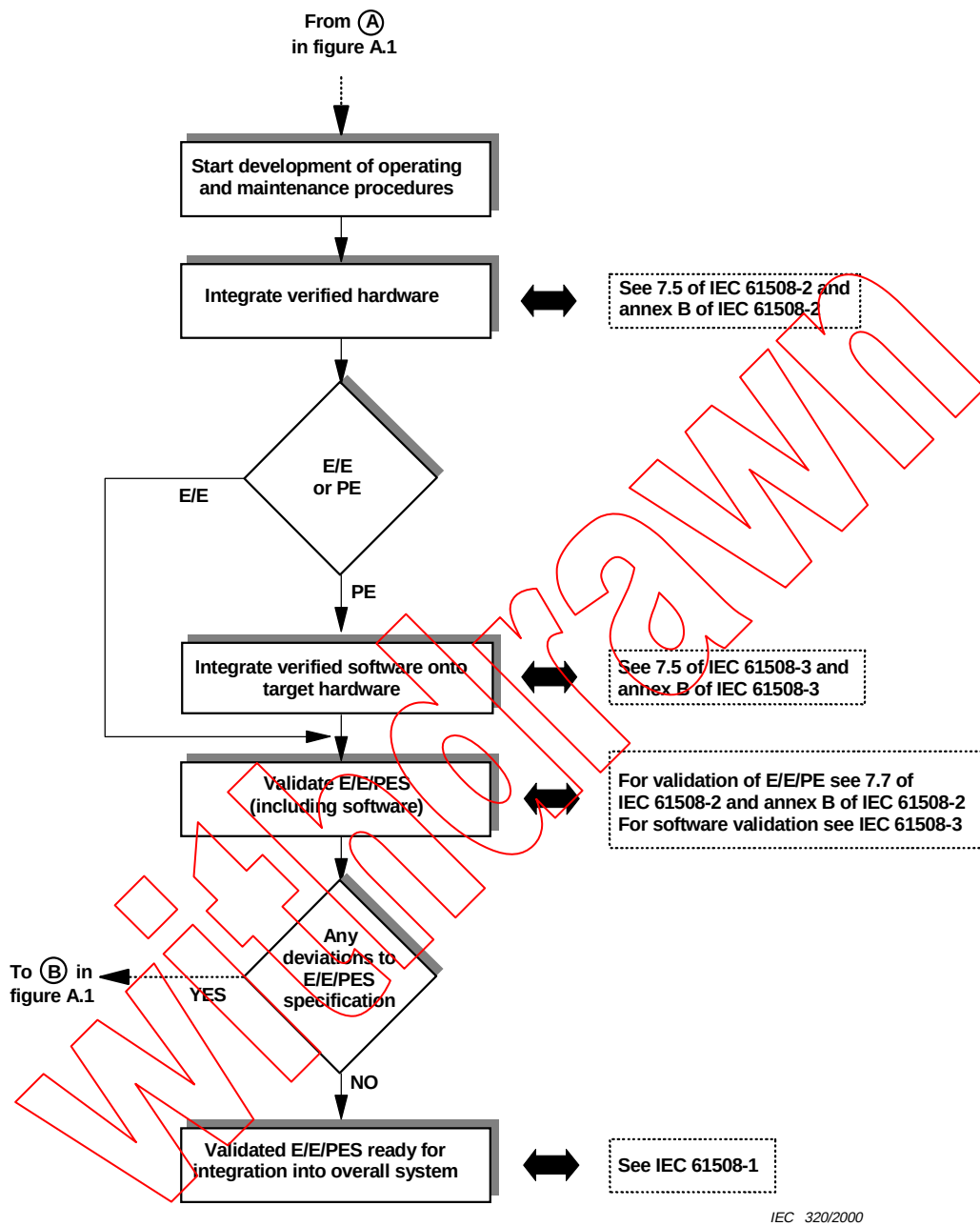
Annex B provides one possible technique for calculating the probabilities of hardware failure for E/E/PE safety-related systems.

NOTE In applying the above steps, alternative measures to those specified in the standard are acceptable provided justification is documented during safety planning (see clause 6 of IEC 61508-1).



NOTE For PE systems, activities for software occur in parallel (see figure A.3).

Figure A.1 – Application of IEC 61508-2



NOTE For PE systems, activities for software occur in parallel (see figure A.3).

Figure A.2 – Application of IEC 61508-2 (continued)

A.3 Functional steps in the application of IEC 61508-3

Functional steps for IEC 61508-3 (see figure A.3) are as follows.

- a) Obtain the requirements for the E/E/PE safety-related systems and relevant parts of the safety planning (see 7.3 of IEC 61508-2). Update the safety planning as appropriate during software development.

NOTE Earlier lifecycle phases have already

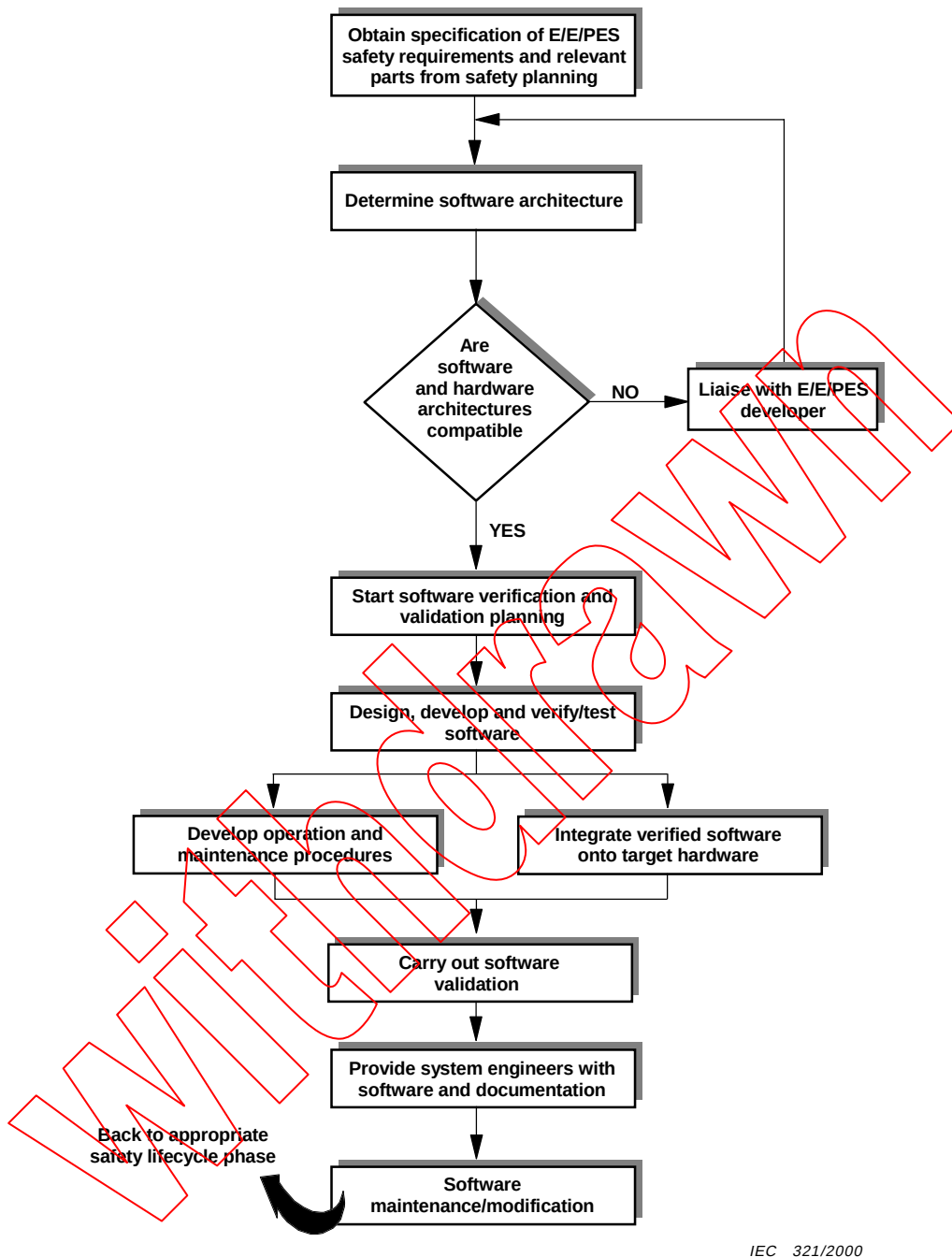
- specified the required safety functions and their associated safety integrity levels (see 7.4 and 7.5 of IEC 61508-1);
 - allocated the safety functions to designated E/E/PE safety-related systems (see 7.6 of IEC 61508-1); and
 - allocated functions to software within each E/E/PE safety-related system (see 7.2 of IEC 61508-2).
- b) Determine the software architecture for all safety functions allocated to software (see 7.4 of IEC 61508-3 and annex A of IEC 61508-3).
 - c) Review with the E/E/PE supplier/developer the software and hardware architecture and the safety implications of the trade-offs between the software and hardware (see figure 4 of IEC 61508-2). Iterate if required.
 - d) Start the planning for software safety verification and validation (see 7.3 and 7.9 of IEC 61508-3).
 - e) Design, develop and verify/test the software according to the
 - software safety planning,
 - software safety integrity level and
 - software safety lifecycle.
 - f) Complete the final software verification activity and integrate the verified software onto the target hardware (see 7.5 of IEC 61508-3), and in parallel develop the software aspects of the procedures for users and maintenance staff to follow when operating the system (see 7.6 of IEC 61508-3, and A.2 k)).
 - g) Together with the hardware developer (see 7.7 of IEC 61508-2), validate the software in the integrated E/E/PE safety-related systems (see 7.7 of IEC 61508-3).
 - h) Hand over the results of the software safety validation to the system engineers for further integration into the overall system.
 - i) If modification of the E/E/PE software is required during operational life then re-activate this IEC 61508-3 phase as appropriate (see 7.8 of IEC 61508-3).

A number of activities run across the software safety lifecycle. These include verification (see 7.9 of IEC 61508-3) and functional safety assessment (see clause 8 of IEC 61508-3).

In applying the above steps, software safety techniques and measures appropriate to the required safety integrity are selected. To aid in this selection, tables have been formulated ranking the various techniques/measures against the four safety integrity levels (see annex A of IEC 61508-3). Cross-referenced to the tables is an overview of each technique and measure with references to further sources of information (see annex C of IEC 61508-7).

Worked examples in the application of the safety integrity tables are given in annex E, and IEC 61508-7 includes a probabilistic approach to determining software safety integrity for pre-developed software (see annex D of IEC 61508-7).

NOTE In applying the above steps, alternative measures to those specified in the standard are acceptable provided justification is documented during safety planning (see clause 6 of IEC 61508-1).



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Figure A.3 – Application of IEC 61508-3

Annex B (informative)

Example technique for evaluating probabilities of hardware failure

B.1 General

This annex provides one possible technique for calculating the probabilities of hardware failure for E/E/PE safety-related systems installed in accordance with IEC 61508-1, IEC 61508-2 and IEC 61508-3. The information provided is informative in nature and should not be interpreted as the only evaluation technique that might be used. It does, however, provide a relatively simple approach for assessing the capability of E/E/PE safety-related systems.

NOTE 1 Other techniques are described for example in ANSI/ISA S84.01-1996, Application of safety instrumented systems for the process industries.

There are a number of techniques available for the analysis of hardware safety integrity for E/E/PE safety-related systems. Two of the more common techniques are reliability block diagrams (see C.6.5 of IEC 61508-7) and Markov models (see C.6.4 of IEC 61508-7). Both methods, if correctly applied, yield similar results, but in the case of complex programmable electronic subsystems (for example where multiple channel cross-voting and automatic testing are employed) there may be some loss of accuracy when reliability block diagrams are used compared to Markov models.

This loss of accuracy may not be significant in the context of the complete E/E/PE safety-related system and when the accuracy of the reliability data used in the analysis is taken into account. For example, field devices often predominate in the analysis of the hardware safety integrity for E/E/PE safety-related systems. Whether the loss of accuracy is significant can only be determined in the particular circumstances. In the case of complex programmable electronic subsystems, reliability block diagrams give results with more pessimistic hardware safety integrity values than Markov models (i.e. reliability block diagrams give a higher probability of failure). This annex uses reliability block diagrams.

Where a failure of the EUC control system places a demand on the E/E/PE safety-related system, then the probability of a hazardous event occurring also depends on the probability of failure of the EUC control system. In that situation it is necessary to consider the possibility of co-incident failure of components in the EUC control system and the E/E/PE safety-related system due to common cause failure mechanisms. The existence of such failures could lead to a higher than expected residual risk unless properly addressed.

