ANSI/IEEE C57.117-1986

An American National Standard

IEEE Guide for Reporting Failure Data for Power Transformers and Shunt Reactors on Electric Utility Power Systems

Sponsor

IEEE Transformers Committee
of the
IEEE Power Engineering Society

Secretariat

Institute of Electrical and Electronics Engineers
of the
National Electrical Manufacturers Association

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Foreword

(This Foreword is not a part of ANSI/IEEE C57.117-1986, IEEE Guide for Reporting Failure Data for Power Transformers and Shunt Reactors on Electric Utility Power Systems.)

The IEEE Transformer Reliability Working Group was formed in 1974 under the Performance Characteristics Subcommittee of the IEEE Transformers Committee. The purpose of this working group was to investigate the feasibility of pursuing transformer reliability on electric utility power systems. To best address the subject of transformer reliability, the IEEE Working Group concentrated on this guide.

Early in the development of this guide, it was recognized that the Edison Electric Institute (EEI), and in particular, the Electrical System and Equipment Committee (ES&E Committee), had an existing data collection system for summarizing equipment outages, and in particular, one category devoted to power transformers. An effort was made to develop this guide in such a manner that common goals between IEEE and EEI could be established. It was the intent that by working together, both groups could develop a single, flexible dynamic system that would benefit the whole transformer industry, both user and manufacturer alike.

The EEI data base summarizes installations and failures for power transformers 2.5 MVA and above. Although the principles proposed in this guide can be used for any homogeneous population, it is anticipated that initial efforts using the principles of this guide will be directed toward large MVA transformers installed on electric utility power systems.

The thrust of this guide is to define reliability terms and to establish guidelines for a data base and reporting mechanism for power transformer failures. In developing this guide it was discovered that the subject of failure analysis could support a document of its own. Accordingly, a separate working group has been formed and assigned a project to perform this task.

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The membership of the working group at the time this guide was published included:

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In order to pursue its goals, the Working Group Chairman established a task force to produce various sections of this guide. The membership of the task force included:

D. J. Cash
J. E. Dind*
C. M. Gardam
J.W. Grimes
R.P. Johnston
J.G. Lackey
H.F. Light
R.J. Whearty

*It is with deep regret that during the writing of this guide, we lost one of our members, J. E. Dind. He had continuously pursued the subject of transformer reliability and will long be remembered by those of us on this working group and task force.

The following persons were on the balloting committee that approved this document for submission to the IEEE Standards Board:

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When the IEEE Standards Board approved this standard on June 19, 1986, it had the following membership:

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An American National Standard

IEEE Guide for Reporting Failure Data for Power Transformers and Shunt Reactors on Electric Utility Power Systems

1. Scope and References

1.1 Scope

1.1.1

This guide addresses the reporting and statistical analysis of reliability of power transformers and shunt reactors used on electric utility power systems. Included are the following types and applications of transformers:

- power transformers
- autotransformers
- regulating transformers
- phase-shifting transformers
- shunt reactors
- HVDC converter transformers
- substation transformers
- transmission tie transformers
- unit transformers
- unit auxiliary transformers
- grounding transformers

For the purpose of abbreviation in this document, the term “transformers(s)” refers to“power transformer(s) and shunt reactor(s).” For further clarification of the meaning of “transformer” as used in this guide, refer to the definitions and 6.5.5 and 6.5.6.

1.1.2

Types of transformers not covered by these guidelines include:

- rectifier transformers
- furnace transformers
- mobile transformers
- dry-type transformers

transformers on industrial and commercial power systems (ANSI/IEEE Std 493-1980 [6][1]applies to these transformers)

electronic transformers

instrument transformers

distribution transformers

1.1.3

The guidelines set forth in this document cover the format for the collection and reporting of data. This guide illustrates the kinds of reports that may be useful to both users and manufacturers of transformers.

1.1.4

The user is cautioned in the direct use of the historical data collected for predicting reliability of future installations. These data are useful in pointing out areas of concern in design, application, installation, operation, and maintenance of transformers and shunt reactors that should be considered when predicting future reliability.

1.1.5

Although the primary scope of this document is the reliability statistic called “failure rate,” it is also recognized that users of the suggested data base may also wish to tabulate and report statistics related to product quality, maintenance, and operating procedures.

CAUTION — Terms such as “failures with a scheduled outage” and “defects” fall into this area of quality reporting and should not be used to develop the statistic called “failure rate.” Defects and failures with a scheduled outage should be tabulated for purposes of immediate and ongoing feedback to manufacturers and operating groups for the improvement of reliability.

1.2 References

[1] ANSI C84.1-1982, American National Standard Voltage Ratings for Electric Power Systems and Equipment (60 Hz).[2]

[2] ANSI C92.2-1981, American National Standard Preferred Voltage Ratings for Alternating-Current Electrical Systems and Equipment Operating at Voltages Above 230 Kilovolts Nominal.

[3] ANSI/IEEE C57.12.80-1978, IEEE Standard Terminology for Power and Distribution Transformers.[3]

[4] ANSI/IEEE C57.21-1981, IEEE Standard Requirements, Terminology and Test Code for Shunt Reactors Over 500 kVA.

[5] ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms.

[6] ANSI/IEEE Std 493-1980, IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems.

[7] Edison Electric Institute, Electrical System and Equipment Committee. Power Transformer Trouble Report—2.5 MVA and Larger.

[1]The numbers in brackets correspond to those of the references listed in 1.2 of this standard.

[2]ANSI publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

[3]ANSI/IEEE publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, or from the Institute of Electrical and Electronics Engineers, Service Center, Piscataway, NJ 08854-4150.

[8] ELECTRA No 88, May 1983. An International Survey on Failures in Large Power Transformers in Service. Paper presented by the Study Committee (Transformers) of Working Group 12.05: A. Bossi (Italy, Convenor), J. E. Dind (Canada), J. M. Frisson (Belgium), U. Khoudiakov (USSR), H. F. Light (USA), D. V. Narke (India), Y. Tournier (France), J. Verdon (France).

2. Definitions

The definitions of terms contained in this document are not intended to embrace all meanings of the terms, but are applicable to the subject treated in this guide.

2.1 accumulated service years: The length of time the transformer is operating from its in-service date until it is retired from service. It is suggested that de-energized time of three months or more not be considered in-service time. See 5.3.2 and 6.5.29.

2.2 component: A part within or associated with a transformer that is viewed as an entity. This is usually a replaceable part, for example, main winding, tap changer motor, etc.

