

Maintainability of equipment —

Part 5: Testability and diagnostic testing

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National foreword

This British Standard is the UK implementation of EN 60706-5:2007. It is identical to IEC 60706-5:2007. It supersedes BS 6548-5:1995 which is withdrawn.

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A list of organizations represented on this committee can be obtained on request to its secretary.

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Part 5: Testability and diagnostic testing
(IEC 60706-5:2007)**

Maintenabilité de matériel -
Partie 5: Testabilité et tests
pour diagnostic
(CEI 60706-5:2007)

Instandhaltbarkeit von Geräten -
Teil 5: Prüfbarkeit und
diagnostisches Prüfen
(IEC 60706-5:2007)

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CENELEC

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Foreword

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INTRODUCTION

Testability is an important feature in the operation and maintenance of a system or equipment and has a significant effect on its availability and maintainability. Diagnostic testing may be carried out manually or with test equipment which may contain various levels of automation. Optimum design for testability requires close cooperation between design, operation and maintenance organizations. This standard is intended to highlight the various aspects of testability and diagnostic testing and to assist in their timely coordination.

In this standard, items to be considered in respect of their testability design may be systems, equipment or functional units which are the objects of a contract, and will be referred to as "products". Each product has to perform its required functions which should be verified during the development and production phases and should be retained over the whole life cycle. For a product to retain its functionality, the functional status of each sub-function should be known at any time while the product is in its operating condition. If a failure occurs, action should be taken to ensure that the fault is recognized and the faulty item localized. This requirement placed on the testability of a product might appear to be quite simple, but if it is not considered at the start of product development, subsequent realization will result in increased work and significantly increased cost. If all requirements are available at the start of development, the development engineer can specify the functional characteristic "testability" without much additional effort and therefore achieve considerable cost savings e.g. by minimizing the number of test steps for verifying the development results. Experience has shown that the extra cost and effort in the development phase can be recovered for example in the production phase since available test equipment can be used. Reliable fault recognition and low in-service maintenance costs increase the market value of a testable product considerably.

As the technologies which are applied in the products covered by this standard are wide-ranging, this document has been written in a neutral manner with regard to technologies and techniques. This standard therefore only provides an assessment basis for making calculations and the basic approach for achieving the required testability of a product. The technical realization of fault recognition and fault localization in the product is the task of the product development engineer and has to be achieved according to the state of the art at the time when the product is being developed. It is therefore not of great importance whether the required test task is realized in hardware or software form, but it is essential that all functions are checked via test paths and that the characteristic values established for testability correspond to the specified target values. If there are deviations from the target values, action should be taken to ensure that the target values are met. These actions should take place at an early stage of development before freezing the design.

MAINTAINABILITY OF EQUIPMENT –

Part 5: Testability and diagnostic testing

1 Scope

The purpose of this part of IEC 60706 is to

- provide guidance for the early consideration of testability aspects in design and development;
- assist in determining effective test procedures as an integral part of operation and maintenance.

This International Standard can be applied to all types of products which may include commercial off-the-shelf (COTS) items. In this respect, it does not matter whether the product belongs to mechanical, hydraulic, electrical or some other technology. In addition, this International Standard applies to the development of any products, with the aim of designing the product characteristics so that they are verifiable (testable).

The objective of this International standard is to ensure that prerequisites relating to the testability of products are defined in the preliminary phases of development, laid down by the customer, implemented, documented and verified during development.

This International Standard also provides methods to implement and assess testability as an integral part of the product design. It recommends that the product testability documentation should be continually updated over the product's life cycle.

2 Normative references

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

IEC 60050-191, *International Electrotechnical Vocabulary – Chapter 191: Dependability and quality of service*

IEC 60706-2, *Maintainability of equipment – Part 2: Maintainability requirements and studies during the design and development phase*

IEC 60706-3, *Maintainability of equipment – Part 3: Verification and collection, analysis and presentation of data*

IEC 60300-3-10, *Dependability management – Part 3-10: Application guide – Maintainability*

3 Terms, definitions and acronyms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions of IEC 60050-191 apply together with the following:

3.1.1**built-in test****BIT**

integrated capability of a test item enabling automatic fault recognition and fault localization

3.1.2**built-in test equipment****BITE**

hardware and/or software assigned to the built-in test

3.1.3**commercial off-the-shelf****COTS**

designates items readily available commercially

3.1.4**criticality**

significance attached to a malfunction

NOTE Criticality is expressed in grades: the higher the grade, the more severe the consequences to be expected from the malfunction.

