

Reliability testing — Compliance tests for constant failure rate and constant failure intensity

ICS 29.020

National foreword

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The UK participation in its preparation was entrusted by Technical Committee DS/1, Dependability and terotechnology, to Subcommittee DS/1/1, Dependability, 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;
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Summary of pages

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Plans d'essai de conformité
d'un taux de défaillance constant
et d'une intensité de défaillance constante**

**Reliability testing –
Compliance tests for constant failure rate
and constant failure intensity**



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CONTENTS

	Page
FOREWORD.....	3
INTRODUCTION.....	4
 Clause	
1 Scope	5
2 Normative references	5
3 Definitions	6
4 Symbols.....	6
5 Nature of requirement and area of application.....	7
6 General test procedure.....	8
7 Sequential test plans.....	10
8 Time/failure terminated test plans.....	12
9 Calendar time/failure terminated test plans for non-repaired/non-replaced items	17
10 Presentation of results	19
 Annexes	
A Tables and graphs for sequential test plans (see clause 7).....	20
B Graphs for fixed time/failure terminated test plans (see 8.1)	38
C Graphs for alternative time/failure terminated test plans (see 8.2)	42
D Example and mathematical reference for sequential test plans (see clause 7)	46
E Examples and mathematical reference for time/failure terminated test plans (see 8.1)	49
F Examples and mathematical reference for the design of alternative time/failure terminated test plans (see 8.2)	51
G Examples and mathematical reference for the calendar time terminated test plans (see clause 9)	58
 Tables	
1 Overview of the sequential test plans given in annex A	11
2 Fixed time/failure terminated test plans	13
 Figures	
1 Example of calculation of T^* for one repaired item	9
2 Example of calculation of T^* for four repaired items	9
3 Example of calculation of T^* for five non-repaired items	10

INTERNATIONAL ELECTROTECHNICAL COMMISSION

RELIABILITY TESTING –

**Compliance tests for constant failure rate
and constant failure intensity**

FOREWORD

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International Standard IEC 61124 has been prepared by IEC technical committee 56: Dependability.

This first edition of IEC 61124 cancels and replaces IEC 60605-7, published in 1978, and its amendment 1 (1990), of which it constitutes a technical revision.

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

FDIS	Report on voting
56/531/FDIS	56/579/RVD

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

Annexes A, B and C form an integral part of this standard.

Annexes D, E, F and G are for information only.

INTRODUCTION

This International Standard is a revision of IEC 60605-7 (1978) and its amendment 1 (1990). The time/failure terminated test plans have been extended to cover 5 % risk. A new clause covering calendar time/failure terminated test plans for non-repaired items has been included. Several annexes have been added dealing with examples and mathematical references. This standard now covers failure intensity (repaired items) as well as failure rate (non-repaired items).

RELIABILITY TESTING –

Compliance tests for constant failure rate and constant failure intensity

1 Scope

This International Standard specifies procedures to test whether an observed value of:

- failure rate;
- failure intensity;
- mean time to failure;
- mean operating time between failures;

complies with a given requirement.

It is assumed (except where otherwise stated) that during the observation period (accumulated relevant test time) the time intervals to or between the failures are independent, and identically exponentially distributed.

NOTE – This assumption implies that the failure rate or failure intensity is constant.

Three types of test plans are prescribed as follows:

- sequential test plans;
- time/failure terminated test plans, including fixed time/failure terminated test plans and alternative time/failure terminated test plans that can be designed to meet a particular need;
- fixed calendar time/failure terminated test plans.

General guidance on the choice of test plans is given in 7.3 of IEC 60605-1.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60050(191): 1990, *International Electrotechnical Vocabulary (IEV) – Chapter 191: Depend-ability and quality of service*

IEC 60605-1: 1978, *Equipment reliability testing – Part 1: General requirements*

IEC 60605-6: 1986, *Equipment reliability testing – Part 6: Test for the validity of a constant failure rate assumption*

IEC 61123: 1991, *Reliability testing – Compliance test plans for success ratio*

ISO 3534-1: 1993, *Statistics – Vocabulary and symbols – Part 1: Probability and general statistical terms*

3 Definitions

For the purpose of this standard the terms and definitions of IEC 60050(191) apply.

