

Zuverlässigkeitswachstum bei Entwurf und Prüfung von ProduktenStatistische Tests und Schätzverfahren
(IEC 56/774/CD:2001, Text Englisch)**DIN****IEC 61164**

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EntwurfReliability growth in product design and test
Statistical test and estimation methods
(IEC 56/774/CD:2001, text in English)**Anwendungswarnvermerk**

Dieser Norm-Entwurf wird der Öffentlichkeit zur Prüfung und Stellungnahme vorgelegt.

Weil die beabsichtigte Norm von der vorliegenden Fassung abweichen kann, ist die Anwendung dieses Entwurfes besonders zu vereinbaren.

Stellungnahmen werden erbeten

- vorzugsweise als Datei per e-Mail an dke@din.de in Form einer Tabelle. Die Vorlage dieser Tabelle kann im Internet unter <http://www.din.de/stellungnahme> abgerufen werden;
- oder in Papierform an die DKE Deutsche Kommission Elektrotechnik Elektronik Informationstechnik im DIN und VDE, Stresemannallee 15, 60596 Frankfurt am Main.

Das internationale Schriftstück IEC 56/774/CD:2001-10 „IEC 61164: Reliability growth in product design and test - Statistical test and estimation methods“ ist unverändert in diesen deutschen Norm-Entwurf übernommen worden.

Fortsetzung Seite 2 und 3
und 42 Seiten IEC-Original

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Nationales Vorwort

Dieser Norm-Entwurf enthält die englische Originalfassung des internationalen Norm-Entwurfs [Committee Draft (CD)] IEC 56/774/CD:2001-10 „IEC 61164: Reliability growth in product design and test - Statistical test and estimation methods“.

Auf eine Übersetzung wird im derzeitigen Entwurfsstadium zugunsten einer schnelleren Verfügbarkeit, Kommentierung und Einflussnahme der deutschen Fachöffentlichkeit verzichtet. Eine deutsche Übersetzung wird bei den weiteren Bearbeitungsstufen des Normvorhabens angefertigt.

Der internationale Norm-Entwurf wurde vom TC 56 „Dependability“ der Internationalen Elektrotechnischen Kommission (IEC) erarbeitet.

Um eine Beschleunigung und Straffung der Normungsarbeit zu erreichen, haben IEC und das Europäische Komitee für Elektrotechnische Normung (CENELEC) vereinbart, dass ein auf IEC-Ebene entstandener internationaler Norm-Entwurf zeitgleich (parallel) bei IEC und CENELEC im CDV-Stadium zur Umfrage und im FDIS-Stadium zur Abstimmung gestellt wird.

Bei der Abstimmung zu dem europäischen Schluss-Entwurf bei CENELEC und dem internationalen Schluss-Entwurf bei IEC [Final Draft International Standard (FDIS)] sind jeweils nur „JA/NEIN“-Entscheidung möglich, wobei „NEIN“-Entscheidungen fundiert begründet werden müssen. Europäische Norm-Entwürfe, die die erforderliche Zustimmung in CENELEC erhalten haben und als Europäische Norm ratifiziert wurden, sind unverändert als Deutsche Normen zu übernehmen.

Für den vorliegenden Norm-Entwurf ist das nationale Arbeitsgremium K 132 „Zuverlässigkeit“ der DKE Deutsche Kommission Elektrotechnik Elektronik Informationstechnik im DIN und VDE zuständig.

Nationaler Anhang NA (informativ)

Zusammenhang mit Europäischen und Internationalen Normen

Für den Fall einer undatierten Verweisung im normativen Text (Verweisung auf eine Norm ohne Angabe des Ausgabedatums und ohne Hinweis auf eine Abschnittsnummer, eine Tabelle, ein Bild usw.) bezieht sich die Verweisung auf die jeweils neueste gültige Ausgabe der in Bezug genommenen Norm.

Für den Fall einer datierten Verweisung im normativen Text bezieht sich die Verweisung immer auf die in Bezug genommene Ausgabe der Norm.

