ANSI/IEEE Std 500-1984 P & V

IEEE Standard Reliability Data for Pumps and Drivers, Valve Actuators, and Valves

Excerpted from ANSI/IEEE Std 500-1984

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Foreword

The material in this volume has been excerpted from ANSI/IEEE Std 500-1984 because of specific interest in reliability data for pumps and drivers, valve actuators, and valves.

Comments are invited to this guide, as are suggestions for additional material. These should be addressed to:

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The Chairman of ANSI-FIRR at the time this guide was approved was S. W. W. Shor.

Shortly after the publication of ANSI/IEEE Std 500-1977, a series of *in-plant* visits were arranged. Team leaders and volunteers were solicited from the industry to physically collect data from maintenance records in-situ. The data are being analyzed on a continuing basis.

The first results of the in-plant reliability data system (IPRDS) effort are given in Appendix D in their respective chapters as reference [17]. The team members and participants were: L. E. Booth, S. Balestreri, R. J. Borkowski, E. P. Collins, F. Deininger, J. P. Drago, A. J. Finocchi, J. R. Fragola, J. B. Fussell, L. O. Hecht, and G. W. Jackson. Also. I. M. Jacobs, B. W. Logan, T. Luisi, F. M. Manning, C. L. Mason, A. S. McClymont, P. K. Niyogi, D. H. Pike, S. W. W. Shor, S. B. Tulloch, Jr, R. K. Turnock, and K. E. Weise.

This guide was prepared by a Working Group of Subcommittee 5, Reliability, of the Nuclear Power Engineering Committee of the IEEE Power Engineering Society.

At the time this guide was approved the members of the working group of SC5-3 were as follows:

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The data contained in this guide were collected from the data sheets and contributed by many experts and consultants. Below is a partial list of these contributors.

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Failure Rates for Pumps and Drivers, Valve Actuators, and Valves

1. Introduction

Two of the most common components of any plant dealing with the transfer of gases, liquids and semiliquids (cement, flour, powdered coal, etc.) are pumps and valves used in nuclear, chemical, food processing, plastics, oil exploration and refining, temperature control, and concrete structure industries. Human safety, structural integrity, and energy control depend upon the reliability and maintainability of these critical items.

The data are derived from ANSI/IEEE Std 500-1984 and are displayed in generic form. They were gathered from a variety of sources and combined statistically to reduce the biases that might be introduced by overlapping sources and those with differing bases. The table of contents for each chapter has been replaced by hierarchical trees to show the manner in which the overall failure rates were generated from the original data. In general the failure rates for each subdivision were combined from the lowest bottom level to the topmost level through a succession of composites, to the final composite for the category.

1.1 Scope. This guide applies to reliability data of pumps and driver, valve actuators, and valves.

1.2 Purpose. This guide is intended to establish methods of collecting and presenting reliability data for use in reliability calculations as outlined in IEEE Std 352-1975.

The data contained in Appendix D are intended for the use of system reliability engineers or design engineers and are derived from the tables presented in ANSI/IEEE Std 500-1984. The data are normally used by design engineers in models developed by the analysts. The objectives of such models and calculations are as follows.

(1) Determination of system adequacy (failure or success probability is only one measure of system adequacy; the designer should balance reliability with other system considerations).

(2) Evaluation of system design alternatives.

(3) Evaluation of, or contribution to, the development of system test intervals, maintenance programs or operating procedures, or both.

(4) To contribute to probabilistic risk assessment studies.

1.3 Definitions

item or equipment hazard rate. The instantaneous failure rate of an item or equipment or its conditional probability of failure versus time.

environmental application factor. A multiplicative constant used to modify a failure rate to incorporate the effects of other normal and abnormal environments.

NOTE: When available, these factors are included in Appendix D in the appropriate chapter prefaces.

failure. The termination of the ability of an item or equipment to perform its required function.

NOTE: Failures may be unannounced and not detected until the next test or demand (unannounced failure), or they may be announced and detected by any number of methods at the instant of occurrence (announced failure).

failure mechanism. The physical, chemical, or other process which results in failure.

NOTE: The circumstance that induces or activates the process is termed the root cause of the failure.

failure mode. The effect by which a failure is observed to occur.

failure mode types. (1) *Catastrophic.* A failure which is both sudden and complete.

NOTE: This failure causes cessation of one or more fundamental functions. This refers to system related failure modes. See Appendix A.

(2) *Degraded.* A failure which is gradual, partial, or both.

NOTE: Such a failure does not cease all function but compromises a function. The function may be compromised by any combination of reduced, increased, or erratic outputs. In time, such a failure may develop into catastrophic failure.

(3) *Incipient.* An imperfection in the state or condition of an item or equipment so that a degraded or catastrophic failure can be expected to result if corrective action is not taken.

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outage times. (1) *Out of Service.* The average time required to get the failure, analyze it, obtain spare parts, repair and return the item or equipment to service, *including* planned delays.

(2) *Restoration.* The average time required to get to the failure, analyze it, obtain spare parts, repair, and return the item or equipment to service, *excluding* planned delays.

(3) *Repair.* The average time required to analyze the failure, repair, and return the item or equipment to service. This excludes planned delays and waiting for spares or tools.

failure rate. The expected number of failures of a given type, per item, in a given time interval (for example, valve failures per million valve hours).
NOTE: For *cyclic* items or equipment insert "in a given number of operating cycles."

operating conditions. The loading or demand cyclic operation, or both, of an item between zero and 100% of its related capability(ies).

operating time. The period of time that an active item or equipment is functioning effectively.

component. The largest entity of hardware for which data are most generally collected and expected to be available (for example, pump with motor, valve with operator, amplifier, pressure transmitter). It is generally an off-the-shelf item procured by the system designer as a basic building block for his system. It should be distinguished from seals, materials, nuts, bolts, and other piece parts from which the component is made.

system. A collection of components arranged to provide a desired function (for example, containment spray system, residual heat removal system, high pressure coolant injection system).

fault. Any undesired state of a component or system. A fault does not necessarily require failure (for example, a pump may not start when required because its feeder breaker was inadvertently left open—a "command fault").

failure. A subset of a fault and represents an irreversible state of a component such that it must be repaired in order for it to provide its design function. A component failure is generally defined in terms of the system in which it resides. For example, any leak might be considered a failure in a system where fission products are to be contained, and yet leaks may be considered as normal or even required states of other systems (for example, pump packing gland leakage). Failures are sometimes classified as either primary or secondary.

(1) A *primary failure* is the so-called "random failure" found in the literature. It results from no external cause.

(2) A *secondary failure* results when the component is subject to conditions which exceed its design envelope (for example, excessive voltage, pressure, shock, vibration, temperature).

common cause failure. Two or more redundant component failures due to a single cause. The common cause events that cause multiple failures are usually secondary events or events which exceed the design envelope of the component.

demand failure rate. The probability (per demand) of failure that a component will fail to operate upon demand when required to start, change state, or function.

operating failure rate. The probability (per hour) of failure for those operating components required to operate or function for a period of time.

standby failure rate. The probability (per hour) of failure for those components which are normally dormant or in a standby state until tested or required to operate to perform their function.

1.4 General. The areas considered in the preparation of the tables of this guide are listed below:

1.4.1 Common Time or Cycle Base. To ensure uniform interpretation, the failure data of all items and equipment have been reduced to a common time or cycle base. Because failures are relatively few, they are estimated for each item or equipment in failures per million hours of operation or in failures per million operating cycles. In each case, upper and lower subjective bonds (expressed as a range) have been established for estimated data, and a 90% confidence interval has been established for statistical data.

1.4.2 Source and Scope of the Failure Data. The sources from which the data were compiled are listed in Appendix C. Failure and outage data obtained from published sources are acknowledged and referenced.

1.4.3 Plant Environment. Consideration of actual plant environments in various plant areas

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and various operating conditions is routinely required in the course of an analysis. In these instances, the appropriate environmental factors, when available, should be applied to the listed failure rates. Specific consideration should be given to an item or equipment which is required to be operable during and after an accident.

1.4.4 Constant Hazard Rate. In all cases, the individual item or equipment hazard rate is assumed constant. Any significant deviations from a constant hazard rate are noted.

1.5 Failure Mode. This guide concentrates on failure modes of items of equipment as described in Appendix A. These failure modes are recorded next to each item or equipment description n the data sheets of the tables.

1.6 Limitations of Data. The user should be aware of certan limitations of the data contained in the tables of this guide. Foremost is that the failure rate reported here is not always developed from an actual count of failures in one or more plants. It has sometimes been developed from a wide range of applications which include fossil-fueled power generating stations and industrial process plants but which are applicable as data sources for reliability analysis.

The data for Ref. 1 resulted partially from the analysis of estimates made by over 200 experts. These estimates were collected by an extensive multistep Delphi survey. Therefore, in some cases, the data developed represent either recorded data or the best collective judgment of a group of specialists.

No claim is made the IEEE standard document for pumps and drivers, valve actuators, and valves represents a random sample of plants. Therefore, both the recommended (REC) values (the geometric means or "best estimates") and the interval reported may be expected to differ from those experienced in-service for some of the failure data reported.

The published failure data values given in the guide are for items used under the conditions discussed in individual references and sources. They are intended to apply only to such use. The user should take appropriate precautions while applying these data under different conditions.

The reliability of an item tends to increase as the applied stresses (such as electrical, mechanical, and environmental) decrease, and vice versa. The user is cautioned to consider the effect of operating conditions in the plant prior to the use of the data contained herein.