In addition, the terms:

- failure rate;
- failure intensity;

are used in the meaning of:

- constant failure rate;
- constant failure intensity;

respectively.

4 Symbols

4.1 List of symbols

α	nominal producer's risk (type I risk)
α'	true producer's risk (type I risk)
β	nominal consumer's risk (type II risk)
β'	true consumer's risk (type II risk)
λ	true failure rate per item
λ_0	specified acceptable failure rate per item
λ_1	unacceptable failure rate per item
$\Delta\rho_0$	auxiliary quantity for determination of c , $\Delta\rho_0 = c - \rho_0$
ρ	expected number of failures during the test at the true failure rate/intensity
	NOTE 1 – ρ is not necessarily an integer.
ρ_0	expected number of failures during the test at the specified acceptable failure rate/intensity, $\rho_0 = w_0 \times T_t^*$
c	acceptable number of events (or failures) during the test
	NOTE 2 – Termination number of failures in IEC 60605-7 (superseded by this standard), corresponds to $c + 1$.
D	discrimination ratio, $D = w_1/w_0$ or $D = m_0/m_1$
D'	true discrimination ratio
m	true mean time to/between events
m_0	specified acceptable mean time to/between events, $m_0 = 1/w_0$
m_1	unacceptable mean time to/between events
n	number of test items
P_a	probability of acceptance
r	observed number of relevant events (or failures) during the test
t^*	relevant test time, assumed to be the same for all test items
t_t^*	relevant test time for all test items stated as termination criterion
$t_{cal,t}^*$	relevant calendar test time stated as termination criterion (see 6.2)

T^*	accumulated relevant test time (see 6.3)
T_a^*	accumulated relevant test time stated as accept criterion
T_e^*	expected accumulated relevant test time to decision
T_r^*	accumulated relevant test time stated as reject criterion
T_t^*	accumulated relevant test time stated as termination criterion
w	true failure rate/intensity per item (see 4.2) NOTE 3 – w is generally unknown.
w_0	specified acceptable failure rate/intensity per item NOTE 4 – w_0 corresponds to acceptable quality level (AQL).
w_1	unacceptable failure rate/intensity per item NOTE 5 – w_1 corresponds to limiting quality (LQ).
z	true failure intensity
z_0	specified acceptable failure intensity per item
z_1	unacceptable failure intensity per item

4.2 Transformation of symbols

Because the procedures in this standard are applicable to different reliability measures the generic symbol " w " is used for failure rate/intensity.

Hence

- for failure intensity $w = z$;
- for failure rate $w = \lambda$.

If the following reliability measures, both designated " m ":

- mean operating time between failures, MTBF;
- mean time to failure, MTTF,

are used, the transformation, under the given assumptions, shall be:

$$w = 1/m$$

Sequential test plans (see clause 7) and fixed time/failure terminated test plans (see 8.1) are based on m as a reliability measure, thus in these cases:

$$m = 1/w$$

5 Nature of requirement and area of application

5.1 Requirement

It is assumed that the requirement is specified in terms of the acceptable constant failure rate/constant failure intensity, w_0 , expressed as the acceptable mean number of relevant failures per time unit, or the acceptable mean operating time to/between failures, m_0 .

If it is necessary to test the constant failure rate/constant failure intensity assumption, the procedures in IEC 60605-6 should be used. See also 6.4.

5.2 *Applicability to repaired and replaced items*

The sequential test plans (clause 7) and the time/failure terminated test plans (clause 8) are applicable to the following:

- non-repaired items;
- non-replaced items;
- repaired items;
- replaced items,

under the assumption that:

- the accumulated relevant test time is calculated as elapsed operating item-time, in accordance with 6.1;
- replaced items belong to the same population as the original items;
- repaired items can be considered "good as new", that is they have the same failure intensity after repair as they had before they failed.