3.1.5**depth of test**

specification of the level to which the unit or sub-unit is to be identified

3.1.6**design level**

level to which the design elements (functional and/or physical units), when they already exist, are assigned within the product breakdown structure

NOTE In some cases “design level” is known as “indenture level”.

3.1.7**diagnosis correctness**

proportion of faults of an item that can be correctly diagnosed under given conditions

3.1.8**diagnostic testing**

test procedure carried out in order to make a diagnosis

3.1.9**false alarm**

indication of failure which, after carrying out failure finding activities, is not found

3.1.10**false alarm rate**

the percentage of false alarms in the total number of failure indications

3.1.11**fault recognition time**

period of time between the instant of failure and fault recognition

3.1.12

fault simulation

inclusion of faults by non-destructive interventions in the hardware units and/or, where necessary, simulation via software in order to verify the diagnostic capability

3.1.13

function

performance required of the item

NOTE A function is always associated if realised with an item of a given level in the product breakdown structure.

3.1.14

functional model

conceptual representation of an item describing the interrelationship and dependencies between its stimuli and measurement (response) terminals

NOTE The functional model, which arises during the development of a product, is in principle a block diagram showing the functions of the product and supplemented to include the test paths envisaged by the developer.

3.1.15

functional test

testing of all the specified functions of hardware units to prove their functional capability

3.1.16

hardware unit

design element which represents functions and/or sub-functions in the form of hardware, possibly including software components

3.1.17

line replaceable unit

LRU

replaceable hardware or software unit which can be replaced directly on the equipment by the user or by a maintenance support facility

3.1.18

maintenance concept

interrelationship between the design levels and the levels of maintenance to be applied for the maintenance of an item

3.1.19

maintenance policy

general approach to the provision of maintenance and maintenance support based on the objectives and policies of owners, users and customers

3.1.20

monitoring

automatic supervision of the functions required for the operation in a selected operational mode; operation should not be affected by this

3.1.21

operational context

circumstances in which an item is expected to operate

3.1.22

parameter

physical quantity that specifies a function

3.1.23**product**

specified deliverable goods or service

NOTE 1 In the context of dependability, a product may be simple (e.g. a device, a software algorithm) or complex e.g. a system or an integrated network comprising of hardware, software, human elements, support facilities and activities).

NOTE 2 Product has its own life cycle phases.

NOTE 3 Product has the same definition as item.

3.1.24**product breakdown structure**

hierarchical tree visualizing the physical composition of a product by assemblies of units and sub-units

3.1.25**shop replaceable unit****SRU**

replaceable hardware or software unit which can be replaced by the user depot/workshop or by the maintenance support facility at the same level or in the company's workshops

3.1.26**signal**

variation of a physical quantity used to represent data

NOTE A signal is represented by one or several parameters.

3.1.27**specification**

detailed definition of the functions of an item for a given level of the product breakdown structure

NOTE Specifications should be derived from the systems requirements and be verifiable.

3.1.28**statement of work****SoW**

document which defines goods and services to be provided.

NOTE The statement of work is prepared or accepted by the customer and defines the work for which a contract is to be placed and which is to be provided by the contractor. It therefore forms the main technical document according to which the bidders present their offers, the contractor performs the work and the customer accepts the goods and services provided.

3.1.29**stimulus**

input signal with defined parameters for the purpose of triggering functions

3.1.30**sub-function**

sub-division of a function (see also function, 3.1.13)

3.1.31**terminal**

generic term for the physical access points to the signals of a test item. Examples of physical implementations or relevant terms for synonymous expressions are

– pin

- connector
- plug/plug-type connector
- test point
- interface
- port

NOTE A terminal is generally identified by a unique identifier.

3.1.32

test concept

description of the results of the system testability requirements analysis and stipulation of the method of how the requirements are to be met

3.1.33

test coverage

ratio of the number of faulty functions actually capable of diagnosis by the given test instruction to the total number of functions

3.1.34

test equipment

tools (hardware and/or software) required for conducting tests

NOTE Due to the technology involved, these are divided into internal (BITE) and external test equipment.

3.1.35

test instruction

document describing how the tests required in the test specification are to be implemented

3.1.36

test path

description of the assignment of hardware units to their terminals, taking the associated test steps into account

NOTE In addition, the test path defines the (functional) relationship between the stimulus and the response.