2.3 failure: The termination of the ability of a transformer to perform its specified function. In the study of power transformer reliability, it is often difficult to distinguish between major and minor failures; therefore, the following failure definitions are given.

2.4 failure with forced outage: Failure of a transformer that requires its immediate removal from service. This is accomplished either automatically or as soon as switching operations can be performed.

2.5 failure with scheduled outage: Failure for which a transformer must be deliberately taken out of service at a selected time.

2.6 defect: Imperfection or partial lack of performance that can be corrected without taking the transformer out of service.

2.7 failure rate: The ratio of the number of “failures with forced outages” of a given population over a given period of time, to the number of accumulated service years for all transformers in that population over the same period of time.

NOTE — The failure rate defined here is composed of “failures with forced outages.” This is used for statistical analysis in system mathematical studies. Other reports may be made using “failure with scheduled outages” and “defects.” Tabulation of scheduled outages and defects needs to be aggressively pursued from the standpoint of reliability improvement. It should be recognized that reliability improvement is different from reliability measurement. Quantitative, mathematically correct, reliability measurement can only be accomplished by counting “failures with a forced outage.” Reliability improvement, on the other hand, can be accomplished through tabulating and reporting a wide variety of problems.

2.8 population: Transformers that have given common specific characteristics.

2.9 reliability: The probability that a transformer will perform its specified function under specified conditions for a specified period of time.

2.10 repair: Any operation that requires the dismantling, modification, or replacement of transformer components that results in restoring the transformer to normal service quality.

2.11 shunt reactor: A reactor intended for connection in shunt to an electric system for the purpose of drawing inductive current. See ANSI/IEEE C57.21-1981 [4], 2.1.2.

2.12 transformer: A static electric device consisting of a winding, or two or more coupled windings, with or without a magnetic core, for introducing mutual coupling between electric circuits. See ANSI/IEEE C57.12.80-1978 [3], 2.1.1.

NOTE — The transformer includes all transformer-related components, such as bushings, LTC’s, fans, temperature gauges, etc, and excludes all system-related components, such as surge arresters, grounding resistors, high-voltage switches, low-voltage switches, and house service equipment.

2.13 user: The owner of the transformer.

3. Purpose

3.1

To promote and facilitate cooperative efforts between users and manufacturers to improve the reliability of power transformers.

3.2

To encourage the collection of sufficient data to allow investigation of all effects on transformer reliability including application, installation methods, operating and maintenance practices, design, construction, and testing of the transformer.

3.3

To provide sufficient information and examples to promote data analysis that is meaningful as well as mathematically correct.

3.4

To ensure consistency of nomenclature and compatibility with similiar efforts by other organizations.

4. Access to Data and Reports

4.1

The usefulness and statistical validity of a reporting system such as suggested in thin guide will depend upon the amount and the quality of input data provided.

4.2

To provide a sufficiently large data base within a reasonable time, sincere, continued efforts to cooperate in providing this data are required from users and manufacturers alike. Efforts to provide the necessary data will be minimal unless all participants clearly see themselves benefiting from the results. For this reason it is suggested that the party or parties who undertake the establishment of a reporting and analysis system consider the following points.

4.2.1 Published Annual Reports

Aggregate reports, that is, summaries made from inputs of all manufacturers or all users or both, will provide more accurate estimates of reliability than will summaries made from data on individual manufacturers or users by virtue of the greater amount of data available.

4.2.2 Direct Access to the Data Base and Outputs from It

If a nationwide, or even worldwide, system of reporting to a central data base is established, direct access to this data base via computer terminal may be a distinct possibility. In designing such a system, those involved may wish to consider the following.

4.2.2.1

When enough product data of a design nature is available in the data base to enable a manufacturer to make investigations for reliability improvement of its own product, then some of this data may be of a proprietary nature.

4.2.2.2

Information in the data base on numbers of transformers installed per year of various types by each manufacturer may also be proprietary.

4.2.2.3

When enough installation data of a users system are available in the data base to enable a user to make investigations for reliability improvement of its own system, then some of this data may be of a proprietary nature.

5. Use of This Guide

5.1

The data collection and reporting system outlined in this guide is developed for transformer reliability analysis on electric utility power systems. The same principles, however, apply equally to users, manufacturers, or any organization that may wish to establish a reporting system for their own population of transformers.

5.2

Diversity in design, application, maintenance practices, etc, may result in nonhomogeneous groups of data being collected. Confidence levels may be applied to aid in determining when enough data is available so that valid conclusions can be drawn.

5.3

The following principles have been identified as important to the successful application of this guide.

5.3.1

No transformer should be entered as a member of the population unless there is intention to implement a system for failure reporting and removal of that transformer from the population when appropriate.

5.3.2

In calculating transformer accumulated service years, provision should be made for excluding time when a transformer is de-energized for a period greater than three months.

5.3.3

Only a “failure with forced outage” may be used to calculate a failure rate for statistical purposes. This is used for statistical analysis in system mathematical studies. Other reports may be made using “failure with scheduled outages” and “defects.” Tabulation of scheduled outages and defects needs to be aggressively pursued from the standpoint of reliability improvement. It should be recognized that reliability improvement is different from reliability measurement. Quantitative, mathematically correct, reliability measurement can only be accomplished by counting "failures with a forced outage." Reliability improvement, on the other hand, can be accomplished through tabulating and reporting a wide variety of problems.

5.3.4

Confidence levels may only be applied to failure rates calculated from failures with forced outage.

5.3.5

If a failure rate statistic is to be associated with a particular manufacturer's transformer, it may only be calculated from failures resulting exclusively from the population of that manufacturer.

5.3.6

It is recommended that before entering failure analysis data into the data base the manufacturer be given ample opportunity to participate in the investigation and agree or disagree on the cause of failure.

6. Establishing a Data Base

6.1

One of the first requirements for a system capable of producing high confidence level failure rate statistics is the establishment of a data base.

6.2

Refer to Form 1, Transformer Population Information (see Fig 1) and note that it is divided into three sections. The user will have ultimate responsibility to supply all the information; however, the user may solicit the aid of the manufacturer.

6.2.1

Section I information is mainly concerned with the rating and construction of the transformer.

6.2.2

Section II information is mainly concerned with the installation of the transformer.

6.2.3

Section III information is concerned with the removal of the transformer from service.

6.3

A suggested procedure to be used in supplying population data to the data base is as follows.