Der Zusammenhang der zitierten Normen mit den entsprechenden Deutschen Normen ist nachstehend wiedergegeben. Zum Zeitpunkt der Veröffentlichung dieser Norm waren die angegebenen Ausgaben gültig.

IEC hat 1997 die Benummerung der IEC-Publikationen geändert. Zu den bisher verwendeten Normnummern wird jeweils 60000 addiert. So ist zum Beispiel aus IEC 68 nun IEC 60068 geworden.

Tabelle NA.1

Europäische Norm	Internationale Norm	Deutsche Norm	Klassifikation im VDE-Vorschriftenwerk
–	IEC 60050(191):1990	IEV Kapitel 191:1995	–
–	IEC 60605-1:1978	DIN IEC 60605-1:1986-03	–
–	IEC 60605-4:1986	DIN IEC 60605-4:1988-05	–
–	IEC 60605-6:1986	DIN IEC 60605-6:1999-04	–
–	IEC 61014:1989	DIN IEC 61014:1993-01	–
–	IEC 60300-3-1:1991	DIN IEC 60300-3-1:1994-02	–

Nationaler Anhang NB (informativ)

Literaturhinweise

IEV Kapitel 191, *Internationales Elektrotechnisches Wörterbuch – Kapitel 191: Zuverlässigkeit und Dienstgüte*; Identisch mit IEC 60050-191:1990

DIN IEC 60605-1, *Elektrotechnik – Prüfung der Zuverlässigkeit von Geräten – Allgemeine Anforderungen*; Identisch mit IEC 60605-1, Ausgabe 1978

DIN IEC 60605-4, *Elektrotechnik – Prüfung der Zuverlässigkeit von Geräten – Teil 4: Schätzwerte und Vertrauensgrenzen*; Identisch mit IEC 60605-4, Ausgabe 1986

DIN IEC 60605-6, *Prüfungen der Zuverlässigkeit von Geräten – Teil 6: Statistische Tests zur Entscheidung über die Hypothese einer konstanten Ausfallrate oder einer konstanten Ausfalldichte* (IEC 60605-6:1997)

DIN IEC 60300-3-1, *Zuverlässigkeitsmanagement – Anwendungsleitfaden – Techniken für die Analyse der Zuverlässigkeit*; Identisch mit IEC 60300-3-1:1991

DIN IEC 61014, *Programme zum Zuverlässigkeitswachstum*, Identisch mit IEC 61014:1989

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**RELIABILITY GROWTH –
STATISTICAL TEST AND ESTIMATION METHODS**

FOREWORD

- 1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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- 3) The documents produced have the form of recommendations for international use and are published in the form of standards, technical specifications, technical reports or guides and they are accepted by the National Committees in that sense.
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International Standard IEC 61164 has been prepared by IEC technical committee 56: Dependability.

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

FDIS	Report on voting
56/XX/FDIS	XX/XX/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

This standard shall be used in conjunction with IEC 1014.

Annexes A and B are for information only.

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

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

INTRODUCTION

This International Standard describes the power law reliability growth model and related projection model and gives step-by-step directions for their use. There are several reliability growth models available, the power law model being one of the most widely used. This standard provides procedures to estimate some or all of the quantities listed in clause 4, 6 and 7 of IEC 61014. Two types of inputs are required. The first one is for the reliability growth planning through analysis and design improvements in the design phase, in terms of the design phase duration, starting reliability, reliability goal, and planned design improvements along with their expected magnitude. The second input, for the reliability growth in the project validation phase is required consisting of a data set of accumulated test times at which relevant failures occurred, or were observed, for a single system, and the time of termination of the test, if different from the time of the final failure. It is assumed that the collection of data as input for the model begins after the completion of any preliminary tests, such as environmental stress screening, intended to stabilize the system's initial failure intensity.

Model parameters estimated from previous test results may be used to plan and predict the course of future reliability growth programmes, if the conditions are similar.

Some of the procedures may require computer programs, but these are not unduly complex. This standard presents algorithms for which computer programs should be easy to construct.