The calendar time/failure terminated test plans in clause 9, however, are applicable to non-repaired and non-replaced items where a fixed number of items are placed on test for a fixed calendar time. This means that the test is running, even though the number of items under test may not remain constant because some items may not survive.

5.3 *Types of test plans*

Test plans are given for three types of tests:

- truncated sequential tests, see clause 7;
- time/failure terminated tests (for fixed time/failure terminated tests see 8.1, and for alternative time/failure terminated tests, see 8.2);
- fixed calendar time terminated tests without repair/replacement, see clause 9.

6 **General test procedure**

6.1 *General characteristics of the test plans and decision criteria*

All test plans and decision criteria are based on either of two characteristics, as follows:

- an acceptable number of relevant failures in a specified relevant test time; or
- an acceptable test time for a specified number of relevant failures.

The detailed criteria for the three types of test plans, with variants, are given in 7.2, 8.1.2, 8.2.2 and 9.2.

6.2 *Data to be recorded*

In order to apply the procedures defined in this standard, the following data shall be recorded:

- the observed number of relevant failures;
- the accumulated relevant test time, or relevant calendar test time.

If it is necessary to test the assumption stated in clause 1, the following data shall also be recorded:

- the time of occurrence of each failure.

6.3 Calculation of accumulated relevant test time, T^*

Figures 1 to 3 explain, using three general cases, how the accumulated relevant test time can be calculated in all types of test plans.

6.3.1 Case 1, one repaired item

For one repaired item under test, the relevant test time is simply the elapsed time under operation (excluding repair and other down times); see figure 1.

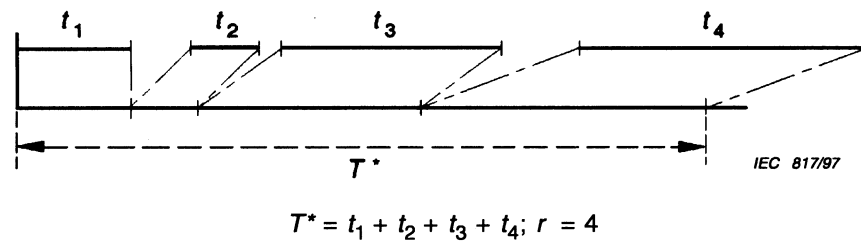


Figure 1 – Example of calculation of T^* for one repaired item

6.3.2 Case 2, more than one repaired item

For more than one repaired item under test, the relevant test time is the sum of all elapsed times under operation (excluding all repair and other down times); see figure 2.

It is assumed that all items can be considered nominally equal and operating under nominally equal conditions (such as environment and load).

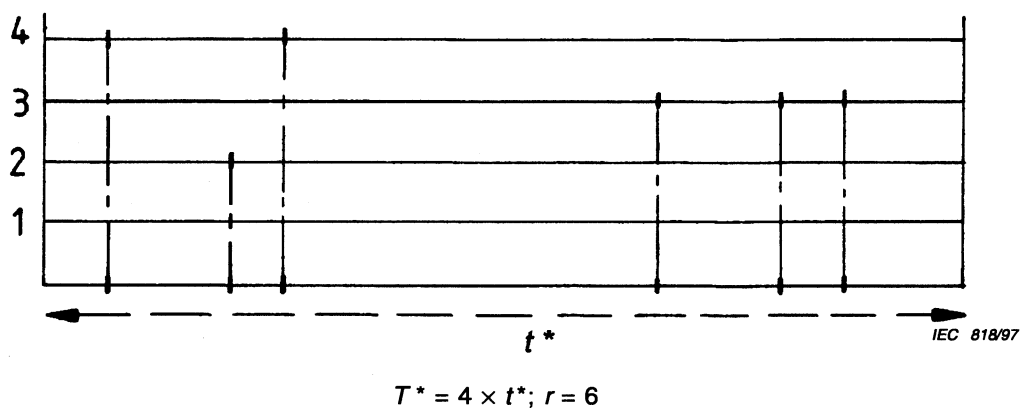
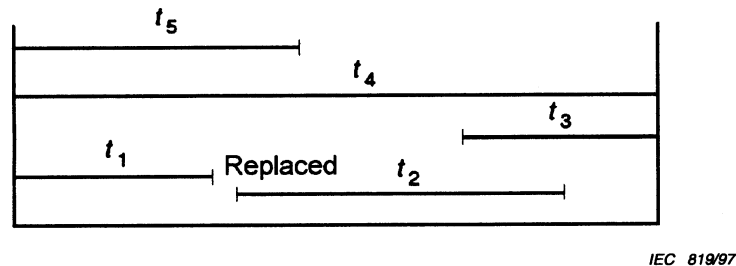


