

Space engineering — Verification

The European Standard EN 14725:2003 has the status of a
British Standard

ICS 49.140

National foreword

This British Standard is the official English language version of EN 14725:2003.

The UK participation in its preparation was entrusted to Technical Committee ACE/68, Space systems and operations, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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This British Standard, was published under the authority of the Standards Policy and Strategy Committee on 22 December 2003

Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 148, an inside back cover and a back cover.

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Amendments issued since publication

Amd. No.	Date	Comments

© BSI 22 December 2003

ISBN 0 580 43129 0

English version

Space engineering - Verification

Raumfahrttechnik - Verifikation

This European Standard was approved by CEN on 1 October 2003.

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COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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Foreword

This document (EN 14725:2003) has been prepared CMC.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 2004, and conflicting national standards shall be withdrawn at the latest by June 2004.

It is based on a previous version¹⁾ originally prepared by the ECSS Space Engineering Working Group, reviewed by the ECSS Technical Panel and approved by the ECSS Steering Board. The European Cooperation for Space Standardization (ECSS) is a cooperative effort of the European Space Agency, National Space Agencies and European industry associations for the purpose of developing and maintaining common standards.

This European Standard is one of the series of space standards intended to be applied together for the management, engineering and product assurance in space projects and applications.

Requirements in this European Standard are defined in terms of what should be accomplished, rather than in terms of how to organize and perform the necessary work. This allows existing organizational structures and methods to be applied where they are effective, and for the structures and methods to evolve as necessary without rewriting the standards.

Annexes A,C,D,E,F,G,H,I,J,K and L are normative. Annex B is informative.

The formulation of this European Standard takes into account the existing ISO 9000 family of documents.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom.

1) ECSS-E-10-02A

1 Scope

This European Standard establishes the requirements for the verification of a space system product.

It specifies the fundamental concepts of the verification process, the criteria for defining the verification strategy and the rules for the implementation of the verification programme.

It includes also in annexes A and B the description of the required documentation (i.e. DRDs) and some guidelines on specific aspects of the verification process such as the model philosophy definition.

This European Standard is intended to apply to different products at different levels (i.e. from a single equipment to the overall system). It is applicable to both the customer and the supplier of the product during all project phases.

The application of these requirements to a particular project is intended to result in an effective product verification and consequently to a high confidence in achieving successful product operations for the intended use.

In preparing this European Standard the following goals have been considered to facilitate its application, effective use and tailoring:

- definition of an envelope of the sets of minimum verification requirements applicable to the different products, so that tailoring is a selection (in reduction) process;
- clear identification of mandatory requirements, tailorable requirements and recommendations by means of the appropriate use of “shall”, “should” and “may” respectively;
- text defining requirements should be selfstanding to the greatest possible extent, to allow direct tailoring.

When viewed from the perspective of a specific project context, the requirements defined in this standard should be tailored to match the genuine requirements of a particular profile and circumstances of a project and with reference to annex B.2.

NOTE Tailoring is a process by which individual requirements of specifications, standards and related documents are evaluated, and made applicable to a specific project by selection, and in some exceptional cases, modification of existing or addition of new requirements.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text, and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN 13701:2001, *Space systems — Glossary of terms*.

EN 13290-4, *Space project management — General requirements — Part 4: Project phasing and planning*.

prEN 13291-2, *Space product assurance — General requirements — Part 2: Quality assurance*.

EN 14097, *Space product assurance — Nonconformance control system*.

EN ISO 14620-1, *Space systems — Safety requirements — Part 1: System safety (ISO 14620-1:2002)*.

ECSS-Q-60, *Space product assurance — EEE components*.

prEN 13291-3, *Space product assurance — General requirements — Part 3: Materials, mechanical parts and processes*.

ECSS-E-10, *Space engineering — System engineering*.

prEN 14824, *Space engineering — Testing*.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this European Standard, the terms and definitions given in EN 13701:2001 and the following apply.

3.1.1

acceptance stage

verification stage with the objective of demonstrating that the product is free of workmanship defects and integration errors and ready for its intended use

3.1.2

analysis

verification method which entails performing a theoretical or empirical evaluation by accepted analytical techniques

NOTE 1 The selected techniques may typically include systematics, statistics, qualitative design analysis, modelling and computer simulation.

NOTE 2 See also EN 13701.

3.1.3

assembly

process of mechanical mating hardware to obtain a low level configuration after the manufacturing process

NOTE See also EN 13701.

3.1.4

in-orbit stage

verification stage valid for projects whose characteristics (e.g. mission, in-orbit operations) require in-orbit verification

3.1.5

inspection

verification method that determines conformance to requirements for constructional features, document and drawing conformance, workmanship and physical conditions without the use of special laboratory equipment, procedures or services

NOTE See also EN 13701.

3.1.6

integration

process of physically and functionally combining lower level products (hardware or software) to obtain a particular functional configuration

3.1.7

model philosophy

definition of the optimum number and characteristics of physical models required to achieve a high confidence in the product verification with the shortest planning and a suitable weighing of costs and risks

3.1.8

post-landing stage

verification stage valid for projects whose characteristics require post-landing verification

EXAMPLE Multimission projects.

3.1.9

pre-launch stage

verification stage with the objective to verify that the flight article is properly configured for launch and, to the extent practical, it is capable to function as planned for launch

3.1.10

qualification stage

verification stage with the objective to demonstrate that the design meets the applicable requirements including proper margins

3.1.11

review-of-design

verification method using validation of previous records or evidence of validated design documents, when approved design reports, technical descriptions and engineering drawings unambiguously show that the requirement is met

3.1.12

test

verification method wherein requirements are verified by measurement of product performance and functions under various simulated environments

NOTE See also EN 13701.

3.1.13

verification level

product architectural level at which the relevant verification is performed

3.2 Abbreviated terms

The following abbreviated terms are defined and used within this European Standard.

Abbreviation	Meaning
AIV	assembly, integration and verification
AOCS	attitude and orbit control system
AR	acceptance review
BB	breadboard
CDR	critical design review
CR	commissioning review
DM	development model

DRD	document requirements definition
ECLS	environmental control and life system
ECSS	European Cooperation for Space Standardization
EEE	electronic electrical and electromechanical
EIDP	end item data package
EM	engineering model
EMC	electromagnetic compatibility
EOL	end-of-life
EQM	engineering qualification model
ESD	electrostatic discharge
EVA	extra vehicular activities
FM	flight model
FMECA	failure mode effects and criticality analysis
FS	flight spare
GPS	global positioning system
GSE	ground support equipment
HFE	human factors engineering
H/W	hardware
I/F	interface
ICD	interface control document
IM	integration model
ISO	International Standard Organization
IVA	intra vehicular activities
LL	lower level
LRR	launch readiness review
MRB	material review board
MU	mock-up
NCR	nonconformance report
OBDAH	on-board data handling

OFT	orbital flight test
P/L	payload
PDR	preliminary design review
PFM	protoflight model
PRR	preliminary requirement review
PTR	post test review
QM	qualification model
QR	qualification review
RCS	reaction control system
RF	radio frequency
RFW	request for waiver
S/C	spacecraft
SS	subsystem
S/W	software
SM	structural model
SRR	system requirements review
STE	special test equipment
STM	structural-thermal model
SVF	software validation facility
TCL	test configuration list
TM	thermal model
TRR	test readiness review
TT&C	telemetry, tracking and command
VCB	verification control board
VCD	verification control document

4 Verification process

4.1 Introduction

The verification process is that part of the supplier's task which demonstrates conformance to applicable requirements. A satisfactory completion of the verification process is the basis for a contractual acceptance (as defined in EN 13701) of the product by the customer.