RELIABILITY GROWTH – STATISTICAL TEST AND ESTIMATION METHODS

1 Scope

This International Standard gives models and numerical methods for reliability growth assessments based on failure data from a single system which were generated in a reliability improvement programme. These procedures deal with growth, estimation, confidence intervals for system reliability and goodness-of-fit tests.

2 Normative references

The following referenced 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):1990, *International Electrotechnical Vocabulary (IEV) – Chapter 191: Dependability and quality of service*

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

IEC 60605-4:1986, *Equipment reliability testing – Part 4: Procedures for determining point estimates and confidence limits from equipment reliability determination tests*

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

IEC 61014:1989, *Programmes for reliability growth*

IEC 60300-3-1, *Analysis techniques for dependability; Guide on methodology*

3 Definitions

For the purposes of this standard the terms and definitions of IEC 60050(191) and IEC 61014 apply, together with the following additional terms and definitions.

3.1

goal reliability

reliability that the product will have at the end of its predetermined life after the product improvements are completed

3.2

initial reliability

reliability that is estimated for the product in earlier design stages before any potential failure modes or their causes have been mitigated by the design improvement

3.3

reliability growth model – design

mathematical model that takes into consideration potential design improvements, and their magnitude to express mathematically reliability growth from the initial to the goal during the design period.

3.4

equivalent product failure rate

product failure rate calculated from its reliability as estimated for a predetermined time period

3.5

delayed modification

corrective modification, which is incorporated into the system at the end of a test

NOTE A delayed modification is not incorporated during the test.

3.6

improvement effectiveness factor

fraction by which the intensity of a systematic failure is reduced by means of corrective modification

3.7

type I test

test which is terminated at a predetermined time or test with data available through a time which does not correspond to a failure

NOTE Type I test is sometimes called time terminated test.

3.7

type II test

reliability growth test which is terminated upon the accumulation of a specified number of failures, or test with data available through a time which corresponds to a failure

NOTE Type II test is sometimes called failure-terminated test.

4 Symbols

For the purpose of this international standard, the following symbols apply.

D	total number of predicted design modifications within the design period
t_D	total duration of the design period
t	time variable during the design phase (from 0 to t_D)
$d(t)$	number of design modifications at any given time from 0 to t_D
α_D	growth rate during the design period
λ_{e0}	initial calculated product equivalent failure rate
$\lambda_e(t)$	product equivalent failure rate as a function of time during the design period (0 to t_D)
R_0	Initial product reliability before introduction of design improvements
R_G	product reliability goal to be attained through design improvement
$R(t)$	product reliability increase as a function of time and design improvements during the design phase (0 to t_D)
λ_{eG}	goal product equivalent failure rate that correspond to the reliability goal of the product
T	product predetermined lifetime or any time of interest such as warranty or mission
λ, β	scale and shape parameters for the power law model
CV	critical value for hypothesis test

d	number of intervals for grouped data analysis
$\bar{E}, E_i, E_j$	mean and individual improvement effectiveness factors
I	number of distinct types of category B failures observed
i, j	general purpose indices
K_A	number of category A failures
K_B	number of category B failures
K_i	number of i th type category B failures observed; $K_B = \sum_{i=1}^k K_i$
M	parameter of the Cramér-von Mises test (statistical)
N	number of relevant failures
N_i	number of relevant failures in i th interval
$N(T)$	accumulated number of failures up to test time T
$E[N(T)]$	expected accumulated number of failures up to test time T
$t(i-1); t(i)$	endpoints of i th interval of test time for grouped data analysis
T	current accumulated relevant test time
T_i	accumulated relevant test time at the i th failure
T_N	total accumulated relevant test times for type II test
T^*	total accumulated relevant test times for type I test
$\chi^2_{\gamma}(\nu)$	γ fractile of the χ^2 distribution with ν degrees of freedom
z	general symbol for failure intensity
u_{γ}	γ fractile of the standard normal distribution
z_p	projected failure intensity
$z(T)$	current failure intensity at time T
$\theta(T)$	current instantaneous mean time between failures
θ_p	projected mean time between failures
p_j	probability of success at the stage i of system modification in design phase described in barlow, Proschan, and Scheuer discrete reliability growth model