The calculations are based on the following assumptions:

- the resulting average probability of failure on demand for the subsystem is less than 10^{-1} , or the resultant probability of failure per hour for the subsystem is less than 10^{-5} ;
- component failure rates are constant over the life of the system;
- the sensor (input) subsystem comprises the actual sensor(s) and any other components and wiring, up to but not including the component(s) where the signals are first combined by voting or other processing (for example for two sensor channels, the configuration would be as shown in figure B.1);

- the logic subsystem comprises the component(s) where the signals are first combined, and all other components up to and including where final signal(s) are presented to the final element subsystem;
- the final element (output) subsystem comprises all the components and wiring which process the final signal(s) from the logic subsystem including the final actuating component(s);
- the hardware failure rates used as inputs to the calculations and tables are for a single channel of the subsystem (for example, if 2oo3 sensors are used, the failure rate is for a single sensor and the effect of 2oo3 is calculated separately);
- the channels in a voted group all have the same failure rates and diagnostic coverage;
- the overall hardware failure rate of a channel of the subsystem is the sum of the dangerous failure rate and safe failure rate for that channel, which are assumed to be equal;

NOTE 2 This assumption affects the safe failure fraction (see annex C of IEC 61508-2), but the safe failure fraction does not affect the calculated values for probability of failure given in this annex.

- for each safety function, there is perfect proof testing and repair (i.e. all failures that remain undetected are detected by the proof test), but for the effects of a non-perfect proof test see B.2.5;
- the proof test interval is at least an order of magnitude greater than the diagnostic test interval;
- for each subsystem there is a single proof test interval and mean time to restoration;

NOTE 3 The mean time to restoration is defined in 7.4.3.2.2, note 5 of IEC 61508-2 as including the time taken to detect a failure. In this annex, the single assumed value of mean time to restoration for both detected and undetected failures includes the diagnostic test interval but not the proof test interval. For undetected failures, the mean time to restoration used in the calculations should not include the diagnostic test interval, but since the mean time to restoration is always added to the proof test interval, which is at least an order of magnitude greater than the diagnostic test interval, the error is not significant.

- multiple repair teams are available to work on all known failures;
- the expected interval between demands is at least an order of magnitude greater than the mean time to restoration;
- for all subsystems operating in low demand mode of operation, and for 1oo2, 1oo2D and 2oo3 voted groups operating in high demand or continuous mode of operation, the fraction of failures specified by the diagnostic coverage is both detected and repaired within the mean time to restoration used to determine hardware safety integrity requirements;

EXAMPLE If a mean time to restoration of 8 h is assumed, this includes the diagnostic test interval which is typically less than 1 h, the remainder being the actual repair time.

NOTE 4 For 1oo2, 1oo2D and 2oo3 voted groups, it is assumed that any repair is on-line. Configuring an E/E/PE safety-related system, so that on any detected fault the EUC is put into a safe state, improves the average probability of failure on demand. The degree of improvement depends on the diagnostic coverage.

- for 1oo1 and 2oo2 voted groups operating in high demand or continuous mode of operation, the E/E/PE safety-related system always achieves a safe state after detecting a dangerous fault; to achieve this, the expected interval between demands is at least an order of magnitude greater than the diagnostic test intervals, or the sum of the diagnostic test intervals and the time to achieve a safe state is less than the process safety time;

NOTE 5 The process safety time is defined in 7.4.3.2.5 of IEC 61508-2 as the period of time between a failure occurring in the EUC or the EUC control system (with the potential to give rise to a hazardous event) and the occurrence of the hazardous event if the safety function is not performed.

- when a power supply failure removes power from a de-energize-to-trip E/E/PE safety-related system and initiates a system trip to a safe state, the power supply does not affect the average probability of failure on demand of the E/E/PE safety-related system; if the system is energized to trip, or the power supply has failure modes that can cause unsafe operation of the E/E/PE safety-related system, the power supply should be included in the evaluation;
- where the term channel is used, it is limited to only that part of the system under discussion, which is usually either the sensor, logic or final element subsystem;
- the abbreviated terms are described in table B.1.

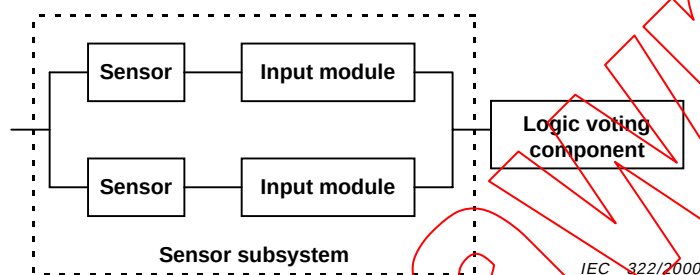


Figure B.1 – Example configuration for two sensor channels

Table B.1 – Terms and their ranges used in this annex
(applies to 1oo1, 1oo2, 2oo2, 1oo2D and 2oo3)

Abbreviation	Term (units)	Parameter ranges in tables B.2 to B.5 and B.10 to B.13
T_1	Proof-test interval (h)	One month (730 h) ¹ Three months (2 190 h) ¹ Six months (4 380 h) One year (8 760 h) Two years (17 520 h) ² 10 years (87 600 h) ²
$MTTR$	Mean time to restoration (hour)	8 h
DC	Diagnostic coverage (expressed as a fraction in the equations and as a percentage elsewhere)	0 % 60 % 90 % 99 %
β	The fraction of undetected failures that have a common cause (expressed as a fraction in the equations and as a percentage elsewhere) (tables B.2 to B.5 and B.10 to B.13 assume $\beta = 2 \times \beta_D$)	2 % 10 % 20 %
β_D	Of those failures that are detected by the diagnostic tests, the fraction that have a common cause (expressed as a fraction in the equations and as a percentage elsewhere) (tables B.2 to B.5 and B.10 to B.13 assume $\beta = 2 \times \beta_D$)	1 % 5 % 10 %
λ	Failure rate (per hour) of a channel in a subsystem	$0,1 \times 10^{-6}$ $0,5 \times 10^{-6}$ 1×10^{-6} 5×10^{-6} 10×10^{-6} 50×10^{-6}
PFD_G	Average probability of failure on demand for the group of voted channels (if the sensor, logic or final element subsystem comprises of only one voted group, then PFD_G is equivalent to PFD_S , PFD_L or PFD_{FE} respectively)	
PFD_S	Average probability of failure on demand for the sensor subsystem	
PFD_L	Average probability of failure on demand for the logic subsystem	
PFD_{FE}	Average probability of failure on demand for the final element subsystem	
PFD_{SYS}	Average probability of failure on demand of a safety function for the E/E/PE safety-related system	
PFH_G	Probability of failure per hour for the group of voted channels (if the sensor, logic or final element subsystem comprises of only one voted group, then PFH_G is equivalent to PFH_S , PFH_L or PFH_{FE} respectively)	
PFH_S	Probability of failure per hour for the sensor subsystem	
PFH_L	Probability of failure per hour for the logic subsystem	
PFH_{FE}	Probability of failure per hour for the final element subsystem	
PFH_{SYS}	Probability of failure per hour of a safety function for the E/E/PE safety-related system	
λ_D	Dangerous failure rate (per hour) of a channel in a subsystem, equal to $0,5 \lambda$ (assumes 50 % dangerous failures and 50 % safe failures)	
λ_{DD}	Detected dangerous failure rate (per hour) of a channel in a subsystem (this is the sum of all the detected dangerous failure rates within the channel of the subsystem)	
λ_{DU}	Undetected dangerous failure rate (per hour) of a channel in a subsystem (this is the sum of all the undetected dangerous failure rates within the channel of the subsystem)	
λ_{SD}	Detected safe failure rate (per hour) of a channel in a subsystem (this is the sum of all the detected safe failure rates within the channel of the subsystem)	
t_{CE}	Channel equivalent mean down time (hour) for 1oo1, 1oo2, 2oo2 and 2oo3 architectures (this is the combined down time for all the components in the channel of the subsystem)	
t_{GE}	Voted group equivalent mean down time (hour) for 1oo2 and 2oo3 architectures (this is the combined down time for all the channels in the voted group)	
t_{CE}'	Channel equivalent mean down time (hour) for 1oo2D architecture (this is the combined down time for all the components in the channel of the subsystem)	
t_{GE}'	Voted group equivalent mean down time (hour) for 1oo2D architecture (this is the combined down time for all the channels in the voted group)	
T_2	Interval between demands (h)	

¹ High demand or continuous mode only.
² Low demand mode only.

B.2 Average probability of failure on demand (for low demand mode of operation)

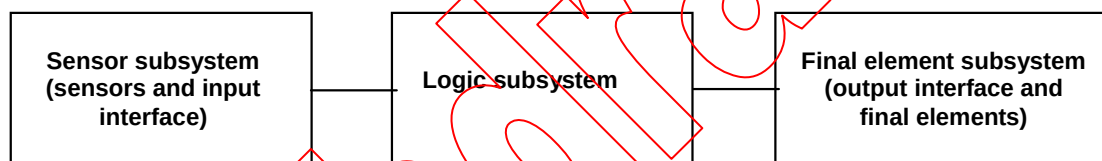
B.2.1 Procedure for calculations

The average probability of failure on demand of a safety function for the E/E/PE safety-related system is determined by calculating and combining the average probability of failure on demand for all the subsystems which together provide the safety function. Since in this annex the probabilities are small, this can be expressed by the following (see figure B.2):

$$PFD_{SYS} = PFD_S + PFD_L + PFD_{FE}$$

where

- PFD_{SYS} is the average probability of failure on demand of a safety function for the E/E/PE safety-related system;
- PFD_S is the average probability of failure on demand for the sensor subsystem;
- PFD_L is the average probability of failure on demand for the logic subsystem; and
- PFD_{FE} is the average probability of failure on demand for the final element subsystem.



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Figure B.2 – Subsystem structure

To determine the average probability of failure on demand for each of the subsystems, the following procedure should be adhered to for each subsystem in turn.

- a) Draw the block diagram showing the sensor subsystem (input) components, logic subsystem components or final element subsystem (output) components. For example, sensor subsystem components may be sensors, barriers, input conditioning circuits; logic subsystem components may be processors and scanning devices; and final element subsystem components may be output conditioning circuits, barriers and actuators. Represent each subsystem as one or more 1oo1, 1oo2, 2oo2, 1oo2D or 2oo3 voted groups.
- b) Refer to the relevant table from tables B.2 to B.5 which are for six-month, one-year, two-year and 10-year proof-test intervals. These tables also assume an 8 h mean time to restoration for each failure once it has been revealed.
- c) For each voted group in the subsystem, select from the relevant table of tables B.2 to B.5
 - architecture (for example, 2oo3);
 - diagnostic coverage of each channel (for example, 60 %);
 - the failure rate (per hour), λ , of each channel (for example, 5.0E-06);

- the common cause failure β -factors, β and β_D , for the interaction between the channels in the voted group (for example, 2 % and 1 % respectively).

NOTE 1 It is assumed that every channel in the voted group has the same diagnostic coverage and failure rate (see B.1).

NOTE 2 It is assumed in tables B.2 to B.5 (and in tables B.10 to B.13) that the β -factor in the absence of diagnostic tests (also used for undetected dangerous failures in the presence of diagnostic tests), β , is 2 times the β -factor for failures detected by the diagnostic tests, β_D .

- Obtain, from the relevant table from tables B.2 to B.5, the average probability of failure on demand for the voted group.
- If the safety function depends on more than one voted group of sensors or actuators, the combined average probability of failure on demand of the sensor or final element subsystem, PFD_S or PFD_{FE} , is given in the following equations, where PFD_{Gi} and PFD_{Gj} is the average probability of failure on demand for each voted group of sensors and final elements respectively:

$$PFD_S = \sum_i PFD_{Gi}$$

$$PFD_{FE} = \sum_j PFD_{Gj}$$

B.2.2 Architectures for low demand mode of operation

NOTE 1 This subclause should be read sequentially, since equations which are valid for several architectures are only stated where they are first used.

NOTE 2 The equations are based on the assumptions listed in B.1.

B.2.2.1 1oo1

This architecture consists of a single channel, where any dangerous failure leads to a failure of the safety function when a demand arises.

