TECHNICAL MANUAL

SURVEY OF RELIABILITY AND AVAILABILITY INFORMATION FOR POWER DISTRIBUTION, POWER GENERATION, AND HEATING, VENTILATING AND AIR CONDITIONING (HVAC) COMPONENTS FOR COMMERCIAL, INDUSTRIAL, AND UTILITY INSTALLATIONS

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION IS UNLIMITED

HEADQUARTERS, DEPARTMENT OF THE ARMY

22 JULY 2006

REPRODUCTION AUTHORIZATION/RESTRICTIONS

Technical Manual
No. 5-698-5

HEADQUARTERS
DEPARTMENT OF THE ARMY
Washington, DC, 22 July 2006

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION IS UNLIMITED

SURVEY OF RELIABILITY AND AVAILABILITY INFORMATION FOR POWER DISTRIBUTION, POWER GENERATION, AND HEATING, VENTILATING & AIR CONDITIONING (HVAC) COMPONENTS FOR COMMERCIAL, INDUSTRIAL, AND UTILITY INSTALLATIONS

CONTENTS

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION AND BACKGROUND

1-1. Purpose

The purpose of this manual is to explain the process of how the reliability data in appendix B of this manual regarding power generation, power distribution and Heating Ventilation and Air Conditioning (HVAC) components was developed. This manual is intended to summarize the entire process of obtaining the reliability metrics of the pre-described components and what types of facilities provided the data so that the facility engineer can understand the foundation behind the reliability metrics. Upon reading this document the facility engineer should be able to make a more knowledgeable assessment for applications of the data to support government, commercial, industrial and utility installations.

1-2. Scope

The information in this manual reflects the efforts of extensive hours of research and analysis, along with the cooperation and time of numerous facilities, in order to ascertain reliability characteristics of power generation, power distribution and HVAC components. This effort was sponsored by the U.S. Army Corps of Engineers, Power Reliability Enhancement Program (PREP) in order to establish reliability, availability, and maintainability characteristics of over 200 components related to command, control, communication, computers, intelligence, surveillance and reconnaissance (C4ISR) facilities. This manual describes the data collection and summarization of all of over 200 components. Collection of the data began in October 1991 and the final report was delivered in early 1994.

1-3.   References

Appendix A contains a complete list of references used in this manual.

1-4.   Background

The Power Reliability Enhancement Program established the data collection effort to determine the effects that "new technology" had on equipment, i.e., equipment installed after 1971, in regards to reliability and availability. Previous data collection efforts were completed in the early 1970's by the Institute of Electronics and Electric Engineers (IEEE) Gold Book using data compiled in the 1950's and 1960's. However, PREP understood that this data was not only outdated, but also it did not fully address maintenance which plays a major role on availability. Therefore, the PREP office decided a new data collection effort must be undertaken in order to accurately assess their C4ISR facilities.

   a. The results in this manual represent the culmination of a 24,000 man-hour effort to collect operational and maintenance data on over 200 power generation components, power distribution components and HVAC components. Some of the major components of focus of the data collection effort were gas turbine generators, diesel engine generators, electrical switchgear, cables, circuit breakers, boilers, piping, valves, pumps, motors and chillers. The information was obtained on a variety of commercial and industrial facility types. The primary focus of facility types were office buildings, hospitals, water treatment facilities, power generation plants, utilities, manufacturing facilities, school universities and bank computer centers. These facilities were chosen because they have similar types of components and applications with varying degrees of maintenance quality and operational characteristics.

b. In order to provide an accurate overall reliability analysis of the equipment, data collection guidelines and goals were established to ensure that sufficient operational and maintenance data were collected from the various facilities. If the database was to be representative of the average use of equipment then it was necessary to collect data from facilities with varying degrees of maintenance policies. Otherwise if the data represented only facilities with new equipment with an operational time of eight hours a day and a high degree of maintenance policies, then the data would only be applicable or accurate for those types of facilities.

c. Other minimum requirements were established to develop a comprehensive database that did not skew data in any one direction. Statistically, the more data collected, the more representative the data will be overall. Therefore, the final database had the following minimum requirements on each component:

(1) A minimum sample size of 40 like components from various sites would be sampled. Of the 40 components, data on no more than 10 like components from a single site could be used in the database.

(2) A minimum of five years of operational data would be collected for each component per site.

(3) A minimum of 3.5 million calendar hours collected for each component. This requirement can be met by either five years of data and a minimum sample size of 80 components using data on no more than 10 like components from a single site or 10 years of data and a minimum sample size of 40 components using data on no more than 10 like components from a single site.

d. In order to track both the component information (containing over 6,000 records of operational and maintenance data) and the contact information (containing over 4,000 records identifying information sources) a database system with flexible output capabilities was developed. The flexibility of the database's output capabilities aided in assessing the varying levels of data quality and maintenance quality during the analysis phase of the project. The final version of the database was loaded into Microsoft Access for universal portability.

e. The results of the data summarization indicated that the maintenance quality level was a major predictor of equipment availability. Therefore, the availability values presented represent an average level of maintenance across all of the data sources.

f. In addition, the data and the information obtained and presented in this technical manual can aid facility designers and engineers in evaluating different designs to minimize production/mission failure and to estimate the down times associated with various systems or sub-systems. The application theory to apply this data to your facility can be found in TM 5-698-3, *Reliability Primer for C4ISR Facilities,* and TM 5-698-1, *Reliability/Availability for Electrical and Mechanical Systems for C4ISR Facilities*. Facility types that require more maintenance time and systems that may benefit from redundancy or replacement can also be identified.