4.2 Verification objectives

The verification objectives shall be primarily to:

- a) qualify the design;
- b) ensure that the product is in agreement with the qualified design, is free from workmanship defects and acceptable for use;
- c) verify that the space system (including tools, procedures and resources) will be able to fulfil mission requirements;
- d) confirm product integrity and performance after particular steps of the project life cycle (e.g. pre-launch, in-orbit and post-landing).

4.3 Verification process logic

4.3.1 General

The verification process activities shall be incrementally performed at different levels and in different stages, applying a coherent bottom-up building-block concept and utilizing a suitable combination of different verification methods.

4.3.2 Verification process flow

The verification process flow shall be basically subdivided in the following steps:

- a) identification and classification of all the requirements to be verified;
- b) selection of verification criteria (e.g. methods/levels/stages) and models against identified requirements;
- c) establishing the planning for the associated verification activities;
- d) customer concurrence;
- e) identification of verification documentation;
- f) performance of verification tasks and verification control;
- g) completion of verification control and evidence of verification closeout;
- h) customer review and final approval.

4.3.3 Verification approach

4.3.3.1 Definition

To reach the verification objectives a verification approach shall be defined in an early phase of the project by analyzing the requirements to be verified taking into account;

- design peculiarities,
- qualification status of candidate solution,
- availability and maturity of verification tools,
- verification and test methodologies,

- programmatic constraints, and
- cost and schedule.

4.3.3.2 Verification approach derivation

The basic verification approach shall be derived through an iteration process, based on technical/cost/schedule considerations, which defines the “what”, “how”, “where” and “when” of verification by;

- identifying a consistent set of verifiable project requirements which can be subjected to the verification process,
- selecting methods of verification,
- selecting levels of verification and the associated model philosophy,
- selecting facilities,
- identifying resources required, and
- identifying the stages and the events in which the verification is implemented.

4.3.4 Verification closeout

4.3.4.1 General

The verification process shall be considered completed when the customer and the supplier mutually agree that, on the basis of proper documented evidence, the identified requirements have been verified and the associated verification objectives fully reached.

4.3.4.2 Verification closeout exceptions

The requirements not fully verified at a certain level shall be identified and resolved with the customer.

4.4 Verification methods

4.4.1 General

Verification shall be accomplished by one or more of the following verification methods:

- test;
- analysis;
- review-of-design;
- inspection.

4.4.2 Test

When requirements are verified by measuring product performance and function under various simulated environments, the method shall be referred to as “test”.

4.4.2.1 Test principles and procedures

These measurements can require the use of special equipment, instrumentation and simulation techniques. Established principles and procedures shall be used to determine conformance to requirements (see prEN 14824).

4.4.2.2 Test evaluation

The analysis of data derived from test shall be considered an integral part of the test.

4.4.2.3 Demonstration

When relevant, test also includes the demonstration of qualitative operational performance and requirements. The performance, as demonstrated, shall be observed and recorded.

4.4.3 Analysis

4.4.3.1 General

When verification is achieved by performing theoretical or empirical evaluation by accepted techniques, the method shall be referred to as “analysis”.

4.4.3.2 Analytical techniques

The analytical techniques shall be selected from amongst systematic, statistical and qualitative design analysis, modelling and computational simulation.

4.4.3.3 Similarity

Verification by similarity is considered to be part of analysis. It shall be applied if it can be shown that the article under verification is similar to another article that has already been verified to equivalent or more stringent requirements.

The verification activity consists of the assessment and review of prior test data, hardware configuration and applications.

4.4.4 Review-of-design

When verification is achieved by validation of records or by evidence of validated design documents or when approved design reports, technical descriptions, engineering drawings unambiguously show the requirement is met, the method shall be referred as “review-of-design”.

4.4.5 Inspection

When verification is achieved by visual determination of physical characteristics (such as construction features, hardware conformance to document drawing or workmanship requirements) the method shall be referred to as “inspection”.

4.5 Verification levels

The requirement verification shall be performed incrementally at different verification levels. The number and type of verification levels depend on the complexity of the project and on its characteristics.

The typical verification levels for a space project (in line with the definition of EN 13292) are:

- equipment (e.g. valves, batteries and individual electronic boxes);

- subsystem (e.g. electrical power, attitude control, structure, thermal control and software);
- element (e.g. launcher, satellite and ground station);
- system (e.g. manned infrastructure system).

Below the equipment level there is the parts and materials level. The general requirements for the evaluation, approval and procurement of parts and materials are defined in ECSS-Q-60 and prEN 13291-3.

Requirements for parts and materials defined in the customer's specification of a product shall be subjected to formal verification.

The identification of the critical verification levels is driven by technical and programmatic considerations (e.g. functional architecture and overhead cost) having in mind that verification is carried out against the applicable requirements under the responsibility of the organization upon which the requirements are placed.

4.6 Verification stages

4.6.1 General

The verification process shall be implemented in subsequent verification stages all along the program life cycle.

The stages depend upon project characteristics and identify a type of verification.

The classical verification stages are;

- qualification,
- acceptance,
- pre-launch,
- in-orbit,
- post-landing.

4.6.2 Qualification

4.6.2.1 General

In this stage the verification objective shall be to demonstrate that the design meets all applicable requirements and includes proper margins.

4.6.2.2 Qualification article

The articles involved should be fully representative of the design to be qualified. Deviations to this approach may be allowed, based on cost, schedule and risk considerations, by using articles representative in form, fit and function to the extent necessary to meet the qualification objective.

4.6.2.3 Re-qualification

This stage may also include requalification in the case that the design is modified after initial qualification has been achieved.

4.6.3 Acceptance

4.6.3.1 General

In this stage the verification objective shall be to demonstrate that the item is free of workmanship defects and integration errors and is ready for subsequent operational use.

4.6.3.2 Acceptance article

The involved article shall be manufactured in agreement with the qualified design and shall perform as the qualified product.