2. Data Processing

2.1 Data Processing for Pumps, Valve Actuators and Valves. In most cases, the minimum and maximum values given in the tables represent the geometric means of individual values obtained from various sources. As such they should be interpreted as ranges and not as specific confidence bounds. However, in some specific cases (discussed in 2.3), *low* and *high* values are the 90% confidence interval around the best estimate.

In the analysis and pooling of the failure-rate estimates, care should be taken to ensure that the analytical techniques are no more sophisticated than the pool of estimates to which they are applied.

Therefore it was decided that the simple procedure of unweighted geometric averaging was preferred for the first edition. This was based on the subjective observation that the distribution of estimates was better represented by failure-rate exponent averages than by mantissa averages.

Given

$\hat{\lambda}_{min,i}$ = individual estimate of minimum failure rate

$\hat{\lambda}_{max,i}$ = individual estimate of maximum failure rate

$\hat{\lambda}_{b,i}$ = individual best estimate of failure rate

n = the number of individual estimates

The geometric averages are obtained using the following equations:

$$\hat{\lambda}_{min} = \text{anti-log}_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\log_{10}\hat{\lambda}_{min,i}\right]$$

or

$$\left[\prod_{i=1}^{n}\hat{\lambda}_{min,i}\right]^{1/n}$$

$$\hat{\lambda}_{max} = \text{anti-log}_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\log_{10}\hat{\lambda}_{max,i}\right]$$

or

$$\left[\prod_{i=1}^{n}\hat{\lambda}_{max,i}\right]^{1/n}$$

$$\hat{\lambda}_{b} = \text{anti-log}_{10}\left[\frac{1}{n}\sum_{i=1}^{n}\log_{10}\hat{\lambda}_{b,i}\right]$$

or

$$\left[\prod_{i=1}^{n}\hat{\lambda}_{b,i}\right]^{1/n}$$

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where

$\hat{\lambda}_{min}$, $\hat{\lambda}_{max}$, and $\hat{\lambda}_b$ = accepted combined estimates of the minimum, maximum, and most likely (best estimate) failure rates, respectively.

This heuristic technique has been useful in Delphi pollings, such as this one, where a consensus is sought on several properties of a distribution for a random variable. Since Delphi procedures deal, in part, with opinion (not exclusively recorded information) they are not purely statistical procedures.

Where recorded data was available it was combined with the Delphi results by the same heuristic technique.

2.2 Data Processing for IEEE Pump and Valve Failure Rate Document. The 1984 edition of IEEE Std 500 has separate entries for each data source including ANSI/IEEE Std 500-1977 which is designated in Appendix C as reference [1] for data source. The separation of the data entries allows the user to combine data by any method deemed appropriate.

When combining the data, two factors should be kept in mind;

(1) Since data sources such as Licensee Event Reports (LER) data summaries, Nuclear plant reliability data system (NPRDS), and Inplant reliability data system (IPRDS) often report on the same nuclear plants then not all the data points are statistically independent

(2) ANSI/IEEE Std 500-1977 contains information obtained by way of Delphi process and published data sources, thus it cannot be treated properly without consideration of bias due to expert opinion [1].[1]

For the purposes of this edition, a weighted geometric means was chosen as the maximum likelihood (ML) estimator.

The maximum likelihood (ML) estimator is determined by the following modification of the geometric mean as described in [1].

$$\hat{\theta} = \prod_{i=1}^{n} \hat{\theta}_i^{W_i}$$

where

$\hat{\theta}$ = the ML of failure rates or outage times

i = data source number, 1, 2, 3 . . .

W_i = a dispersion dependent weighting factor for each data source

and

$$W_i = \frac{\sigma_i^{-2}}{\sum_{i=1}^{\hat{n}} \sigma_i^{-2}}$$

where

σ_i^{-2} = reciprocal of the variance of the log of each data source

If the available measure of dispersion are ranges only, a suitable function of the ranges can be substituted for σ_i^2.

The weighting factor W_i is important because it reduces the influence of data sources with large ranges and vice versa it increases the impact of data with narrower ranges. Data sources with wide ranges of course indicate insufficient data or data from an immature data base. Likewise, for Delphi data, experts with less confidence in their estimates tended to give wider ranges. Wider range Delphi information thus carries less weight than it would in a simple unweighted geometric mean approach.

There are cases where no measure of dispersion is available. In these cases, the maximum likelihood estimator $\hat{\theta}$ was determined by taking the unweighted geometric mean for all data points not having measures of dispersion and combining that result with the others by the following relation,

$$W_j = \frac{j}{(j+k)}$$

where

W_j = weighting factor with dispersion

j = number of data points with dispersion

k = number of data points without dispersion

$$W_k = \frac{k}{(j+k)}$$

W_k = weighting factor without dispersion

$\hat{\theta}_{j,k} = \hat{\theta}_j^{W_j} \hat{\theta}_k^{W_k}$

= weighted geometric mean for combined observations with and without measures of dispersion

2.3 Statistical Data from a Single Population. In some cases, data were available which were amenable to statistical treatment. If the data came from a single population with a failure rate λ (exponential density), it was treated as a x^2 distribution (see [2]). It has also been shown in [3] that the x^2 distribution can be used to construct confidence bands. In particular, IEEE Std 352-1974 gives the confidence interval on λ data as

$$\frac{x^2\alpha/2;\,2n}{2T^*} \leqslant \lambda \leqslant \frac{x^2\,1-\alpha/2;\,2n+2}{2T^*}$$

[1]The numbers in brackets refer to the references in Section 4.

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where

n = number of failures observed

$\alpha = 1 -$ confidence level desired

The recommended value of λ is

$\hat{\lambda} = n/T^*$

T^* = accumulated item or equipment test or operating hours over a fixed calendar time.

The associated upper and lower confidence bonds on λ are given by:

$$\lambda_L = \frac{x^2\ \alpha/2;\ 2n}{2T^*} \text{ and}$$

$$\lambda_u = \frac{x^2\ 1-\alpha/2;\ 2n+2}{2T^*}$$

where

λ_L and λ_u = lower and upper bonds, respectively.

The value of x^2 can readily be obtained from standard tabulations [4] and [5] for the cases where the problem degrees of freedom ν are less than 30, and by the following approximation for $\nu > 30$:

$$x^2 = \frac{1}{2}\left[(2\nu - 1)^{1/2} + Z\right]^2 \qquad [6]$$

where

Z = value of the standard normal variable at the desired confidence interval and where the number of degrees of freedom is given for the upper and lower bonds by:

$\nu_L = 2n$

$\nu_u = 2n + 2.$

The procedure used for establishing the data base and calculating the component failure rate is as follows: From the plant equipment lists, piping and instrument diagrams, and process flow diagrams, a population card was formulated for each component containing information such as the component identification number, system, and type, type of operator, process fluid, and size. System codes were assigned from descriptive information derived from plant equipment lists and piping & instrument drawings (P&ID's).

The failure rate estimate is calculated after determining the appropriate numerator (number of failures) and denominator (component hours or demands) from the data base. To determine the numerator of the failure rate estimate, the analysts reviewed all the corrective maintenance records collected from the plant visit for related failures. These records were separated, reviewed again, and classified. Analyzing the failure and repair text, the analysts assigned the following codes: failure cause(s), failure severity, and failure mode. The data reported on the maintenance record such as component name, failure date, failure and repair text, as well as the code assignments from the analyst were entered into the computer. A computer program then matched the individual failure and repair record with the population record on the basis of the component identification number. A population record/failure and repair record set was thus generated for each population record, containing the failure and repair history of each component. The total number of failures for a particular component of interest was used as the numerator for the failure rate estimate. Information was gathered to determine the denominator of the failure rate estimate: the total number of service hours for a time-dependent failure rate or the total number of demands for a demand failure probability. For each component analysts assigned the service hours (calendar hours in the system) and an estimated number of demands (12 actuations per year) to each component.

3. Data Format

The format for the presentation of the data is shown in Fig 1. The following paragraphs describe the sections of the format. A detailed description of the data sheets and hierarchical development is found in each chapter of Appendix D.

3.1 Chapter. The chapter identifies the broadest hierarchical breakdown (for example pumps, valves, actuators and valves.)

3.2 Section. The section is the second level of the hierarchy. The bases for the divisions vary from chapter to chapter but are usually based on functional or physical differences.

3.3 Subsection. The subsection is the third hierarchical level. In those instances where data are collected to only this level, the subsection is located in the item or equipment description.

3.4 Item or Equipment Description. The item or equipment description may represent the third or fourth hierarchical level. In those instances where the subsection is left blank, the description represents the third level. In all other times it represents the fourth level.

3.5 Failure Mode. This column contains a brief description of the manner in which the failure occurred (where such information was available). A further discussion of failure modes is presented in each chapter preface and in Appendix A.

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3.6 Failure Rate. The failure-rate columns present various values of the failure-rate range. The low and high values establish the range, and represent, respectively, the best and worst data points. The recommended values (REC) should be used to determine the best estimates and the high and low values can be used as range estimates.

Two types of rates are presented: failure per 10^6 hours and failures per 10^6 cycles. The cyclic failure rate is used in specific instances to describe demand probabilities as noted in each chapter.

3.7 Outage Times. Outage times are divided into three separately entered categories; out of service, restoration (designated as restore), or repair. All time entries are in hours. The low and high columns represent the highest and lowest observed data points. the outage times are designated *, § or † respectively in each chapter data sheet of Appendix.