CHAPTER 2
DATABASE DEVELOPMENT

2-1. Database conception

The heart of the data analysis is the database. The database is a tool that not only stores the data but also provides a user-friendly tool to download the data and most importantly to report it in the format the individual user needs it. Without addressing these specific needs the database becomes more of hindrance and would slow down the analysis process. Therefore before starting this data collection process the database issue was addressed by the staff.

   a. A computerized database named PREPIS (Power Reliability Enhancement Program Information System) was developed to assist technical staff in organizing, tracking, analyzing, and reporting all of the technical and contact information during the execution of the data collection program.

   b. The two major components in PREPIS were contact and equipment records. The contact record contained site information and was comprised of 6208 contact records. The equipment records contained performance and maintenance information and included 4043 equipment records.

   c. This comprehensive database system was organized functionally to support the following tasks:

   (1) Record individual site information

   (2) Prioritize site visits

   (3) Collect and organize site data

   (4) Input and verify data

   (5) Analyze and summarize data

   (6) Generate reports

   d. The output record generator contained several "canned" reports designed for data summary and availability calculations. Some of the reports were designed to allow the user the flexibility to select a multitude of query topics. The format of the report generator allowed construction of custom reports for individual needs.

   e. Although this database was adequate for the task when it was developed in 1991, as new, more popular and efficient database tools were developed it became apparent that a more portable, user friendly database tool was needed. In addition, several inquiries of the database resulted in a significant effort to recreate data reports to satisfy requests. Obviously, a better method was needed to minimize this time.

2-2. Database update

In 1998 the arduous task was begun to create a common database that would provide similar abilities as before but improve upon them and allow for the information to be easily transferable from personal computer (PC) to PC. These requirements lead the involved personnel to agree upon choosing Microsoft Office Access for this task because of its industry wide use and flexibility.

a. Once the data was transferred into Microsoft Office Access, simple reports and queries were written allowing the user the ability to develop customized data extraction scenarios on a PC. The following is a list of the reliability metrics that the database is capable of reporting on the components in any combination:

(1) Reliability

(2) Operational Availability

(3) Inherent Availability

(4) Unit Years (total calendar hours of data divided by 8760)

(5) Number of failures recorded

(6) Failure Rate

(7) Mean Time Between Failures

(8) Mean Time to Repair

(9) Mean Time to Maintain

(10) Mean Down Time

(11) Mean Time Between Maintenance

(12) Average Hours of Downtime per Year

b. The new database provides a tremendous amount of flexibility. It provides the capability of running a customized report on any component in the database with different combinations of metrics. Since the database and the reports run on one of the most popular and readily available databases, they can easily be placed on a CD or other portable storage media device and transferred to anyone with Microsoft Office Access.

c. This new database also aids the data collection and analysis procedure due to its compatibility with Microsoft EXCEL. Because EXCEL is the preferred software package for collecting and analyzing site specific data, this task is simplified. Once the engineer formats the data in EXCEL, it can easily be downloaded to the ACCESS database for storage and future reports.

CHAPTER 3
DATA COLLECTION

3-1. Overview

One of the major hurdles in this project was identifying potential contributors with similar equipment and then obtaining access to their records to support the development of reliability and maintainability metrics for the components being tracked. This process included identifying contacts, identifying data contributors, and performing site visits.

3-2. Identifying contacts

The first step of data collection was to identify contacts at various facilities that could potentially contribute data to the program. Through the identification procedure over four thousand (4000) facilities were identified.

   a. In order to collect statistically valid data it was important that a stratified survey of different facility categories, applications and operating conditions be conducted. Data was collected from the following facility types: communication centers, office building complexes, educational building complexes, hospital complexes, manufacturing facilities, electric generating plants, municipal buildings, housing/hotel, recreational facilities, petroleum processing facilities, and other miscellaneous facilities.

   b. These facilities were targeted because they used similar equipment and also provided a variation in applications and maintenance objectives. This was established in an effort to reduce any bias that would result from collecting data in one type of facility. Collecting data from these various facility types was not only necessary to reduce bias, but also to help assure a good coverage across the majority of equipment types of interest. To facilitate this, the following guidelines were developed to assist in the selection of potential sites:

   (1) Locations surveyed were required to have varying degrees of maintenance practices.

   (2) A number of sites for each facility category were predetermined; this was required to eliminate any skewing of the data caused by the influence of limited data.

   (3) Component size was also a basis of site selection to ensure that similar technologies were being compared.

   (4) Equipment age was also considered to ensure that data from both the newer high-efficiency generation of equipment and the older technology generation were included. This permitted the determination of reliability and maintainability metrics as a function of time.

   c. Varying degrees of maintenance practices was required because it is known that maintenance policies and practices directly affect equipment availability. If a facility has a high level maintenance policy, their availability typically will be lower but the overall reliability typically will increase. On the contrary, a facility with too little maintenance will have a high availability but as the equipment ages, a decrease in reliability. During a prolonged period of operation time with little maintenance, availability and reliability both decrease drastically. Therefore it is apparent that the amount of maintenance performed can drastically affect the performance parameters being collected.

d. A process of identification and certification of data was developed to ensure that each data collection trip was successful. Prior to visiting a facility, the analyst surveyed the site facility manager to assess whether or not that the data they had met the imposed 5 year minimum of operational data. This minimum was established for the data to ensure a sound statistical basis for the analysis.

3-3.   Data contributors

The second step of data collection was to identify those contacts which were willing and capable of contributing the required data to the program. This was accomplished by making phone calls to potential data contributors to introduce the program and solicit participation.   All communications with the contact were logged in a database for tracking purposes.

a. Once a facility was identified a phone call was made in an attempt to speak to the facility maintenance manager. Most of the time, this first call was not totally successful. A message would be left and the analyst would record the direction of the phone call along with the date and time. Hopefully, the contact would call back, but in the event he did not, at least one more attempt would be made to contact him.

b. The formal procedure for making the contacts was developed early in the program. The procedure outlined below was the standardized approach which proved to be fairly successful.

(1) Identify contacts in a specific geographic region from the database contact list so that multiple sites could be visited on one trip.