3.1.37

test sequence

series of test steps

3.1.38

test specification

document in which test sequences, parameters and functions are specified

3.1.39

test step

smallest unit in a test conducted on a hardware unit

3.1.40

test task

sum of all the tests necessary to meet the specifications of fault recognition and localization

3.1.41

testability

design characteristic which determines the degree to which an item can be functionally tested under stated conditions

3.2 Acronyms

ATE	automatic test equipment
ATS	automatic testing system
BIT	built-in test
BITE	built-in test equipment
COTS	commercial off-the-shelf
DP	data processing
FL	fault localization
FM	functional monitoring
FME(C)A	failure mode, effects, (and criticality) analysis
FR	fault recognition
FT	functional test
FTA	fault tree analysis
HWE	hardware unit
LCC	life cycle cost
LORA	level of repair analysis
LRU	line replaceable unit
PCB	printed circuit board
SoW	statement of work
SRU	shop replaceable unit
SF	sub-function
TS	technical specification

4 Description of testability and diagnostic testing

4.1 General

The efficient and cost effective operation and maintenance of products is aided by ensuring that testability is considered during design and also during all the phases of the life cycle. Applicable diagnostic testing methods are then incorporated into the product as a component of the maintenance concept. Implementation of testability and diagnostic testing is accomplished throughout the life cycle of a product.

Life cycle cost (LCC) is an increasingly important aspect in evaluating the quality of any design. In addition to the immediate acquisition cost, many customers demand control of the costs associated with day to day operation, maintenance and logistic support. These costs are primarily influenced by the product's reliability, maintainability and maintenance support characteristics. In this context, the application of diagnostic testing techniques can be a significant contributory factor in the reduction of certain cost elements in the LCC. Constraints resulting from LCC optimization efforts should therefore be taken into account whenever diagnostic testing requirements are established.

This International Standard is intended to be applicable to all phases of the life cycle, i.e. from the time when the need for a product is identified through the design and development phase, to the manufacturing and installation phase and finally to the operation and maintenance phase as follows (see also Figure 1).

a) Design and development phase

From the concept down to the realization of a product, the requirements placed on a

product should be adapted to the specific needs of its field of application, where necessary passing through several pre-phases.

b) Manufacturing and installation phase

During this phase, it may be necessary to verify the diagnostic techniques using actual equipment and assess the product's effectiveness. Documentation can be prepared and training can now occur for operational and maintenance personnel.

c) Operation and maintenance phase

There may be a change to tested equipment due to obsolescence. The testing function may need to be continued and replacement or upgrading of equipment should take into account a continuing need for diagnostic testing. In the latter case, a redesign should be carried out in a new development phase.

By applying this International Standard, the preconditions are assumed to be fulfilled for generating the necessary product data/information and that this can be verified and updated over the product's complete life cycle.

Annex B gives an example of how testability is developed, documented and verified with regard to product/system design.

Diagnostic testing can consist of

- functional testing with the purpose of verifying that a function can still be performed;
- condition monitoring which is intended to track the condition of equipment that degrades over time.

Condition monitoring is closely related to the concepts covered by diagnostic testing, and cannot, and should not, be dissociated from it. However, it is not the intention that full coverage of condition monitoring should be part of this standard.