3.8 Reference. The reference (REF) column identifies the origin of the data given in the data source reference section of Appendix D.

4. References

[1] MARTZ, H. F. and BRYSON, M. C., *A Statistical Model for Combining Biased Expert Opinions,* Los Alamos Report LA-UR-83-531. Los Alamos Scientific Laboratory, PO Box 1663, Los Alamos, New Mexico 87545.

[2] EPSTEIN, B., *Tests for the Validity of the Assumption that the Underlying Distribution of Life is Exponential.* Technometrics. Feb and May 1960.

[3] MILLER, I., and FRUEND, J., *Probability and Statistics for Engineers.* Englewood Cliffs, NJ: Prentice Hall, Inc, 1965, p 373.

[4] MANN, N. R., SCHAEFER, R. E., and SINGPURWALLA, N. D., *Methods for Statistical Analysis of Reliability and Life Data.* New York: John Wiley and Sons, 1974, ch 9, pp 119–164.

[5] Biometrika, vol 32 (1941–1942).

[6] CALABRO, S. R., *Reliability Principles and Practices.* New York: McGraw Hill, 1962.

Fig 1
Typical Data Report Sheet

CHAPTER: SECTION: SUBSECTION:

ITEM OR EQUIPMENT DESCRIPTION

FAILURE MODE	FAILURE RATE								(*) OUT OF SERVICE (†) REPAIR TIME OR (§) RESTORE (HOURS)			
	FAILURES/10^6 HOURS				FAILURES/10^6 CYCLES							
	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF

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Appendixes

(These Appendixes are not a part of IEEE Std 500-1984, IEEE Guide to the Collection and Presentation of Electrical, Electronic, Sensing Component, and Mechanical Equipment Reliability Data for Nuclear-Power Generating Stations.)

Appendix A

A Discussion of the Term *Failure Mode*

A1. Introduction

Failure terms are usually assumed to be so well understood that they do not necessarily require definitions. They are seldom questioned in everyday usage. Even in formal test plans and procedures *failure* usually can never be so well defined as to avoid debates on some of the anamolous events which can occur in the testing or performance evaluation of materials, components, items, equipment, personnel, or complex systems, or a combination of these. Therefore, to establish a definition for *failure mode*, an examination of the concepts of failure as they relate to the testing and operation of systems, equipment, personnel, parts, and materials must be undertaken.

A2. Failure Concepts

Failures of hardware may be defined perhaps most commonly in abstract functional terms such as: *the loss of ability (or inability) to perform a required function (or functions).* Failures of an operator may be defined on such terms as: (1) *noncompliance with established procedures;* (2) *improper actions (or improper inaction);* or (3) *operator error*, or a combination of these. Failures of equipment or materials may be defined technically in terms of definative specification parameters which were not met during established tests or inspections. Failures of complex systems may be defined in terms of system functions which are disabled or degraded by the failure. These failures may also be defined in terms of the degradation or loss of specific functions by the subsystem in which the failure occurred. In tracing a system failure to the lowest level of assembly or part involved in the failure event there will often be a chain of interrelated events (or failures) — each of which had an effect upon another element (or elements) in the chain.

A3. Failure Types

A3.1 Statistical Types. Some types of failures are classified on the basis of the statistical distributions representing their frequency of occurrence. These include the exponentially — distributed *random* failures, having a *constant* hazard rate; and, the Gaussian or Weibull — distributed *wear out* failures, having an increasing hazard rate. The only statistical type of failures used in Appendix D is the *constant* hazard rate.

A3.2 Failure Tracing Types. In tracing system failures, often a *primary*, *independent*, or root-cause failure (which initiated a series of events leading to the failure of the system) and one or more *secondary*, *dependent*, or contributing failures. These are failures which were caused directly or indirectly by the root-cause failure.

When discussing failure tracing it is helpful to characterize failure causes as root causes, contributing causes and immediate causes. Briefly, a root cause can be characterized as the basic or fundamental cause of a failure. Root cause should not be confused with *failure mechanism* (see A4). These are generally a myriad of contributing causes that lead to the failure. Contributing causes follow root causes and lead up to an immediate cause. The immediate cause is the cause that immediately preceeds the failure mode (see Fig A1).

A4. Failure Mechanism

The failure mechanism defines the physics of the failure. This involves the description and sequence of those mechanical, electrical, or chemical processes or a combination of these, which occurred during the period in which the failed item changed from an operational item to a failed item. For example, electrical or mechanical overloads which involve a level of

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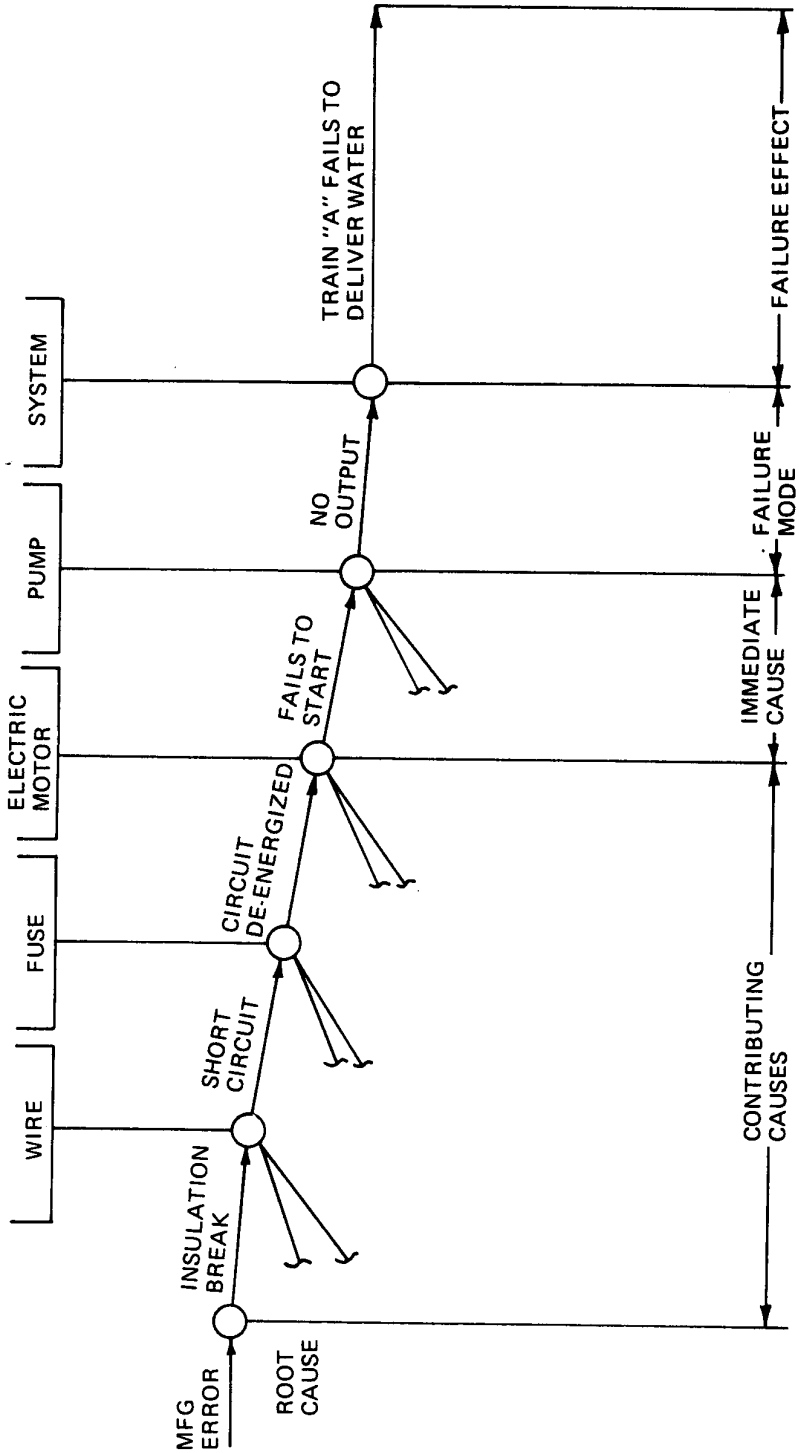

Fig A1
The Relationship of Failure Causes, Modes, and Effects for a Pump

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stress which exceeds the rated electrical or mechanical strength of an item will cause physical damage resulting in loss of functional capability. The failure mechanism is the process which occurred to change the physical or functional characteristic, or both, of the materials in the failed item (for example, *relay coil wire burned open by electrical overload*).

A5. Failure Modes

When failures occur in a system element they often occur in a variety of ways. For example, a relay can fail in the closed position (for example, when contacts are welded shut) or the open position (for example, when contacts fail to close on demand because of such problems as an open coil). A *failure mode* is defined as: *the effect by which a failure is observed to occur* and is usually characterized by description of the manner in which a failure occurs. It is a description of the failure itself. A failure mode provides a descriptive characterization of the failure event in generic terms — not in terms of the *failure mechanism:* which occurred, and not in terms of the *failure effect* (see below). In the case of a relay which fails to close on command, the failure mode is *fails to open* or *fails to close*.

An important thing to recognize in defining a failure mode is that each failure mode must be defined and considered at a particular indenture level (that is, a failure mode at the part level usually has an effect upon a higher-level of indenture which, in turn, may be involved in another, different failure mode) (as shown in Fig A1). This is the so called system-related failure mode approach as described in Appendix A of ANSI/IEEE Std 500-1977.