(2) Contact, by phone, a prospective study participant and explain the PREP program.

(3) If the contact was willing to participate, send background information (form letter and survey) describing who we are, what we are trying to accomplish, and the type of data we are looking for in the study.

(4) If there was a favorable response, this person was contacted again for a data collection visit and questioned as to other locations in the area meeting our requirements.

c. A flowchart detailing this procedure is shown in figure 3-1 and identifies the database priority codes that were established.

```
         ┌─────────────┐                    ┌─────────────┐
         │    AO-1     │───────────────────▶│     AC      │
         └─────────────┘                    └─────────────┘
                ▲
 ╭─────────╮    │
 │  New    │    ┌─────────────┐             ┌─────────────┐
 │ Contact │    │    AO-2     │────────────▶│     IC      │
 ╰─────────╯    └─────────────┘             └─────────────┘
      │         ▲                            ▲   ▲
      │         │                            │   │
      │         ┌─────────────┐              │   │
      │         │    AO-3     │──────────────┘   │
      │         └─────────────┘                  │
      │         ▲                                │
      │         │                                │
      │         ┌─────────────┐                  │
      └────────▶│    AO-4     │──────────────────┘
                └─────────────┘
```
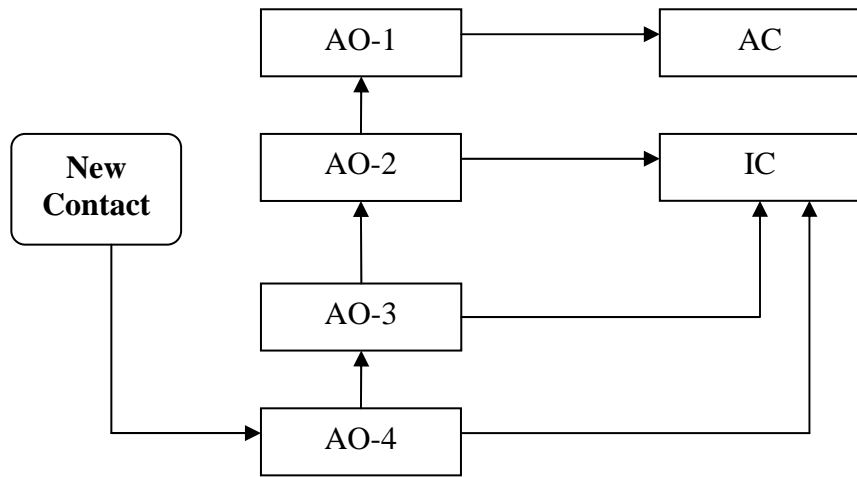
AO-1: Ready to visit/visit set up
AO-2: Communications in progress
AO-3: Ready to contact
AO-4: Facility identified/information incomplete (address/location)
AC: Visited and all data has been collected/received
IC: No, or insufficient data, or unwilling/unable to help

Figure 3-1. Flowchart of PREP database priority codes

   d. Of the four thousand plus facilities identified, one thousand five hundred ninety three (1593) were actually called and were closed either because the data was collected or the facility was determined to not be a viable contributor of data. All correspondence with potential data contributors was recorded whether the solicitation resulted in a visit or not. These phone calls resulted in approximately a ten percent success rate at finding a facility with the required data and actually collecting data. This resulted in a total of 162 sites that were contacted and visited. Figure 3-2 represents the distribution of eleven facility types that were used in the study. As indicated in figure 3-2, the majority of the data contributors fall into two categories. Those categories are electric generating plants and hospitals which combined made up 58% of the total contributors.
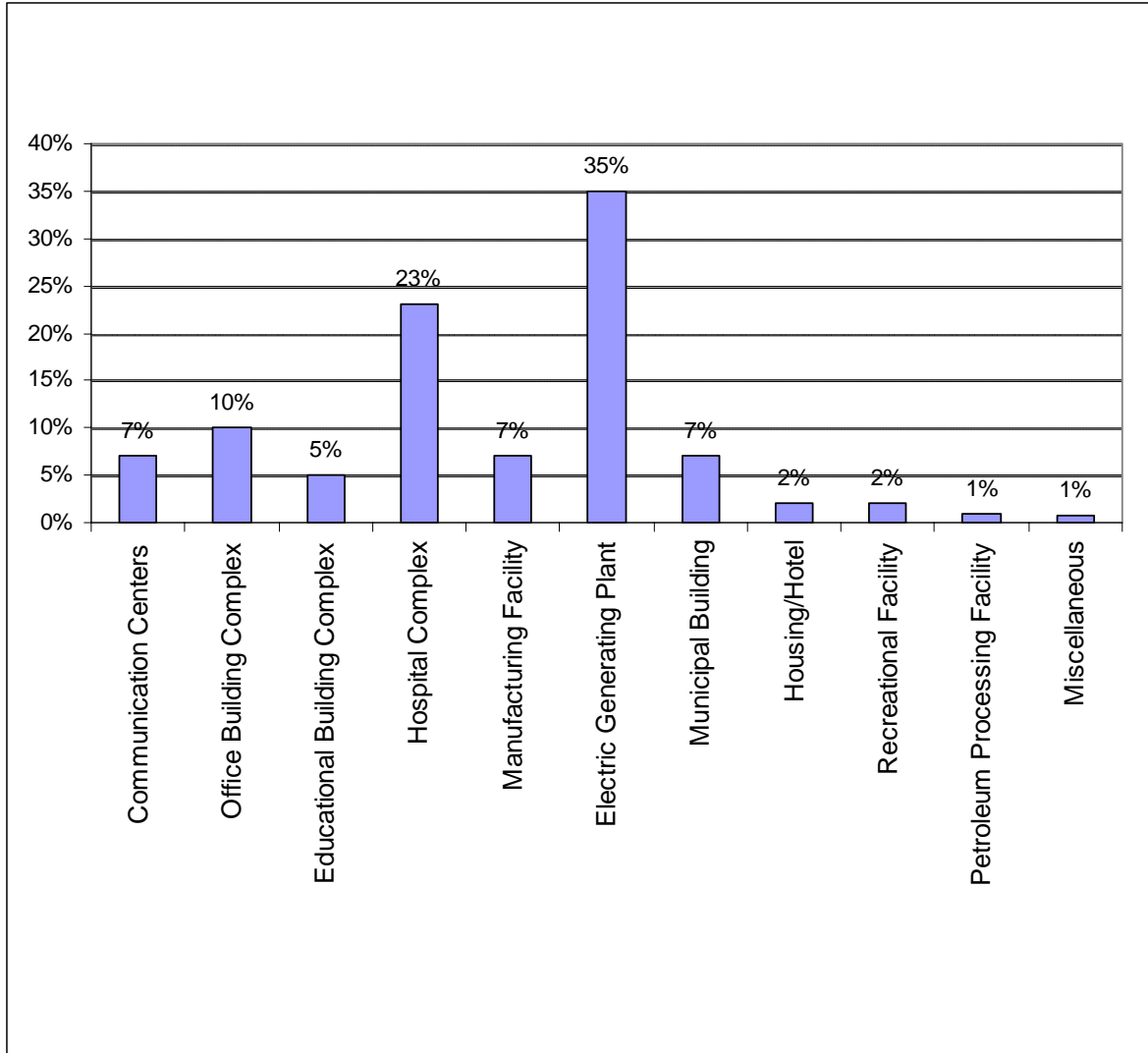
Figure 3-2. Distribution of data contributors