6.3.1

A user participating in the suggested system has the responsibility to supply information in Section I of the Population Form (Fig 1). When the aid of a manufacturer is desired, it may be obtained by placing a statement similar to the following in the specification:

The manufacturer of this transformer is to supply all information in Section I of the Transformer Population Information form. This information is to be sent to the user at the time of delivery of the transformer.

6.3.2

A blank copy of the Transformer Population Information form then becomes part of the transformer specification. The manufacturer will fill in Section I of the form and forward it to the user. The user would supply the information in Section II. Upon completion, the data would be entered into the population data file. This would usually take place just prior to, or concurrent with, a transformer being energized.

6.3.3

Should it be necessary to remove a transformer from the data base, Section III would be completed and submitted by the user.

6.4

Occasionally, it may be necessary, although not desirable, to enter an incomplete population data set into the data bank. This can be accomplished by supplying the manufacturer's name along with the serial number and the available information. Additional information may be entered in the same manner at a later date to complete the data set. When a transformer is removed from service, it also should be reported. The manufacturer's name and serial number should be included to identify the transformer each time data are submitted.

6.5

For the purposes of this guide, the following suggested items are chosen for inclusion in a population data base. Refer to Form I (Fig 1), Transformer Population Information.

Section I of the suggested report form includes information regarding the rating and construction.

6.5.1 Manufacturer

The transformer manufacturer's identity is necessary to establish a data base for each manufacturer.

6.5.2 Serial Number

This, along with the manufacturer's name, is the unique identification for the transformer.

6.5.3 Plant Location

The city where the transformer was manufactured.

TRANSFORMER POPULATION INFORMATION

SECTION I — RATING AND CONSTRUCTION

(1) MANUFACTURER

____

(2) SERIAL NUMBER

____

(3) PLANT LOCATION

____

(4) MANUFACTURED DATE ____ / ____ (M/Y)

(5) TYPE

____ (1) POWER TRANSFORMER
____ (2) AUTO TRANSFORMER
____ (3) REGULATING TRANSFORMER
____ (4) PHASE SHIFTING TRANSFORMER
____ (5) SHUNT REACTOR
____ (6) HVDC CONVERTER TRANSFORMER

(6) APPLICATION

____ (1) SUBSTATION TRANSFORMER
____ (2) TRANSMISSION TIE TRANSFORMER
____ (3) UNIT TRANSFORMER
____ (4) UNIT AUXILIARY TRANSFORMER
____ (5) GROUNDING TRANSFORMER

(7) LOAD TAP CHANGER TYPE

____ (1) NO LTC
____ (2) REACTANCE BRIDGING/ARCING IN LIQUID
____ (3) REACTANCE BRIDGING/ARCING IN VACUUM
____ (4) RESISTANCE BRIDGING/ARCING IN LIQUID
____ (5) RESISTANCE BRIDGING/ARCING IN VACUUM
____ (6) OTHER (SPECIFY)

____

(8) LOAD TAP CHANGER AUX. EQUIPMENT

____ (1) REGULATING WINDING
____ (2) TAPPED MAIN WINDING
____ (3) SERIES TRANSFORMER
____ (4) NO SERIES TRANSFORMER
____ (5) OTHER (SPECIFY)

____

(10) ____ NO. OF PHASES

(11) CONSTRUCTION

____ (1) CORE FORM
____ (2) SHELL FORM

(12) CONSTRUCTION OF CORE

____ (1) STACKED CORE, ROUND WINDING
____ (2) STACKED CORE, RECT. WINDING
____ (3) WOUND CORE, RECT. WINDING
____ (4) GAPPED CORE, SHUNT REACTOR
____ (5) CORELESS, SHUNT REACTOR

(13) INSULATING MEDIUM

____ (1) OIL
____ (2) HI TEMP HYDRO CARBON
____ (3) SILICONE
____ (4) OTHER (SPECIFY)

____

(14) TEMP RISE (CENTIGRADE)

____ (1) 55
____ (2) 55/65
____ (3) 65
____ (4) OTHER (SPECIFY)

____

(15) COOLING

____ (1) OA
____ (2) OA/FA
____ (3) OA/FA/FA
____ (4) OA/FA/FOA
____ (5) OA/FOA/FOA
____ (6) FOA — 2 STAGE
____ (7) OW
____ (8) FOW
____ (9) OTHER (SPECIFY)

____

(16) MVA(MVAR) RATINGS FOR ABOVE COOLING

____ / ____ / ____ / ____

(17) % IMPEDANCE AT RATED VOLTAGE FOR ABOVE MINIMUM COOLING RATING

____ (1) H TO X
____ (2) H TO Y
____ (3) X TO Y

(18) FLUID PRESERVATION SYSTEM

____ (1) SEALED TANK
____ (2) INERT GAS-PRESSURE
____ (3) CONSERVATOR
____ (4) CONSERVATOR/DIAPHRAGM
____ (5) OTHER SPECIFY

____

(19) SHIPMENT (PRIMARY)

____ (1) RAILROAD
____ (2) TRUCK
____ (3) SHIP

(20) FILLED DURING SHIPMENT

____ (1) DRY AIR
____ (2) NITROGEN
____ (3) LIQUID

(21) FACTORY TEST PERFORMED

____ (1) ANSI ROUTINE TESTS
____ (2) INSULATION POWER FACTOR
____ (3) IMPULSE
____ (4) FRONT OF WAVE
____ (5) SWITCHING SURGE
____ (6) ONE HOUR INDUCED
____ (7) PARTIAL DISCHARGE
____ (8) SHORT CIRCUIT
____ (9) TEMPERATURE
____ (10) GAS IN OIL ANALYSIS
____ (11) OTHER (SPECIFY)

____

(9) WINDINGS

	RATED VOLT.(kV)	RATED BIL(kV)	CONNECTION	WINDING CONFIG-URATION	SPECIAL CONNECTION	CONDUCTOR MATERIAL	TAP CHANGER	GROUNDING
H								
X								
Y								
			(A) DELTA (B) WYE (C) GRD WYE (D) ZIG ZAG	(A) DISK (B) HELICAL (C) LAYER (D) SHEET (E) PANCAKE (SHELL FORM)	(A) NONE (B) SERIES MULT. INT. RATIO (C) SERIES MULT. NON-INT. RATIO (D) DELTA WYE (E) SPECIAL TAPS	(A) AL (B) CU	(A) LTC (B) DETC (C) NONE	(A) UNGROUNDED (B) SOLIDLY (C) REACTANCE (D) RESISTANCE

SECTION II — INSTALLATION

(22) USER

____

(23) STATION NAME

____

(24) USER IDENTIFICATION NO. (OPT.)