Figure 2 – Example of calculation of T^* for four repaired items (negligible repair time)

6.3.3 Case 3, non-repaired items

For non-repaired items, only one relevant test time exists for each item (lifetime), namely the time to first event (failure). The accumulated relevant test time in this – and only in this – case is the sum of these lifetimes; see figure 3.



$$T^* = t_1 + t_2 + t_3 + t_4 + t_5; r = 3$$

Figure 3 – Example of calculation of T^* for five non-repaired items

6.4 Relevant calendar test time, $t_{\text{cal},t}^*$

The relevant calendar test time, $t_{\text{cal},t}^*$ is the elapsed time when the test is running.

7 Sequential test plans

7.1 Characteristics

Sequential test plans are characterized by decision rules for accepting or rejecting compliance, or continuing the test at any test time. They are determined by selected values of risks and discrimination ratio. To implement a test plan, m_0 shall be specified (or derived).

Associated operating characteristic curves and expected relevant test time to decision are included, see annex A. An example and a mathematical reference are given in annex D.

7.2 Common test procedure

- Specify acceptable mean time to/between events (failures), m_0 , according to requirement or agreement;
- choose risks, $\alpha = \beta$, and discrimination ratio, D , considering that low values of $\alpha = \beta$ and D make a more powerful test, but require longer time and/or more items;
- select an appropriate test plan from table 1 and annex A;
- note the test times, T_a^* for accept, and T_r^* for reject;
- perform the test and apply the decision criteria according to 7.3.

7.3 Decision criteria

The accumulated relevant test time and the number of relevant failures shall be compared with the accept and reject criteria continuously during the test; or at intervals not greater than the length of the test cycle and the monitoring interval (see 8.1 and 9.1 of IEC 60605-1).

The following criteria shall apply:

- if the elapsed $T^* \geq T_a^*$ (stated as multiples of m_0) for the observed r , the specified requirement is regarded as being complied with, and the test shall be terminated; *accept*;
- if the elapsed T^* is between the limits, that is $T_r^* < T^* < T_a^*$, no decision can be taken; *continue testing*;
- if the elapsed $T^* \leq T_r^*$ (stated as multiples of m_0) for the observed r , the specified requirement is regarded as not being complied with, and the test shall be terminated; *reject*.

7.4 Tables and graphs

Table 1 summarizes the sequential test plans given in annex A. Annex A provides, for each test plan, a decision graph and decision table, and graphs of operating characteristic curve and expected relevant time to decision.

Table 1 – Overview of the sequential test plans given in annex A

Test plan	Characteristics of the plan			Expected test time for decision in multiples of m_0 for $m = m_0$	True risks	
	Nominal risks		Discrimination ratio		$m = m_0$	$m = m_1$
	α %	β %		D	T_e^* / m_0	α' %
A.1	10	10	1,5	17,3	11,5	12,5
A.2	10	10	2	5,1	12,8	12,8
A.3	10	10	3	2,0	11,1	10,9
A.4	10	10	5	0,6	12,4	13,0
A.5	20	20	1,5	7,6	22,7	23,2
A.6	20	20	2	2,4	22,3	22,5
A.7	20	20	3	1,1	18,2	19,2
A.8	30	30	1,5	3,4	31,9	32,8
A.9	30	30	2	1,3	29,3	29,9
NOTE – The true risks α' and β' differ from the nominal α and β due to approximation and the truncation made in the test plans.						