   e. These contacts were the key to the success of this program. Without the cooperation and support of the people involved from the many facilities, this effort would have been very difficult. Even during times of budget and personnel reduction these facilities donated their time, understanding the importance of this program and provided high quality data to support the Power Reliability Enhancement Program.

   f. A concerted effort was employed to develop an extensive contact database using manufacturers, facilities, societies, and locations of any potential data contributor utilizing PREP components. Manufacturers were contacted not only for possible collection of actual maintenance data, but also for any warranty data that may be available. Several manufacturers participated, including Caterpillar, Westinghouse Electric and Electro-Motive Diesel.

   g. Several professional societies were also contacted. With their cooperation and support the program was provided substantial merit and integrity.   Some of the societies contacted included American Gas Association, National Association of Power Engineers, American Society of Mechanical Engineers, Association of Physical Plant Administrators, and the Association of Energy Engineers:

CHAPTER 4
DATA SUMMARIZATION AND CLASSIFICATION

4-1. Data transformation

In order to eliminate inaccuracies in the database, the transition from raw data to completed, analyzed data, needed to proceed smoothly. This meant that the data collection effort and the data summarization needed to compliment one another.

 a. Data summarization was very important in that it was the process that transformed the raw data collected at a facility into a standardized format that could be used to develop the reliability and maintainability metrics associated with the components being tracked. If there were difficulties transcribing the raw data during the summarization process then inaccuracies would certainly develop.

 b. Realizing that it was essential to provide an accurate database, Alion personnel needed to identify and implement procedures that would enhance the data summarization process prior to collecting the data. The data collectors would know exactly what data, regarding the components, they would be looking for. The data categories that Alion personnel would focus on were identified as:

 (1) Nameplate information including manufacturer, model number, serial number and size.

 (2) Installation date of component.

 (3) Operation profile of how many hours per day, month, or year the component is required to operate.

 (4) Record of preventative maintenance intervals. If records of completion with dates are not available, how stringent is the site at carrying out these tasks to the prescribed interval.

 (5) Dates of all other events with descriptions that provide the ability to identify the event as a failure or preventative maintenance action.

 (6) If available, the time needed to perform the maintenance event whether preventative or corrective maintenance due to failure.

 c. To ensure that they gathered the most detail on the maintenance events the team would bring a photo copier with them to copy all of the hard copy records from the site. This included maintenance performed by the facilities personnel and also any outside contractors. Fortunately, outside contractor records are typically kept for several years at a facility for warranty issues.

 d. Other standards developed were definitions for components and defining the difference between a preventative maintenance action and a failure. These definitions can be seen in the Glossary and their calculations can be seen in table 5-1.

 e. Once the data was collected, then the summary process began. The first decision that would be made upon reviewing the data was to determine which items had enough complete data to conduct an accurate summarization. As with every data collection program, there are varying degrees of completeness in the data gathered. Due to time restraints during the visit, it is

impossible to review all of the data to determine its completeness. It was determined during the summary process that a total of twenty-eight (28) of the one hundred sixty-two (162) facilities, which were visited, had data which was subsequently rejected due to a variety of deficiencies.

4-2. Data issues

During any data collection effort the goal is always to gather specific information on the component that will be needed for a complete analysis. However, it is often difficult to determine during the collection effort if there are "holes" in the information. It is not uncommon to find out during the summarization process that a complete, thorough time line of information on a component is not documented in the data. Data quality would certainly influence the confidence level that the end user, the facility engineer, would have in the data.

   a. Variations on completeness of data were commonly discovered at this phase. Some data sources had complete records and could give statistics on operational characteristics on every piece of equipment from installation date to that current moment of time. Other sources only recorded a date and a very brief description of an event making it difficult to classify the event as a preventative maintenance task or a corrective action due to a failure.

   b. Analysts were required to sort through numerous maintenance records on components one sheet at a time. Every event would be entered into a spread sheet and a determination based on the data would be made to classify an event as a preventative maintenance task or a failure. Metrics such as time to repair or total time the equipment was down (unavailable) would also be documented if the information was available.

   c. Most of the components that had the greatest detail on maintenance events were the components that served to be most vital to the facilities operations, such as cooling towers and boilers. Smaller, less expensive components, such as valves and filters were typically not tracked by the facility either due to the fact that they did not fail often or were not deemed vital to facility operations. Therefore, the amount of data points on these smaller types of components was limited.