$N(t)$	Number of non-random type defects remaining at time $t > 0$ in IBM/Rosner continuous reliability growth model
g	fraction that a system/equipment is debugged as given in the IBM/Rosner reliability growth model
K	number of failure classes
E	Exposure of item
μ_{NS}	failure rate of non-systematic (residual) failures
μ_S	failure rate of systematic failures
μ_k	failure rate of the k^{th} failure class
D	number of potential design weaknesses
D_k	number of potential design weakness in failure class k
$p_{k,j}$	probability that the j^{th} potential design weakness associated with failure class k will result in failure
t^E	expected design phase time to achieve target reliability, $R_G(T)$
$R_i(T)$	Initial reliability at time T
$R_G(T)$	goal or target reliability at time T
α	parameter to represent the expected growth rate
λ_k	the expected number of design weaknesses associated with failure class k that will result in failure

5 Reliability growth models used for systems/products in design phase

5.1 Modified power law mode for planning of reliability growth

The statistical procedure for the power law model in the product design phase regards the implementation of the design reliability improvements by mitigation of a failure mode or by reduction of its probability of occurrence, and the time from the beginning of design to that improvement. The assumption of a power law is justified by the fact that the early improvements were those that are the highest reliability contributors, that is, the failure modes with the highest probability of occurrence will be addressed first, followed by improvements of lesser and lesser reliability contribution.

5.1.1 Planning model for the reliability growth during the product design period

The main equations for this model (Krasich) are given in this clause, while all derivations and rationale are shown in Annex A.

If the initial product reliability for the predetermined product operational time T was estimated to be $R_0(T)$, then the initial equivalent failure rate corresponding to the time T is calculated to be:

$$\lambda_{e0} = -\frac{\ln[R_0(T)]}{T}$$

Assuming that the power law applies, and with modification such to allow that the product failure rate is equal to the initial failure rate when no design improvements are done, failure rate of the design at any time during the design period is:

$$\lambda_e(t) = \lambda_{e0} \cdot [1 + d(t)]^{-\alpha}, \text{ or}$$

$$\lambda_e(t) = \lambda_{e0} \cdot \left(1 + D \cdot \frac{t}{t_D}\right)^{-\alpha_D}$$

In above equations, $d(t)$ is a number of design changes at any time during the design period. With a linear approximation, the number of design changes as a function of time is:

$$d(t) = D \cdot \frac{t}{t_D}$$

The goal product equivalent failure rate given the product reliability goal $R_G(T)$ is:

$$\lambda_{eG} = \frac{-\ln[R_G(T)]}{T}$$

During the design period, continuous improvement of product reliability as a function of time t (the reliability growth model)(from 0 to t_D) can be written as:

$$R(t) = \exp(-\lambda(t) \cdot T)$$

With the further derivations and substitutions, the Krasich reliability growth model for the design phase $0 < t < t_D$, becomes:

$$R(t) = R_0(T) \left[\frac{t_D + t \left(\frac{\ln[R_G(T)]}{\ln[R_0(T)]} \right)^{\frac{1}{\alpha_D}} - t}{t_D} \right]^{-\alpha_D}$$

An example of a reliability growth model where the initial product fifteen-year reliability is 0,72, and the goal fifteen-year reliability is 0,95, has to show an improvement during the five-month product design period according to the model shown in Figure 1.