A6. Failure Effects

The effects of a failure within a system may be propagated to higher and lower levels of assembly — or the system design may prevent such propagation. The propagation and interrelationships of failure modes and failure effects have been well illustrated in such documents as the PRA Procedures Guide vol 1 (NUREG/CR-2300). Failure mode and effect analysis is a formal approach to the analysis of failure modes and their propagated effects involves the loss or degradation of functions and also the effects of failures on system safety (that is, hazards to personnel, or property, or the environment, or a combination of these). In a typical system, failure of a part affects the function of the assembly of which it is a part. This *effect* also initiates a *failure mode* at the assembly level. The *effect* of this assembly *failure mode*, in turn becomes a *failure mode* at the next higher level (for example, the subsystem). Therefore, as failure modes and effects occur at successively higher levels of indenture each *failure effect* may give rise to a new *failure mode*. In the operational and maintenance man-machine interfaces, the common failure syndroms (that is, failure indications) are usually identified by some established terminology (for example, Loss Of Cooling Accident, LOCA).

A7. Development of Failure Modes

The purpose of the tables is to present failure and repair information, therefore it should not be interpreted as a failure reporting, failure investigation, or cause tracing tool; that can only be accomplished by carefully researching the referenced data sources.

The failure modes shown in the tables are a brief description of the manner in which the failures occurred as reported in the data sources. So as to make the reported descriptions consistent from one data source to another, failure modes were reworded on a common basis. For instance, *functioned without a signal* and *false trip* were replaced by *spurious* response. In the case of pumps, *failed to run once started* and *failed to continue to run* were replaced by *failed to run* since *failed to start* was already a part of the failure mode description. In general the failure modes are similar if not identical to those shown in Figs A2 and A3.

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				Failure Severity		
				Catastrophic	Degraded	Incipient
Change in item or equipment condition	Change in operation			1. Failure to operate (run) 2. No output	1. Low output 2. High output 3. Erratic output 4. Locked in one mode of operation 5. Output above or below specified requirements	Discovered through: 1. Local inspection (overheating, leaks, contamination, noise, severe vibration, odor, cracks, etc) 2. Testing: (output above or below specified limits while in stand-by mode of operation) 3. Monitoring (trend towards failure)
	Change of state	Change without demand		A spurious: 1. Start/Stop 2. Insertion 3. Withdrawal 4. Actuation 5. Response 6. Opening 7. Closing	1. Premature or delayed actuation (an actuation that occurs out of timing sequence) 2. Won't stay open or closed	Discovered through: 1. Testing: Failure or diminished ability to transmit or retain energy during the stand-by mode of operation 2. Local inspection
		No change on demand		Failure to: 1. Start 2. Stop 3. Insert 4. Withdraw 5. Actuate 6. Respond to command 7. Open 8. Close	Improper Response: 1. Partially open, close, etc 2. Oscillation (failure to assume a fixed position)	

Fig A2
Failure Mode Matrix
Active Item or Equipment

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	Failure Severity			
	Catastrophic	Degraded	Incipient	
Change in item or equipment condition	Failure to retain or transmit energy 1.0 Breach of pressure or static fluid boundary 1.1 Major leaks 1.1.1 External leaks 1.1.2 Internal leaks 1.2 Explosions 1.3 Implosions 2.0 Loss of energy transport or exchange capability 2.1 Blocked or stopped flow 2.2 Loss of heat transfer capability (scale buildup) 2.3 Major heat loss (loss of insulation) 3.0 Loss of structural integrity 3.1 Failure to support or brace 3.1.1 Fracture (of all members) 3.1.2 Physical distortion (permanent set) 3.1.3 Distortion under load (without perm. set) 3.2 Failure to fasten or join 3.2.1 Removable fastener failure 3.2.2 Failure of permanent joint 3.2.2.1 Weld failure 3.2.2.2 Imbed failure	Diminished ability to retain or transmit energy 1.0 Degradation of pressure or static fluid boundary 1.1 Minor leaks 1.1.1 External leaks 1.1.2 Internal leaks 2.0 Interference with energy transport or exchange capability 2.1 Restricted flow 2.2 Reduced heat transfer capability 2.3 Minor heat loss 3.0 Structural integrity compromised 3.1 Reduced support capability 3.1.1 Fracture of part of the structural members 3.1.2 Minor physical distortion 3.2 Partial failure to fasten or join	Change in operation	(1) Testing: Failure of diminished ability to transmit or retain energy during the energized mode of operation (2) Local inspection (leaks, vibration, odor, cracks, etc) (3) Monitoring: Monitoring trend towards failure, during the energized mode of operation
			Change of state	(1) Testing: Failure or diminished ability to transmit or retain energy during the stand-by mode of operation (2) Local inspection

Fig A3
Failure Mode Matrix
Passive Item or Equipment

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Appendix B
The Delphi Procedure

This guide utilized a Delphi procedure (see [1],[2] to secure from over 200 experts located throughout the county, initial failure-rate and failure-mode estimates on components used in the power industry. Since nuclear plants are historically reliable (the total of equipment failures is well under 300 a year) it was impossible to secure estimates of failure rate by relying exclusively on plant operating failure data. However, even though operating data were not spcifically available, information existed throughout the industry in various forms. It was known that published data sources existed external to the industry which might be to some degree applicable. During the course of the Delphi procedure the working group examined published data sources not only in the power apparatus and instruments industries but also in aerospace and other industries.

Thus the data from which Appendix D was synthesized were found in the following forms:

(1) Statistical operating data from nuclear facilities.

(2) Statistical operating data from fossil-fired generating stations and other large industry data (such as the chemical industry).

(3) Statistical failure data from transmission grids and industrial plants with judgment used to estimate the population from which the failures were observed so that a failure rate could be calculated.

(4) Failure and population estimated data made by individuals familiar with the operating and failure histories of specific generic types of devices.

(5) Data extracted from published sources for other industries which were judged to have some level of applicability to nuclear-power generating station components.

It should be noted that individual experts were instructed to generate estimated data only when statistical sources of data remained unavailable to them.[3]

[2]The numbers in brackets in Appendix B refer to the references in B4.

[3]On the average, 80% of the data included in the document resulted from statistical data falling into one of the first three categories given above.

B1. Use of the Delphi in the Development of Ref [1]

Individuals familiar with the failure modes and failure rates in the power industry are usually specialists on a certain range of equipment that represents but a small segment of the components in any power plant. In addition, the number of experts available to participate in estimating failure rates for some of the specialized equipment might be small. However, much of this knowledge resides in the years of experience on the part of these specialists. Therefore:

(1) Over a hundred individuals were needed for coverage of the scope of components in a nuclear power plant.

(2) Only a small number of individuals have direct knowledge of any one subset of components. These small groups of individuals are not unique: for example, there may be overlapping memberships.

(3) Much expert judgmental data had to be integrated.

The unique nature of the problem dictated that a specific Delphi approach be taken from established principles of the Delphi method outlined in B3. The objectives of this approach as applied to the document were to:

(1) Develop a logical structure for consideration of all the components in a nuclear-power generating station and for their modes of failure. (See B2.1.)

(2) Solicit reliability data, or estimates, or both, for components on the first Delphi round while allowing respondents to further develop possible modes of failure on the forms indicated in B2.2.

(3) Solicit on the second round, estimates of newly defined failure modes and reliability data for any additional components.

(4) Solicit, on the third round, re-examination of any areas where there appears to be significant polarization of disagreement among those responding to a particular question. Solicit evaluation of the magnitudes and range of relevant published data.

(5) Solicit, on the fourth round, any final changes in component reliability data, or estimates, or both, that the respondents desire.

(6) Retain at all times the anonymity of re-

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spondents so that responses are not misrepresented as reflecting an organization in which the particular respondent may be employed.

(7) Structure the procedure and questions so that only those specializing in a particular set of components will respond to that set.

Over 150 professionals provided input as chapter administrators, experts, and consultants. These primary respondents were encouraged to utilize colleagues and associates as they deemed necessary or desirable to broaden the scope of the response.

To further refine the results of the responses, it was recognized that the performance of a Delphi group increases as its collective expertise increases. This fact includes within it the subtle problem of discovering an independent measure of expertise. Several approaches to the solution of this problem have been proposed. See [1]. Of the approaches investigated only those of ordinal self-ranking were considered to be of any practical value. This method was employed by the Delphi experts on an individual basis using a scale of 1 to 5. Experience dictated that when estimates occur in the tails of distributions, the estimators responsible usually rated their expertise lower than those within the mean of the group, and even this result did not occur very often. Also, by the very nature of the experts selection process, most of the participants were judged *a priori* by their peers to be in the 4 or 5 category. In actuality, the experts ranked themselves for the most part as either a 4 or a 5. Thus, the expert weighting of the data did not essentially change the results which would have been obtained from an unweighted group.

B2. Delphi Questionnaires

B2.1 Pre-Questionnaire Period. The pre-questionnaire period exhibited activity at all levels of the organization. The project administration developed a general questionnaire form and the instructions for its use. A schedule was established for completing the Delphi, and the Delphi technique, and the use of the forms was explained to the chapter administrators. The project administration also assisted and guided the chapter administrators in the preparatory work leading to the Delphi.