4.6.3.3 Re-certification

This stage may also include recertification in the case that the representative configuration is disassembled (e.g. due to failure or repair actions), or where it has undergone long-term storage.

4.6.4 Pre-launch

The verification objective of the pre-launch stage shall be to verify that the article is properly configured for launch and early operations and, to the extent practicable, it is capable to function as planned for launch.

4.6.5 Inorbit

4.6.5.1 General

This stage is valid for projects whose characteristics (e.g. mission or in-orbit operations) require in-orbit verification.

In particular, the in-orbit stage verification objective shall be to supplement ground testing by providing operating conditions which cannot be fully or cost effectively duplicated or simulated on the ground.

At the beginning of this stage a commissioning process is often carried out for particular types of products.

4.6.5.2 In-orbit re-verification

In addition, during the in-orbit stage, verification of hardware and software shall be repeated:

- subsequent to modification of previously verified hardware or software;
- following repair or replacement of failed hardware/software;
- when a functional path has not normally been used for a specified period;
- subsequent to in-orbit anomalies or contingencies.

4.6.6 Post-landing

This stage is valid for projects whose characteristics require post-landing verification (e.g. multimission projects).

Post-landing stage verification objective shall be to verify:

- selected functions (at periodical intervals) during storage periods;
- the product status after the mission;

- consequences of in-orbit anomalies.

5 Verification strategy

5.1 Preparation

As a basis for the verification process, mandatory technical requirements shall be properly specified for each product (see ECSS-E-10). An adequate verification strategy, in which appropriate methods, levels, stages and models have been selected, shall be prepared by the supplier and submitted to the customer for agreement.

The selection of verification methods, levels, stages and associated models is a compromise between cost, schedule, performance and associated risks (see EN 13290-1).

5.2 Requirements classification

5.2.1 Requirements identification

The requirements applicable to a particular product are contained in technical specifications and interface control documents.

The first step of the verification process shall be to identify the requirements to be verified and classify them.

5.2.2 Requirements documentation

The requirements shall be generated and allocated top-down at the different project levels in order to form a tree of technical specifications and interface control documents containing consistent performance, design, interface, environmental, operational and support requirements (see ECSS-E-10).

5.2.3 Requirement characteristics

In order to facilitate the verification implementation in terms of planning, execution, control and reporting, the requirement generation and allocation activity shall ensure specific requirements characteristics.

Each requirement shall be;

- traceable,
- unique and associated to a proper identifier (for instance a document and subclause number),
- single and not a combination of several requirements,
- verifiable using one or more approved verification methods,
- unambiguous,
- referenced as necessary to other requirements (with applicable document and subclause identification), and
- should be associated with a specific title.

In other words a successful verification starts with a satisfactory set of project requirements. Each requirement shall be seen as both the origin and the conclusion of the verification process, and shall be treated as fundamental technical information rather than a constituent of a verbose text.

5.2.4 Requirement criticality

The requirement criticality, in terms of technical and programmatic impacts on the verification implementation, shall be assessed by early involvement of the verification team in the requirement definition process since it drives the verification strategy.

5.2.5 Requirements not to be tracked

Some requirements shall not be tracked if in practice they are;

- obvious in their execution (for example, requirements for test procedure or report),
- redundant with other requirements, or
- purely descriptive (for example, definitions).

These requirements shall be identified and marked with a proper non-tracking decision.

5.2.6 Requirement categories

The requirements to be verified shall be grouped in categories to facilitate the definition of verification strategy.

The grouping criteria should provide the possibility of identifying a homogeneous verification strategy for the category itself.

The requirement categories depend on the project characteristics and organization. Typical requirement categories are shown in Table 1.

5.2.7 Requirements traceability

The requirement traceability associated with the requirement categorization shall be utilized to assist coherence and completeness of the selected verification strategy.

5.2.8 Verification matrix

The verification strategy shall be reflected in a verification matrix which shows for all requirements the selected verification methods for the different verification levels in the applicable verification stages (see subclause 6.6).

Table 1 — Typical requirement categorization

Mechanical	(including structural environment, debris or meteoroid protection, and mechanisms)
Thermal	(including thermal environment, thermal control, thermal protection and aerothermal)
Guidance navigation and control	(AOCS, rendezvous and docking and piloting)
Propulsion	(including RCS)
Power	(including power generation and distribution)
Landing	(including parachute and retrorockets)
Communication	(including antennas and RF)
Data management	(including OBDH and software)
ECLS	(including atmosphere control and contamination)
Mission	(including mission definition, life, pointing, stability, orbit and alignment)
Configuration	(including physical properties, interfaces, composition, modularity, accessibility and light tightness)
Human factors	(including human factor engineering, man in the loop, IVA, EVA and crew related aspects)
EMC	(including ESD, lightning and magnetic cleanliness)
Quality factors	(including safety, reliability, availability and maintainability)
Flight operations	(including autonomy, control authority, failure management and operation procedures)
Ground operations	(including ground processing, launch site, post landing and control center)
Support	(including GSE, spares, logistics and training)
Microgravity	(including audible noise and human vibration)

5.3 Selection of methods, levels and stages of verification

5.3.1 General

The selection of suitable methods, levels and stages of verification shall be dependent upon the project characteristics and the associated requirement categories.

5.3.2 Selection of verification method

After identification of the requirement to be verified the potential verification methods and alternatives in each particular case shall be seen in the context of the overall flow, the testing techniques, and the analytical tools available and assessed for feasibility against the criteria indicated below:

- method is technically feasible;
- verification facilities are available;
- sufficient level of confidence can be achieved with reasonable fidelity, accuracy, and validity;
- risks to personnel, flight hardware and facilities are acceptable;
- impact on schedule is acceptable;
- verification costs are acceptable.

5.3.3 Selection of verification level

The selection of verification levels shall take into account programmatic aspects such as: standardized hardware levels (e.g. service modules), make or buy decisions (e.g. off-the-shelf equipment), reduction of overhead costs (e.g. deletion of subsystem level) and responsibility.

5.3.4 Selection of verification stages

The verification stages shall be selected taking into consideration the project characteristics and associated life cycle. In particular the stages selection shall be seen in close relationship with the adopted model philosophy (see subclause 5.4).

5.3.5 Additional rules for selection

Beside the aspects associated with a specific requirement category, the following additional rules shall be applied to the selection of methods, levels and stages of verification:

- a) All safety critical functions shall be verified by test.
- b) Test should be the preferred verification method when it is practical, cost effective and safe; alternative methods may be selected, considering requirement criticality, cost effectiveness and schedule.
- c) Analysis should be used when flight conditions cannot be accurately simulated on the ground or when it is not economically feasible to test the entire spectrum of flight conditions. Analysis and test methods are very often complementary.
- d) If several verification methods are possible, each having the same level of confidence on the verification results, the selection shall be oriented to minimize the required effort.