____

(25) IN-SERVICE DATE ____ / ____ (M/Y)

(26) FLUID FIELD PROCESSED

____ (1) FILTRATION
____ (2) FILTRATION WITH VACUUM FILL
____ (3) HOT FLUID DEGASIFICATION PROCESS
____ (4) NONE

(27) MANUFACTURERS FIELD SERVICE

____ (1) SUPERVISED INSTALLATION
____ (2) INSPECTION DURING INSTALLATION
____ (3) PRESENT WHEN ENERGIZED
____ (4) NONE

(28) FIELD TESTS PERFORMED

____ (1) DOBLE
____ (2) DIELECTRIC OF FLUID
____ (3) LEAK TEST
____ (4) MEGGER WINDING
____ (5) MEGGER CORE
____ (6) RATIO
____ (7) RESISTANCE
____ (8) DEW POINT
____ (9) LOW VOLTAGE EXCITATION
____ (10) INSULATION POWER FACTOR
____ (11) GAS IN OIL ANALYSIS
____ (12) TOTAL COMBUSTIBLE GAS
____ (13) OTHER (SPECIFY)

____

SECTION III — REMOVAL FROM SERVICE

(29) REMOVED FROM SERVICE DATE ____ / ____ (M/Y) (NOTE: FILL IN SECTION 1, ITEMS 1 AND 2 ALSO)

Figure 1— Form 1: Transformer Population Information

6.5.4 Manufactured Date

The date of final electrical tests by the manufacturer.

6.5.5 Transformer Type

6.5.5.1 Power Transformer

A transformer that transfers electric energy in any part of the circuit between the generator and the distribution primary circuits. See ANSI/IEEE C57.12.80-1978 [3], 2.3.1.2.

6.5.5.2 Autotransformer

A transformer in which at least two windings have a common section. See ANSI/IEEE C57.12.80-1978 [3], 2.1.4.

6.5.5.3 Regulating Transformer

A transformer used to vary the voltage, or the phase angle, or both, of an output circuit (referred to as the [regulated circuit]) controlling the output within specified limits, and compensating for fluctuations of load and input voltage (and phase angle, when involved) within specified limits. See ANSI/IEEE C57.12.80-1978 [3], 2.2.2.

6.5.5.4 Phase-Shifting Transformer

A transformer that advances or retards the voltage phase-angle relationship of one system with respect to another. See ANSI/IEEE C57.12.80-1978 [3], 2.2.3.

6.5.5.5 Shunt Reactor

A reactor intended for connection in shunt to an electric system for the purpose of drawing inductive current. See ANSI/IEEE C57.21-1981 [4], 2.1.2.

6.5.5.6 HVDC Converter Transformer

A HVDC converter transformer is a transformer used to tie an ac system to a dc transmission system.

6.5.6 Transformer Application

6.5.6.1 Substation Transformer

A power transformer, connected at a transmission or subtransmission voltage, to serve directly a primary distribution system or a customer load. This may or may not be equipped with a load tap changer for voltage regulation.

6.5.6.2 Transmission Tie Transformer

A transformer, commonly an autotransformer, used to transfer power from one transmission voltage to another. It may or may not be equipped with a load tap changer for voltage regulation.

6.5.6.3 Unit Transformer

A transformer installed at a generating station to transform generated voltage to the transmission system voltage.

6.5.6.4 Unit Auxiliary Transformer

A transformer installed at a generating station to supply the auxiliary power system.

6.5.6.5 Grounding Transformer

A transformer intended primarily to provide a neutral point for grounding. See ANSI/IEEE C57.12.80-1978 [3], 2.2.7.

6.5.7 Load Tap Changer Type

These can generally be divided into reactance bridging or resistance bridging type tap changers with either arcing in vacuum or arcing in liquid.

6.5.8 Load Tap Changer Auxiliary Equipment

Regulation of the output voltage is usually accomplished with an auxiliary regulating winding. Certain smaller transformers may use a load tap changer directly connected to main winding taps to increase or decrease the number of turns for regulation without the use of a regulating winding. Load tap changing may be accomplished with or without a booster transformer in series with the winding being regulated to reduce the current being interrupted. This is called a series transformer. Check the appropriate item.

6.5.9 Windings

Fill in the nameplate nominal voltage and rated BIL for each winding. For the third through eighth columns, insert the appropriate letter from the listing below each column. Note under [special connections] series multiple can be integral ratio, for example, 2:1, 3:1, etc, or nonintegral ratio, for example, 4:3, 3:2, etc.

6.5.10 Number of Phases

Enter the number of phases, usually either 1 or 3.

6.5.11 Construction

Check appropriate item.

6.5.12 Construction of Core

Check appropriate item.

6.5.13 Insulating Medium

Check appropriate item. Enter medium, if “other.”

6.5.14 Temperature Rise °C

Check appropriate item. Give “other” temperature rise.

6.5.15 Cooling

Check appropriate item. Explain “other.”

6.5.16 MVA (MVAR) Rating for Above Cooling

Give maximum rating at rated temperature rise. For 55/65 °C rated transformer list 55 °C ratings for OA, FA, FOA with 65 °C rating for maximum, for example, 30/40/50/56 MVA. For a single-phase transformer give the single-phase rating.

6.5.17 Percent Impedance at Rated Voltage for Minimum Cooling Rating

Impedance should be given in percent at the minimum MVA rating of the transformer and rated voltages.

6.5.18 Fluid Preservation System

Check appropriate item.

6.5.19 Shipment

Check appropriate item of primary means of shipment. It is possible that two or more methods could be utilized before transformer arrives at installation site.

6.5.20 Filled During Shipment

Check appropriate item.

6.5.21 Factory Tests Performed

Check all appropriate items. Explain “other.”

Section II of the report form includes information that is applicable to the installation.

6.5.22 User

User company’s name is necessary to establish a data base for each user.

6.5.23 Station Name

Name of substation or plant where transformer is installed.

6.5.24 User Identification Number (Optional)

Refers to the company equipment number if applicable.

6.5.25 In-Service Date

This is the date that the transformer was energized. This information is necessary to establish the in-service life.

6.5.26 Fluid Field Processed

Check the appropriate item for fluid treatment during installation.

6.5.27 Manufacturer’s Field Service

Check appropriate item.