   d. Other problems included incomplete or non-current versions of the equipment's blueprints. Technicians manually developed parts lists, recording data from nameplates and relying on facility engineers for component descriptions. Data on components that did not fail frequently and were not recorded by facility personnel was sometimes developed based on verbal information from experienced technicians.

   e. An example of a situation like this would be if the technician had been employed at the facility for eight years and could remember that he only had to perform maintenance on a particular type of valve three times. The analyst could then make a fairly accurate assessment of the component based on the technician's judgment.   In this hypothetical example, however, the analyst would have to determine if this technician would be the only individual that would have made the repair or would have knowledge of the repair.

   f. Due to all of these varying degrees of data completeness, it became apparent that analyzing personnel needed to categorize the different data quality levels to ensure that the final data collection included fair data representation for each component. To quantify this data completion (or quality) index, the technicians classified the data into four levels; perfect data, not perfect

data, verbal/inspection data, and soft data. The distribution of the data collected at the various levels is shown in figure 4-1 and are defined as follows:
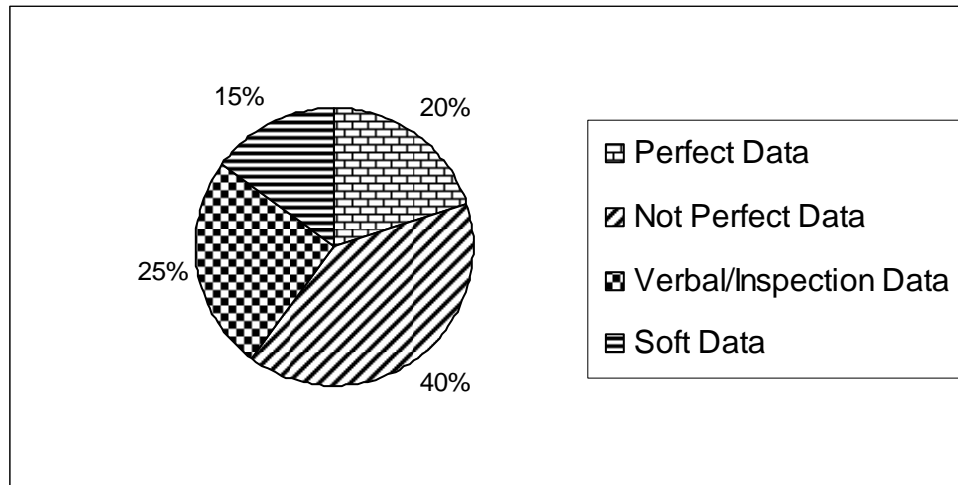
Figure 4-1. Distribution of data quality levels

(1) Perfect Data: Data needed for a valid, complete reliability study, including a parts list, failure history data with time-to-failure statistics, parts description data, operational periods, and ten continuous years of recorded data. No engineering judgment or data extrapolation is required. The PREPIS equipment record database is comprised of 20% of this type of data.

(2) Not Perfect Data: Data with no serious flaws, but the data collection process demanded additional time to ensure useful information was gathered. Examples include parts list determined by inspection, incomplete blueprints or less than ten years of data. The PREPIS equipment record database contains 40% of this type of data.

(3) Verbal/Inspection Data: Data with serious gaps that required additional documentation and verification prior to its inclusion in the database. Items included were typically major items, such as generator sets and boilers. Senior maintenance personnel were interviewed to extract the necessary information to fill the data gaps. These interviews were used as support documentation to recorded data, not as data source information. About 25% of this type of data exists in the PREPIS equipment record database.

(4) Soft Data: Data that relied on the memories of experienced maintenance personnel from the participating facility; it was often extracted from log books containing maintenance personnel entries, filing cabinets with work order forms, and repair records when outside repair support was needed. Engineering judgment was often used to determine numerous performance parameters. This type of data was the most difficult and time consuming to summarize and was only used when no other data sources were available. The PREPIS equipment record database is comprised of 15% of this type of data.

4-3.   Maintenance policies and classifications

Maintenance policies and practices have a major influence on reliability and longevity of components. Different facilities, depending on numerous factors, have a variety of approaches to maintenance. Therefore, if data was collected only at facilities with a high degree of

maintenance, then the reliability values would only be accurate for those types of facilities. This information would not be pertinent to facilities with minimal maintenance practices.

a. The major intent of the data collection effort was to minimize the effects of maintenance policies and procedures on the calculated availability values. This was accomplished by collecting data from a variety of locations having various maintenance policies. Technical personnel developed a code to categorize each facility's maintenance policies and procedures into one of three levels:

(1)   Code "1": *Above average* maintenance policy. The facility not only followed a scheduled, preventative maintenance policy that was equivalent or similar to the manufacturer's suggested policy, but also went beyond it, such as using redundant units, specialized equipment tests (thermograph, vibration analysis, oil analysis), and complete spare parts kits for equipment.

(2)   Code "2": *Average* maintenance policy. Facility used either in-house maintenance crews performing scheduled, preventative maintenance according to the equipment manufacturer's suggested PM schedule or a combination of in-house maintenance crews and outside contractors. In both cases, it was verified that they did follow a fairly rigid schedule.

(3)   Code "3": *Below average* maintenance policy. Facility's actual policy was less than average. It may have instituted a scheduled maintenance policy but not followed it or it may have had no maintenance policy. Symptoms such as leaky valves with rags tied around them, dirty air filters, squeaky bearings, loose belts, and general house keeping because of unavailable manpower were typical signs that maintenance at a facility was less than desirable.

b. Each location was then compared to each other and to the average maintenance policy. An overall viewpoint of the different types of maintenance policies that Alion personnel visited can be seen in figure 4-2. This clearly shows that the majority of the facilities that the technicians visited practiced an average level of maintenance; that is, they adhered to the manufacturers recommended maintenance policy. It is also indicates that approximately the same number of facilities that had below average maintenance policies as those facilities that had an above average maintenance policy were data contributors.