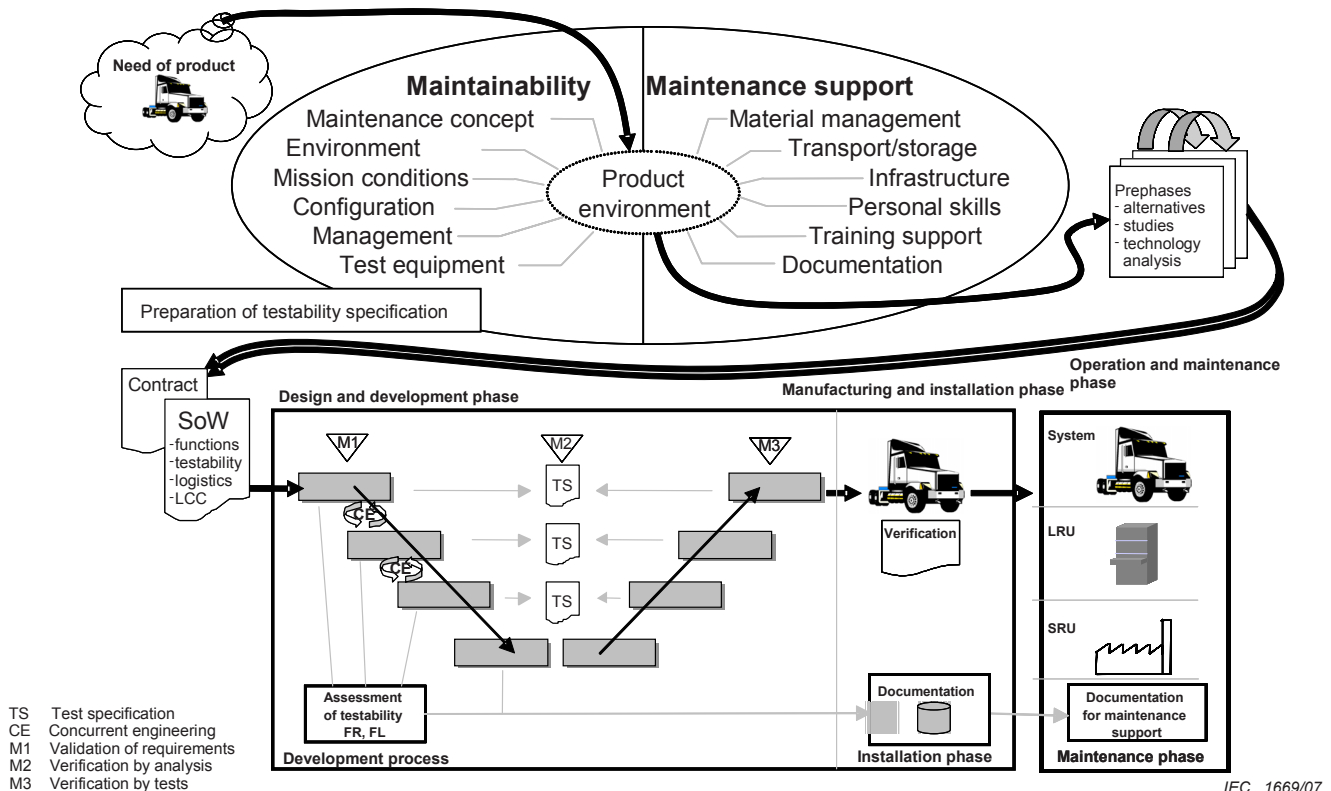


Figure 1 – Testability and diagnostic testing during the life cycle

4.2 Objectives of testability

Testability during design and development is closely aligned with maintainability, availability and safety and the main objective of testability is to address the following questions for each of the system functions.

- a) Can the function's failures be detected by a diagnostic test ? Certain functions cannot be completely tested because of safety constraints or because the test may be destructive (such as testing the overspeed mechanism on a rotor).
- b) Is it practical to test? The criticality of the function's failure, the test costs (the test equipment cost, the test equipment maintenance costs as well as the test activity costs) and the use of better and cheaper alternatives may result in the conclusion that it is not cost effective to test.

NOTE For both the cases in a) and b), alternative methods should be adopted to ensure the performance of these functions is maintained during the life of the product. Together, these elements contribute to the test coverage. A low test coverage value may be detrimental in that the system cannot be tested to confirm operational performance during its life cycle, but it may also indicate that the maintainability and maintenance capability is such that testing is not necessary.

- c) In what stages in the life cycle should the item be tested? The ability to test should be considered for each stage in the life cycle; testing a function at unit level may be possible, but impractical at system level. This can best be explained by an example: consider a washing machine and its function to discharge waste water. It would be useful, from a user perspective, to run a pre-operation stage test to confirm that the function can be performed prior to operation (running an operational stage test would provide little benefit). The design for this function may not require the introduction of test equipment to test this function because
 - 1) the life of the pump and associated equipment well exceeds the life of the product (other failures and the expense of their repair may define the product's life);
 - 2) the maintenance task to remove a possible blockage can be easily accommodated;
 - 3) units that perform this function can be fully tested at the unit stage and at the system level stage prior to delivery;
 - 4) determining the stages to test can also influence the life cycle cost;
- d) To what depth should it be tested? The depth of test is also an important criterion and, as in the above example, it is closely aligned to the maintenance concept. The depth of test specifies the level to which the unit or sub-unit is to be identified. For example, a system test may identify the unit to be replaced, but can also identify the sub-unit that needs to be replaced with little or no impact on the cost. This may reduce the costs associated with the test equipment required at the unit level to identify and replace the faulty sub-unit.

It is a basic principle in the design of testability that all functions developed should be verifiable. It should, however, be noted that test coverage of 100 % is not necessarily desirable, as testing can create failures that manifest themselves during operation, which may be worse than not testing, e.g. real failures introduced by testing or false alarms. Nor is test coverage of 100 % recommended for all safety issues, as the test itself may prejudice the safety of the system. It is more important that tests give substantial confidence in the operation of the system. To achieve this, deviations from test coverage of 100 % should always be thoroughly substantiated.