8 Time/failure terminated test plans

8.1 Fixed time/failure terminated test plans

8.1.1 Characteristics

Fixed time/failure terminated test plans are characterized by decision rules for accepting or rejecting compliance when the test time for termination has been reached, or the acceptable number of relevant failures has been exceeded. The test plans are determined by selected values of risks and discrimination ratio. To implement a test plan, m_0 shall be specified (or derived).

Examples and a mathematical reference are given in annex E.

8.1.2 Common test procedure

- Specify acceptable mean time to/between events (failures), m_0 , according to requirement or agreement;
- choose risks, $\alpha = \beta$, and discrimination ratio, D , considering that low values of $\alpha = \beta$ and D make a more powerful test, but require longer time and/or more items;
- select an appropriate test plan from table 2, consulting annex B;
- note the test time for termination, T_t^* , and the acceptable number of failures, c ;
- perform the test and apply the decision criteria according to 8.1.3.

8.1.3 Decision criteria

The following decision criteria shall apply:

- if $r \leq c$ at T_t^* (stated as multiples of m_0), the specified requirement is regarded as being complied with; *accept*;
- if $r > c$ at or before T_t^* (stated as multiples of m_0), the specified requirement is regarded as not being complied with; *reject*.

8.1.4 Tables and graphs

Table 2 summarizes the recommended time/failure terminated test plans. Relevant test time is accumulated until either a predetermined amount of relevant test time has been exceeded (accept), or a predetermined number of relevant failures has occurred (reject).

Graphs of operating characteristic curves and expected relevant time to decision are given in annex B.

Table 2 – Fixed time/failure terminated test plans

Test plan No.	Characteristics of the plan			Test time for termination in multiples of m_0	Acceptable number of failures	True risks	
	Nominal risks		Discrimination ratio			$m = m_0$	$m = m_1$
	α %	β %	D	T_t^* / m_0	c	α' %	β' %
B.1	5	5	1,5	54,1	66	5,0	4,8
B.2	5	5	2	15,7	22	5,0	5,0
B.3	5	5	3	4,8	8	5,6	5,1
B.4	5	5	5	1,8	4	3,6	5,5
B.5	10	10	1,5	30,0	36	12,0	9,9
B.6	10	10	2	9,4	13	9,6	10,6
B.7	10	10	3	3,1	5	9,4	9,9
B.8	10	10	5	1,1	2	10,0	8,8
B.9	20	20	1,5	14,1	17	18,0	21,7
B.10	20	20	2	3,9	5	20,0	21,0
B.11	20	20	3	1,46	2	18,1	18,8
B.12	30	30	1,5	5,3	6	28,3	32,0
B.13	30	30	2	1,84	2	28,0	28,9

NOTE – The test time for termination (in multiples of m_n) is equal to the expected number of failures during the test at the specified acceptable failure rate/intensity, that is $T_t^* / m_0 = T_t^* \times w_0 = p_0$.

8.2 Design of alternative time/failure terminated test plans

8.2.1 Characteristics

Alternative time/failure terminated test plans are characterized by decision rules for accepting or rejecting compliance when the test time for termination has been reached or the acceptable number of relevant failures has been exceeded. The test plans are determined by selected values of risks and test time. The test time is chosen independently of w_0 which enables test plans to be designed individually to meet particular needs including, for example, economy, resources or time scheduling.

The derived discrimination ratio is used to evaluate the test plan. In order to implement a test plan, w_0 shall be specified (or derived). The transformation of failure rate/failure intensity and mean time to failure/mean operating time between failures to w_0 is given in 4.2.

It is also possible to choose different test plan parameters, and determine unknown parameters as indicated in 8.2.4 to 8.2.7.