B2.2 First Round Questionnaire. Chapter administrators issued their modified questionnaire forms (Fig B1) to the Delphi experts, and they explained the use of the form. The Delphi experts were free to use any data sources in answering the questionnaires. Those most commonly used sources were recorded data from the expert's company or personal files, personal experience, and published data. The experts also added any comments and suggestions that they considered were pertinent. The questionnaires were then returned to the chapter administrators. The chapter administrators collected the completed questionnaires, evaluated the suggestions and comments, and sent the forms to the project administration. The comments provided valuable supplementary information about the various equipment types. These comments were evaluated and edited by the chapter administrators and are given in the chapter prefaces. The completed forms and suggestions for improvements were sent to the project administration, which, in turn, had experts from the data processing chapter evaluate, compile, and display the data.

B2.3 Second, Third, and Fourth Round Questionnaires. The second generation Delphi questionnaire (Fig B2) was developed by the project administration and was based upon the development plan and comments from the first questionnaire. The chapter administrators again modified the general questionnaire form to make them unique to their chapters and sent the forms and the compiled data to their experts. Experts were given the opportunity to either reaffirm or change their previous estimates, based upon the compiled results from the first questionnaire. The process from this point was identical to that in the first questionnaire. The pattern repeated itself through the fourth questionnaire with the specific exceptions discussed in B2.1.

B2.4 Post-Questionnaire Period. Only the project administration and data processing chapter personnel were active during the post-questionnaire period. They analyzed and compiled the questionnaires from all the rounds, correlated the data, and tested them against existing data sources. When completed, the data were placed into the failure rate tables of Appendix D.

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(1) Estimated Failure Rate Under *Operating* Applications Min_____ Best Est_____ Max_____ (fail/10^6 hrs)
Min_____ Best Est_____ Max_____ (fail/10^6 cycles)

(2) Estimated Failure Rate Under *All* Applications Max_____ (fail/10^6 hrs)
Max_____ (fail/10^6 cycles)

(3) Type of Experience_____

(4) Rate Your Expertise (Overall)_____

1 = Low

5 = High

6 = Recorded Data

(5) Estimate Based on Recorded Data? If so, indicate:

Source of Data_____

Number of Operating Hours_____

Number of Failures_____

(6) Failure Modes	(7) Mode Percentage	(8) Environmental Factors			(9) Rate Your Expertise (Failure Modes)
		High Temperature	High Radiation	High Humidity	

Rate Your Expertise (Environmental Factors) (10)

(11) Questions/Comments:_____

Fig B1
IEEE Project 500 — Initial Delphi Failure Rate Estimate Format

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(1) Estimated Failure Rate Under *Operating* Applications
Min_____ Best Est_____ Max_____ (fail/10^6 h)
Min_____ Best Est_____ Max_____ (fail/10^6 cycles)

(2) Estimated Failure Rate Under *All* Applications
Max _____ (fail/10^6 h)
_____ (fail/10^6 cycles)

(3) Type of Experience_____

(4) Rate Your Expertise (Overall)_____

1 = Low
5 = High
6 = Recorded Data

(5) Basis for Estimate
Source of Data (If Applicable)
_____
Cumulative Number of Operating Hours (On *both* failed and unfailed components — parts x number of hours)_____

Number of Failures_____

Population_____

(6) Failure Modes	(7) Mode Percentage

(8) Environmental Factors
A factor less than 1 decreases the rate
A factor equal to 1 does not change the rate
A factor greater than 1 increases the rate

High Temperature_____

High Radiation_____

High Humidity_____

Other (Identify)_____
_____

(9) Rate your Expertise
Failure Modes_____

Environmental Factors_____

(10) Questions/Comments:
_____
_____

Fig B2
IEEE Project 500 — Modified Delphi Failure-Rate Estimate Format

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B3. The Delphi Method

The *Delphi method* (see [1]), represents the concept of establishing a feedback system for the written communication of data and information among a group of professionals. It characteristically involves:

(1) A group of specialists or experts on the topic of concern and an administrative team needed to carry out the exercise.

(2) The design of a structure that focuses on the nature of the problem being considered.

(3) A series of questionnaires that utilize the overall structure in terms of specific issues or data.

(4) Anonymous response to the questionnaires on the part of the respondents.

(5) An opportunity for respondents to revise judgments based upon summaries of the group's response prepared by the administrative team.

(6) Anywhere from two to five iterations of the material through the questionnaire — summary — revision — new questionnaire process.

The Delphi method is, therefore, a technique to solicit, synthesize, and correct or improve individual and group judgment. The concept was developed in the 1950s by the RAND Corporation. See [2] and [3]. Studies using the Delphi method have been conducted on groups from five to five hundred in size. There have been over five hundred published reports on Delphi exercises, and it is estimated that proprietary studies using the Delphi method conducted in corporations represent over two thousand additional studies.

A number of successful applications have been documented in a recent book (see [1]) together with criteria and guidelines on the design and application of Delphi.

Those active in the area currently view Delphi as a communication process structured around a particular problem. Studies using the Delphi method have been implemented by way of computer terminals as well as by paper and pencil. A major justification for the technique lies in the fact that in many situations so-called *classical* statistical data do not exist, and for many information gathering efforts other communication schemes are impossible. Typical reasons which invalidate other schemes are: group size, travel costs, time constraints or psychological bias, or both, or organizational problems.

In the case of Appendix D, the need for statistical failure rate estimates has long been realized by the nuclear industry and its government regulators. Since the standardized collection and statistical analysis of historical data has not been centrally organized, any project which relies upon *classical data* alone cannot hope to provide failure rate information broken down to the level of sophistication presently required by the industry. However, the industry has long recognized that, despite its isolation, a wealth of valuable data is available even today. These data are locked up in the years of personal experience of hundreds of experts. The Delphi provides a procedure that finally allows this valuable resource to be tapped for the benefit of all parties concerned.

Typical ways to gather this information is to:

(1) Interview every one of these individuals at least twice to establish consistency among differences in responses.

(2) Hold many hundreds of small group meetings with associated travel costs and assume all the experts are able to give the time involved.

(3) Launch a wide number of small studies with the organizations employing these specialists.

The first two approaches are prohibitively expensive to conduct and the last is impractical because the individuals in a particular area are not unique to any one organization. Most of the experts involved have severe constraints on available time. Therefore, the Delphi appeared to be the only mechanism available for gathering reliable information in an efficient and timely manner. The resulting emphasis of the Delphi is that of an exercise where the specific knowledge of small groups of respondents is tapped, but within the context of an overall structure.

As a result of the above conditions and the value of the specific data being collected, these particular data do not suffer from some of the difficulties facing those exercises that deal with broad concepts and heterogeneous mixtures of expertise.

B4. References

[1] LINSTONE, H. A. and TUROFF, M. *The Delphi Method: Techniques and Applications.* Addison-Wesley Inc, MA, 1975.

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Appendix C

Development of the Hierarchical Trees and Limitations of the Individual Data Sheet Entries

Although every effort has been made to make the tables uniform and consistent, there are exceptions that are worth noting. This includes the general philosophy behind the development of the hierarchical trees that is given in each chapter preface.

The relationship of differences in failure rates to differences in design configurations has been apparent in most reliability data bases in recent years. However, many other factors influence that difference. Early documents did attempt to identify factors other than design differences and incorporate those factors into the generic hierarchial structure. Subclassification of equipment by voltage is one such example.

Two new factors influence the hierarchial structure. First, outage times (particularly repair times) tend to be related to size. Second, presently available data sources contain a mixture of information as to size, application, and design configuration. Some data sources only describe the equipment in terms of size or application, or design configuration, but not in any combination of the three. Thus, so as to use some data sources a new conversion for the development of hierarchical structures was necessary.

C1. Alpha Numeric Indexing of the Hierarchical Trees

Previous documents used the same numeric indexing method as is commonly used in report writing so as to uniquely identify various levels of the generic hierarchy.

It has become clear that a purely numerical method of indexing was not practical when combining various data sources into one *composite* because there is not uniform way to distinguish size, application, and design configuration which would not vary from chapter to chapter. To avoid this potential source of confusion, an alpha-numeric system was adopted which designates the size category as (a), the application category as (b) and the design difference category as purely numeric. For a hypothetical "chapter 30" hierarchical tree shown in Fig C1 would provide the framework for the organization of the data sheets.

C2. Composites

When combining information from several data sources into a *composite* it was always possible to bring forth a composite number for failure rates as described in 2.2 of the guide. This was possible because all references provided failure rate information as a minimum. Since not all references contain failures per cycle or outage times, it was not always possible to propagate failures per cycle or outage times. If in Fig C1, level 30.X had outage times whereas 30.a and 30.b did not, then forming an estimate of outage time at the 30-"kluge"[4] level could not be justified.

C3. Round-Off Error

So as to limit the data entries to three digits and four decimal places, round-off errors are given on the data sheets. The sum of the entries under the failure categories of catastrophic, degraded, and incipient often will not add up to the *all modes* failure category at the top of the column. In a similar manner the breakdown of each category into subcategories may not add to the value given for that failure category.

[4]A nondescript item that performs an imaginary function.