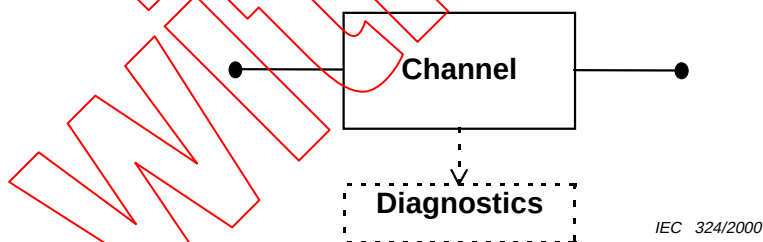


Figure B.3 – 1oo1 physical block diagram

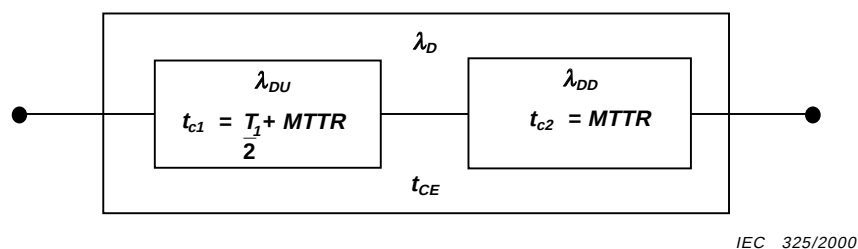


Figure B.4 – 1oo1 reliability block diagram

Figures B.3 and B.4 contain the relevant block diagrams. The dangerous failure rate for the channel is given by

$$\lambda_D = \lambda_{DU} + \lambda_{DD} = \frac{\lambda}{2}$$

Figure B.4 shows that the channel can be considered to comprise of two components, one with a dangerous failure rate λ_{DU} resulting from undetected failures and the other with a dangerous failure rate λ_{DD} resulting from detected failures. It is possible to calculate the channel equivalent mean down time t_{CE} , adding the individual down times from both components, t_{c1} and t_{c2} , in direct proportion to each component's contribution to the probability of failure of the channel:

$$t_{CE} = \frac{\lambda_{DU}}{\lambda_D} \left(\frac{T_1}{2} + MTTR \right) + \frac{\lambda_{DD}}{\lambda_D} MTTR$$

For every architecture, the detected dangerous failure rate and the undetected dangerous failure rate are given by

$$\lambda_{DU} = \frac{\lambda}{2} (1 - DC) ; \lambda_{DD} = \frac{\lambda}{2} DC$$

For a channel with down time t_{CE} resulting from dangerous failures

$$PFD = 1 - e^{-\lambda_D t_{CE}} \approx \lambda_D t_{CE} \quad \text{since } \lambda_D t_{CE} \ll 1$$

Hence, for a 1001 architecture, the average probability of failure on demand is

$$PFD_G = (\lambda_{DU} + \lambda_{DD}) t_{CE}$$

B.2.2.2 1002

This architecture consists of two channels connected in parallel, such that either channel can process the safety function. Thus there would have to be a dangerous failure in both 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.

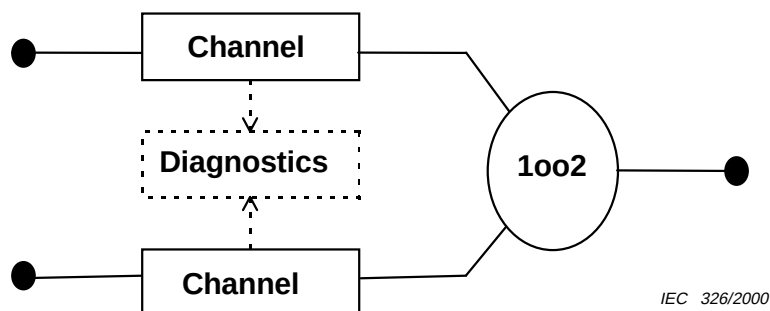
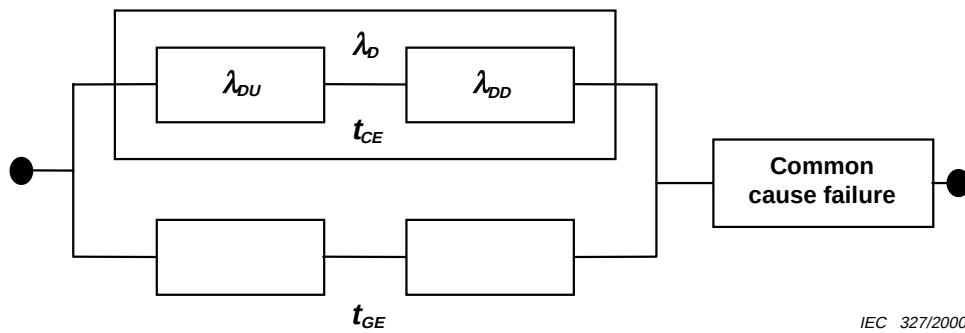


Figure B.5 – 1002 physical block diagram



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Figure B.6 – 1oo2 reliability block diagram

Figures B.5 and B.6 contain the relevant block diagrams. The value of t_{CE} is as given in B.2.2.1, but now it is necessary to also calculate the system equivalent down time t_{GE} , which is given by

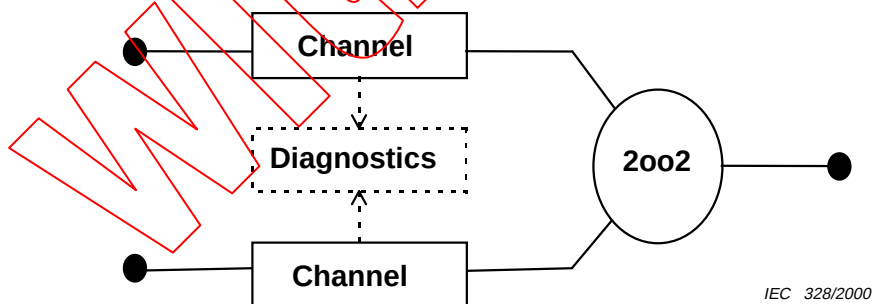
$$t_{GE} = \frac{\lambda_{DU}}{\lambda_D} \left(\frac{T_1}{3} + MTTR \right) + \frac{\lambda_{DD}}{\lambda_D} MTTR$$

The average probability of failure on demand for the architecture is

$$PFD_G = 2 \left((1 - \beta_D) \lambda_{DD} + (1 - \beta) \lambda_{DU} \right)^2 t_{CE} t_{GE} + \beta_D \lambda_{DD} MTTR + \beta \lambda_{DU} \left(\frac{T_1}{2} + MTTR \right)$$

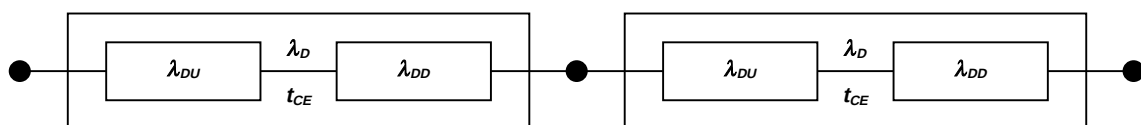
B.2.2.3 2oo2

This architecture consists of two channels connected in parallel so that both channels need to demand the safety function before it can take place. 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.



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Figure B.7 – 2oo2 physical block diagram



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Figure B.8 – 2oo2 reliability block diagram

Figures B.7 and B.8 contain the relevant block diagrams. The value of t_{CE} is as given in B.2.2.1, and the average probability of failure on demand for the architecture is

$$PFD_G = 2\lambda_D t_{CE}$$

B.2.2.4 1oo2D

This architecture consists of two channels connected in parallel. During normal operation, both channels need to demand the safety function before it can take place. In addition, if the diagnostic tests in either channel detect a fault then the output voting is adapted so that the overall output state then follows that given by the other channel. If the diagnostic tests find faults in both channels or a discrepancy that cannot be allocated to either channel, then the output goes to the safe state. In order to detect a discrepancy between the channels, either channel can determine the state of the other channel via a means independent of the other channel.

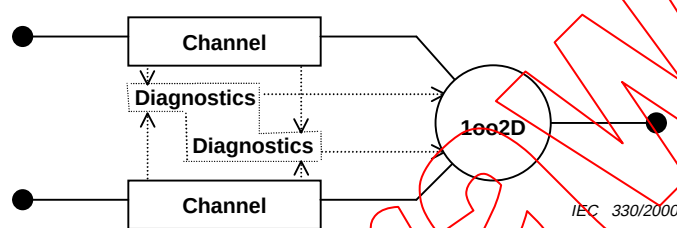


Figure B.9 – 1oo2D physical block diagram

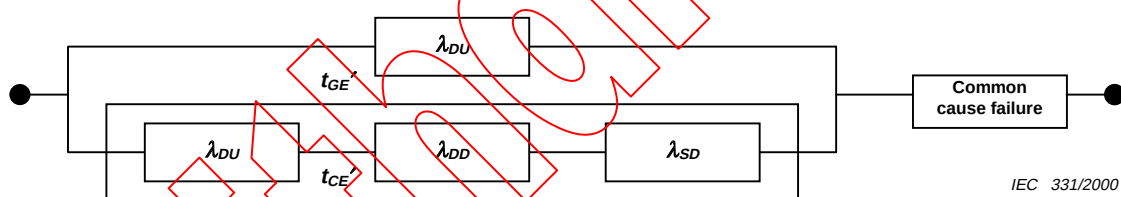


Figure B.10 – 1oo2D reliability block diagram

The detected safe failure rate for every channel is given by

$$\lambda_{SD} = \frac{\lambda}{2} DC$$

Figures B.9 and B.10 contain the relevant block diagrams. The values of the equivalent mean down times differ from those given for the other architectures in B.2.2 and hence are labelled t_{CE}' and t_{GE}' . Their values are given by

$$t_{CE}' = \frac{\lambda_{DU} \left(\frac{T_1}{2} + MTTR \right) + (\lambda_{DD} + \lambda_{SD}) MTTR}{\lambda_{DU} + \lambda_{DD} + \lambda_{SD}}$$

$$t_{GE}' = \frac{\lambda_{DU} \left(\frac{T_1}{3} + MTTR \right) + (\lambda_{DD} + \lambda_{SD}) MTTR}{\lambda_{DU} + \lambda_{DD} + \lambda_{SD}}$$

The average probability of failure on demand for the architecture is

$$PFD_G = 2(1-\beta)\lambda_{DU}((1-\beta)\lambda_{DU} + (1-\beta_D)\lambda_{DD} + \lambda_{SD})t_{CE}'t_{GE}' + \beta_D\lambda_{DD}MTTR + \beta\lambda_{DU}\left(\frac{T_1}{2} + MTTR\right)$$

B.2.2.5 2oo3

This 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 other two channels.

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.

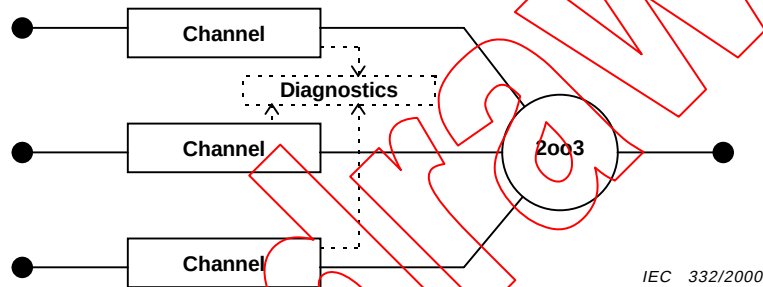


Figure B.11 – 2oo3 physical block diagram

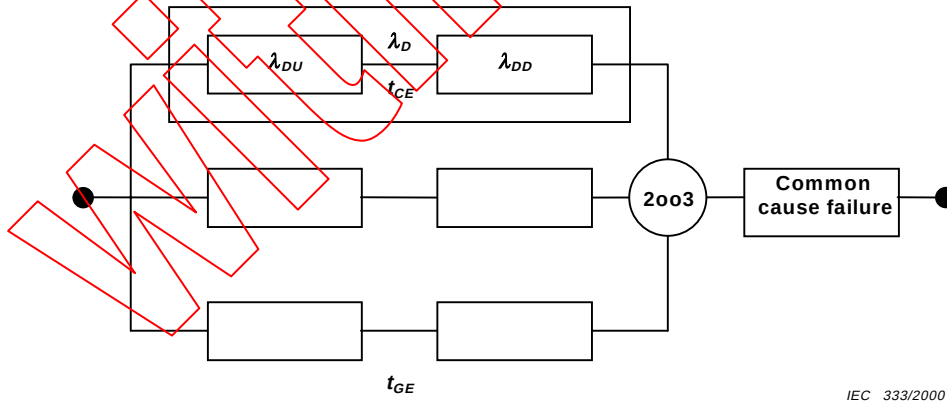


Figure B.12 – 2oo3 reliability block diagram

Figures B.11 and B.12 contain the relevant block diagrams. The value of t_{CE} is as given in B.2.2.1 and the value of t_{GE} is as given in B.2.2.2. The average probability of failure on demand for the architecture is

$$PFD_G = 6((1-\beta_D)\lambda_{DD} + (1-\beta)\lambda_{DU})^2 t_{CE}t_{GE} + \beta_D\lambda_{DD}MTTR + \beta\lambda_{DU}\left(\frac{T_1}{2} + MTTR\right)$$

B.2.3 Detailed tables for low demand mode of operation

Table B.2 – Average probability of failure on demand for a proof test interval of six months and a mean time to restoration of 8 h