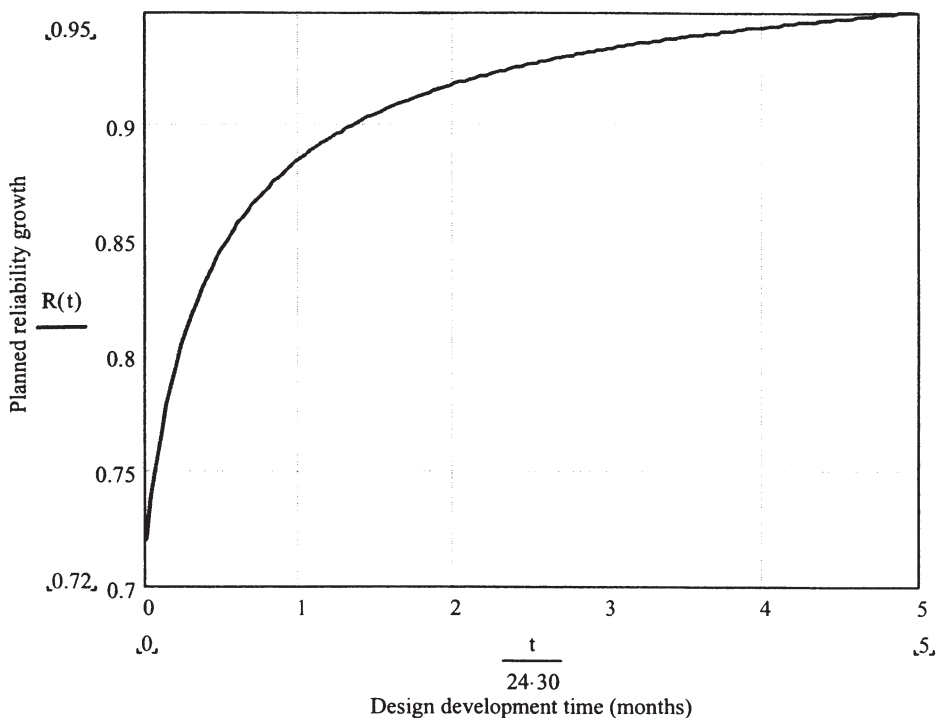


Figure 1 – Reliability growth model example for the design phase

5.1.2 Tracking of the achieved reliability growth

Tracking of the achieved reliability growth means a simple recalculation of the assessed product reliability at the time the design was improved, to account for the changes. The reliability value calculated for the same predetermined life or mission period is simply plotted on the same plot with the reliability growth model, for the corresponding design time.

The resultant entries to the graph can then be fitted with a best-fit line, or the values on the graph may be simply be connected with the straight lines and the resultant achieved reliability is compared to the reliability growth model.

Use of the Fault Tree Analysis with commercial software makes the reliability adjustments and obtaining the new reliability assessment value easy and quick to accomplish. This is especially the case when the reliability improvement is simply isolation of an environmental effect (for example an addition of a stiffener for minimizing vibration effect), as those effects model using a fault tree methodology and special gates are much easier to model than using any other reliability modelling technique.

After completion of the product design and with the introduction of the product validation phase, the planned reliability growth test may further improve product reliability, or uncover failure modes that were not accounted for during analytical evaluations. The final reliability assessment of the completed design can then serve as the reliability goal for the reliability growth testing.

An example of practical derivation and application of the planning growth model for reliability improvement in design phase is shown in A.1.1. This real life example shows step by step how the model is constructed and how it is used.

5.2 Bayesian approach for modelling of planned reliability growth in design

A model is presented to describe the growth of reliability during the design phase of a repairable item (Lesley Walls and John Quigley). It is assumed a design has been developed to a sufficient level of detail to provide an initial estimate of reliability. It is further assumed that target reliability is specified. Changes to the design will be made with a view to improving reliability until the target is achieved. The model aims to capture the possible timings of the design changes.

The model assumes that design review and re-assessments result in changes with the aim of improving reliability and achieving the target. The rate of growth as measured by advancing the initial reliability to the target reliability is a function of the removal of aspects of design that contribute to systematic failures. It is assumed through using the model under consideration that there are greater improvements to reliability in the earlier re-design compared with later stages of re-design.

The model can be used in two ways:

- to predict the length of time required to achieve target reliability by forecasting the reliability of the design – this assumes that the expected growth rate can be quantified; or
- to estimate the growth rate required to achieve the target reliability from the initial estimate during a specified design period duration – this assumes that the duration of the design phase is fixed.