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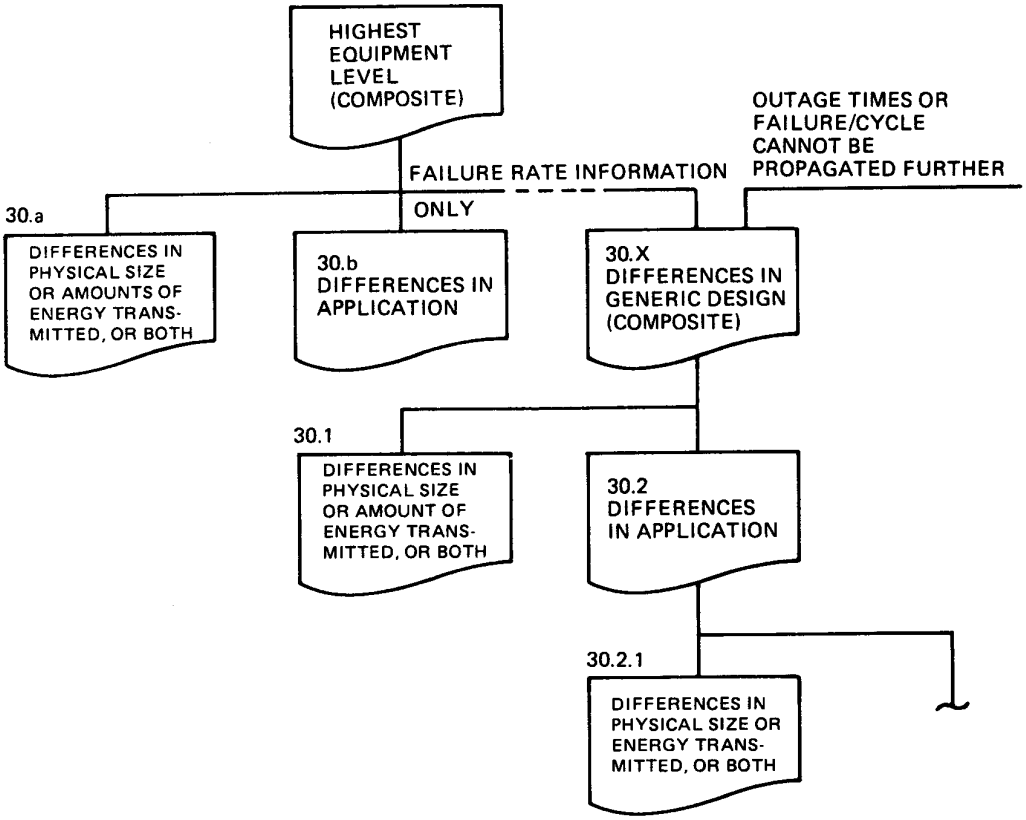

Fig C1
Hypothetical Hierarchical Tree

C4. Notation

So as to have the decimal point fall in the same position in all columns the following format was adopted: 123.1234, or three digits followed by four decimal positions. A number such as 7156, will be entered as 7.16E3. The notation E3 standing for 10 to the third power. There are no negative exponents.

The data under the service columns are shown as "Out of Service (*)", "Repair Time (†)", or "Restore (§)". The data in the columns under these headings, are referenced by (*), (†) and (§), which are always given in the column under the heading LOW, in the fourth decimal place. For example:

LOW	REC	HIGH
6.25 *	26.4	324.0
†	12.0	
§	18.0	

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Appendix D

Reliability Data for Pumps, Actuators, and Valves

(The data of this Appendix were developed and reviewed by a Subcommittee of the IEEE Nuclear Power Engineering Committee, but have not been reviewed by NPEC or the IEEE Standards Board.)

The current data base does not permit distinction between failure rate estimates in standby and operating modes for all applicable components and all failure modes. When this distinction is not possible the quoted failure-rate estimates must be used and interpreted with care.

References

The sources referenced in Appendix D data pages are as follows:

[1] ANSI/IEEE Std 500-1977, IEEE Guide to the Collection and Presentation of Electrical, Electronic, ad Sensing Component Reliability Data for Nuclear-Power Generating Stations.
[2] Interim EGG-EA-5B16, April 1982, Data Summaries of Licensee Event Reports of Valves at US Commercial Nuclear Power Plants.
[3] Corps of Engineers (HND) R/M Data Base, Ground Stationary Equipment, Rep No 16, 04/12/73.
[4] Nonelectric Parts Reliability Data (NPRD-2) Summer 1981, Reliability Analysis Center, Rome Air Development Center, Griffiss Air Force Base, NY 13441.
[5] Utility "A"
[6] Nuclear Unit Productivity Analysis (Special EPRI Report No 46) Aug 1976 (Nonredundant Equipment Only).
[7] Gas Turbine Manufacturer "A"
[8] Architectural Engineering Company "A"
[9] NUREG/CR-1205 Jan 1980, Data Summaries of Licensee Event Reports of Pumps at US Commercial Nuclear Power Plants.
[10] NUREG/CR-2232, Nuclear Plant Reliability Data System (NPRDS) 1980 Annual Reports of Cumulative System and Component Reliability.
[11] ANSI/IEEE Std 493-1980, IEEE Recommended Practice for Design of Reliable Industrial and Commerical Power Systems (Gold Book).
[12] NUREG/CR 2886, May 1982, In-Plant Reliability Data System (IPRDS) Interim Draft Report on the Reliability Characteristics of Selected Pumps in Four Nuclear Plants.
[13] Pressurized Water Reactor — Plant No 10.
[14] EPRI Rep No AP 2071, Oct 1981, Component Failure and Repair Data for Coal Fired Power Units.
[15] R&D Status Report-Advanced Power Systems Division, EPRI Journal, March 1982, p 37.
[16] Architectural Engineering Company "B".

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Chapter 1
Valve Operators and Actuators

Preface

D1.1 Introduction. This chapter contains failure rates, failure modes, and environmental effects which are the basic ingredients necessary for performing an effective reliability analysis on valve operators and actuators.

This information on valves collected from the Delphi questionnaires and IEEE team visits to nine operating power plants contains data on a variety of applications including a balance of nuclear and fossil fuel-plant applications. The team visits to operating plants included at least four engineers from IEEE who were knowledgeable in the field of power applications. They reviewed and copied maintenance records for the previous five-year period and completed lists of the plant installation instruments and operating parts.

D1.2 Hierarchical Tree. Figure D7 is a pictorial representation of the hierarchical structure of Chapter 1 and the procedures in which composites were formed for the various levels of information regarding valve operators and actuators, failure rates, and outage times.

If the design calls for a solenoid operated electric, pneumatic, self operated, hydraulic or mechanical operated device, and data are not presently available for so specific a device, the data for the broader drive class may be used to approximate this device, provided that the failure-rate range and the recommended value are considered.

D1.3 The reduced data used in this chapter were taken from the complete failure rate compendium, ANSI/IEEE Std 500-1984. The figures and tables have been reproduced from the same plates and hence carry the designations of Chapter 7 as in the original volume.

Although Chapter 2, Valves, includes the actuators in most cases, this chapter on the actuators is introduced for those whose interest includes the actuator failure rates as separate entities.

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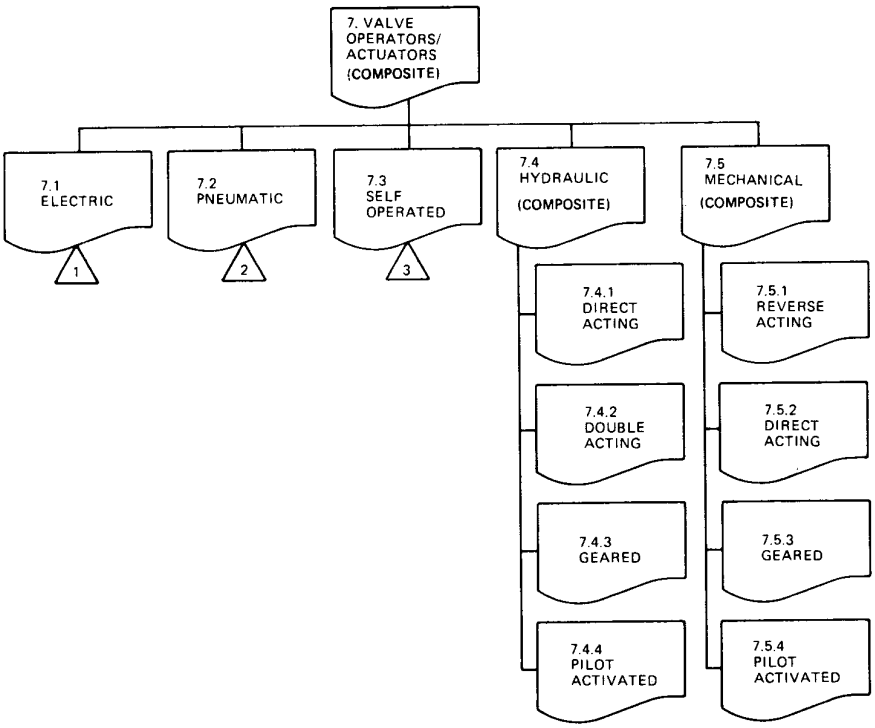
Fig D7
Hierarchical Tree
Valve Operators/Actuators