Architecture	DC	$\lambda = 1.0E-07$			$\lambda = 5.0E-07$			$\lambda = 1.0E-06$		
		$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$
1001 (see note 2)	0 %	1.1E-04			5.5E-04			1.1E-03		
	60 %	4.4E-05			2.2E-04			4.4E-04		
	90 %	1.1E-05			5.7E-05			1.1E-04		
	99 %	1.5E-06			7.5E-06			1.5E-05		
1002	0 %	2.2E-06	1.1E-05	2.2E-05	1.1E-05	5.5E-05	1.1E-04	2.4E-05	1.1E-04	2.2E-04
	60 %	8.8E-07	4.4E-06	8.8E-06	4.5E-06	2.2E-05	4.4E-05	9.1E-06	4.4E-05	8.8E-05
	90 %	2.2E-07	1.1E-06	2.2E-06	1.1E-06	5.6E-06	1.1E-05	2.3E-06	1.1E-05	2.2E-05
	99 %	2.6E-08	1.3E-07	2.6E-07	1.3E-07	6.5E-07	1.3E-06	2.6E-07	1.3E-06	2.6E-06
2002 (see note 2)	0 %	2.2E-04			1.1E-03			2.2E-03		
	60 %	8.8E-05			4.4E-04			8.8E-04		
	90 %	2.3E-05			1.1E-04			2.3E-04		
	99 %	3.0E-06			1.5E-05			3.0E-05		
1002D	0 %	2.2E-06	1.1E-05	2.2E-05	1.1E-05	5.5E-05	1.1E-04	2.4E-05	1.1E-04	2.2E-04
	60 %	8.8E-07	4.4E-06	8.8E-06	4.4E-06	2.2E-05	4.4E-05	8.9E-06	4.4E-05	8.8E-05
	90 %	2.2E-07	1.1E-06	2.2E-06	1.1E-06	5.6E-06	1.1E-05	2.2E-06	1.1E-05	2.2E-05
	99 %	2.6E-08	1.3E-07	2.6E-07	1.3E-07	6.5E-07	1.3E-06	2.6E-07	1.3E-06	2.6E-06
2003	0 %	2.2E-06	1.1E-05	2.2E-05	1.2E-05	5.6E-05	1.1E-04	2.7E-05	1.1E-04	2.2E-04
	60 %	8.9E-07	4.4E-06	8.8E-06	4.6E-06	2.2E-05	4.4E-05	9.6E-06	4.5E-05	8.9E-05
	90 %	2.2E-07	1.1E-06	2.2E-06	1.1E-06	5.6E-06	1.1E-05	2.3E-06	1.1E-05	2.2E-05
	99 %	2.6E-08	1.3E-07	2.6E-07	1.3E-07	6.5E-07	1.3E-06	2.6E-07	1.3E-06	2.6E-06

NOTE 1 This table gives example values of PFD_G , calculated using the equations in B.2.2 and depending on the assumptions listed in B.1. If the sensor, logic or final element subsystem comprises of only one group of voted channels, then PFD_G is equivalent to PFD_S , PFD_L or PFD_{FE} respectively (see B.2.1).

NOTE 2 The table assumes $\beta = 2 \times \beta_D$. For 1001 and 2002 architectures, the values of β and β_D do not affect the average probability of failure.

Table B.2 (continued)

Architecture	DC	$\lambda = 5.0E-06$			$\lambda = 1.0E-05$			$\lambda = 5.0E-05$		
		$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$
1001 (see note 2)	0 %	5.5E-03			1.1E-02			5.5E-02		
	60 %	2.2E-03			4.4E-03			2.2E-02		
	90 %	5.7E-04			1.1E-03			5.7E-03		
	99 %	7.5E-05			1.5E-04			7.5E-04		
1002	0 %	1.5E-04	5.8E-04	1.1E-03	3.7E-04	1.2E-03	2.3E-03	5.0E-03	8.8E-03	1.4E-02
	60 %	5.0E-05	2.3E-04	4.5E-04	1.1E-04	4.6E-04	9.0E-04	1.1E-03	2.8E-03	4.9E-03
	90 %	1.2E-05	5.6E-05	1.1E-04	2.4E-05	1.1E-04	2.2E-04	1.5E-04	6.0E-04	1.2E-03
	99 %	1.3E-06	6.5E-06	1.3E-05	2.6E-06	1.3E-05	2.6E-05	1.4E-05	6.6E-05	1.3E-04
2002 (see note 2)	0 %	1.1E-02			2.2E-02			>1E-01		
	60 %	4.4E-03			8.8E-03			4.4E-02		
	90 %	1.1E-03			2.3E-03			1.1E-02		
	99 %	1.5E-04			3.0E-04			1.5E-03		
1002D	0 %	1.5E-04	5.8E-04	1.1E-03	3.7E-04	1.2E-03	2.3E-03	5.0E-03	8.8E-03	1.4E-02
	60 %	4.6E-05	2.2E-04	4.4E-04	9.5E-05	4.5E-04	8.9E-04	6.0E-04	2.3E-03	4.5E-03
	90 %	1.1E-05	5.6E-05	1.1E-04	2.2E-05	1.1E-04	2.2E-04	1.1E-04	5.6E-04	1.1E-03
	99 %	1.3E-06	6.5E-06	1.3E-05	2.6E-06	1.3E-05	2.6E-05	1.3E-05	6.5E-05	1.3E-04
2003	0 %	2.3E-04	6.5E-04	1.2E-03	6.8E-04	1.5E-03	2.5E-03	1.3E-02	1.5E-02	1.9E-02
	60 %	6.3E-05	2.4E-04	4.6E-04	1.6E-04	5.1E-04	9.4E-04	2.3E-03	3.9E-03	5.9E-03
	90 %	1.2E-05	5.7E-05	1.1E-04	2.7E-05	1.2E-04	2.3E-04	2.4E-04	6.8E-04	1.2E-03
	99 %	1.3E-06	6.5E-06	1.3E-05	2.7E-06	1.3E-05	2.6E-05	1.5E-05	6.7E-05	1.3E-04

NOTE 1 This table gives example values of PFD_G , calculated using the equations in B.2.2 and depending on the assumptions listed in B.1. If the sensor, logic or final element subsystem comprises of only one group of voted channels, then PFD_G is equivalent to PFD_S , PFD_L or PFD_{FE} respectively (see B.2.1).

NOTE 2 The table assumes $\beta = 2 \times \beta_D$. For 1001 and 2002 architectures, the values of β and β_D do not affect the average probability of failure.

Table B.3 – Average probability of failure on demand for a proof-test interval of one year and mean time to restoration of 8 h

Architecture	DC	$\lambda = 1.0E-07$			$\lambda = 5.0E-07$			$\lambda = 1.0E-06$		
		$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$
1oo1 (see note 2)	0 %	2.2E-04			1.1E-03			2.2E-03		
	60 %	8.8E-05			4.4E-04			8.8E-04		
	90 %	2.2E-05			1.1E-04			2.2E-04		
	99 %	2.6E-06			1.3E-05			2.6E-05		
1oo2	0 %	4.4E-06	2.2E-05	4.4E-05	2.3E-05	1.1E-04	2.2E-04	5.0E-05	2.2E-04	4.4E-04
	60 %	1.8E-06	8.8E-06	1.8E-05	9.0E-06	4.4E-05	8.8E-05	1.9E-05	8.9E-05	1.8E-04
	90 %	4.4E-07	2.2E-06	4.4E-06	2.2E-06	1.1E-05	2.2E-05	4.5E-06	2.2E-05	4.4E-05
	99 %	4.8E-08	2.4E-07	4.8E-07	2.4E-07	1.2E-06	2.4E-06	4.8E-07	2.4E-06	4.8E-06
2oo2 (see note 2)	0 %	4.4E-04			2.2E-03			4.4E-03		
	60 %	1.8E-04			8.8E-04			1.8E-03		
	90 %	4.5E-05			2.2E-04			4.5E-04		
	99 %	5.2E-06			2.6E-05			5.2E-05		
1oo2D	0 %	4.4E-06	2.2E-05	4.4E-05	2.3E-05	1.1E-04	2.2E-04	5.0E-05	2.2E-04	4.4E-04
	60 %	1.8E-06	8.8E-06	1.8E-05	8.9E-06	4.4E-05	8.8E-05	1.8E-05	8.8E-05	1.8E-04
	90 %	4.4E-07	2.2E-06	4.4E-06	2.2E-06	1.1E-05	2.2E-05	4.4E-06	2.2E-05	4.4E-05
	99 %	4.8E-08	2.4E-07	4.8E-07	2.4E-07	1.2E-06	2.4E-06	4.8E-07	2.4E-06	4.8E-06
2oo3	0 %	4.6E-06	2.2E-05	4.4E-05	2.7E-05	1.1E-04	2.2E-04	6.2E-05	2.4E-04	4.5E-04
	60 %	1.8E-06	8.8E-06	1.8E-05	9.5E-06	4.5E-05	8.8E-05	2.1E-05	9.1E-05	1.8E-04
	90 %	4.4E-07	2.2E-06	4.4E-06	2.3E-06	1.1E-05	2.2E-05	4.6E-06	2.2E-05	4.4E-05
	99 %	4.8E-08	2.4E-07	4.8E-07	2.4E-07	1.2E-06	2.4E-06	4.8E-07	2.4E-06	4.8E-06

NOTE 1 This table gives example values of PFD_G , calculated using the equations in B.2.2 and depending on the assumptions listed in B.1. If the sensor, logic or final element subsystem comprises of only one group of voted channels, then PFD_G is equivalent to PFD_S , PFD_L or PFD_{FE} respectively (see B.2.1).

NOTE 2 The table assumes $\beta = 2 \times \beta_D$. For 1oo1 and 2oo2 architectures, the values of β and β_D do not affect the average probability of failure.

Table B.3 (continued)

Architecture	DC	$\lambda = 5.0E-06$			$\lambda = 1.0E-05$			$\lambda = 5.0E-05$		
		$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$
1oo1 (see note 2)	0 %	1.1E-02			2.2E-02			>1E-01		
	60 %	4.4E-03			8.8E-03			4.4E-02		
	90 %	1.1E-03			2.2E-03			1.1E-02		
	99 %	1.3E-04			2.6E-04			1.3E-03		
1oo2	0 %	3.7E-04	1.2E-03	2.3E-03	1.1E-03	2.7E-03	4.8E-03	1.8E-02	2.4E-02	3.2E-02
	60 %	1.1E-04	4.6E-04	9.0E-04	2.8E-04	9.7E-04	1.8E-03	3.4E-03	6.6E-03	1.1E-02
	90 %	2.4E-05	1.1E-04	2.2E-04	5.1E-05	2.3E-04	4.5E-04	3.8E-04	1.3E-03	2.3E-03
	99 %	2.4E-06	1.2E-05	2.4E-05	4.9E-06	2.4E-05	4.8E-05	2.6E-05	1.2E-04	2.4E-04
2oo2 (see note 2)	0 %	2.2E-02			4.4E-02			>1E-01		
	60 %	8.8E-03			1.8E-02			8.8E-02		
	90 %	2.2E-03			4.5E-03			2.2E-02		
	99 %	2.6E-04			5.2E-04			2.6E-03		
1oo2D	0 %	3.7E-04	1.2E-03	2.3E-03	1.1E-03	2.7E-03	4.8E-03	1.8E-02	2.4E-02	3.2E-02
	60 %	9.4E-05	4.5E-04	8.8E-04	2.0E-04	9.0E-04	1.8E-03	1.5E-03	5.0E-03	9.3E-03
	90 %	2.2E-05	1.1E-04	2.2E-04	4.5E-05	2.2E-04	4.4E-04	2.3E-04	1.1E-03	2.2E-03
	99 %	2.4E-06	1.2E-05	2.4E-05	4.8E-06	2.4E-05	4.8E-05	2.4E-05	1.2E-04	2.4E-04
2oo3	0 %	6.8E-04	1.5E-03	2.5E-03	2.3E-03	3.8E-03	5.6E-03	4.8E-02	5.0E-02	5.3E-02
	60 %	1.6E-04	5.1E-04	9.4E-04	4.8E-04	1.1E-03	2.0E-03	8.4E-03	1.1E-02	1.5E-02
	90 %	2.7E-05	1.2E-04	2.3E-04	6.4E-05	2.4E-04	4.6E-04	7.1E-04	1.6E-03	2.6E-03
	99 %	2.5E-06	1.2E-05	2.4E-05	5.1E-06	2.4E-05	4.8E-05	3.1E-05	1.3E-04	2.5E-04

NOTE 1 This table gives example values of PFD_G , calculated using the equations in B.2.2 and depending on the assumptions listed in B.1. If the sensor, logic or final element subsystem comprises of only one group of voted channels, then PFD_G is equivalent to PFD_S , PFD_L or PFD_{FE} respectively (see B.2.1).

NOTE 2 The table assumes $\beta = 2 \times \beta_D$. For 1oo1 and 2oo2 architectures, the values of β and β_D do not affect the average probability of failure.