6.5.28 Field Tests Performed

Check appropriate testing done on the transformer at the time of installation. List under “other” any additional tests performed.

Section III of the suggested report form contains information required when a transformer is taken out of service.

6.5.29 Removed from Service Date

Date transformer is removed from service. If this transformer is later returned to service, it should be re-entered by submission of another Form 1 (Fig 1). It is recommended that three months of de-energization is a minimum time period for removal from the population base. It is recommended that any transformer untanked for repair by the manufacturing facility other than the original equipment manufacturer, not be re-entered into the data base. This is suggested to avoid difficulties in accountability encountered when the original equipment manufacturer is not the agent of repair.

7. Reporting Failures

7.1

Once a transformer is part of the population file, and a failure or defect has occurred, it is desirable to:

7.1.1

Ensure that failure or defect is reported as soon as possible.

7.1.2

Solicit the manufacturer's participation in failure analysis.

7.1.3

Conduct a failure analysis in accordance with a proposed guide being developed by the working group on failure analysis.

7.2

The following items are suggested for inclusion in the failure report system. Refer to Form 2, Transformer Failure or Defect Information (see Fig 2).

7.2.1 Manufacturer

The transformer manufacturer's identity is necessary to establish a data base for each manufacturer.

7.2.2 Serial Number

This, along with the manufacturer“s name, is the unique identification for the transformer.

7.2.3 User

User company's name is necessary to establish a data base for each user.

7.2.4 Station Name

Name of substation or plant where transformer was installed when it failed.

7.2.5 User Identification Number (Optional)

Refers to the company equipment number if applicable.

7.2.6 Failure Date

The date the failure occurred.

7.2.7 Reason for Report

Enter only one reason for report.

7.2.8 When Discovered

Enter when the failure or defect was discovered.

7.2.9 Presumed Causes

Enter the appropriate cause or causes of the failure or defect and attach a separate sheet to elaborate on the details.

7.2.10 Failure Location

Enter the appropriate location or locations of the failure and attach a separate sheet to elaborate on the details.

7.2.11 Failure Resulted In

Enter the appropriate result or results of the failure and attach a separate sheet to elaborate on the details.

7.2.12 Disposition

Enter the disposition of the failed or defective transformer.

7.2.13 Repaired By

Check appropriate item.

7.2.14 Where Repaired

Enter where the repair was made.

7.2.15 Outage Time

Enter the appropriate times, in days, for each of the times associated with a failure or defect.

7.2.16 Have User and Manufacturer Agreed on Failure Cause

Enter the appropriate answer: yes, no, or manufacturer not consulted.

8. Reports from the Data Base

8.1

Installation data are submitted utilizing the Transformer Population Information form (Fig 1) as transformers are placed in service. This establishes a population file. Then, failure data are entered by way of the Transformer Failure Information form (Fig 2) as information on the events becomes availiable. Record accuracy is the responsibility of the participating companies. Reliable output data from the file are possible when population and failure data have been entered.

TRANSFORMER FAILURE INFORMATION

(1) MANUFACTURER

____

(2) SERIAL NUMBER

____

(3) USER

____

(4) STATION NAME

____

(5) USER IDENTIFICATION NO. (OPTIONAL)

____

(6) FAILURE DATE ____ /____ (M/Y)

(7) REASONS FOR REPORT

____ (1) FAILURE WITH FORCED OUTAGE
____ (2) FAILURE WITH SCHEDULED OUTAGE
____ (3) DEFECT

(8) WHEN DISCOVERED

____ (1) DURING INSTALLATION
____ (2) DURING ENERGIZATION
____ (3) IN SERVICE
____ (4) DURING MAINTENANCE, INSPECTION OR TEST
____ (5) DURING REENERGIZATION AFTER MAINTENANCE
____ (6) OTHER (SPECIFY)

____

(9) PRESUMED CAUSES

____ (1) ELECTRICAL DESIGN
____ (2) MECHANICAL DESIGN
____ (3) MANUFACTURING
____ (4) MATERIAL
____ (5) INADEQUATE SHORT CIRCUIT STRENGTH
____ (6) ELECTRICAL WORKMANSHIP
____ (7) MECHANICAL WORKMANSHIP

(9) PRESUMED CAUSES (CONTINUED)

____ (8) IMPROPER STORAGE
____ (9) IMPROPER INSTALLATION
____ (10) IMPROPER APPLICATION
____ (11) IMPROPER MAINTENANCE
____ (12) IMPROPER PROTECTION
____ (13) OVERLOAD
____ (14) EXCESSIVE SHORT CIRCUIT DUTY
____ (15) LOSS OF COOLING
____ (16) OPERATION ERROR
____ (17) TRANSPORTATION
____ (18) LIGHTNING
____ (19) EARTHQUAKE
____ (20) ANIMALS
____ (21) VANDALISM
____ (22) SABOTAGE
____ (23) UNKNOWN
____ (24) OTHER (SPECIFY)

____

(10) FAILURE LOCATION

____ (1) H BUSHING
____ (2) X BUSHING
____ (3) Y BUSHING
____ (4) LEADS-TERMINAL BOARDS
____ (5) H WINDING
____ (6) X WINDING
____ (7) Y WINDING
____ (8) TAP WINDING
____ (9) CONNECTIONS
____ (10) MAGNETIC CIRCUIT
____ (11) SHIELDING INSULATION
____ (12) CORE INSULATION
____ (13) CORE CLAMPING
____ (14) COIL CLAMPING
____ (15) FLUID CIRCULATION SYSTEM
____ (16) TANK
____ (17) HEAT EXCHANGERS
____ (18) DETC
____ (19) LTC
____ (20) CTS
____ (21) ANCILLARY EQUIPMENT
____ (22) UNKNOWN
____ (23) OTHER (SPECIFY)

____

(11) FAILURE RESULTED IN:

____ (1) FLUID CONTAMINATION
____ (2) EXCESS TEMPERATURE
____ (3) DIELECTRIC BREAKDOWN
____ (4) IMPEDANCE CHANGE
____ (5) MECHANICAL BREAKDOWN
____ (6) HIGH COMBUSTIBLE GAS
____ (7) LOSS OF PUMPS
____ (8) LOSS OF FANS
____ (9) TAP CHANGER MALFUNCTION
____ (10) FIRE
____ (11) EXPULSION OF FLUID
____ (12) RUPTURE OF TANK
____ (13) OTHER (SPECIFY)