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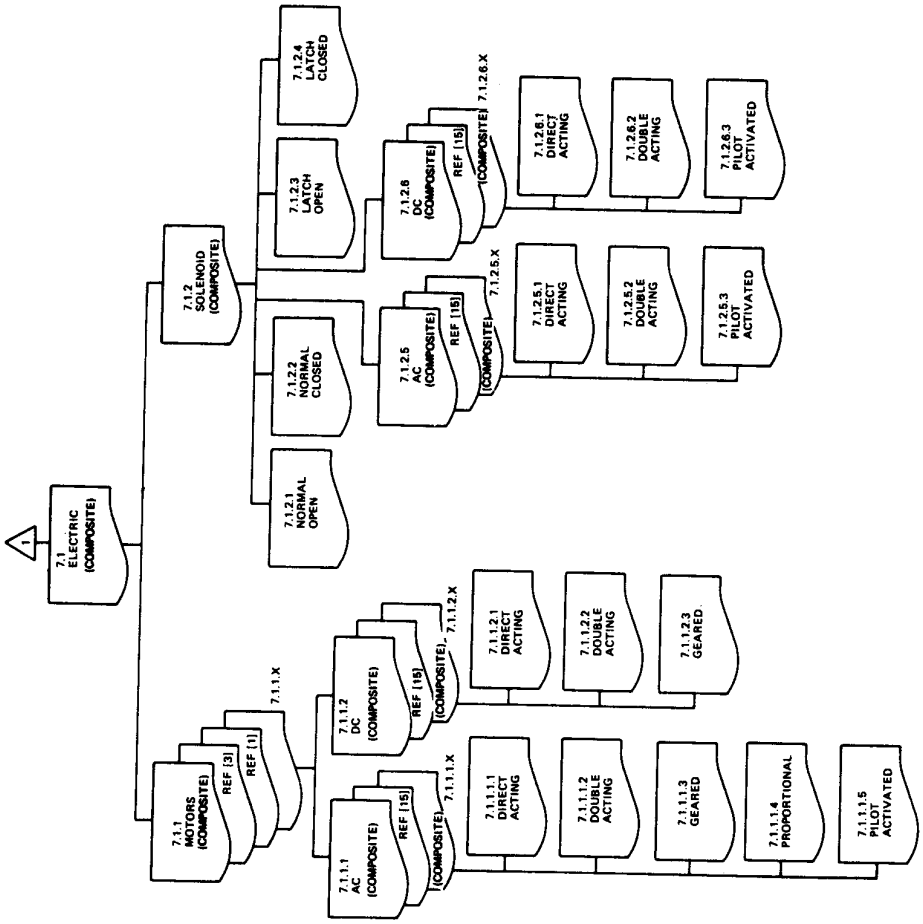

Fig D7 (a)
Valve Operators/Actuators

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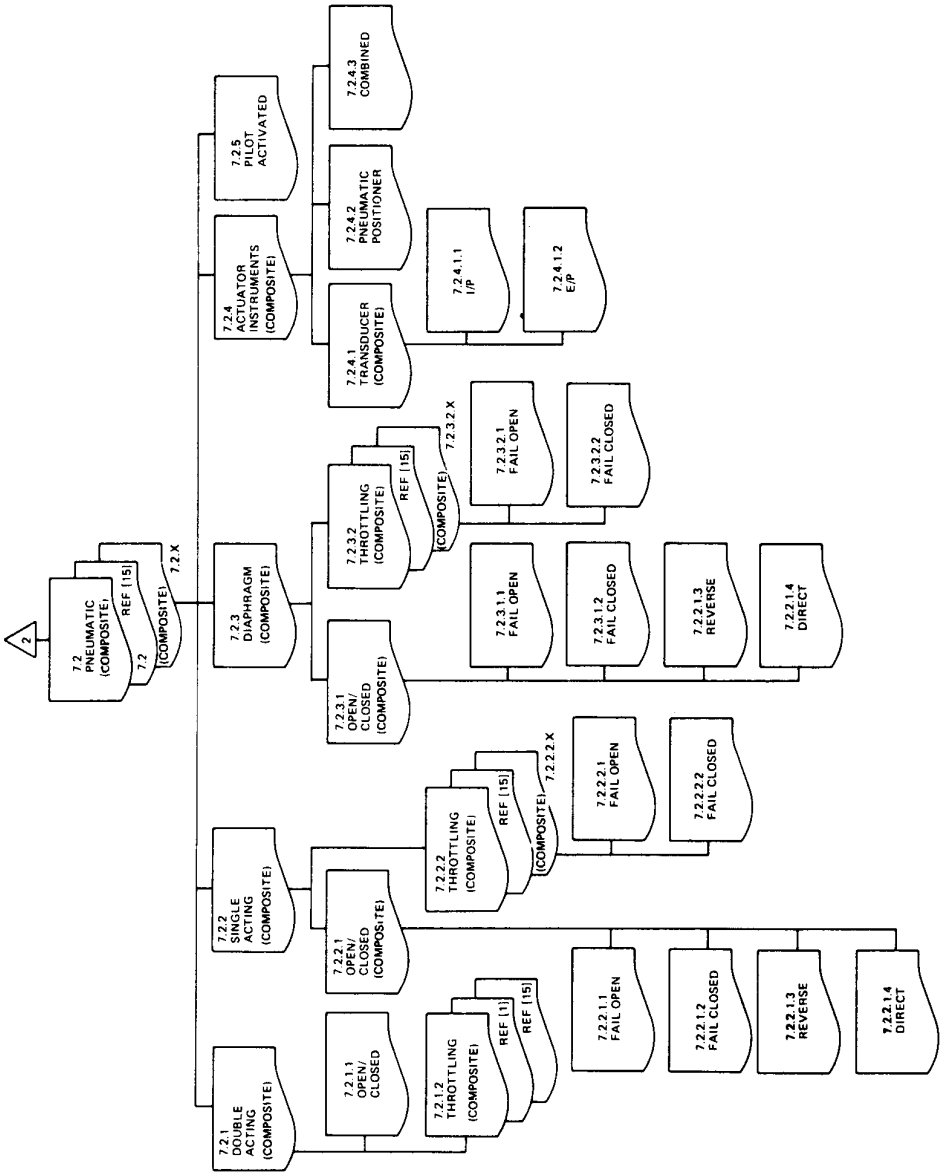

Fig D7 (b)
Valve Operators/Actuators

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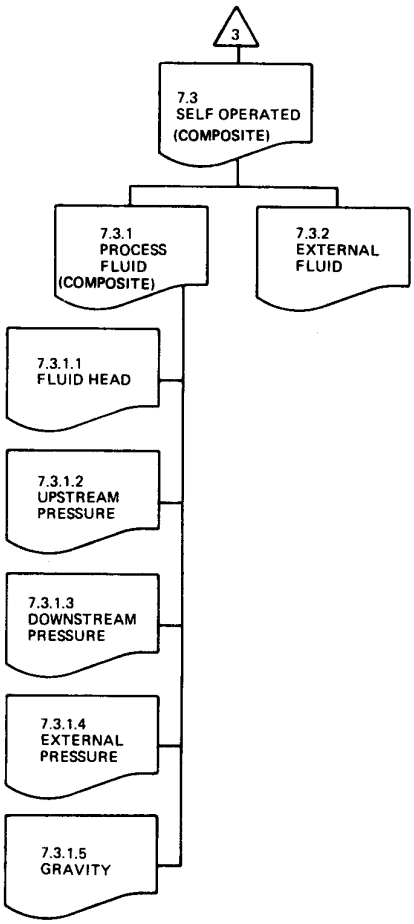

Fig D7 (c)
Valve Operators/Actuators

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D7.3 Failure Modes. The failure modes have been developed on the basis of three mode classes: catastrophic, degraded, and incipient each of which are further developed into subsidiary classes wherever available data permits.

Failure modes are defined in terms of observable effects on the system resulting from some changes in operating characteristic or the state of the device. Thus all failure modes are viewed from the system level rather than the component level.

It must be noted that in Chapter 7 failure modes differ in some cases between the hourly rates and the cyclic rates. Therefore, in these cases, there are two failure modes shown, one for the hourly rate and one for the cyclic rate.

D7.4 Environmental Effects. Such Environmental effects as high temperature, radiation, humidity, and vibration do have an effect on the failure rates of the valves and valve operators. It is important to point out, however, that a valve is usually required to operate after an incident within a relatively short period of time. This means that the environmental changes as a result of an incident have very little chance to affect valves before they are required to operate. On the other hand, the day-to-day environment may have an effect on valve operation which has been considered in this chapter.

Table D7 gives the environmental factors to be used in conjunction with the failure rates listed. These environmental factors are to be multiplied by the failure rates listed for each particular device under consideration.

D7.5 Data Collection and Analysis Notes

D7.5.1 Operating Practices. It is important to conduct periodic preventive maintenance inspections (for leaks etc). It is also important to

Table D7
Valve Operators and Actuators
Environmental Factor Matrix

Hierarchical Code	High Temperature	High Radiation	High Humidity	High Vibration
7.1	1.57	1.57	2.04	—
7.1.1	1.4	1.1	3.0	—
7.1.2	1.73	2.03	1.07	1.33
7.1.2.1	1.73	2.03	1.07	1.33
7.1.2.2	1.70	2.03	1.07	—
7.1.2.3				
7.1.2.4	1.50	1.55	1.10	2.0
7.2	1.52	1.34	1.24	—
7.2.1	1.67	1.91	1.13	—
7.2.1.1	1.63	2.06	1.03	—
7.2.2	1.54	1.45	1.19	—
7.2.2.1	1.58	1.80	1.18	—
7.2.2.2	1.50	1.10	1.20	—
7.2.3	1.58	1.48	1.18	—
7.2.3.1	1.55	1.55	1.15	—
7.2.3.2	1.60	1.40	1.20	—
7.2.4	1.45	1.10	1.35	—
7.3	1.40	1.10	1.35	—
7.3.1	1.40	1.10	1.35	—
7.3.1.1	1.40	1.10	1.35	—
7.3.1.2	1.40	1.10	1.35	—
7.3.1.3	1.40	1.10	1.35	
7.3.1.4	1.40	1.10	1.35	—
7.3.1.5	1.35	1.10	1.35	—
7.3.2	1.35	1.10	1.45	—
7.3.2.1	1.35	1.10	1.45	—

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periodically replace "O" rings, packing, and seals to counter the effects of radiation, aging, and wear. These maintenance actions should be governed by an established and accepted maintenance plan.