Table B.4 – Average probability of failure on demand for a proof-test interval of two years and a mean time to restoration of 8 h

Architecture	DC	$\lambda = 1.0E-07$			$\lambda = 5.0E-07$			$\lambda = 1.0E-06$		
		$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$
1oo1 (see note 2)	0 %	4.4E-04			2.2E-03			4.4E-03		
	60 %	1.8E-04			8.8E-04			1.8E-03		
	90 %	4.4E-05			2.2E-04			4.4E-04		
	99 %	4.8E-06			2.4E-05			4.8E-05		
1oo2	0 %	9.0E-06	4.4E-05	8.8E-05	5.0E-05	2.2E-04	4.4E-04	1.1E-04	4.6E-04	8.9E-04
	60 %	3.5E-06	1.8E-05	3.5E-05	1.9E-05	8.9E-05	1.8E-04	3.9E-05	1.8E-04	3.5E-04
	90 %	8.8E-07	4.4E-06	8.8E-06	4.5E-06	2.2E-05	4.4E-05	9.1E-06	4.4E-05	8.8E-05
	99 %	9.2E-08	4.6E-07	9.2E-07	4.6E-07	2.3E-06	4.6E-06	9.2E-07	4.6E-06	9.2E-06
2oo2 (see note 2)	0 %	8.8E-04			4.4E-03			8.8E-03		
	60 %	3.5E-04			1.8E-03			3.5E-03		
	90 %	8.8E-05			4.4E-04			8.8E-04		
	99 %	9.6E-06			4.8E-05			9.6E-05		
1oo2D	0 %	9.0E-06	4.4E-05	8.8E-05	5.0E-05	2.2E-04	4.4E-04	1.1E-04	4.6E-04	8.9E-04
	60 %	3.5E-06	1.8E-05	3.5E-05	1.8E-05	8.8E-05	1.8E-04	3.6E-05	1.8E-04	3.5E-04
	90 %	8.8E-07	4.4E-06	8.8E-06	4.4E-06	2.2E-05	4.4E-05	8.8E-06	4.4E-05	8.8E-05
	99 %	9.2E-08	4.6E-07	9.2E-07	4.6E-07	2.3E-06	4.6E-06	9.2E-07	4.6E-06	9.2E-06
2oo3	0 %	9.5E-06	4.4E-05	8.8E-05	6.2E-05	2.3E-04	4.5E-04	1.6E-04	5.0E-04	9.3E-04
	60 %	3.6E-06	1.8E-05	3.5E-05	2.1E-05	9.0E-05	1.8E-04	4.7E-05	1.9E-04	3.6E-04
	90 %	8.9E-07	4.4E-06	8.8E-06	4.6E-06	2.2E-05	4.4E-05	9.6E-06	4.5E-05	8.9E-05
	99 %	9.2E-08	4.6E-07	9.2E-07	4.6E-07	2.3E-06	4.6E-06	9.3E-07	4.6E-06	9.2E-06

NOTE 1 This table gives example values of PFD_G , calculated using the equations in B.2.2 and depending on the assumptions listed in B.1. If the sensor, logic or final element subsystem comprises of only one group of voted channels, then PFD_G is equivalent to PFD_S , PFD_L or PFD_{FE} respectively (see B.2.1).

NOTE 2 The table assumes $\beta = 2 \times \beta_D$. For 1oo1 and 2oo2 architectures, the values of β and β_D do not affect the average probability of failure.

Table B.4 (continued)

Architecture	DC	$\lambda = 5.0E-06$			$\lambda = 1.0E-05$			$\lambda = 5.0E-05$		
		$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$
1oo1 (see note 2)	0 %	2.2E-02			4.4E-02			>1E-01		
	60 %	8.8E-03			1.8E-02			8.8E-02		
	90 %	2.2E-03			4.4E-03			2.2E-02		
	99 %	2.4E-04			4.8E-04			2.4E-03		
1oo2	0 %	1.1E-03	2.7E-03	4.8E-03	3.3E-03	6.5E-03	1.0E-02	6.6E-02	7.4E-02	8.5E-02
	60 %	2.8E-04	9.7E-04	1.8E-03	7.5E-04	2.1E-03	3.8E-03	1.2E-02	1.8E-02	2.5E-02
	90 %	5.0E-05	2.3E-04	4.5E-04	1.1E-04	4.6E-04	9.0E-04	1.1E-03	2.8E-03	4.9E-03
	99 %	4.7E-06	2.3E-05	4.6E-05	9.5E-06	4.6E-05	9.2E-05	5.4E-05	2.4E-04	4.6E-04
2oo2 (see note 2)	0 %	4.4E-02			8.8E-02			>1E-01		
	60 %	1.8E-02			3.5E-02			>1E-01		
	90 %	4.4E-03			8.8E-03			4.4E-02		
	99 %	4.8E-04			9.6E-04			4.8E-03		
1oo2D	0 %	1.1E-03	2.7E-03	4.8E-03	3.3E-03	6.5E-03	1.0E-02	6.6E-02	7.4E-02	8.5E-02
	60 %	2.0E-04	9.0E-04	1.8E-03	4.5E-04	1.8E-03	3.6E-03	4.3E-03	1.1E-02	1.9E-02
	90 %	4.4E-05	2.2E-04	4.4E-04	8.9E-05	4.4E-04	8.8E-04	4.7E-04	2.2E-03	4.4E-03
	99 %	4.6E-06	2.3E-05	4.6E-05	9.2E-06	4.6E-05	9.2E-05	4.6E-05	2.3E-04	4.6E-04
2oo3	0 %	2.3E-03	3.7E-03	5.6E-03	8.3E-03	1.1E-02	1.4E-02	>1E-01	>1E-01	>1E-01
	60 %	4.8E-04	1.1E-03	2.0E-03	1.6E-03	2.8E-03	4.4E-03	3.2E-02	3.5E-02	4.0E-02
	90 %	6.3E-05	2.4E-04	4.6E-04	1.6E-04	5.1E-04	9.4E-04	2.4E-03	4.0E-03	6.0E-03
	99 %	4.8E-06	2.3E-05	4.6E-05	1.0E-05	4.7E-05	9.2E-05	6.9E-05	2.5E-04	4.8E-04

NOTE 1 This table gives example values of PFD_G , calculated using the equations in B.2.2 and depending on the assumptions listed in B.1. If the sensor, logic or final element subsystem comprises of only one group of voted channels, then PFD_G is equivalent to PFD_S , PFD_L or PFD_{FE} respectively (see B.2.1).

NOTE 2 The table assumes $\beta = 2 \times \beta_D$. For 1oo1 and 2oo2 architectures, the values of β and β_D do not affect the average probability of failure.

Table B.5 – Average probability of failure on demand for a proof-test interval of 10 years and a mean time to restoration of 8 h

Architecture	DC	$\lambda = 1.0E-07$			$\lambda = 5.0E-07$			$\lambda = 1.0E-06$		
		$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$
1oo1 (see note 2)	0 %	2.2E-03			1.1E-02			2.2E-02		
	60 %	8.8E-04			4.4E-03			8.8E-03		
	90 %	2.2E-04			1.1E-03			2.2E-03		
	99 %	2.2E-05			1.1E-04			2.2E-04		
1oo2	0 %	5.0E-05	2.2E-04	4.4E-04	3.7E-04	1.2E-03	2.3E-03	1.1E-03	2.7E-03	4.8E-03
	60 %	1.9E-05	8.9E-05	1.8E-04	1.1E-04	4.6E-04	9.0E-04	2.7E-04	9.6E-04	1.8E-03
	90 %	4.4E-06	2.2E-05	4.4E-05	2.3E-05	1.1E-04	2.2E-04	5.0E-05	2.2E-04	4.4E-04
	99 %	4.4E-07	2.2E-06	4.4E-06	2.2E-06	1.1E-05	2.2E-05	4.5E-06	2.2E-05	4.4E-05
2oo2 (see note 2)	0 %	4.4E-03			2.2E-02			4.4E-02		
	60 %	1.8E-03			8.8E-03			1.8E-02		
	90 %	4.4E-04			2.2E-03			4.4E-03		
	99 %	4.5E-05			2.2E-04			4.5E-04		
1oo2D	0 %	5.0E-05	2.2E-04	4.4E-04	3.7E-04	1.2E-03	2.3E-03	1.1E-03	2.7E-03	4.8E-03
	60 %	1.8E-05	8.8E-05	1.8E-04	9.4E-05	4.4E-04	8.8E-04	2.0E-04	9.0E-04	1.8E-03
	90 %	4.4E-06	2.2E-05	4.4E-05	2.2E-05	1.1E-04	2.2E-04	4.4E-05	2.2E-04	4.4E-04
	99 %	4.4E-07	2.2E-06	4.4E-06	2.2E-06	1.1E-05	2.2E-05	4.4E-06	2.2E-05	4.4E-05
2oo3	0 %	6.2E-05	2.3E-04	4.5E-04	6.8E-04	1.5E-03	2.5E-03	2.3E-03	3.7E-03	5.6E-03
	60 %	2.1E-05	9.0E-05	1.8E-04	1.6E-04	5.0E-04	9.3E-04	4.7E-04	1.1E-03	2.0E-03
	90 %	4.6E-06	2.2E-05	4.4E-05	2.7E-05	1.1E-04	2.2E-04	6.3E-05	2.4E-04	4.5E-04
	99 %	4.4E-07	2.2E-06	4.4E-06	2.3E-06	1.1E-05	2.2E-05	4.6E-06	2.2E-05	4.4E-05

NOTE 1 This table gives example values of PFD_G , calculated using the equations in B.2.2 and depending on the assumptions listed in B.1. If the sensor, logic or final element subsystem comprises of only one group of voted channels, then PFD_G is equivalent to PFD_S , PFD_L or PFD_{FE} respectively (see B.2.1).

NOTE 2 The table assumes $\beta = 2 \times \beta_D$. For 1oo1 and 2oo2 architectures, the values of β and β_D do not affect the average probability of failure.

Table B.5 (continued)

Architecture	DC	$\lambda = 5.0E-06$			$\lambda = 1.0E-05$			$\lambda = 5.0E-05$		
		$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$
1oo1 (see note 2)	0 %	>1E-01			>1E-01			>1E-01		
	60 %	4.4E-02			8.8E-02			>1E-01		
	90 %	1.1E-02			2.2E-02			>1E-01		
	99 %	1.1E-03			2.2E-03			1.1E-02		
1oo2	0 %	1.8E-02	2.4E-02	3.2E-02	6.6E-02	7.4E-02	8.5E-02	>1E-01	>1E-01	>1E-01
	60 %	3.4E-03	6.6E-03	1.1E-02	1.2E-02	1.8E-02	2.5E-02	>1E-01	>1E-01	>1E-01
	90 %	3.8E-04	1.2E-03	2.3E-03	1.1E-03	2.8E-03	4.9E-03	1.8E-02	2.5E-02	3.5E-02
	99 %	2.4E-05	1.1E-04	2.2E-04	5.1E-05	2.3E-04	4.5E-04	3.8E-04	1.3E-03	2.3E-03
2oo2 (see note 2)	0 %	>1E-01			>1E-01			>1E-01		
	60 %	8.8E-02			>1E-01			>1E-01		
	90 %	2.2E-02			4.4E-02			>1E-01		
	99 %	2.2E-03			4.5E-03			2.2E-02		
1oo2D	0 %	1.8E-02	2.4E-02	3.2E-02	6.6E-02	7.4E-02	8.5E-02	>1E-01	>1E-01	>1E-01
	60 %	1.5E-03	4.9E-03	9.2E-03	4.2E-03	1.1E-02	1.9E-02	7.1E-02	9.9E-02	>1E-01
	90 %	2.3E-04	1.1E-03	2.2E-03	4.7E-04	2.2E-03	4.4E-03	3.0E-03	1.2E-02	2.3E-02
	99 %	2.2E-05	1.1E-04	2.2E-04	4.4E-05	2.2E-04	4.4E-04	2.2E-04	1.1E-03	2.2E-03
2oo3	0 %	4.8E-02	5.0E-02	5.3E-02	>1E-01	>1E-01	>1E-01	>1E-01	>1E-01	>1E-01
	60 %	8.3E-03	1.1E-02	1.4E-02	3.2E-02	3.5E-02	4.0E-02	>1E-01	>1E-01	>1E-01
	90 %	6.9E-04	1.5E-03	2.6E-03	2.3E-03	3.9E-03	5.9E-03	4.9E-02	5.4E-02	6.0E-02
	99 %	2.7E-05	1.2E-04	2.3E-04	6.4E-05	2.4E-04	4.6E-04	7.1E-04	1.6E-03	2.6E-03

NOTE 1 This table gives example values of PFD_G , calculated using the equations in B.2.2 and depending on the assumptions listed in B.1. If the sensor, logic or final element subsystem comprises of only one group of voted channels, then PFD_G is equivalent to PFD_S , PFD_L or PFD_{FE} respectively (see B.2.1).

NOTE 2 The table assumes $\beta = 2 \times \beta_D$. For 1oo1 and 2oo2 architectures, the values of β and β_D do not affect the average probability of failure.

B.2.4 Example for low demand mode of operation

Consider a safety function requiring a SIL2 system. Suppose that the initial assessment for the system architecture, based on previous practice, is for one group of three analogue pressure sensors, voting 2oo3. The logic subsystem is a redundant 1oo2D configured PES driving a single shut-down valve plus a single vent valve. Both the shut-down and vent valves need to operate in order to achieve the safety function. The architecture is shown in figure B.13. For the initial assessment, a proof-test period of one year is assumed.