Graphs for determining test plan parameters are given in annex C, including the associated operating characteristic curves. Examples and a mathematical reference are given in annex F.

8.2.2 Common test procedure

- Specify the acceptable failure rate/failure intensity per item, w_0 , according to requirement or agreement;
- choose risks, $\alpha = \beta$, test time for each item, t_t^* , and number of test items, n , according to resources;
- design the test plan according to 8.2.3 and 8.2.4 using the figures in annex C;
- evaluate the test plan especially regarding the derived discrimination ratio D , and perhaps redesign with modified parameters to satisfy the need;
- perform the test with the stated test time, $T_t^* = n \times t_t^*$, and the derived acceptable number of failures, c , and apply the decision criteria according to 8.2.3.

8.2.3 Decision criteria

- If $r \leq c$ at T_t^* the specified requirement is regarded as being complied with; *accept*.
- If $r > c$ at or before T_t^* the specified requirement is regarded as not being complied with; *reject*.

8.2.4 Design procedures, general

The procedures in 8.2.5 to 8.2.7 may be applied directly to tests in which:

- replacement/repair occurs, and replacement/repair times are negligible;
- replacement/repair does not occur, and $w_0 \times t_t^* < 0,1$ is valid.

In such cases $T_t^* = n \times t_t^*$.

However, the procedures may also be applied to tests in which:

- replacement/repair occurs, and replacement/repair times are long;
- replacement/repair does not occur, and $w_0 \times t_t^* > 0,1$.

In such cases, the formulae involving accumulated relevant test time, T_t^* , (see 6.3) shall be used, and in the formulae $n \times t_t^*$ shall be replaced by T_t^* . This implies that n and t^* cannot be separated, as in 8.2.7.

In each case, when applicable, the values of α and β , as stated in table 2, shall be considered as preferred values.

8.2.5 Common case, deriving c and D

This procedure is particularly suitable for cases where the following test plan parameters are specified:

- relevant test time for each item, assumed to be the same for all items, stated as termination criterion, t_t^* ;
- number of test items, n ;

- equal nominal producer's and consumer's risks, $\alpha = \beta$ (for $\alpha \neq \beta$, refer to F.2.3.7);
- maximum value of the discrimination ratio, if required.

On the basis of these parameters, the unknown parameters:

- actual discrimination ratio, D ;
- acceptable number of failures, c ;

are derived, using the figures in annex C, as stated below.

If the derived actual discrimination ratio, D , exceeds the specified maximum value, or is otherwise judged to be unsuitable, the test time shall be exceeded, or other test plan parameters modified. The calculations are then repeated and reappraised until the conditions are fulfilled.

General procedure

- a) Calculate $p_0 = w_0 \times t_t^* \times n$

NOTE – If $p_0 < 1$, it is generally recommended to extend either test time t_t^* , or number of items n , in order to achieve suitable test plans.

Procedure for p_0 between 1 and 5

- Find in figure C.1 the p_0 (already calculated) on the dashed curve for the specified $\alpha = \beta$;
- find the nearest solid c curve to this point in the vertical direction, and thus determine c ;
- read the discrimination ratio D from the c curve at the p_0 value;
- from this latter point, by interpolation between the dashed curves, the true $\alpha' = \beta'$ risks may be estimated; alternatively, the risks may be read from the corresponding operating characteristic curve in figure C.2;
- if the values determined for D and $\alpha' = \beta'$ are not acceptable, increase or decrease c by 1.

Example 1

Specified: $p_0 = 2,7$; $\alpha = \beta = 10 \%$

To be derived: c, D, α', β'

From figure C.1: $c = 4$ with $D = 2,75$ and $\alpha' = \beta' \approx 14 \%$

Procedure for p_0 between 5 and 500

- Read the discrimination ratio D in figure C.3 for the p_0 (already calculated) on the curve for the specified $\alpha = \beta$;
- read Δp_0 in figure C.4 for the p_0 calculated on the curve for the specified $\alpha = \beta$;
- calculate c by adding Δp_0 and p_0 and rounding to the nearest integer, that is $c = (\Delta p_0 + p_0)_{\text{rounded}}$.