There are many cases of maintenance-induced failures, so care should be exercised to minimize such errors.

D7.5.2 Testing. Periodic surveillance testing is essential to the verification of the reliability of valves, but caution should be used in defining these schedules to ensure that excessive testing does not induce failures. Cases have been reported wherein excessive testing has caused valve failures.

The following listing of failure mode categories occur under the component listings in Chapter 7.

Valve Operators and Actuators Failure Modes Breakdown

All Modes (the sum of catastrophic, degraded and incipient)
- Catastrophic
  - Spurious opening
  - Spurious closing
  - Failure to open on demand
  - Failure to close on demand
- Degraded
  - Premature or delayed actuation (actuation that occurs out of timing sequence)
  - Partially opening
  - Partially closing
- Incipient

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CHAPTER: 7 Valve Operators & Actuators

SECTION:

SUBSECTION:

ITEM OR EQUIPMENT DESCRIPTION

FAILURE MODE	FAILURE RATE								(*) OUT OF SERVICE (†) REPAIR TIME OR (§) RESTORE (HOURS)			
	FAILURES/10^6 HOURS				FAILURES/10^6 CYCLES **							
	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF
ALL MODES	0.01	1.73	999.0		0.10	2.27	63.25		1.0 *	35.06	7.28E3	
CATASTROPHIC	0.004	0.69	400.0		0.04	0.91	25.30					
Spurious Opening	0.002	0.34	200.0		0.02	0.45	12.65					
Spurious Closing	0.002	0.35	200.0		0.02	0.46	12.65					
DEGRADED	0.006	1.04	599.0		0.06	1.36	37.95					
Premature or Delayed Actuation	0.006	1.04	599.0									
Partially Opening					0.024	0.54	15.18					
Partially Closing					0.036	0.82	22.77					

** One Cycle = One Demand

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CHAPTER: 7 Valve Operators & Actuators SECTION: 7.1 Electric SUBSECTION: 7.1.1 Motors

ITEM OR EQUIPMENT DESCRIPTION

FAILURE MODE	FAILURE RATE								(*) OUT OF SERVICE (†) REPAIR TIME OR (§) RESTORE (HOURS)			
	FAILURES/10^6 HOURS				FAILURES/10^6 CYCLES **							
	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF
ALL MODES	0.01	0.63	500		0.72	4.87	50.0		1.0 *	41.50	6.49E3	
CATASTROPHIC	0.004	0.25	200.0		0.29	1.95	20.0					
Spurious Opening	0.002	0.13	100.0		0.15	0.98	10.0					
Spurious Closing	0.002	0.12	100.0		0.14	0.97	10.0					
DEGRADED	0.006	0.38	300.0		0.43	2.92	30.0					
Partially Opening					0.17	1.17	12.0					
Partially Closing					0.26	1.75	18.0					

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CHAPTER: 7 Valve Operators & Actuators SECTION: 7.1 Electric SUBSECTION: 7.1.1 Motors

ITEM OR EQUIPMENT DESCRIPTION

FAILURE MODE	FAILURE RATE								(*) OUT OF SERVICE (†) REPAIR TIME OR (§) RESTORE (HOURS)			
	FAILURES/10^6 HOURS				FAILURES/10^6 CYCLES **							
	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF
ALL MODES	0.10	0.62	2.24	1	5.0	10.0	50.0	1				
CATASTROPHIC	0.04	0.25	0.90		2.5	5.0	25.0					
Spurious Opening	0.02	0.13	0.45									
Spurious Closing	0.02	0.12	0.45									
Failure to Open on Demand					1.25	2.50	12.50					
Failure to Close on Demand					1.25	2.50	12.50					
DEGRADED	2.5	5.0	10.00									
Premature or Delayed Actuation	0.06	0.37	1.34									
Partially Opening					1.0	2.0	10.0					
Partially Closing					1.5	3.0	15.0					

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CHAPTER: 7 Valve Operators & Actuators SECTION: 7.1 Electric SUBSECTION: 7.1.1 Motors

ITEM OR EQUIPMENT DESCRIPTION: Valve Operator Electric Motor (8 Inch Butterfly)

FAILURE MODE	FAILURE RATE								(*) OUT OF SERVICE (†) REPAIR TIME OR (§) RESTORE (HOURS)			
	FAILURES/10^6 HOURS				FAILURES/10^6 CYCLES **							
	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF
ALL MODES		0.63		3					†	2.0		3

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CHAPTER: 7 Valve Operators & Actuators SECTION: 7.1 Electric SUBSECTION: 7.1.1 Motors

ITEM OR EQUIPMENT DESCRIPTION 7.1.1.X Composite

FAILURE MODE	FAILURE RATE								(*) OUT OF SERVICE (†) REPAIR TIME OR (§) RESTORE (HOURS)			
	FAILURES/10^6 HOURS				FAILURES/10^6 CYCLES **							
	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF
ALL MODES	0.01	3.91	500.0		0.72	3.75	17.10		1.0 *	41.50	6.49E3	
CATASTROPHIC	0.004	1.56	200.0		0.36	1.88	8.55					
Spurious Opening	0.002	0.78	100.0									
Spurious Closing	0.002	0.78	100.0									
Failure to Open on Demand					0.18	0.94	4.28					
Failure to Close on Demand					0.18	0.94	4.27					
DEGRADED	0.006	2.35	300.0		0.56	1.87	8.55					
Premature or Delayed Actuation	0.006	2.35	300.0									
Partially Opening					0.22	0.75	3.42					
Partially Closing					0.34	1.12	5.13					

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CHAPTER: 7 Valve Operators & Actuators SECTION: 7.1 Electric SUBSECTION: 7.1.1 Motors

ITEM OR EQUIPMENT DESCRIPTION 7.1.1.1

FAILURE MODE	FAILURE RATE								(*) OUT OF SERVICE (†) REPAIR TIME OR (§) RESTORE (HOURS)			
	FAILURES/10^6 HOURS				FAILURES/10^6 CYCLES **							
	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF
ALL MODES	0.50	28.2	500.0						1.0 *	41.50	6.49E3	

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CHAPTER: 7 Valve Operators & Actuators

SECTION: 7.1 Electric

SUBSECTION: 7.1.1 Motors

ITEM OR EQUIPMENT DESCRIPTION 7.1.1.1 AC

FAILURE MODE	FAILURE RATE								(*) OUT OF SERVICE (†) REPAIR TIME OR (§) RESTORE (HOURS)			
	FAILURES/10^6 HOURS				FAILURES/10^6 CYCLES **							
	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF
ALL MODES	1.0	62.0	180.0	15					15.0 *	41.0	105.0	15

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CHAPTER: 7 Valve Operators & Actuators SECTION: 7.1 Electric SUBSECTION: 7.1.1 Motors

ITEM OR EQUIPMENT DESCRIPTION 7.1.1.1 AC, 7.1.1.1.X Composite

FAILURE MODE	FAILURE RATE								(*) OUT OF SERVICE (†) REPAIR TIME OR (§) RESTORE (HOURS)			
	FAILURES/10^6 HOURS				FAILURES/10^6 CYCLES **							
	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF
ALL MODES	0.50	3.16	500.0						1.0 *	96.20	6.49E3	

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CHAPTER: 7 Valve Operators & Actuators SECTION: 7.1 Electric SUBSECTION: 7.1.1.1 Motors

ITEM OR EQUIPMENT DESCRIPTION 7.1.1.1 AC, 7.1.1.1.1 Direct Acting

FAILURE MODE	FAILURE RATE								(*) OUT OF SERVICE (†) REPAIR TIME OR (§) RESTORE (HOURS)			
	FAILURES/10^6 HOURS				FAILURES/10^6 CYCLES **							
	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF
ALL MODES	1.50	14.5	150.0	15					1.0 *	486.0	1.06E3	15

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CHAPTER: 7 Valve Operators & Actuators SECTION: 7.1 Electric SUBSECTION: 7.1.1 Motors

ITEM OR EQUIPMENT DESCRIPTION 7.1.1.1 AC, 7.1.1.1.2 Double Acting

FAILURE MODE	FAILURE RATE								(*) OUT OF SERVICE (†) REPAIR TIME OR (§) RESTORE (HOURS)			
	FAILURES/10^6 HOURS				FAILURES/10^6 CYCLES **							
	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF
ALL MODES	1.30	13.0	130.0	15					*	69.0		15

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CHAPTER: 7 Valve Operators & Actuators SECTION: 7.1 Electric SUBSECTION: 7.1.1 Motors

ITEM OR EQUIPMENT DESCRIPTION 7.1.1.1 AC, 7.1.1.1.3 General

FAILURE MODE	FAILURE RATE								(*) OUT OF SERVICE (†) REPAIR TIME OR (§) RESTORE (HOURS)			
	FAILURES/10^6 HOURS				FAILURES/10^6 CYCLES **							
	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF	LOW	REC	HIGH	REF
ALL MODES	1.0	2.80	5.0	15					1.0 *	392.0	6.49E3	15

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