Figure 4-2. Comparison of maintenance policies
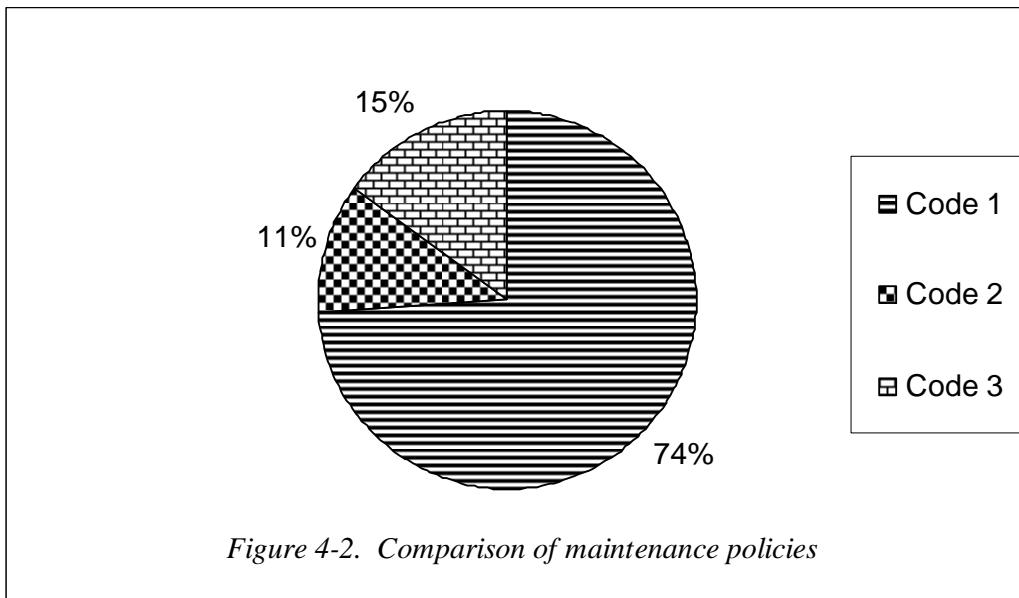
CHAPTER 5
CONCLUSIONS

5-1. Results

Located in appendix B are the results from the data collection effort representing the PREP database. This database contains the reliability and maintainability metrics for over 200 components that were the focus of this study.

   a. The database is presented in a hierarchical structure to provide the analyst with numeric options if the exact component is not identified. As an example, the CATEGORY of Accumulator is comprised of two CLASSES (Pressurized and Unpressurized). Each of the CLASSES is comprised of individual data points. A reliability numeric is derived for each data point listed within a CLASS and displayed in columns in the database report.

   b. The numeric is then rolled-up to the CLASS level to indicate a combination of information within each CLASS. Subsequently the data from the CLASS level is rolled-up into the CATEGORY level. The reliability numeric becomes more generically applied to the item as the information is rolled-up to the next higher level. Where we had various sizes as with transformer capacities, information was combined to create a general transformer number.

   c. In table 5-1 are the reliability and maintainability metrics with associated formulas that were used to develop the PREP database. Acronyms and definitions of each category are provided in the glossary. These definitions are referenced in several reliability publications and the formulas can be verified in the *Reliability Toolkit: Commercial Practices Edition*, page 12, or MIL-HDBK-339, *Custom Large Scale Integrated Circuit Development & Acquisition for space Vehicles*, or in the IEEE standard definition publication.

Table 5 -1. Reliability and Maintainability Calculations

Calculated Data	Formula for Calculation
Ai, Inherent Availability	$Ai = MTBF/(MTBF+MTTR)$
Ao, Operational Availability	$Ao = MTBM/(MTBM+MDT)$
λ, Failure Rate (failures/hour(h))	$\lambda = Tf/Tp$
λ_y, Failure Rate (failures/year(y))	$\lambda_y = Tf/(Tp / 8760)$
MDT, Mean Down Time (h)	$MDT = (Rdt + Rlt + Mdt) / Tde$
MTBF, Mean Time Between Failures (h)	$MTBF = Tp / Tf$
MTBM, Mean Time Between Maintenance (h)	$MTBM = Tp / Tde$
MTTM, Mean Time To Maintain (h)	$MTTM = Mdt / Tma$
MTTR, Mean Time To Repair (h)	$MTTR = Rdt / Tf$
R(t), Reliability (for time interval t)	$R(t) = e^{-\lambda t}$
Hrdt/Year, Hours Downtime per Year	$Hrdt/Year = (1 - Ao) \times 8760$

     Where:

     Mdt (maintenance downtime): The total downtime for preventative maintenance (including logistics delay time, which includes spare parts availability, crew availability, etc) for a given Tp. (hours).

     Rdt (repair downtime): The total downtime for corrective maintenance (excluding logistics delay time) for a given Tp. (hours).

Rlt (repair logistics time): The total logistics delay time for corrective maintenance for a given Tp. (hours).

Tde (total downtime events): The total number of downtime events (including both preventative maintenance and corrective maintenance) during the Tp

Tf (total failures): The total number failures during the Tp

Tma (total maintenance actions): The total number of preventative maintenance actions which take the component down during the Tp

Tp (total period): The calendar time over which data for the item was collected (hours)

t : time interval.

d. Also you will note, in the database located in appendix B, some items have no failures during the time of the analysis. Therefore, for these items with 0 failures, reliability statistics are calculated using the Chi Squared 60% confidence interval based on time truncated data. This common approach to data with no failures associated with the data collection time frame is explained in MIL-HDBK-338B, *Electronic Reliability Design Handbook*, section 8.3.2.5.2, Confidence Limits – Exponential Distribution. These items are identified by an asterisk (*) in the database report. Any metrics for which no data were available at the time of the analysis are identified by x's.