Details about the mathematical formulation of the model are given in Annex A.

5.2.1 Data requirements

Data are required about the target reliability ($R_G(T)$) and either the duration of the design phase (t_D) or the expected growth rate during design (α) according to the purpose of the model application.

The failure rate of non-systematic failures should be estimated from earlier designs (μ_{NS}).

A list of all potential design weaknesses (D) should be compiled and allocated to classes of failure (K) as required. The probability of each design weakness (j) associated with each failure class (k) resulting in failure during the specified life of the item (p_{kj}) should be established. Moreover, these should be aggregated into the expected number of design weaknesses that will result in failure (λ_k) associated with each failure class (j) through summing the probabilities associated with each failure class.

$$\lambda_k = \sum_{j=1}^{D_k} p_{kj}$$

Failure rates for all relevant classes of design weaknesses (μ_k) should be estimated from historical data for relevant items.

5.2.2 Estimates of reliability growth and related parameters

In this section we provide equations that can be used to compute the key parameters; namely an estimate of initial reliability, the reliability growth curve, the expected time until the target reliability will be achieved and an estimate of the growth rate.

5.2.2.1 Estimate of initial reliability

The initial reliability of the design is calculated by

$$R_i(T) = \exp \left(- \left[\mu_{NS} \times T + \sum_{k=1}^K \lambda_k \times (1 - e^{-\mu_k \times T}) \right] \right)$$

5.2.2.2 Estimate of reliability curve during design phase

The reliability growth curve at time t of the design phase is given

$$R(t) = \exp \left(- \left[\mu_{NS} \times T + \sum_{k=1}^K \lambda_k \times e^{-\alpha \times t} \times (1 - e^{-\mu_k \times T}) \right] \right)$$

5.2.2.3 Expected time to reach target reliability

Given a growth rate has been provided, an estimate of the expected time, t^E , to reach the target reliability is given by

$$t^E = \frac{\ln \left[\frac{\sum_{k=1}^K \lambda_k \times (1 - e^{-\mu_k \times T})}{-\ln |R_G(T)| - \mu_{NS} \times T} \right]}{\alpha}$$

5.2.2.4 Estimate of growth rate required for fixed duration design phase

The expected growth rate required to reach the target reliability given the initial estimate of reliability and the specified duration of the design phase, t_D , is given by:

$$\alpha = \frac{\ln \left[\frac{\sum_{k=1}^K \lambda_k \times (1 - e^{-\mu_k \times T})}{-\ln |R_G(T)| - \mu_{NS} \times T} \right]}{t_D}$$

5.2.3 Tracking reliability growth during design phase

The tracking of reliability growth with Walls-Quigley model is the same as described with Krasich model for tracking of reliability growth in product design phase.

6 Reliability growth planning a tracking in the product reliability growth testing

6.1 Continuous reliability growth models

6.1.1 The power law model

The statistical procedures for the power law reliability growth model use the original relevant failure and time data from the test. Except in the projection technique (see 7.6), the model is applied to the complete set of relevant failures (as in IEC 61014, Figure 2, characteristic (3)) without subdivision into categories.

The basic equations for the power law model are given in this clause. Background information on the model is given in Annex B.

The expected accumulated number of failures up to test time T is given by:

$$E[N(T)] = \lambda T^\beta, \text{ with } \lambda > 0, \beta > 0, T > 0$$

where

λ is the scale parameter;

β is the shape parameter (a function of the general effectiveness of the improvements; $0 < \beta < 1$, corresponds to reliability growth; $\beta = 1$ corresponds to no reliability growth; $\beta > 1$ corresponds to negative reliability growth).

The current failure intensity after T h of testing is given by:

$$z(T) = \frac{d}{dT} E[N(T)] = \lambda \beta T^{\beta-1}, \text{ with } T > 0$$

Thus, parameters λ and β both affect the failure intensity achieved in a given time. The equation represents in effect the slope of a tangent to the $N(T)$ against T characteristic at time T as shown in IEC 61014, Figure 6.