- e) Verification of critical requirements (for instance related to new technologies) should be achieved as early as possible (e.g. at the lowest suitable level) to have early feedback in the programme.
- f) To bypass difficulties of testing (i.e. size of facilities, or test representativeness) in presence of complex systems or to minimize expensive system testing a combined approach may be selected, which includes a test campaign at a lower level and analysis at a higher level.
- g) If, in particular, environmental testing at higher level is impracticable or too costly, lower level testing shall be carried out, completed by analysis, to demonstrate conformance to higher level requirements.
- h) When mission characteristics require in-flight verification, the verification shall not rely on in-orbit activities alone; requirements shall be verified with proper methods prior to the first flight in case of a multimission project.
- i) Internal and external interface verification shall be carried out at the appropriate level of responsibility. In case of testing the use of actual interfaces is preferable to the use of simulators.
- j) A lower level verification should be completed prior to an associated higher level verification.
- k) Duplication of verification activities on different levels should be avoided.
- l) All verifications associated with any stage should be completed prior to the start of the next stage. In particular, qualification should be finished before the start of acceptance.
- m) Verification of software shall include a test in the target hardware environment.
- n) In addition to the combination of the verification activities between the different levels, the verification of complex functional chains (typically operational performances and mechanisms actuation) should anticipate integrated end-to-end testing.
- o) All physical or functional requirements for a given product should be verified on that particular product level to the maximum extent feasible and reasonable.

5.4 Selection of models

5.4.1 Number and type of models

Models shall be selected defining the optimum number and type of physical models required to achieve a high confidence in the product verification with the shortest schedule and a suitable weigh of costs and risks.

5.4.2 Model philosophy definition

Model philosophy shall be defined by means of an iterative process which combines programmatic constraints, verification strategies and the integration and test programme, taking into account the development status of the candidate design solution (see also ECSS-E-10A Figure 6).

Model philosophy shall be defined early in the project and frozen as soon as possible due to its impact on the project implementation

5.4.3 Model applicability

The various types of models and model philosophies are described in annex B.1 together with associated guidelines. Their applicability depends on the specific project requirements. The following main rules shall be observed:

- a) The number of models should be minimized and their reuse between different levels maximized to reduce costs.

- b) Parallel models should be utilized in order to suitably separate the test activities from each other and consequently to reduce risks of schedule slippage.
- c) Design verification (qualification) shall be carried out on hardware and software which is representative of the end item configuration (e.g. prototype models, flight models in case of protoflight or hybrid approach).
- d) Workmanship verification (acceptance) shall be carried out on the final hardware and software (e.g. flight models, and spares).
- e) In exceptional cases, selected design parameters may be verified using development models, subject to customer concurrence.

5.5 Verification by test

5.5.1 General

A test programme shall be defined in line with the selected verification approach and model philosophy, on the basis of the verification strategies for the different requirement categories.

5.5.2 Test programme definition

In defining the test programme the following rules shall be taken into account:

- a) Critical items and interfaces shall be tested early in the programme.
- b) Allowance shall be made for the possibility of alternate paths (work around plans, contingencies).
- c) The test flow shall minimize the incidence of the regression testing.
- d) The reuse of models, simulators and support equipment shall be maximized.
- e) Test feasibility shall be confirmed early in the programme.

5.5.3 Integration flow

The test program shall be coordinated with the integration flow to optimize both test and integration activities.

5.5.4 Integration tests

Interface or integrity tests shall be performed as part of the integration flow to check quality and status of the inprogress configuration.

If these tests have a verification purpose, they shall be included in the overall test programme.

5.5.5 Reintegration tests

In response to the requirements of fault-finding or during the postlanding phase in the case of a multi-mission or to carry out modifications or repairs, equipment may be disassembled (de-integrated).

In this case de-integration and re-integration shall be performed in a controlled manner and shall be properly documented. All interfaces which were broken by de-integration shall be re-verified and all relevant integration tests shall be repeated.

These tests are also called regression tests.

5.5.6 Test versus verification stages

The overall test programme shall cover development, qualification, acceptance, pre-launch, in-orbit and post-landing testing as necessary; in this respect the test programme shall be tailored to each specific project or product and shall comply with the standard test requirements defined in prEN 14824.

5.5.7 Test versus verification levels

The overall test programme shall cover the different verification levels as necessary; in this respect it shall be tailored to each specific project and product and shall comply with the standard test requirements defined in prEN 14824.

5.5.8 Test matrices

Starting from the applicable verification matrix, test matrices should be established, to show the correlation of requirements categories with the test to be performed at the different levels in the various verification stages.

They identify the test verification events to be used for planning purposes.

5.6 Verification by analysis

5.6.1 General

An analysis programme compatible with the selected verification approach shall be defined on the basis of the verification strategies for the various requirement categories.

5.6.2 Analysis programme definition

In defining the analysis programme, the following factors shall be taken into account:

- a) The analytical technique shall be validated (verification by analysis is dependant on the quality of the analytical techniques and on the experience gained in using them).
- b) Analysis may be used in support of test or vice versa.
- c) When analysis is supported by test data, testing shall be performed on a representative model.
- d) Analysis for verification may be based on design analysis.

5.6.3 Verification analysis criteria

5.6.3.1 Applied criteria

In performing the verification analyses, the following criteria shall be applied:

- Modelling system used shall be described, and its usage justified.
- Product configuration to which the analysis is applied shall be identified.
- All boundary conditions shall be stated.
- All assumptions used in the analysis shall be stated.
- Field of investigation and the range of validity of the results shall be defined.

- Analytical uncertainty shall be taken into account such that specified performance is demonstrated with an adequate margin.
- Analysis shall cover both the nominal and the worst case conditions.

5.6.3.2 Similarity criteria

For an article “A” to be considered as “verified by similarity” to an article “B” the following criteria shall be satisfied:

- Article “A” is a minor variation of article “B” (i.e. by substitution of parts and materials with equivalent reliability items).
- Articles “A” and “B” perform equivalent functions (with “B” qualified for an equivalent or longer operating life with variations only in terms of performance such as accuracy, sensitivity or input- output characteristics).
- Articles “A” and “B” are produced by the same manufacturer using identical tools and manufacturing processes (in case specific technology or knowledge are required).
- Environments encountered by article “B” during its verification life cycle are equal to or more severe than the verification environments intended for article “A”.
- Article “B” was not qualified by similarity.

5.6.4 Analysis versus verification stages

Verification by analysis should be used in the qualification stage only.

5.6.5 Analysis versus verification levels

Verification by analysis may be used at all verification levels.

5.6.6 Analysis matrices

Starting from the applicable verification matrix, analysis matrices may be established, showing the correlation of the requirements categories with the analyses to be performed at the different levels.

These matrices identify the analysis verification events to be used for planning purposes.