5-2. Benefits

The information collected in this study can be useful in determining various performance capabilities along with maintenance strategies. The actual values that can be predicted for a specific system from the use of this data are not necessarily the actual results that the facility may encounter. The value of using the data is to establish a baseline for the facility to use as a comparison.

a. Upon review of this document the facility engineer should be able to make a more knowledgeable assessment of the quality and history of the data provided in appendix B of this manual. The background information and the description of the whole analysis process should provide a level of accuracy of the data. With a better understanding of the data history, the facility engineer or designer can apply the data with a more comfortable level of confidence.

b. The data and procedure can be used in different manners to aid the facility designer and facility engineer. The designer can use the data to evaluate different designs. The engineer can estimate the length of downtime by adding the failure time to the production or mission loss and can estimate the total length of time from line stop to line start as a result of failures.

c. The data will facilitate evaluations of new designs or redesigns in order to minimize the production/mission failure with estimates on money saved by avoiding downtime. With the data the engineer can estimate the downtimes associated with the systems or sub-systems and compare these results to the actual times. This could identify problem areas that may need more (or less) maintenance time and systems that may benefit from redundancy or replacement.

d. The data represented in the PREP database is the foundation for conducting many types analyses. This data is invaluable for supporting these different analyses used to measure efficiencies and deficiencies in a facility's system.

APPENDIX A

REFERENCES

REQUIRED PUBLICATIONS

Government Publications

MIL-HDBK-338B, *Electronic Reliability Design Handbook,* 1 October, 1998 (cited in paragraph 5-1d)

MIL-HDBK-339, *Custom Large Scale Integrated Circuit Development & Acquisition for Space Vehicles,* 4 September 1992, (cited in paragraph 5-1c)

TM-5-698-1, *Reliability/Availability for Electrical and Mechanical Systems for C4ISR Facilities,* 14 March, 2003, (cited in paragraph 1-4f)

TM-5-698-3, *Reliability Primer for C4ISR Facilities,* 10 July, 2003, (cited in paragraph 1-4f)

Non-Government Publications

Reliability Toolkit: Commercial Practices Edition, Reliability Information Analysis Center, 6000 Flanagan Rd., Suite 2, Utica, NY 13502-1348. (cited in paragraph 5-1c)

RELATED PUBLICATIONS

Non-Government Publications

Hutchinson Educational
London, England

   System Reliability Modeling and Evaluation, Singh, C. and Billinton, R Hutchinson Educational, London, England, 1977.

Institute of Electrical and Electronics Engineers (IEEE)
445 Hoes Lane, Piscataway, New Jersey, 08854-1331

   Design of Reliable Industrial and Commercial Power Systems, IEEE Standard 493-1990, New York, New York, 1997.

   Fundamentals of Reliability Techniques as Applied to Industrial Power Systems, Dickinson, W.H., Gannon, P.E., Heising, C.R., Patton, A.D., and McWilliams, D.W, Conference Record 1971, IEEE, IEEE Industrial Commercial Power Systems Technical Conference, 71C18-IGA, p. 10-31, New York, New York , 1971.

   IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems, Table 2, IEEE Standard 493-1980, IEEE, New York, New York, 1980.
   NOTE: In general, failure duration is actual hours downtime per failure based on industry averages. Data from "All Equipment Failures" are used, as opposed to median plant averages, which use data of all plants that reported actual outage time on equipment failures.

University Computing Company
1930 Hi Line Drive, Dallas, TX 75207

   GO, Electric Power Software Center, University Computing Company, Dallas, TX,

APPENDIX B
PREP DATABASE
VERSION 4.2

The header below represents the header in the database. Each column heading is explained in the text boxes. The formulas, representing the column heading, are contained in the table in Section V above.

| | | | Instantaneous probability that a component will be up. Ai considers only downtime for repair due to failures. No logistics delay time, preventative maintenance, etc. is included. | | Unit Years represents the number of calendar hours collected for each item divided by 8760. | | | Average time between failures in hours

Failure Rate based on a year. | | | | Average downtime for preventative maintenance. This includes any logistics delay time. | Average time between all maintenance events that cause downtime, both preventative and corrective maintenance, and also includes any associated logistics delay time. |

| Name of the Category (Example: Boiler) and the Class (Example: Boiler, Hot Water) of the item | |

| Category/ Class | Item Number | Reliability | Inherent Availability | Operational Availability | Unit Years | Failures | Failure Rate (Failures/Year) | MTBF | MTTR | MTTM | MDT | MTBM | Hrdt/Year |

Number assigned to the Item (Example: 13)

Probability of the item failing in a one year period

Instantaneous probability that a component will be up but differs from inherent availability in that it includes ALL downtime. Included is downtime for both corrective maintenance and preventative maintenance, including any logistics delay time.

The number of failures recorded for each item during the data collection

Mean time to replace or repair a failed component. Logistics delay time associated with the repair, such as parts acquisitions, crew mobilization, are not included.

Average downtime caused by preventative and corrective maintenance, including any logistics delay time.

Average hours the item is expected to be not functional in a one year period, caused by both preventative maintenance and failures. This includes any logistics delay time.