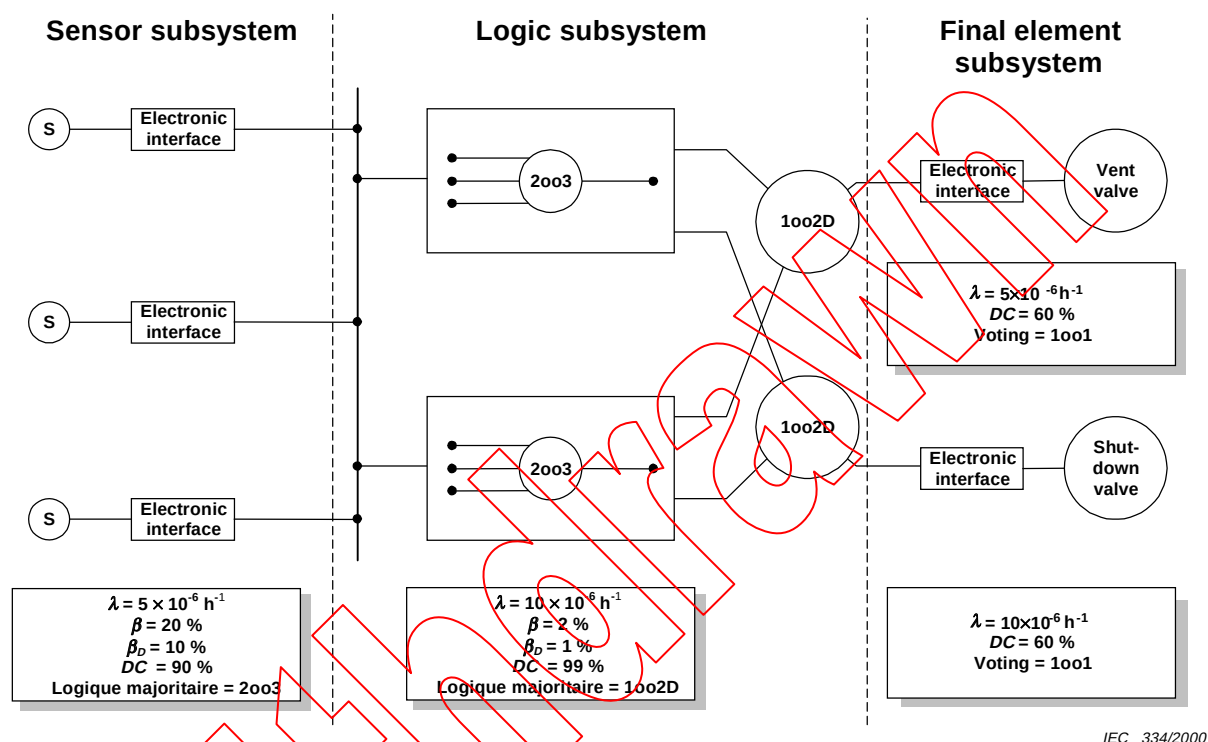


Figure B.13 – Architecture of an example for low demand mode of operation

Table B.6 – Average probability of failure on demand for the sensor subsystem in the example for low demand mode of operation (one year proof-test interval and 8 h MTTR)

Architecture	DC	$\lambda = 5.0\text{E-}06$		
		$\beta = 2 \%$ $\beta_D = 1 \%$	$\beta = 10 \%$ $\beta_D = 5 \%$	$\beta = 20 \%$ $\beta_D = 10 \%$
2oo3	0 %	6.8E-04	1.5E-03	2.5E-03
	60 %	1.6E-04	5.1E-04	9.4E-04
	90 %	2.7E-05	1.2E-04	2.3E-04
	99 %	2.5E-06	1.2E-05	2.4E-05

NOTE This table is abstracted from table B.3.

Table B.7 – Average probability of failure on demand for the logic subsystem in the example for low demand mode of operation (one year proof-test interval and 8 h MTTR)

Architecture	DC	$\lambda = 1.0\text{E-}05$		
		$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$
1oo2D	0 %	1.1E-03	2.7E-03	4.8E-03
	60 %	2.0E-04	9.0E-04	1.8E-03
	90 %	4.5E-05	2.2E-04	4.4E-04
	99 %	4.8E-06	2.4E-05	4.8E-05
NOTE This table is abstracted from table B.3.				

Table B.8 – Average probability of failure on demand for the final element subsystem in the example for low demand mode of operation (one year proof-test interval and 8 h MTTR)

Architecture	DC	$\lambda = 5.0\text{E-}06$	$\lambda = 1.0\text{E-}05$
1oo1	0 %	1.1E-02	2.2E-02
	60 %	4.4E-03	8.8E-03
	90 %	1.1E-03	2.2E-03
	99 %	1.3E-04	2.6E-04
NOTE This table is abstracted from table B.3.			

From tables B.6 to B.8 the following values are derived

For the sensor subsystem,

$$PFD_S = 2,3 \times 10^{-4}$$

For the logic subsystem,

$$PFD_L = 4,8 \times 10^{-6}$$

For the final element subsystem,

$$\begin{aligned} PFD_{FE} &= 4,4 \times 10^{-3} + 8,8 \times 10^{-3} \\ &= 1,3 \times 10^{-2} \end{aligned}$$

Therefore, for the safety function,

$$\begin{aligned} PFD_{SYS} &= 2,3 \times 10^{-4} + 4,8 \times 10^{-6} + 1,3 \times 10^{-2} \\ &= 1,3 \times 10^{-2} \\ &\equiv \text{ safety integrity level 1} \end{aligned}$$

To improve the system to meet safety integrity level 2, one of the following could be done:

a) change the proof-test interval to six months

$$\begin{aligned}
 PFD_S &= 1,1 \times 10^{-4} \\
 PFD_L &= 2,6 \times 10^{-6} \\
 PFD_{FE} &= 2,2 \times 10^{-3} + 4,4 \times 10^{-3} \\
 &= 6,6 \times 10^{-3} \\
 PFD_{SYS} &= 6,7 \times 10^{-3} \\
 &\equiv \text{ safety integrity level 2}
 \end{aligned}$$

b) change the 1001 shutdown valve (which is the output device with the lower reliability) to 1002 (assuming $\beta = 10\%$ and $\beta_D = 5\%$)

$$\begin{aligned}
 PFD_S &= 2,3 \times 10^{-4} \\
 PFD_L &= 4,8 \times 10^{-6} \\
 PFD_{FE} &= 4,4 \times 10^{-3} + 9,7 \times 10^{-4} \\
 &= 5,4 \times 10^{-3} \\
 PFD_{SYS} &= 5,6 \times 10^{-3} \\
 &\equiv \text{ safety integrity level 2}
 \end{aligned}$$

B.2.5 Effects of a non-perfect proof test

Faults in the safety system that are not detected by either diagnostic tests or proof tests are found only by an incidence of demand that requires the safety function affected by the fault. Thus, for these totally undetected faults, the expected demand rate on the safety system governs the effective down time.

An example of this is given below for a 1002 architecture. T_2 is the time between demands on the system:

$$t_{CE} = \frac{\lambda_{DU}}{2\lambda_D} \left(\frac{T_1}{2} + MTTR \right) + \frac{\lambda_{DU}}{2\lambda_D} \left(\frac{T_2}{2} + MTTR \right) + \frac{\lambda_{DD}}{\lambda_D} MTTR$$

$$t_{GE} = \frac{\lambda_{DU}}{2\lambda_D} \left(\frac{T_1}{3} + MTTR \right) + \frac{\lambda_{DU}}{2\lambda_D} \left(\frac{T_2}{3} + MTTR \right) + \frac{\lambda_{DD}}{\lambda_D} MTTR$$

$$PFD_G = 2((1 - \beta_D)\lambda_{DD} + (1 - \beta)\lambda_{DU})^2 t_{CE} t_{GE} + \beta_D \lambda_{DD} MTTR + \beta \frac{\lambda_{DU}}{2} \left(\frac{T_1}{2} + MTTR \right) + \beta \frac{\lambda_{DU}}{2} \left(\frac{T_2}{2} + MTTR \right)$$

Table B.9 below gives the numeric results of a 1002 system with a 100 % one-year proof test compared against a 50 % proof test where the demand period T_2 is assumed to be 10 years. This example has been calculated assuming a failure rate of 1×10^{-5} per hour, a β value of 10 % and a β_D value of 5 %.

Table B.9 – Example for a non-perfect proof test

Architecture	DC	$\lambda = 1.0\text{E-}05$	
		100 % proof test	50 % proof test ($T_2 = 10$ years)
		$\beta = 10 \%$ $\beta_D = 5 \%$	$\beta = 10 \%$ $\beta_D = 5 \%$
1002	0 %	2.7E-03	6.6E-02
	60 %	9.7E-04	2.6E-02
	90 %	2.3E-04	6.6E-03
	99 %	2.4E-05	7.0E-04

B.3 Probability of failure per hour (for high demand or continuous mode of operation)

B.3.1 Procedure for calculations

The method for calculating the probability of failure of a safety function for an E/E/PE safety-related system operating in high demand or continuous mode of operation is identical with that for calculating for a low demand mode of operation (see B.2.1), except that average probability of failure on demand ($PF_{D_{SYS}}$) is replaced with probability of a dangerous failure per hour (PFH_{SYS}).

The overall probability of a dangerous failure of a safety function for the E/E/PE safety-related system, PFH_{SYS} , is determined by calculating the dangerous failure rates for all the sub-systems which together provide the safety function and adding together these individual values. Since in this annex the probabilities are small, this can be expressed by the following:

$$PFH_{SYS} = PFH_S + PFH_L + PFH_{FE}$$

where

- PFH_{SYS} is the probability of failure per hour of a safety function for the E/E/PE safety-related system;
- PFH_S is the probability of failure per hour for the sensor subsystem;
- PFH_L is the probability of failure per hour for the logic subsystem; and
- PFH_{FE} is the probability of failure per hour for the final element subsystem.

B.3.2 Architectures for high demand or continuous mode of operation

NOTE 1 This subclause should be read sequentially, since equations which are valid for several architectures are only stated where they are first used. See also B.2.2.

NOTE 2 The calculations are based on the assumptions listed in B.1.

B.3.2.1 1001

Figures B.3 and B.4 show the relevant block diagrams.

$$\lambda_D = \lambda_{DU} + \lambda_{DD} = \frac{\lambda}{2}$$

$$t_{CE} = \frac{\lambda_{DU}}{\lambda_D} \left(\frac{T_1}{2} + MTTR \right) + \frac{\lambda_{DD}}{\lambda_D} MTTR$$

$$\lambda_{DU} = \frac{\lambda}{2} (1 - DC); \lambda_{DD} = \frac{\lambda}{2} DC$$

If it is assumed that the safety system puts the EUC into a safe state on detection of any failure, for a 1oo1 architecture the following is obtained

$$PFH_G = \lambda_{DU}$$

B.3.2.2 1oo2

Figures B.5 and B.6 show the relevant block diagrams. The value of t_{CE} is as given in B.3.2.1.

$$PFH_G = 2((1 - \beta_D)\lambda_{DD} + (1 - \beta)\lambda_{DU})^2 t_{CE} + \beta_D \lambda_{DD} + \beta \lambda_{DU}$$

B.3.2.3 2oo2

Figures B.7 and B.8 show the relevant block diagrams. If it is assumed that each channel is put into a safe state on detection of any fault, for a 2oo2 architecture the following is obtained

$$PFH_G = 2\lambda_{DU}$$

B.3.2.4 1oo2D

Figures B.9 and B.10 show the relevant block diagrams.

$$\lambda_{SD} = \frac{\lambda}{2} DC$$

$$t_{CE}' = \frac{\lambda_{DU} \left(\frac{T_1}{2} + MTTR \right) + (\lambda_{DD} + \lambda_{SD}) MTTR}{\lambda_{DU} + \lambda_{DD} + \lambda_{SD}}$$

$$PFH_G = 2(1 - \beta)\lambda_{DU}((1 - \beta)\lambda_{DU} + (1 - \beta_D)\lambda_{DD} + \lambda_{SD})t_{CE}' + \beta_D \lambda_{DD} + \beta \lambda_{DU}$$

B.3.2.5 2oo3

Figures B.11 and B.12 show the relevant block diagrams. The value of t_{CE} is as given in B.3.2.1.

$$PFH_G = 6((1 - \beta_D)\lambda_{DD} + (1 - \beta)\lambda_{DU})^2 t_{CE} + \beta_D \lambda_{DD} + \beta \lambda_{DU}$$

B.3.3 Detailed tables for high demand or continuous mode of operation

Table B.10 – Probability of failure per hour (in high demand or continuous mode of operation) for a proof-test interval of one month and a mean time to restoration of 8 h