____

(12) DISPOSITION

____ (1) REPAIRED
____ (2) SCRAPPED
____ (3) USE AS IS
____ (4) USE AS SPARE
____ (5) DERATED

(13) REPAIRED BY

____ (1) ORIGINAL EQUIPMENT MANUFACTURER
____ (2) OTHER MANUFACTURER
____ (3) OWNER
____ (4) INDEPENDENT CONTRACTOR

(14) WHERE REPAIRED

____ (1) FACTORY
____ (2) ON SITE
____ (3) REPAIR SHOP

(15) OUTAGE TIME (DAYS)

____ (1) REQUIRED TO REPAIR
____ (2) REQUIRED TO REPLACE
____ (3) WAITING
____ (4) TOTAL OUTAGE

(16) HAVE USER AND MANUFACTURER AGREED ON FAILURE CAUSES

____ (1) YES
____ (2) NO
____ (3) MANUFACTURER NOT CONSULTED

NOTE: ATTACH A SEPARATE SHEET WHEN NECESSARY TO ELABORATE ON THE DETAILS.

Figure 2— Form 2: Transformer Failure Information

8.2

Each failure record will indicate whether or not the manufacturer has been consulted and whether or not the manufacturer has concurred. This will permit summary reports to be generated showing the percentage of concurrence and consultation.

8.3

In an effort to fully utilize a system of this nature, it would be desirable for the output information to meet the needs of the entire industry, and subgroups within the industry (for example, users, manufacturers, and individuals). Some influences on transformer reliability that users and manufacturers might want to investigate are:

8.3.1

Basic Impulse Insulation Level (BIL)

8.3.2

Load Tap Changer (LTC)

8.3.3

De-Energized Tap Changer (DETC)

8.3.4

Oil preservation system

8.3.5

Factory and field testing

8.3.6

Conductor material

8.3.7

Impedance

8.3.8

Storage time

8.3.9

Construction of transformer, that is, shell form versus core form

8.3.10

MVA rating

8.3.11

Autotransformers with and without tertiaries

8.3.12

Comparison of autotransformers versus two winding transformers

8.3.13

Comparison of three-phase transformers to single-phase transformers

8.3.14

Maintenance

8.3.15

Age of transformer

8.4

To meet the needs of the entire industry, 8.6 suggests some reports that might be generated periodically. To meet the needs of subgroups within the industry, 8.7 suggests custom outputs that might be tailored to meet their interests.

8.5

The analysis that is made to answer some of the previous questions may be used in some of the following ways:

8.5.1

By manufacturers to refine transformer design and/or manufacturing to improve reliability.

8.5.2

By users and/or consultants to select among several engineering alternatives during system design and analysis.

8.5.3

By users to compare performance of various manufacturers.

8.5.4

By users and manufacturers to evaluate adequacies of existing testing and explore need for added testing and revised or new standards.

8.5.5

By users and/or consultants to relate reliability and economics during system design and analysis.

8.5.6

By users to refine maintenance and/or operating procedures.

8.6 Periodic Outputs

8.6.1

Trend indicators, shown in table, graph, or chart form, will be of interest to the transformer industry as a whole. This information would display whether transformer reliability is getting better or worse in general.

8.6.1.1

See Example 1.

8.6.1.2

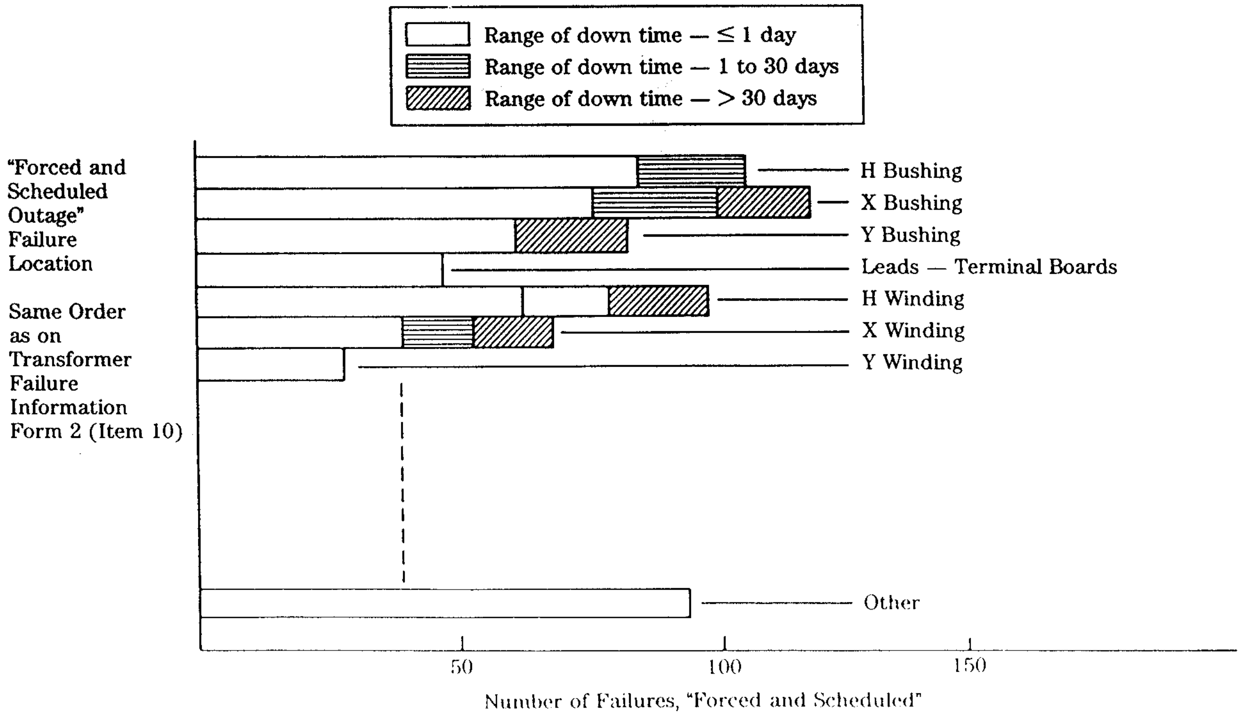
See Example 2.