5.7 Verification by review of design

5.7.1 General

A review-of-design programme compatible with the selected verification approach shall be defined on the basis of the verification strategies for the different requirements categories.

5.7.2 Review of design programme definition

In defining the review-of-design programme, the following factors shall be taken into account:

- a) Activity shall consist of reviewing a document or drawing for conformance to a specific requirement.
- b) Activity should be carried out simultaneously with the product design reviews.
- c) Activity may include the review of lower level records (e.g. requirement verified by test at a lower level).

5.7.3 Review of design versus verification stages

Verification by review-of-design should be used in the qualification stage only.

5.7.4 Review-of-design versus verification levels

Verification by review-of-design may be used at all verification levels.

5.7.5 Review-of-design matrices

Starting from the applicable verification matrix, review-of-design matrices may be established, showing the correlation of the requirement categories with the review-of-design activities to be performed at the different levels.

These matrices identify the review-of-design verification events to be used for planning purposes.

5.8 Verification by inspection

5.8.1 General

An inspection programme compatible with the selected verification approach and model philosophy shall be defined on the basis of the verification strategies for the different requirement categories.

5.8.2 Inspection programme definition

In defining the inspection programme the following factors shall be taken into account:

- a) Activity shall consist of inspecting hardware and software for conformance to applicable documentation.
- b) Inspection could be complementary to the review-of-design.
- c) Activity should be carried out together with quality assurance tasks during the manufacturing or integration process.
- d) Activity may be performed by the crew during the in-orbit verification.

5.8.3 Inspection versus verification stages

Verification by inspection may be used in all stages.

5.8.4 Inspection versus verification levels

Verification by inspection may be used at all verification levels.

5.8.5 Inspection matrices

Starting from the applicable verification matrix, inspection matrices may be established, showing the correlation of the requirement categories with the inspections to be performed at the different levels in the applicable verification stages.

These matrices identify the inspection verification events to be used for planning purposes.

5.9 Re-flight verification

5.9.1 Re-flight verification programme

A new verification programme based on the previous flight shall be established by reviewing and assessing existing documentation, on the basis of the requirements for the new flight and by inspecting the hardware and software to be reflown.

5.9.2 Re-flight verification activities

The following covers both, re-flight with or without design changes.

For planning and identification activities the following documents shall be reviewed, analysed and assessed.

- a) End item data package (EIDP)
EIDP shall be checked item by item to identify re-verification activities.
- b) FMECA
FMECA shall be reviewed for validity.
- c) Historical records shall be analysed for events during integration, test, mission, re- integration and transport.
- d) Nonconformance (NCR) and deviations shall be screened for potential transfer to a “new” NCR/deviation (see ECSS-Q-20-09). The previous NCR/deviation- no. shall be recorded as reference on the new established NCR/deviation for traceability.
- e) Mission anomaly and failure reports shall be reviewed for their impact on re-flight verification.
- f) Specifications and I/F requirement documents
For the planned re-flight of a product, specifications and I/F requirement, documents shall be reviewed with respect to applicability of existing requirements, new requirements, new accommodation, new environment and activities for refurbishment including design changes.
This may result in an update of the specification with new or changed verifications.
- g) Structural analysis, the fracture control analysis, or the life limited item list shall identify those areas (e.g. joints) which requires access (requirement for deintegration) for visual inspection or non- destructive- inspection before re-flight.

6 Verification implementation

6.1 General aspects

The following general aspects shall be considered by those involved in establishing and implementing a verification programme:

- a) Ensure the definition of correct verification criteria for each requirement by participating in the preparation of specifications.
- b) Verification has an impact on the design (e.g. modularity, testability, and accessibility).
- c) Ensure a coherent approach to verification implementation throughout the various levels in order to achieve a verified product.
- d) Ensure early verification of critical items to reduce the risks of late failure identification.

- e) Optimize the design and use of ground support equipment, simulators and test software (e.g. re-use for flight operations).
- f) Minimize cost and schedule by avoiding duplication of tasks.
- g) Optimize the use of test facilities.
- h) Plan for feedback to the verification activity from the in-orbit results in case of multi-mission projects or recurring products.
- i) Ensure suitable coverage of the interface verification.
- j) Investigate innovative solutions which may reduce overall verification costs.
- k) Provide adequate visibility and objective evidence of verifications performed.

6.2 Verification responsibilities

6.2.1 Assignment of responsibility

The supplier shall assign clear responsibility for the implementation of the verification programme.

The verification personnel shall be involved from the early project phases in order to follow a concurrent engineering approach which avoids separation between verification requirement definition and verification implementation.

Typical verification responsibilities are described in annex B.5.

6.2.2 Verification control board (VCB)

The VCB shall be established with the participation of customer and supplier.

The objective of the VCB is to assess and approve the status of the verification process including the approval of the verification close-out through the VCD.

Verification status should be carried out periodically during the execution of the project implementation and on the occasions of the important reviews.

6.2.3 Test readiness review (TRR) and post test review (PTR)

The supplier shall convene reviews to declare the readiness for test and to review the preliminary results in order to declare the test completion.

These reviews shall be carried out prior to and after each main integration and test activity (see prEN 13291-2).

The customer should be invited to attend each review.

6.2.4 Nonconformance review board (NRB)

When a major nonconformance is detected during verification activities, a nonconformance report shall be written and processed by the NRB (see ECSS-Q-20-09).

In particular, the use of a failure questionnaire is strongly recommended to collect statistical information for entry into a database which holds verification lessons learnt as a result of verification activities.

6.2.5 Verification responsibilities documentation

Verification responsibilities shall be documented by the supplier and approved by the customer (see subclause 6.6 for documentation details).

No verification process activity should start before the approval of the governing document.

6.3 Verification planning

6.3.1 Establishment of planning activity

On the basis of the logic of the verification process and taking into account the model philosophy, the verification strategies, the integration and test programme, the analysis/review- of- design inspection programme and the identified verification tools, a verification planning activity shall be established which synchronizes the verification activities with the project milestones and programmatic constraints.

The level of detail varies with the type of product and in relationship with the actual phase of the project.

6.3.2 Verification planning content

The verification planning activity shall take into account the following elements:

- product tree (starting from the lowest level);
- applicable models;
- estimated time effort for procurement/design/manufacturing of each model;
- utilization of models (in line with the model philosophy);
- estimated time effort for the integration of models;
- selected test programme and sequences at different levels with estimated time and resources;
- analysis, review- of- design and inspection activities suitably combined on the basis of the verification strategies and estimated time and resources;
- activities and time associated with the procurement of the required verification tools;
- project milestones and the relevant verification output.

6.3.3 Phasing with project life cycle

The verification planning shall be properly phased with the project life cycle.

Figure 1 shows a typical verification process with its output in relation to the project phases and milestones (as described in EN 13290-4).

Guidelines for verification activities are described in annex B.4.