Example 2

Specified:	$\rho_0 = 40; \alpha = \beta = 10 \%$
To be derived:	c, D
From figure C.3:	$D (10 \%) = 1,45$
From figure C.4:	$c (10 \%) = (40 + 7,8)_{\text{rounded}} = 48$

8.2.6 Deriving risks, $\alpha = \beta$

In addition to w_0 , the following test plan parameters shall be specified:

- test time t_t^* ;
- number of test items n ;
- discrimination ratio D .

For small values of ρ_0 , true risks are determined; for large values of ρ_0 , nominal risks $\alpha = \beta$.

General procedure

- a) Calculate $\rho_0 = w_0 \times t_t^* \times n$ or $\rho_0 = w_0 \times T_t^*$

Procedure for ρ_0 between 1 and 5

- a) Find in figure C.1 the nearest c curve to the point (ρ_0, D) , and thus determine c ;
- b) read in figure C.2 the true risks α' and β' from the corresponding operating characteristic curve for $\rho = \rho_0$ and $\rho = D \times \rho_0$, respectively.

Example 1

Specified:	$\rho_0 = 1; D = 3$
To be derived:	c, α', β'
From figure C.1:	$c = 1$
From figure C.2:	$\alpha' = 26,5 \%, \beta' = 19,5 \%$

Procedure for ρ_0 between 5 and 500

- a) Identify in figure C.3 the point (ρ_0, D) and interpolate between the $\alpha = \beta$ curves to estimate the nominal risks $\alpha = \beta$;
- b) use in figure C.4 the nominal risks $\alpha = \beta$ to determine $\Delta\rho_0$ and then calculate as above, that is $c = (\Delta\rho_0 + \rho_0)_{\text{rounded}}$.

Example 2

Specified:	$\rho_0 = 40; D = 1,5$
To be derived:	$c, \alpha = \beta$
From figure C.3:	$\alpha = \beta \approx 8 \%$
From figure C.4:	$\Delta\rho_0 = 8,7$ and thus $c = (48,7)_{\text{rounded}} = 49$

8.2.7 Deriving n or t_t^*

In addition to w_0 , one of the following sets of test plan parameters shall be specified

- a) – test time t_t^* ;
 - risks $\alpha = \beta$;
 - discrimination ratio D .
- b) – number of test items n
 - risks $\alpha = \beta$;
 - discrimination ratio D .

Common procedure in cases a) and b)

- a) Find D and the ρ_0 value corresponding to $\alpha = \beta$ risks, from either figure C.1. or figure C.3;
- b) use the ρ_0 value to determine c from either figure C.1 or figure C.4;
- c) calculate $T_t^* = \rho_0 / w_0$ from the ρ_0 value;
- d) using the T_t^* , calculate either the number of test items n for specified t_t^* , $n = T_t^* / t_t^*$ or test time t_t^* for specified n , $t_t^* = T_t^* / n$.

NOTE – This procedure is particularly suitable for components.

9 Calendar time/failure terminated test plans for non-repaired/non-replaced items

9.1 Characteristics

Fixed calendar time/failure terminated test plans for non-repaired/non-replaced items are characterized by decision rules for accepting or rejecting compliance when the test time for termination has been reached, or the acceptable number of relevant failures has been exceeded. The test plans are determined by selected values of risks and discrimination ratios. To implement a test plan, w_0 shall be specified (or derived). The transformation of failure rate and mean time to failures to w_0 is indicated in 4.2.

Since no replacement/repair takes place, the number of items under test will generally not remain constant, and the accumulated time of operation is not relevant. Thus, the compliance test plans for success ratio, table 2 of IEC 61123, should be used.

However, if the number of items is large compared to the number of failures, the time/failure terminated test plans (clause 8) may be used.

An example and a mathematical reference are given in annex G.