8.6.1.3

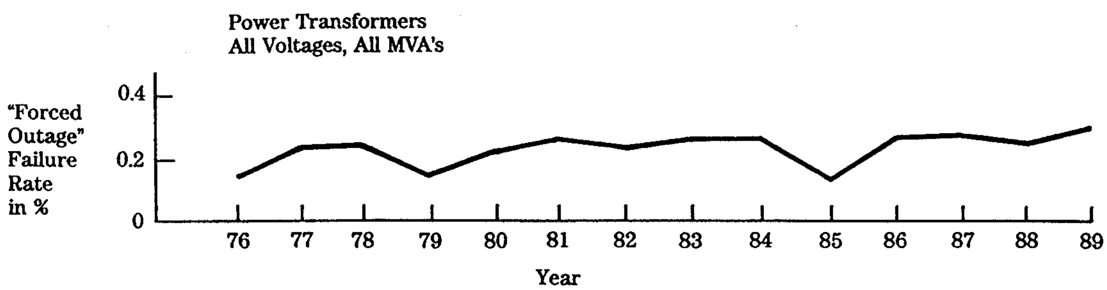
See Example 3.

Rated Nominal Voltage (kV) of H Winding	Number of Transformers	Number of Transformer Years of Service	Number of "Forced Outage" Failures	"Forced Outage" Failure Rate
115				
138				
161				
230				
345				
500				
765				
All				

Example 1
"Forced outage" failure rate.
All MVA ratings by voltage class.
For time period of 1984 to 1990.



Example 2 "Forced and scheduled outage" failure location. (Item 10 of Failure Information form [Fig 2].) All transformers greater than 50 MVA also indicating range of down time. For time period of 1980 to 1987.



Example 3 "Forced outage" failure rate. All MVA's and voltages. For time period of 1976 to 1989.

8.7 Custom Output

8.7.1

A user or manufacturer may request an output of only those characteristics and populations of particular interest, subject to the limitations described in 4.2. Only data of interest are received whereby a clutter of irrelevant output is avoided. If provision is made for file access from remote on-line terminals, reports could be produced whenever they are desired.

Annex A

(Informative)

A.1 Reliability Estimation and Mathematics

A.1.1 Product Life Cycles

Complex products of all kinds often follow a common pattern of failure. Electronic systems, tractors, transformers, or automobiles all have a similar life cycle in regard to when they fail and how often they fail.

This does not mean that tractors and transformers have the same life or the same reliability. It simply means that there are three distinct phases that a complex product goes through in its life cycle. The chances of failure are much different during each phase, but most assemblies of a large number of component parts exhibit these three characteristic periods in their life—called infant mortality, useful life, and wear out.

The *infant mortality* is characterized by a rapidly decreasing failure rate. These failures are usually the result of identifiable causes such as errors in design or manufacture, acceptance of a weak batch of material and other weaknesses in quality control, or errors in use and application of the product. Some products can be debugged by simulated use or overstressing in a scheme of testing or burn-in. Other products are “serviced-in” during the first months of their life by replacing weak components under a warranty policy (automobiles, for example).

The *useful life* phase in a product’s life cycle begins after the rate of failure has decreased to some basic and constant value for that product. During this phase, failures are relatively infrequent and random in occurrence. They are the results of limitations inherent in the design (as opposed to errors, acts of God, or acts of vandalism), manufacturing limitations and processing capabilities, plus accidents caused by usage or inadequate maintenance. If a product is properly applied, operated, and maintained during its useful life, failures will be as infrequent as possible for that design. The only way to reduce failures further would be to redesign the product. For this reason, it is this phase of the life cycle and, specifically, the failure rate during this phase, that is of interest to those attempting to measure the reliability of a specific product. It follows that when characterizing a group of products by rate, it is not enough to group them solely by manufacturer. *It is important that the group be of the same model year (automobiles), generation of design (transformers), and have the same maintenance service and be applied under the same operating procedures and controls.*

The *wear out* phase characterizes the end of a product’s life cycle. Here, the failure rate (or the chance of failure) begins to increase. Failures are caused by embrittlement of metals, wear, aging of insulation, etc. Reliability improvement at this stage requires preventive replacement of these dying components before they result in a catastrophic failure.

A.1.2 Transformer Life Cycle

For the typical power transformer, the infant mortality phase has been significantly reduced by adherence to industry-wide testing standards. The art and science of power transformer testing has evolved over decades and is being constantly improved and fine-tuned year by year. A transformer’s thermal, magnetic, mechanical, and dielectric system is stressed and/or overstressed by an elaborate system of nationally standardized tests. Compared to many products sold today, power transformers offer few, if any, significant problems due to “infant mortality.”

The useful life phase of a power transformer’s life cycle begins with its commissioning into service and may last 30 years or more. The magnitude of the constant failure rate exhibited by a transformer during this phase varies with design, type of transformer, and application. But as a class, power transformers have one of the lowest failure rates of all electrical equipment. For purposes of measuring this failure rate, it is practical to consider that the useful life of a transformer begins at energization.

When it comes to determining when the wearout phase of a transformer's life begins, the effect of temperature over time is presently considered to be the most important factor. The control of mechanical and dielectric stresses will also have a significant effect on useful life. Extending the transformer's useful life to the fullest often depends upon following accepted standards for loading and operating transformers and, thereby, controlling the effects of temperature and other stresses on the insulation system. For example, there are often good reasons for loading beyond nameplate rating, but when done beyond accepted norms for the industry, it should be done with the realization that a shorter useful life will result. The implications for measurement of failure rate are obvious. *Transformers operated beyond the agreed upon industry norms for transformer application and protection should not be part of the population being used to measure failure rate.*

A.1.3 Reliability Measures

It should be clear from the previous discussion of life cycles that the important phase of a power transformer's life (for purposes of measuring reliability) is the time between its initial energization and the point at which it begins to wear out. During that period, and only during that period, is there something constant that can be measured, namely, the failure rate. During that period, the failure rate is a measure of the basic design of the transformer as well as the operating and maintenance practices employed.

Unfortunately, it is nearly impossible to measure when a transformer's useful life ends and the wear-out phase begins. To do so would require a 20 to 40 year history of a large group of transformers of the same design—all operating on the same system, for example, under the same operating principles and maintenance practices. A practical alternative is to set an arbitrary cut-off of 25 or 30 years to represent what experience tells us is the useful life phase of transformers in the population being measured. Transformers older than this cut-off age would not be used, then, to measure failure rate.

Failure rate can be defined as the number of random (unscheduled) occurrences of failure of a product to perform its intended function divided by the length of time the product was functioning. Using this definition, "failure per year" has no meaning. To be useful as a reliability measure, failure rate must be expressed in terms of failures per transformers of similar characteristics that have been in service for a different length of time. In this case, the failure rate for this group would be estimated by dividing the total number of failures experienced by the total service years of all transformers in the group.