6.3.4 Verification planning documentation

Dedicated documentation shall be generated by the supplier to provide proper evidence of the verification process planning and shall form the basis of the subsequent implementation (for details on documentation see subclause 6.6.2.4).

The documentation shall be approved by the customer.

6.4 Verification tools

6.4.1 General

The degree of verification applied to tools used to support the verification programme shall be established.

Formal verification procedures shall be applied to tools which are specified as deliverable items.

6.4.2 Tools validation

Evidence that the tools are suitable for their intended use shall be provided.

6.4.3 Ground support equipment (GSE)

6.4.3.1 Introduction

Ground support equipment is used to support assembly, integration, test, handling, transport and launch campaign activities.

6.4.3.2 GSE validation

The GSE shall be validated based on expected environmental conditions and operational constraints.

Hazards to personnel, flight hardware, facilities and environments shall be processed in accordance with EN ISO 14620-1.

6.4.3.3 GSE test program

A test programme shall be established in order to validate the functions and performance of all GSE equipment and the compatibility of the interfaces with flight items and facilities.

6.4.3.4 Modified or redesigned GSE

Modified or redesigned GSE, or GSE used in a new application, shall be revalidated to the extent necessary prior to use.

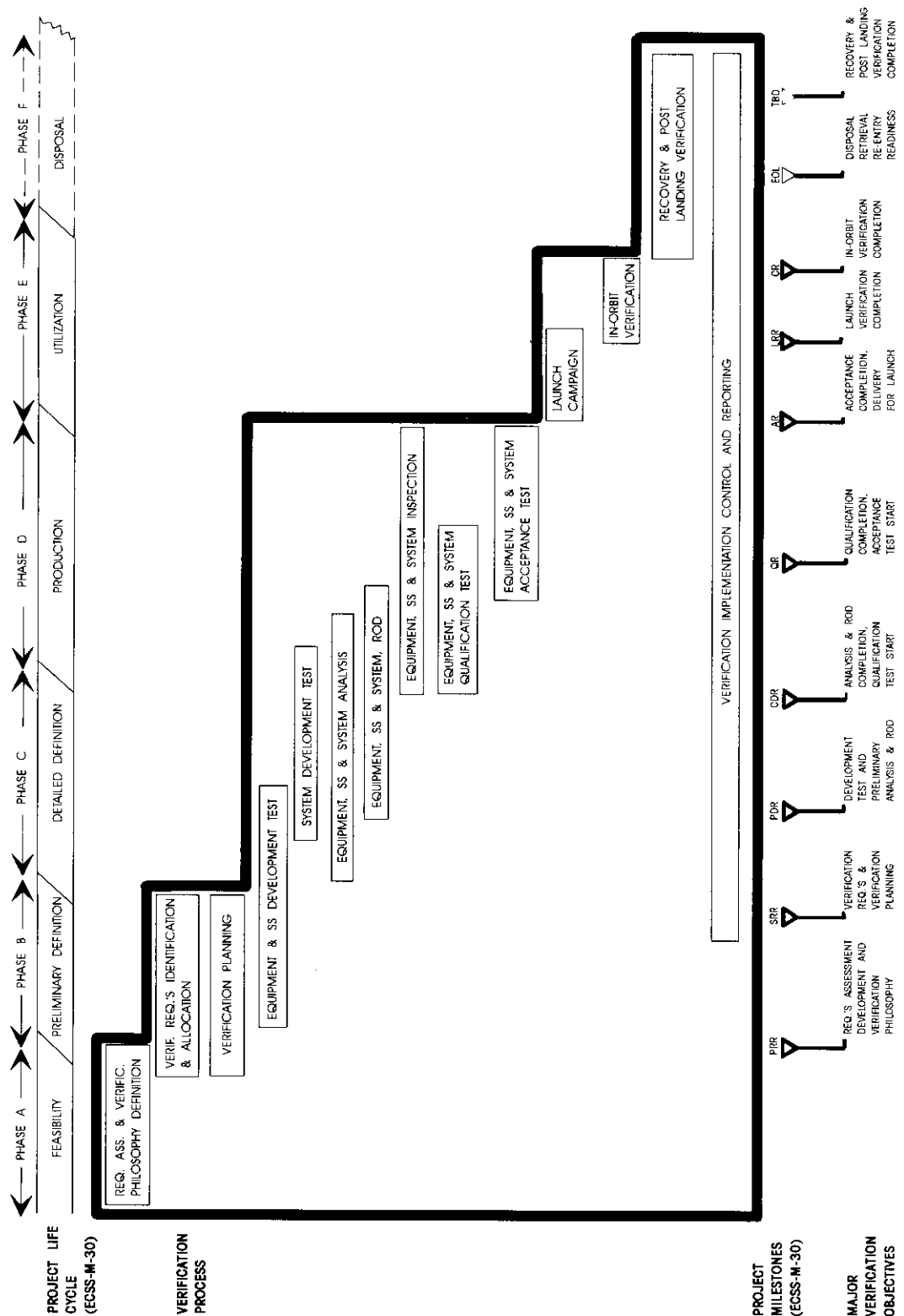


Figure 1 — Typical verification process phasing with the project life cycle

6.4.4 Software validation facility (SVF)

6.4.4.1 SVF support

The SVF shall provide a test bench able to support all phases of onboard software test and validation. It is used prior to the integration of the software into the target hardware during the software development activity, as a tool to support independent software validation and to support software maintenance.

In particular, the SVF shall support;

- a) modelling of the environment in which the software has to operate (including the capability for margins and error injection),
- b) verification of the onboard software in operational conditions, using non-intrusive methods, and
- c) debugging and troubleshooting of onboard software.

6.4.4.2 SVF validation

The SVF shall be validated by comparing the results of test simulation activities with the required performance.

6.4.5 Simulators

6.4.5.1 Use of simulators

Simulators may be used at all levels to simulate items, functions, conditions or interfaces in absence of the real hardware and software during integration and test activities.

6.4.5.2 Simulators validation

Validation shall demonstrate that the simulator characteristics are consistent with the test to be supported.

6.4.6 Software tools for verification by analysis

6.4.6.1 Utilization

Software tools are often utilized to carry out the analytical verification.

6.4.6.2 Analytical software tools validation

Tools already validated for similar applications shall be preferred.

Their suitability for the intended application shall be assessed.

Nonvalidated tools shall be subjected to a validation process prior to their use.

6.4.7 Integration and test facilities and equipment

6.4.7.1 Introduction

Integration and test facilities and laboratory test equipment may be used to support the integration and test programme.

6.4.7.2 Integration and test facilities and equipment validation

The suitability of such facilities and equipment in terms of performance and calibration shall be demonstrated as part of the overall integration and test process.