Architecture	DC	$\lambda = 1.0\text{E-}07$			$\lambda = 5.0\text{E-}07$			$\lambda = 1.0\text{E-}06$		
		$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$
1001 (see note 2)	0 %	5.0E-08			2.5E-07			5.0E-07		
	60 %	2.0E-08			1.0E-07			2.0E-07		
	90 %	5.0E-09			2.5E-08			5.0E-08		
	99 %	5.0E-10			2.5E-09			5.0E-09		
1002	0 %	1.0E-09	5.0E-09	1.0E-08	5.0E-09	2.5E-08	5.0E-08	1.0E-08	5.0E-08	1.0E-07
	60 %	7.0E-10	3.5E-09	7.0E-09	3.5E-09	1.8E-08	3.5E-08	7.1E-09	3.5E-08	7.0E-08
	90 %	5.5E-10	2.8E-09	5.5E-09	2.8E-09	1.4E-08	2.8E-08	5.5E-09	2.8E-08	5.5E-08
	99 %	5.1E-10	2.5E-09	5.1E-09	2.5E-09	1.3E-08	2.5E-08	5.1E-09	2.5E-08	5.1E-08
2002 (see note 2)	0 %	1.0E-07			5.0E-07			1.0E-06		
	60 %	4.0E-08			2.0E-07			4.0E-07		
	90 %	1.0E-08			5.0E-08			1.0E-07		
	99 %	1.0E-09			5.0E-09			1.0E-08		
1002D	0 %	1.0E-09	5.0E-09	1.0E-08	5.0E-09	2.5E-08	5.0E-08	1.0E-08	5.0E-08	1.0E-07
	60 %	7.0E-10	3.5E-09	7.0E-09	3.5E-09	1.8E-08	3.5E-08	7.0E-09	3.5E-08	7.0E-08
	90 %	5.5E-10	2.8E-09	5.5E-09	2.8E-09	1.4E-08	2.8E-08	5.5E-09	2.8E-08	5.5E-08
	99 %	5.1E-10	2.5E-09	5.1E-09	2.5E-09	1.3E-08	2.5E-08	5.1E-09	2.5E-08	5.1E-08
2003	0 %	1.0E-09	5.0E-09	1.0E-08	5.1E-09	2.5E-08	5.0E-08	1.1E-08	5.0E-08	1.0E-07
	60 %	7.0E-10	3.5E-09	7.0E-09	3.6E-09	1.8E-08	3.5E-08	7.2E-09	3.5E-08	7.0E-08
	90 %	5.5E-10	2.8E-09	5.5E-09	2.8E-09	1.4E-08	2.8E-08	5.6E-09	2.8E-08	5.5E-08
	99 %	5.1E-10	2.5E-09	5.1E-09	2.5E-09	1.3E-08	2.5E-08	5.1E-09	2.5E-08	5.1E-08

NOTE 1 This table gives example values of PFH_G , calculated using the equations in B.3.2 and depending on the assumptions listed in B.1. If the sensor, logic or final element subsystem comprises of only one group of voted channels, then PFH_G is equivalent to PFH_S , PFH_L or PFH_{FE} respectively (see B.3.1 and B.2.1).

NOTE 2 The table assumes $\beta = 2 \times \beta_D$. For 1001 and 2002 architectures, the values of β and β_D do not affect the average probability of failure.

Table B.10 (continued)

Architecture	DC	$\lambda = 5.0\text{E-}06$			$\lambda = 1.0\text{E-}05$			$\lambda = 5.0\text{E-}05$		
		$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$
1001 (see note 2)	0 %	2.5E-06			5.0E-06			>1E-05		
	60 %	1.0E-06			2.0E-06			1.0E-05		
	90 %	2.5E-07			5.0E-07			2.5E-06		
	99 %	2.5E-08			5.0E-08			2.5E-07		
1002	0 %	5.4E-08	2.5E-07	5.0E-07	1.2E-07	5.2E-07	1.0E-06	9.5E-07	2.9E-06	5.3E-06
	60 %	3.7E-08	1.8E-07	3.5E-07	7.7E-08	3.6E-07	7.1E-07	5.4E-07	1.9E-06	3.6E-06
	90 %	2.8E-08	1.4E-07	2.8E-07	5.7E-08	2.8E-07	5.5E-07	3.3E-07	1.4E-06	2.8E-06
	99 %	2.5E-08	1.3E-07	2.5E-07	5.1E-08	2.5E-07	5.1E-07	2.7E-07	1.3E-06	2.5E-06
2002 (see note 2)	0 %	5.0E-06			1.0E-05			>1E-05		
	60 %	2.0E-06			4.0E-06			>1E-05		
	90 %	5.0E-07			1.0E-06			5.0E-06		
	99 %	5.0E-08			1.0E-07			5.0E-07		
1002D	0 %	5.4E-08	2.5E-07	5.0E-07	1.2E-07	5.2E-07	1.0E-06	9.5E-07	2.9E-06	5.3E-06
	60 %	3.6E-08	1.8E-07	3.5E-07	7.3E-08	3.5E-07	7.0E-07	4.3E-07	1.8E-06	3.6E-06
	90 %	2.8E-08	1.4E-07	2.8E-07	5.5E-08	2.8E-07	5.5E-07	2.8E-07	1.4E-06	2.8E-06
	99 %	2.5E-08	1.3E-07	2.5E-07	5.1E-08	2.5E-07	5.1E-07	2.5E-07	1.3E-06	2.5E-06
2003	0 %	6.3E-08	2.6E-07	5.1E-07	1.5E-07	5.5E-07	1.0E-06	1.8E-06	3.6E-06	5.9E-06
	60 %	4.1E-08	1.8E-07	3.5E-07	9.2E-08	3.7E-07	7.2E-07	9.1E-07	2.2E-06	3.9E-06
	90 %	2.9E-08	1.4E-07	2.8E-07	6.2E-08	2.8E-07	5.6E-07	4.4E-07	1.5E-06	2.9E-06
	99 %	2.6E-08	1.3E-07	2.5E-07	5.2E-08	2.5E-07	5.1E-07	3.0E-07	1.3E-06	2.6E-06

NOTE 1 This table gives example values of PFH_G , calculated using the equations in B.3.2 and depending on the assumptions listed in B.1. If the sensor, logic or final element subsystem comprises of only one group of voted channels, then PFH_G is equivalent to PFH_S , PFH_L or PFH_{FE} respectively (see B.3.1 and B.2.1).

NOTE 2 The table assumes $\beta = 2 \times \beta_D$. For 1001 and 2002 architectures, the values of β and β_D do not affect the average probability of failure.

Table B.11 – Probability of failure per hour (in high demand or continuous mode of operation) for a proof test interval of three months and a mean time to restoration of 8 h

Architecture	DC	$\lambda = 1.0E-07$			$\lambda = 5.0E-07$			$\lambda = 1.0E-06$		
		$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$
1oo1 (see note 2)	0 %	5.0E-08			2.5E-07			5.0E-07		
	60 %	2.0E-08			1.0E-07			2.0E-07		
	90 %	5.0E-09			2.5E-08			5.0E-08		
	99 %	5.0E-10			2.5E-09			5.0E-09		
1oo2	0 %	1.0E-09	5.0E-09	1.0E-08	5.1E-09	2.5E-08	5.0E-08	1.1E-08	5.0E-08	1.0E-07
	60 %	7.0E-10	3.5E-09	7.0E-09	3.6E-09	1.8E-08	3.5E-08	7.2E-09	3.5E-08	7.0E-08
	90 %	5.5E-10	2.8E-09	5.5E-09	2.8E-09	1.4E-08	2.8E-08	5.6E-09	2.8E-08	5.5E-08
	99 %	5.1E-10	2.5E-09	5.1E-09	2.5E-09	1.3E-08	2.5E-08	5.1E-09	2.5E-08	5.1E-08
2oo2 (see note 2)	0 %	1.0E-07			5.0E-07			1.0E-06		
	60 %	4.0E-08			2.0E-07			4.0E-07		
	90 %	1.0E-08			5.0E-08			1.0E-07		
	99 %	1.0E-09			5.0E-09			1.0E-08		
1oo2D	0 %	1.0E-09	5.0E-09	1.0E-08	5.1E-09	2.5E-08	5.0E-08	1.1E-08	5.0E-08	1.0E-07
	60 %	7.0E-10	3.5E-09	7.0E-09	3.5E-09	1.8E-08	3.5E-08	7.1E-09	3.5E-08	7.0E-08
	90 %	5.5E-10	2.8E-09	5.5E-09	2.8E-09	1.4E-08	2.8E-08	5.5E-09	2.8E-08	5.5E-08
	99 %	5.1E-10	2.5E-09	5.1E-09	2.5E-09	1.3E-08	2.5E-08	5.1E-09	2.5E-08	5.1E-08
2oo3	0 %	1.0E-09	5.0E-09	1.0E-08	5.4E-09	2.5E-08	5.0E-08	1.2E-08	5.1E-08	1.0E-07
	60 %	7.1E-10	3.5E-09	7.0E-09	3.7E-09	1.8E-08	3.5E-08	7.7E-09	3.6E-08	7.0E-08
	90 %	5.5E-10	2.8E-09	5.5E-09	2.8E-09	1.4E-08	2.8E-08	5.7E-09	2.8E-08	5.5E-08
	99 %	5.1E-10	2.5E-09	5.1E-09	2.5E-09	1.3E-08	2.5E-08	5.1E-09	2.5E-08	5.1E-08

NOTE 1 This table gives example values of PFH_G , calculated using the equations in B.3.2 and depending on the assumptions listed in B.1. If the sensor, logic or final element subsystem comprises of only one group of voted channels, then PFH_G is equivalent to PFH_S , PFH_L or PFH_{FE} respectively (see B.3.1 and B.2.1).

NOTE 2 The table assumes $\beta = 2 \times \beta_D$. For 1oo1 and 2oo2 architectures, the values of β and β_D do not affect the average probability of failure.

Table B.11 (continued)

Architecture	DC	$\lambda = 5.0E-06$			$\lambda = 1.0E-05$			$\lambda = 5.0E-05$		
		$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$
1oo1 (see note 2)	0 %	2.5E-06			5.0E-06			>1E-05		
	60 %	1.0E-06			2.0E-06			1.0E-05		
	90 %	2.5E-07			5.0E-07			2.5E-06		
	99 %	2.5E-08			5.0E-08			2.5E-07		
1oo2	0 %	6.3E-08	2.6E-07	5.1E-07	1.5E-07	5.4E-07	1.0E-06	1.8E-06	3.6E-06	5.9E-06
	60 %	4.0E-08	1.8E-07	3.5E-07	9.2E-08	3.7E-07	7.2E-07	8.9E-07	2.2E-06	3.9E-06
	90 %	2.9E-08	1.4E-07	2.8E-07	6.1E-08	2.8E-07	5.5E-07	4.2E-07	1.5E-06	2.9E-06
	99 %	2.5E-08	1.3E-07	2.5E-07	5.1E-08	2.5E-07	5.1E-07	2.8E-07	1.3E-06	2.5E-06
2oo2 (see note 2)	0 %	5.0E-06			1.0E-05			>1E-05		
	60 %	2.0E-06			4.0E-06			>1E-05		
	90 %	5.0E-07			1.0E-06			5.0E-06		
	99 %	5.0E-08			1.0E-07			5.0E-07		
1oo2D	0 %	6.3E-08	2.6E-07	5.1E-07	1.5E-07	5.4E-07	1.0E-06	1.8E-06	3.6E-06	5.9E-06
	60 %	3.7E-08	1.8E-07	3.5E-07	7.9E-08	3.6E-07	7.1E-07	5.7E-07	1.9E-06	3.7E-06
	90 %	2.8E-08	1.4E-07	2.8E-07	5.6E-08	2.8E-07	5.5E-07	2.9E-07	1.4E-06	2.8E-06
	99 %	2.5E-08	1.3E-07	2.5E-07	5.1E-08	2.5E-07	5.1E-07	2.5E-07	1.3E-06	2.5E-06
2oo3	0 %	9.0E-08	2.8E-07	5.3E-07	2.6E-07	6.3E-07	1.1E-06	4.5E-06	5.9E-06	7.6E-06
	60 %	5.1E-08	1.9E-07	3.6E-07	1.4E-07	4.1E-07	7.5E-07	2.0E-06	3.2E-06	4.7E-06
	90 %	3.2E-08	1.4E-07	2.8E-07	7.2E-08	2.9E-07	5.6E-07	7.1E-07	1.8E-06	3.1E-06
	99 %	2.6E-08	1.3E-07	2.5E-07	5.3E-08	2.6E-07	5.1E-07	3.2E-07	1.3E-06	2.6E-06

NOTE 1 This table gives example values of PFH_G , calculated using the equations in B.3.2 and depending on the assumptions listed in B.1. If the sensor, logic or final element subsystem comprises of only one group of voted channels, then PFH_G is equivalent to PFH_S , PFH_L or PFH_{FE} respectively (see B.3.1 and B.2.1).

NOTE 2 The table assumes $\beta = 2 \times \beta_D$. For 1oo1 and 2oo2 architectures, the values of β and β_D do not affect the average probability of failure.