Calculated in this way, failure rate, which is symbolized by the Greek letter lambda (λ), may be used to estimate the reliability (R) of a transformer.

Reliability is really a statement of the probability of not failing for a stated period of time. It does not make sense, in other words, to state that the reliability of a product is 0.905. The statement is not complete without mentioning the period of time involved. It does make sense, though, to say that the 20 year reliability of a product is 0.905. That is the same as saying, for a given failure rate, this product has a 90.5% chance of surviving 20 or more years without a failure.

Failure rate and reliability are related in the following way:

$$R = e^{-\lambda t}$$

where

t	= time in years
λ	= failure rate in failures per transformer-years of service
e	= 2.718

Example: Given a constant 0.5% failure rate (λ = 0.005), the probability of a transformer surviving t years of service without a failure would be as shown below.

For $\lambda = 0.005$

t	***R***
1	0.995
5	0.975
10	0.951
20	0.905
30	0.861

Other measures of failure frequency in common use are the mean time between failures (MTBF) and the mean time to failure (MTTF). The concept of mean time between failures is meaningful for products that are frequently repaired after failure and placed back in service. Mean time to failure is used for products whose mission is either successful or it is not. In either case, MTBF and MTTF are both considered to be the reciprocal of the failure rate for purposes of estimating reliability. For instance,

$$R = e^{-t/\mathrm{MTTF}}$$

The idea of product or system availability *(A)* is also commonly used and may be defined as the time a system is available to perform its intended function as a fraction of the total elapsed time. Availability is most simply calculated from the following formula:

$$A = \frac{\mathrm{MTTF}}{\mathrm{MTTF} + \mathrm{MTTR}}$$

where MTTR is the mean time to repair the system.

Availability is a common measure used in substation design, in which case, the failure rate (or MTTF) of the transformer and its mean time to repair would just be two of many component inputs. Similar data on all components of the substation may be pooled to calculate a MTTF and MTTR of the station—hence, its availability. Availability recognizes the additional concepts of maintainability and minimum repair times.

A.1.4 Estimating Reliability

An extremely important consideration in the estimation of reliability parameters, such as failure rate, is the fact that we are working with estimates. All estimates are not equal predictors of the truth and not all estimates warrant equal confidence. The more information we have with which to make an estimate, naturally, the more confidence we can place in that estimate. Fortunately, there are ways to make quantitative judgments about the quality or the “confidence limit” of an estimate. Appraising an estimate by associating it with a confidence limit is important because there is no practical way to make estimates in which we have 100% confidence; in fact, some estimates of failure rates will be quite gross—either because of little data or because of “stretching” the definition of the population to get more data. All populations should be clearly defined and all estimates should be adjusted to reflect the desired level of confidence associated with them. The method of doing this is quite simple.

From the table of confidence limit factors provided, choose the desired level of confidence you wish to have in the estimate. Using that column of factors, choose the factor associated with the observed number of failures. Then multiply the failure rate estimate by the table factor.

Example: A certain utility has been purchasing transformers for 12 years with the BIL reduced two steps. These transformers are rated 12/16/20 MVA, 230-69 kV and have been purchased from several manufacturers.

Transformers bought to this specification and installed at various times during the past 12 years have accumulated a total of 162 transformer-years of service. To date, there have been 6 dielectric failures in this group of transformers. The utility wants to estimate the failure rate of the population of transformers purchased to this specification with a confidence level of 95%.

The failure rate estimated by a sample of 6 failures is 6 failures divided by 162 transformer-years of service or 3.7% (λ = 0.0370).

The upper confidence limit factor corresponding to a confidence level of 95% and an observed number of failures of 6 is 1.97. (See Table A.1.)

By multiplying the same estimate (λ) by the upper confidence limit factor (1.97), the utility can now state, with 95% confidence, that the true failure rate (λ) of the population is no worse than 7.29%. In other words,

$$\begin{aligned} \lambda = & \leq 1.97\hat{\lambda} \\ & \leq 1.97(0.0370) \\ & \leq 0.0729 \end{aligned}$$

By calculating failure rate estimates in this way, a valid comparison can be made with another population of transformers purchased with only one step reduced BIL. Because a confidence limit is applied that is based on the number of failures observed, comparisons can be made with populations having widely different numbers of observed failures.

Table A.1—Factors for Determining the Upper Confidence Limit on Estimates of Failure Rate

Number of Failures Observed (*r*)	Confidence Level			
	80%	**90%**	**95%**	**99%**
1	2.99	3.89	4.74	6.64
2	2.14	2.66	3.15	4.20
3	1.84	2.23	2.58	3.35
4	1.68	2.00	2.29	2.90
5	1.58	1.85	2.10	2.62
6	1.51	1.76	1.97	2.43
7	1.46	1.68	1.88	2.29
8	1.42	1.62	1.80	2.18
9	1.39	1.58	1.75	2.09
10	1.37	1.54	1.70	2.01
11	1.34	1.51	1.66	1.95
12	1.32	1.48	1.62	1.90
13	1.31	1.46	1.59	1.86
14	1.30	1.44	1.56	1.82

Table A.1—Factors for Determining the Upper Confidence Limit on Estimates of Failure Rate (Continued)

Number of Failures Observed (r)	Confidence Level			
	80%	**90%**	**95%**	**99%**
15	1.28	1.42	1.54	1.78
16	1.27	1.40	1.52	1.75
17	1.26	1.39	1.50	1.72
18	1.25	1.37	1.48	1.70
19	1.24	1.36	1.47	1.68
20	1.24	1.35	1.45	1.66
21	1.23	1.34	1.44	1.64
22	1.22	1.33	1.43	1.62
23	1.22	1.32	1.42	1.60
24	1.21	1.32	1.41	1.59
25	1.21	1.31	1.40	1.57
26	1.20	1.30	1.39	1.56
27	1.20	1.29	1.38	1.55
28	1.19	1.29	1.37	1.54
29	1.19	1.28	1.36	1.52
30	1.19	1.28	1.36	1.51

NOTES:

1 — From published tables of chi-square (x^2) distribution such that:

$$\lambda \leq \left(\frac{x^2 \alpha;2r+2}{2r}\right)\hat{\lambda}$$

α = 1 – confidence level in per unit

2 — Estimates made using the confidence level factors in this table are valid regardless of the point in time at which the estimate is made. Different factors apply if an estimate is made based on the service-years accumulated at the time of the most recent failure.