Nevertheless, the objectives of testability should not contradict higher ranking objectives, e.g. availability.

- e) How should false alarms and no fault found be managed? The system test may detect and report a failure to the user when a failure does not truly exist. This may cause unnecessary investigations and result in the report of a false alarm. It may also generate unnecessary maintenance action that concludes in a No Fault Found diagnosis. False alarm rates for the various resolutions should not exceed the defined criteria and, where possible, be reduced to zero. Methods that are recognised to minimise these occurrences may involve feedback systems that constantly assess the environment and recalibrate themselves to allow for component degradation within the defined criteria. Repeating a test to eliminate a false alarm (the scenario of the test may have changed sufficiently for the alarm not to be generated) will increase the test time and should be avoided.

Faults can be indicated where no faults exist. This can be due to a number of reasons:

- 1) if a fault found in the system and the diagnostic identifies the faulty item, but upon removal of the item and testing the item independently no fault can be identified, then you have to check the test specification from the system in relation to the test specification from the faulty item;
- 2) poor diagnostics (the test does not adequately identify the faulty part);
- 3) interface difficulties (for example, a connector fault may have resulted in a unit being removed and a re-connection removes the failure);
- 4) poor test equipment including BITE (for example, a detected failure that does not exist);
- 5) intermittent fault (rogue units can sometimes contain faults that are not evident except in certain circumstances);
- 6) design tolerance tiering problems (a failure at system test may not register failure at unit test). Rogue units can have extreme values in the tolerance band that results in continual rejection;
- 7) software faults (faults appearing during usage that are not suitably tested);
- 8) maintainer and user difficulties (inadequate training, speed of turn around, lack of spares) can all result in good units being rejected.

All the above symptoms can have an adverse affect upon operations and support and should be eliminated or minimised wherever possible;

- f) Can system testing be tailored? System testing is concerned with providing assurance that a system will function correctly given defined inputs and within a defined environment. The testability requirements and ability to localise a fault does not necessarily dictate the test procedure. Testing an overall function, with subsequent deeper testing if necessary, can provide substantial timesaving and greatly improve user friendliness. Use of tools such as FMECA (see Annex B) and FTA can assist in defining the sequence of lower level testing by determining the most probable sub-function to have failed.

4.3 Objectives of diagnostic testing

The objective of diagnostic testing is to provide the most cost effective, rapid and unambiguous method of fault identification to a level determined by the maintenance concept for the equipment under test. Good diagnostic testing will

- increase equipment availability;
- decrease maintenance costs;
- reduce the risk of consequential damage;

- improve the safety of the system;
- optimize the operational use.

To achieve the objective, the diagnostic system should

- provide confidence type checks to confirm the serviceability of the equipment for its intended role;
- recognize catastrophic and degradation failures;
- localize faults with respect to the failed function or LRU;
- warn of impending wear-out failures, by evaluation of wear-out states;
- provide data for operation and maintenance of the equipment.

The principal applications of diagnostic testing facilities are

- safety and functional checks prior to the operation of the system;
- performance monitoring during operation;
- equipment failure identification in the operating environment to failed assembly or LRU level;
- detailed fault localization in the designated repair facility.

4.4 Methods used for diagnostic testing

The possible procedures which can be applied for diagnostic testing range from purely manual measurements and evaluation of mechanical characteristics to fully automated diagnosis of entire processes and installations, with the testing of single components and complex systems. The broad diagnostic methods applied fall into two main categories:

- external diagnosis that utilizes test equipment discrete from the product which is only connected when required. The test equipment used may be of a general purpose nature, adapted for the purpose from standard or specially designed for the equipment to be tested. Computer controlled ATE may also be involved;
- internal diagnosis that utilizes permanently built-in test equipment (BITE) which may be continuously or intermittently operated during the operation of the system. In addition, special tests, in the reduced, or non-operating state of the system, may also be performed.

4.5 Methods used for condition monitoring

In addition to diagnostic testing which tests for discrete faults, many products also benefit from condition monitoring. This is performed as a part of preventive maintenance to monitor degradation of condition and performance.

Methods used for condition monitoring will vary with the type of equipment and may include

- vibration analysis;
- fluid/lubricant analysis;
- ultrasonic detection;
- thermography;
- alarms and shutdowns built into the control system.