6.5 Verification execution and control

6.5.1 Monitoring

The implementation of the verification programme shall be monitored following a day-by-day verification control concept oriented to identifying potential problems, with the object of reducing the risk of cost increase and schedule slippage.

6.5.2 Verification database

The verification process should be supported by a verification database which allows;

- systematic traceability of all requirements at each verification level,
- possibility to perform coherence checks between products and levels,
- monitoring of the verification process throughout the project life cycle,
- identification of impacts at the various levels in case of change of requirements or criticalities during lower level verification,
- immediate and flexible reporting of data in support of the preparation of the project verification documentation,
- minimization of repetitive jobs,
- elimination of errors, and
- integration into the higher level of the lower level verification data.

6.5.3 Reverification

Each requirement should be verified only once, but additional reverification shall be performed in the following cases:

- following failure and repair as decided by NRB (see EN 14097);
- after disassembly or demating;
- for products to be re-flown;
- after refurbishment, maintenance or design changes;
- following changes of requirements after initial verification.

6.5.4 Verification execution evidence

The documented evidence of verification or reverification that is performed shall be provided by the supplier to the customer (for details on documentation see subclause 6.6).

6.5.5 Verification closeout

The documented evidence of verification close-out shall be provided by the supplier and submitted for agreement by the customer (for details on documentation see subclause 6.6). If a document provided for verification closeout has been approved the related verification shall be considered closed.

6.5.6 Test effectiveness

In order to optimize the test activities an evaluation shall be performed considering the ability of specific tests to detect failures (test effectiveness).

The optimization of test activities shall consider associated costs and risks.

The evaluation of the test effectiveness should be based on statistical data.

This evaluation is based on the fact that the failures detected during ground testing are only a portion of the spacecraft infant mortality failures; some failures escape testing and they may end up as early flight failures.

The most effective tests shall be selected to reduce early flight failures.

6.5.7 Verification lessons learnt

The lessons learnt from the verification process (including test effectiveness results) shall be collected and fed forward into the definition of the next verification programme.

6.6 Verification documentation

6.6.1 Documentation steps

The verification process and its implementation activities shall be documented by means of a specific set of verification documents.

This activity is a compromise between minimizing documentation effort, to meet cost constraints and the requirement to properly trace the verification events, which is fundamental in order to reduce risks and to facilitate recovery actions in case of problems.

The verification process documentation is summarized in Figure 2.

NOTE The arrows in Figure 2 reflect the logical connection between documents and do not necessarily represent the process flow.

With this approach, taking as an example a system thermal requirement to be verified with a thermal balance test and the associated analysis in the qualification stage, the following documentation steps should apply:

- Requirement is identified in the relevant system specification together with its verification entries (i.e. “T” and “A” methods at “System” level in “Qualification” stage) in the associated verification matrix.
- System assembly, integration and verification plan defines the relevant verification events and associated flows (i.e. thermal balance test and thermal analysis), outlining them in the dedicated activity sheets.
- Specific test requirements, which take into account project general test requirements contained in the test requirement specification, are subsequently detailed in a thermal balance test specification which is followed by several test procedures with the relevant step-by-step instructions.
- Test results are summarized in the dedicated test report.

- In parallel the required analysis is carried out in relationship to the test activities (i.e. test prediction/correlation) and the results presented in the relevant analysis report.
- Synthesis of the performed verification activities (test plus analysis) is described in the verification report.
- System verification control document currently traces the status of the verification implementation and finally gives the evidence of the requirement verification closeout.

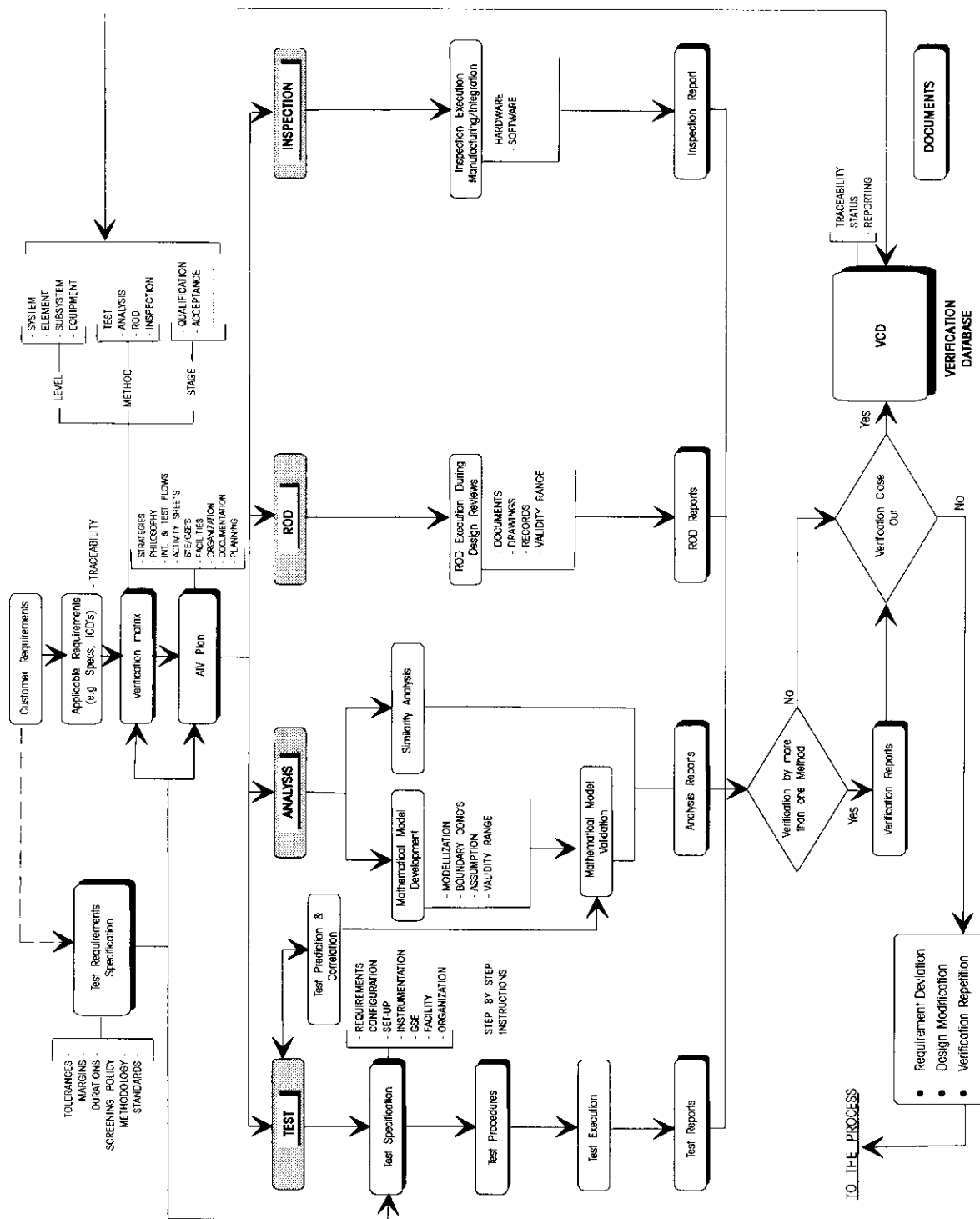


Figure 2 — Verification documentation

6.6.2 Verification documents

6.6.2.1 General

The applicability of the following verification documents to projects and products shall be considered (refer to annex A for DRD numbers).