Table B.12 – Probability of failure per hour (in high demand or continuous mode of operation) for a proof test interval of six months and a mean time to restoration of 8 h

Architecture	DC	$\lambda = 1.0\text{E-}07$			$\lambda = 5.0\text{E-}07$			$\lambda = 1.0\text{E-}06$		
		$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$
1oo1 (see note 2)	0 %	5.0E-08			2.5E-07			5.0E-07		
	60 %	2.0E-08			1.0E-07			2.0E-07		
	90 %	5.0E-09			2.5E-08			5.0E-08		
	99 %	5.0E-10			2.5E-09			5.0E-09		
1oo2	0 %	1.0E-09	5.0E-09	1.0E-08	5.3E-09	2.5E-08	5.0E-08	1.1E-08	5.1E-08	1.0E-07
	60 %	7.0E-10	3.5E-09	7.0E-09	3.6E-09	1.8E-08	3.5E-08	7.4E-09	3.5E-08	7.0E-08
	90 %	5.5E-10	2.8E-09	5.5E-09	2.8E-09	1.4E-08	2.8E-08	5.6E-09	2.8E-08	5.5E-08
	99 %	5.1E-10	2.5E-09	5.1E-09	2.5E-09	1.3E-08	2.5E-08	5.1E-09	2.5E-08	5.1E-08
2oo2 (see note 2)	0 %	1.0E-07			5.0E-07			1.0E-06		
	60 %	4.0E-08			2.0E-07			4.0E-07		
	90 %	1.0E-08			5.0E-08			1.0E-07		
	99 %	1.0E-09			5.0E-09			1.0E-08		
1oo2D	0 %	1.0E-09	5.0E-09	1.0E-08	5.3E-09	2.5E-08	5.0E-08	1.1E-08	5.1E-08	1.0E-07
	60 %	7.0E-10	3.5E-09	7.0E-09	3.5E-09	1.8E-08	3.5E-08	7.2E-09	3.5E-08	7.0E-08
	90 %	5.5E-10	2.8E-09	5.5E-09	2.8E-09	1.4E-08	2.8E-08	5.5E-09	2.8E-08	5.5E-08
	99 %	5.1E-10	2.5E-09	5.1E-09	2.5E-09	1.3E-08	2.5E-08	5.1E-09	2.5E-08	5.1E-08
2oo3	0 %	1.0E-09	5.0E-09	1.0E-08	5.8E-09	2.6E-08	5.1E-08	1.3E-08	5.3E-08	1.0E-07
	60 %	7.1E-10	3.5E-09	7.0E-09	3.8E-09	1.8E-08	3.5E-08	8.3E-09	3.6E-08	7.1E-08
	90 %	5.5E-10	2.8E-09	5.5E-09	2.8E-09	1.4E-08	2.8E-08	5.8E-09	2.8E-08	5.5E-08
	99 %	5.1E-10	2.5E-09	5.1E-09	2.5E-09	1.3E-08	2.5E-08	5.1E-09	2.5E-08	5.1E-08

NOTE 1 This table gives example values of PFH_G , calculated using the equations in B.3.2 and depending on the assumptions listed in B.1. If the sensor, logic or final element subsystem comprises of only one group of voted channels, then PFH_G is equivalent to PFH_S , PFH_L or PFH_{FE} respectively (see B.3.1 and B.2.1).

NOTE 2 The table assumes $\beta = 2 \times \beta_D$. For 1oo1 and 2oo2 architectures, the values of β and β_D do not affect the average probability of failure.

Table B.12 (continued)

Architecture	DC	$\lambda = 5.0\text{E-}06$			$\lambda = 1.0\text{E-}05$			$\lambda = 5.0\text{E-}05$		
		$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$
1oo1 (see note 2)	0 %	2.5E-06			5.0E-06			>1E-05		
	60 %	1.0E-06			2.0E-06			1.0E-05		
	90 %	2.5E-07			5.0E-07			2.5E-06		
	99 %	2.5E-08			5.0E-08			2.5E-07		
1oo2	0 %	7.6E-08	2.7E-07	5.2E-07	2.1E-07	5.9E-07	1.1E-06	3.1E-06	4.7E-06	6.8E-06
	60 %	4.6E-08	1.8E-07	3.6E-07	1.1E-07	3.9E-07	7.3E-07	1.4E-06	2.7E-06	4.3E-06
	90 %	3.0E-08	1.4E-07	2.8E-07	6.6E-08	2.9E-07	5.6E-07	5.5E-07	1.6E-06	3.0E-06
	99 %	2.6E-08	1.3E-07	2.5E-07	5.2E-08	2.5E-07	5.1E-07	2.9E-07	1.3E-06	2.6E-06
2oo2 (see note 2)	0 %	5.0E-06			1.0E-05			>1E-05		
	60 %	2.0E-06			4.0E-06			>1E-05		
	90 %	5.0E-07			1.0E-06			5.0E-06		
	99 %	5.0E-08			1.0E-07			5.0E-07		
1oo2D	0 %	7.6E-08	2.7E-07	5.2E-07	2.1E-07	5.9E-07	1.1E-06	3.1E-06	4.7E-06	6.8E-06
	60 %	3.9E-08	1.8E-07	3.5E-07	8.7E-08	3.7E-07	7.1E-07	7.8E-07	2.1E-06	3.8E-06
	90 %	2.8E-08	1.4E-07	2.8E-07	5.6E-08	2.8E-07	5.5E-07	3.0E-07	1.4E-06	2.8E-06
	99 %	2.5E-08	1.3E-07	2.5E-07	5.1E-08	2.5E-07	5.1E-07	2.5E-07	1.3E-06	2.5E-06
2oo3	0 %	1.3E-07	3.2E-07	5.5E-07	4.2E-07	7.7E-07	1.2E-06	8.4E-06	9.2E-06	1.0E-05
	60 %	6.7E-08	2.0E-07	3.7E-07	2.0E-07	4.6E-07	8.0E-07	3.6E-06	4.6E-06	6.0E-06
	90 %	3.6E-08	1.5E-07	2.8E-07	8.8E-08	3.1E-07	5.8E-07	1.1E-06	2.1E-06	3.4E-06
	99 %	2.6E-08	1.3E-07	2.5E-07	5.5E-08	2.6E-07	5.1E-07	3.6E-07	1.4E-06	2.6E-06

NOTE 1 This table gives example values of PFH_G , calculated using the equations in B.3.2 and depending on the assumptions listed in B.1. If the sensor, logic or final element subsystem comprises of only one group of voted channels, then PFH_G is equivalent to PFH_S , PFH_L or PFH_{FE} respectively (see B.3.1 and B.2.1).

NOTE 2 The table assumes $\beta = 2 \times \beta_D$. For 1oo1 and 2oo2 architectures, the values of β and β_D do not affect the average probability of failure.

Table B.13 – Probability of failure per hour (in high demand or continuous mode of operation) for a proof-test interval of one year and a mean time to restoration of 8 h

Architecture	DC	$\lambda = 1.0E-07$			$\lambda = 5.0E-07$			$\lambda = 1.0E-06$		
		$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$
1oo1 (see note 2)	0 %	5.0E-08			2.5E-07			5.0E-07		
	60 %	2.0E-08			1.0E-07			2.0E-07		
	90 %	5.0E-09			2.5E-08			5.0E-08		
	99 %	5.0E-10			2.5E-09			5.0E-09		
1oo2	0 %	1.0E-09	5.0E-09	1.0E-08	5.5E-09	2.5E-08	5.0E-08	1.2E-08	5.2E-08	1.0E-07
	60 %	7.1E-10	3.5E-09	7.0E-09	3.7E-09	1.8E-08	3.5E-08	7.9E-09	3.6E-08	7.1E-08
	90 %	5.5E-10	2.8E-09	5.5E-09	2.8E-09	1.4E-08	2.8E-08	5.7E-09	2.8E-08	5.5E-08
	99 %	5.1E-10	2.5E-09	5.1E-09	2.5E-09	1.3E-08	2.5E-08	5.1E-09	2.5E-08	5.1E-08
2oo2 (see note 2)	0 %	1.0E-07			5.0E-07			1.0E-06		
	60 %	4.0E-08			2.0E-07			4.0E-07		
	90 %	1.0E-08			5.0E-08			1.0E-07		
	99 %	1.0E-09			5.0E-09			1.0E-08		
1oo2D	0 %	1.0E-09	5.0E-09	1.0E-08	5.5E-09	2.5E-08	5.0E-08	1.2E-08	5.2E-08	1.0E-07
	60 %	7.0E-10	3.5E-09	7.0E-09	3.6E-09	1.8E-08	3.5E-08	7.3E-09	3.5E-08	7.0E-08
	90 %	5.5E-10	2.8E-09	5.5E-09	2.8E-09	1.4E-08	2.8E-08	5.5E-09	2.8E-08	5.5E-08
	99 %	5.1E-10	2.5E-09	5.1E-09	2.5E-09	1.3E-08	2.5E-08	5.1E-09	2.5E-08	5.1E-08
2oo3	0 %	1.1E-09	5.1E-09	1.0E-08	6.6E-09	2.6E-08	5.1E-08	1.6E-08	5.5E-08	1.0E-07
	60 %	7.3E-10	3.5E-09	7.0E-09	4.1E-09	1.8E-08	3.5E-08	9.6E-09	3.7E-08	7.2E-08
	90 %	5.6E-10	2.8E-09	5.5E-09	2.9E-09	1.4E-08	2.8E-08	6.2E-09	2.8E-08	5.6E-08
	99 %	5.1E-10	2.5E-09	5.1E-09	2.5E-09	1.3E-08	2.5E-08	5.1E-09	2.5E-08	5.1E-08

NOTE 1 This table gives example values of PFH_G , calculated using the equations in B.3.2 and depending on the assumptions listed in B.1. If the sensor, logic or final element subsystem comprises of only one group of voted channels, then PFH_G is equivalent to PFH_S , PFH_L or PFH_{FE} respectively (see B.3.1 and B.2.1).

NOTE 2 The table assumes $\beta = 2 \times \beta_D$. For 1oo1 and 2oo2 architectures, the values of β and β_D do not affect the average probability of failure.

Table B.13 (continued)

Architecture	DC	$\lambda = 5.0E-06$			$\lambda = 1.0E-05$			$\lambda = 5.0E-05$		
		$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$	$\beta = 2\%$ $\beta_D = 1\%$	$\beta = 10\%$ $\beta_D = 5\%$	$\beta = 20\%$ $\beta_D = 10\%$
1oo1 (see note 2)	0 %	2.5E-06			5.0E-06			>1E-05		
	60 %	1.0E-06			2.0E-06			1.0E-05		
	90 %	2.5E-07			5.0E-07			2.5E-06		
	99 %	2.5E-08			5.0E-08			2.5E-07		
1oo2	0 %	1.0E-07	2.9E-07	5.4E-07	3.1E-07	6.8E-07	1.1E-06	5.8E-06	6.9E-06	8.5E-06
	60 %	5.6E-08	1.9E-07	3.7E-07	1.6E-07	4.3E-07	7.7E-07	2.5E-06	3.7E-06	5.1E-06
	90 %	3.3E-08	1.4E-07	2.8E-07	7.7E-08	2.9E-07	5.7E-07	8.2E-07	1.9E-06	3.2E-06
	99 %	2.6E-08	1.3E-07	2.5E-07	5.3E-08	2.5E-07	5.1E-07	3.2E-07	1.3E-06	2.6E-06
2oo2 (see note 2)	0 %	5.0E-06			1.0E-05			>1E-05		
	60 %	2.0E-06			4.0E-06			>1E-05		
	90 %	5.0E-07			1.0E-06			5.0E-06		
	99 %	5.0E-08			1.0E-07			5.0E-07		
1oo2D	0 %	1.0E-07	2.9E-07	5.4E-07	3.1E-07	6.8E-07	1.1E-06	5.8E-06	6.9E-06	8.5E-06
	60 %	4.4E-08	1.8E-07	3.6E-07	1.0E-07	3.8E-07	7.3E-07	1.2E-06	2.5E-06	4.1E-06
	90 %	2.8E-08	1.4E-07	2.8E-07	5.7E-08	2.8E-07	5.5E-07	3.3E-07	1.4E-06	2.8E-06
	99 %	2.5E-08	1.3E-07	2.5E-07	5.1E-08	2.5E-07	5.1E-07	2.5E-07	1.3E-06	2.5E-06
2oo3	0 %	2.1E-07	3.8E-07	6.1E-07	7.3E-07	1.0E-06	1.4E-06	>1E-05	>1E-05	>1E-05
	60 %	9.9E-08	2.3E-07	4.0E-07	3.3E-07	5.8E-07	9.0E-07	6.8E-06	7.5E-06	8.4E-06
	90 %	4.4E-08	1.5E-07	2.9E-07	1.2E-07	3.3E-07	6.0E-07	1.9E-06	2.9E-06	4.1E-06
	99 %	2.7E-08	1.3E-07	2.5E-07	5.8E-08	2.6E-07	5.1E-07	4.4E-07	1.4E-06	2.7E-06

NOTE 1 This table gives example values of PFH_G , calculated using the equations in B.3.2 and depending on the assumptions listed in B.1. If the sensor, logic or final element subsystem comprises of only one group of voted channels, then PFH_G is equivalent to PFH_S , PFH_L or PFH_{FE} respectively (see B.3.1 and B.2.1).

NOTE 2 The table assumes $\beta = 2 \times \beta_D$. For 1oo1 and 2oo2 architectures, the values of β and β_D do not affect the average probability of failure.