4.6 Concept of testability

Testability is the design characteristic of a product which guarantees that the functional capability of that unit can be assessed in a timely and efficient manner and that faults can be recognized and, where necessary, localized. It is a primary component of ensuring the maintainability of a product.

Diagnostic testing is the resultant maintenance action that occurs as a part of preventive maintenance as described in the maintenance concept. Test coverage is the degree to which diagnostic testing can be applied. Diagnostic testing consists of two steps: fault recognition (FR) and fault localization (FL). Fault recognition identifies whether a fault exists and fault localization determines the specific nature of the fault.

Diagnostic testing should also consider tolerance chains. For a particular parameter, there is usually an upper limit and a lower limit that bounds the pass and fail regions. A unit function may have tight limits, but as the unit is integrated, these limits are affected by the variability of other units that contribute to the final system function. In addition to the tolerance chains, the accuracy of the test equipment undertaking the test should be considered before the actual pass/fail tolerance band can be defined for a particular test. The test results gathered during development provide an estimation of the process width (the summation of the function production yield and the accuracy of the test equipment, including the accuracy of the test equipment stimuli as well as the reading accuracy of the measuring device). It is not the intention that full coverage of tolerance chains should be part of this standard.

The specifications relating to functionality, including testability, in the form of the characteristic value for the quality of the fault recognition and fault localization have a direct impact on the basic functional features of the product. If the rule "functions that are to be developed should be verifiable via parameters" is followed, then FR and FL are developed concurrently from the very beginning as an integral part of the functionality. In this way, the cost of a product will remain within the prescribed limits. If elements of the FR and FL are integrated at a later date, this will lead not only to considerable delays but also to a reduced product quality with extremely high costs of rework/corrective action.

5 Testability specification

5.1 General

Appropriate contractual provisions are a key prerequisite for efficient conversion of diagnostic testing requirements into measurable practical achievements. In order to enable optimum design, development and supply of diagnostic test procedures, the customer should provide a detailed specification of testability requirements and constraints. For this purpose, the customer should provide the supplier with the following documents:

- a statement of work (SoW). This document contains all the functional requirements related to testing. Within this document, the customer specifies all of the expected functions/functionalities, including testability;
- a testability specification. In this document the contractor (developer) determines the means (hardware, software) to realize the operational and test engineering functions and performance features required by the SoW.

5.2 Statement of work

The SoW contains detailed descriptions of the customer's needs and is intended to form the basis of the design and development programme. Updating is possible, if additional information becomes available in the course of development. However, modifications should be mutually agreed upon, as they will often incur additional time and cost penalties. The requirements should include

- objectives of diagnostic testing (see 4.3);
- operational concept (see 5.3 and Table 1);
- maintenance concept (see 5.3 and Table 2);
- qualitative description of the economical environment (see 4.1);
- preferred methods and solutions (see 4.4).

5.3 Specification

The testability specification determines the testability requirements for the product and possibly for the development phase. The testability specification should define each of the test stages and the associated function elements for which the test specification is applicable. These should include the following.

- a) Tasks and applications of diagnostic testing should include:
 - 1) a list of safety faults for which a fault recognition of as close to 100 % as possible is required;
 - 2) a list of critical faults for which a test coverage of 100 % is required or supporting evidence to justify why the test can be omitted;
 - 3) a lower limit of test coverage for all other functions or global test coverage for all functions (functions to be used for test coverage have to be determined);
 - 4) a maximum value of the fault recognition time;
 - 5) target (maximum) values of the fault localization time;
 - 6) a target and minimum value of the diagnosis correctness;
 - 7) a maximum value of the false alarm rate.
- b) Design for testability should include:
 - 1) general requirements;
 - 2) detailed requirements by checklists;
 - 3) design criteria for testability.
- c) Times and procedures for the following:
 - 1) testability verification;
 - 2) safety verification.

The consequences of not meeting the specified requirements according to the above elements should be defined in advance.

Test tasks that should be specified are further described in 5.4.3. The need for evaluation of alternative methods (see 5.6) should be identified at this stage.

Diagnostic testing activities are closely interconnected with the processes of the product's operation and maintenance. Therefore, the operational and maintenance concepts are important factors to be considered when diagnostic testing requirements are established. They should both be defined as early as possible in the system life cycle, preferably in the concept and definition phase. The operational concept should be the first consideration in order for the system to properly fulfill its requirement. The maintenance concept should be designed to allow the operational need to be met with the most efficient use of resources at minimum cost. A