6.6.2.2 Verification matrix

The verification matrix shall define for each requirement the corresponding verification method at the applicable verification level in the relevant verification stage. It may be included in the product specification.

The verification matrix is the starting point for the VCD.

This document shall be in accordance with the DRD in annex C.

6.6.2.3 Test requirement specification

The test requirement specification is typically a system support specification applicable to all verification levels through the relevant product specifications (e.g. system, subsystem and equipment specification).

It shall contain the general test requirements in terms of type of tests, sequences, margins, durations, tolerances, screening policy and methodology.

This document should be a tailored version of prEN 14824.

6.6.2.4 Assembly integration and verification (AIV) plan

The AIV plan shall be the master plan for the project verification process and shall demonstrate how the requirements will be verified by a coherent implementation approach. This plan includes the assembly, integration and test planning.

In specific circumstances (e.g. project with a complex production cycle) the assembly and integration plan may be a separate document.

For certain lower level product (e.g. simple equipment) the AIV plan could be practically coincident with the test plan.

It shall contain the overall verification approach, the model philosophy, the hardware matrix, the verification strategies for each requirement category, the analysis, review of design and inspection programme, the assembly integration and test programme, the verification activity sheets and the relevant planning, the selected test facilities, the verification tools, the verification control methodology, the involved documentation, the verification management and organization. The document shall be in accordance with the DRD in annex D.

6.6.2.5 Verification control document (VCD)

The verification control document shall list all the requirements to be verified with the selected methods in the applicable stages at the defined levels (in this sense it replaces the verification matrix) and provides traceability during the phase C/D, how and when each requirement is planned to be verified and is actually verified. The document shall be in accordance with the DRD in annex E.

The VCD requires formal concurrence by the customer and becomes part of the EIDP as detailed in prEN 13291-2.

6.6.2.6 Test specification

The test specification can be prepared for specific test activity(ies) described in the AIV plan activity sheets with the objective to detail the test requirements for special purposes (e.g. to interface with a test facility).

This document reflects an intermediate step in the test process definition between the overall planning (AIV plan) and the specific test procedure. It can be combined with the above documents depending on actual project requirements.

The test specification shall contain the activity objectives, the selected approach, the article configuration, the set-up description, the necessary GSE, the equipment and instrumentation, the conditions for the activity, the required facilities, the sequence of activities with the detailed verification requirements, the success criteria, the organization and responsibilities, the involved documentation, the relationship with product assurance activities, the schedule. The document shall be in accordance with the DRD in annex F.

6.6.2.7 Test procedure

The test procedure shall provide detailed stepbystep instructions for conducting test activities in agreement with the relevant test requirements.

The test procedure shall contain the activity objective, the applicable documents, the references to the relevant test specification, the participants required, the article and tools configuration list, the step-by-step procedures.

The document shall be in accordance with the DRD in annex G.

6.6.2.8 Test report

The test report shall describe test performance, results and conclusions in the light of the test requirements.

This report shall contain the introduction, the test description, the test results including the as-run test procedures, the considerations and conclusions with particular emphasis on the close-out of the relevant verification requirements including any deviation.

The document shall be in accordance with the DRD in annex H.

6.6.2.9 Analysis report

The analysis report shall describe, for each analysis, the relevant assumptions, utilized methods, techniques and results.

It shall contain proper evidence that the relevant requirements are verified and the indication of deviations.

The document shall be in accordance with the DRD in annex I.

6.6.2.10 Review of design report

The review of design report shall describe each verification activity performed for reviewing documentation.

It shall contain proper evidence that the relevant requirements are verified and the indication of any deviation.

The document shall be in accordance with the DRD in annex J.

6.6.2.11 Inspection report

The inspection report shall describe each verification activity performed for inspecting hardware.

It shall contain proper evidence that the relevant requirements are verified and the indication of any deviation.

The document shall be in accordance with the DRD in annex K.

6.6.2.12 Verification report

The verification report may be prepared in cases when more than one of the defined verification methods are utilized to verify a requirement or a specific set of requirements.

It shall explain the approach followed and how the verification methods were combined to achieve the verification objectives.

The positive achievement constitutes the completion of verification for the particular requirement.

The document shall be in accordance with the DRD in annex L.

6.6.3 Other documents

In addition to the above major documentation, other offline documents may be part of the verification process to provide the necessary traceability and event record, such as: test configuration list (TCL), enditem data packages, logbooks (including work items and deviation work items), nonconformance reports (NCRs), request for waivers (RFWs), manuals, simulation plans, verification tools documentation.

Annex A (normative)

Verification documents

In line with the requirements of subclause 6.6, the following document requirements definitions as listed in the DRD index of Table A.1 are applicable to the verification documentation.

The Table includes the DRD number, title, applicability to project phases (as described in EN 13290-4), delivery and remarks.

The DRDs, the applicability to project phases and the delivery events have to be tailored for the specific project in line with the requirements of this standard.

As a general rule, the content of the verification documentation shall be clear and precise, without possibility of different interpretation.

Table A.1 — EN 14725 DRD index

DRD number	DRD title	Applicable to (phase)							Deliver at	Remarks
		0	A	B	C	D	E	F		
EN 14725 annex C	Verification matrix		X	X	X				PRR, SRR, CDR	Will be eventually incorporated in the VCD as soon as frozen
EN 14725 annex D	Assembly, integration and verification (AIV) plan		X	X	X	X	X	X	PRR, SRR, CDR, QR, AR, LRR, EOL	Includes assembly, integration and test plan
EN 14725 annex E	Verification control document (VCD)			X	X	X	X	X	Periodically as a minimum at SRR, CDR, QR, AR, LRR, EOL	
EN 14725 annex F	Test specification				X	X			Several months before test	
EN 14725 annex G	Test procedure				X	X	X	X	Few weeks before test	
EN 14725 annex H	Test report				X	X	X	X	Few weeks after tests	
EN 14725 annex I	Analysis report				X	X	X	X	Few weeks after analysis	
EN 14725 annex J	Review -of -design report				X	X			Few weeks after review - of - design	
EN 14725 annex K	Inspection report				X	X	X	X	Few weeks after inspection	
EN 14725 annex L	Verification report				X	X	X	X	Few weeks after completion of the last verification activities	