PREP   Roll Up Report by Category, Class and Item

Category/Class	Item Number	Reliability	Inherent Availability	Operational Availability	Unit Years	Failures	Failure Rate (Failures/Year)	MTBF	MTTR	MTTM	MDT	MTBM	Hrdt/ Year
Accumulator	Item: H1-000	0.993467721	0.999993849	0.999884828	1373.3	9	0.00655	1336648	8.22	0.8375	0.880	7638	1.0089
Pressurized	Item: H1-100	0.993913727	0.999992102	0.999841861	982.8	6	0.00610	1434920	11.33	1.0000	0.897	5672	1.3853
Unpressurized.	Item: H1-200	0.992345933	0.999998246	0.999992983	390.4	3	0.00768	1140104	2.00	0.0000	0.421	60005	0.0615
Air Compressor	Item: H2-000	0.964395571	0.999966392	0.999377084	799.9	29	0.03625	241630.3	8.12	0.3086	0.326	523	5.4567
Electric	Item: H2-100	0.926805720	0.999919556	0.999207149	315.7	24	0.07601	115246	9.27	0.1602	0.178	224	6.9454
Fuel	Item: H2-200	0.989726301	0.999996935	0.999487902	484.2	5	0.01033	848275.2	2.60	2.0000	2.006	3916	4.4860
Air Dryer, All Types	Item: H4-000	0.997716217	0.999998695	0.999926162	437.4	1	0.00229	3831360	5.00	1.0000	0.946	12814	0.6468
Air Handling Unit	Item: H5-000	0.989056337	0.999997032	0.999875595	1817.5	20	0.01100	796075.2	2.36	xxx	99.036	796075	1.0898
Non-humid	Item: H5-200	0.989056337	0.999997032	0.999875595	1817.5	20	0.01100	796075.2	2.36	xxx	99.036	796075	1.0898
w/o Drive	Item: H5-210	0.989056337	0.999997032	0.999875595	1817.5	20	0.01100	796075.2	2.36	0.0000	99.036	796075	1.0898
Arrester, Lightning	Item: E1-000	0.998679474	0.999999397	0.999999397	1513.5	2	0.00132	6629340	4.00	0.0000	4.000	6629340	0.0053
Battery	Item: E2-000	0.993006248	0.999990299	0.999969547	10543.8	74	0.00702	1248161.	12.11	0.1490	0.217	7140	0.2668
Rechargeable	Item: E2-100	0.993006248	0.999990299	0.999969547	10543.8	74	0.00702	1248161.	12.11	0.1490	0.217	7140	0.2668
Gel Cell-Sealed, Strings.	Item: E2-110	0.980061731	0.999995402	0.999967422	2333.7	47	0.02014	434961.4	2.00	0.0000	0.152	4660	0.2854
Lead Acid, String.	Item: E2-120	0.992563514	0.999972627	0.999968207	3215.3	24	0.00746	1173590.	32.13	0.0000	1.023	32190	0.2785
Nickel-Cadmium.	Item: E2-130	0.999399558	0.999999292	0.999971403	4994.8	3	0.00060	14584865	10.33	0.0000	0.163	5701	0.2505
Blower	Item: H7-000	0.999825378	1.000000000	0.999960812	2920.3	0	0.00017	50160988	xxx	0.0692	0.069	1765	0.3433
w/o Drive	Item: H7-100	0.999825378	1.000000000	0.999960812	2920.3	0	0.00017	50160988	xxx	0.0000	0.069	1765	0.3433
Boiler	Item: H8-000	0.878642210	0.999360697	0.995132436	1113.0	144	0.12938	67708.83	43.29	3.2844	3.738	768	42.639
Hot Water	Item: H8-100	0.959008598	0.999985268	0.999501894	358.4	15	0.04186	209292.8	3.08	1.0000	1.005	2018	4.3634
Steam	Item: H8-200	0.842870823	0.999064090	0.993057393	754.6	129	0.17094	51245.58	47.96	3.6062	4.120	593	60.817
High Pressure.	Item: H8-210	0.928026957	0.999619462	0.991492148	468.6	35	0.07469	117277.7	44.63	3.0000	3.162	372	74.528
Low Pressure.	Item: H8-220	0.719936234	0.998154400	0.995621239	286.1	94	0.32859	26659.1	49.20	0.0000	116.734	26659	38.357
Bus Duct, All types/100ft	Item: E3-000	0.999696290	1.000000000	1.000000000	1679.0	0	0.00030	28838917	xxx	xxx	xxx	xxx	0.0000
Cabinet Heaters	Item: E4-000	0.999897930	0.999999994	0.999978224	9796.7	1	0.00010	85819128	0.50	1.6476	1.647	75612	0.1908
Forced Air Flow													
Steam or Hot Water	Item: E4-100	0.999897930	0.999999994	0.999978224	9796.7	1	0.00010	85819128	0.50	2.0000	1.647	75612	0.1908

* - Time Truncated, Chi Squared, 60% Single Side Confidence Interval

xxx - Data Not Available at Time of Analysis

Category/Class	Item Number	Reliability	Inherent Availability	Operational Availability	Unit Years	Failures	Failure Rate (Failures/Year)	MTBF	MTTR	MTTM	MDT	MTBM	Hrdt/ Year
Cable, AC Per 1000 ft.	Item: E6-000	0.998679301	0.999998900	0.999987359	698411	923	0.00132	6628468	7.29	4.2810	4.440	351270	0.1107
Cable, AC, 0-600V	Item: E6-100	0.998924937	0.999998890	0.999995587	130155	140	0.00108	8143981	9.04	6.3706	6.882	1559723	0.0387
Above Ground	Item: E6-110	0.999904380	0.999999953	0.999995381	62745.1	6	0.00010	91607820	4.33	4.6194	4.616	999358	0.0405
In Conduit	Item: E6-111	0.999932074	0.999999938	0.999990264	29442.9	2	0.00007	128959932	8.00	13.0000	13.010	1336372	0.0853
In Trays	Item: E6-112	0.968468243	1.000000000	1.000000000	15.9	0	0.03204	273411.8	0.00	0.0000	xxx	xxx	0.0000
No Conduit	Item: E6-113	0.999879838	0.999999966	0.999999904	33286.3	4	0.00012	72896904	2.50	0.0000	0.078	816772	0.0008
Below Ground	Item: E6-120	0.998014135	0.999997900	0.999995780	67409.9	134	0.00199	4406794	9.25	26.6382	13.768	3262488	0.0370
In Duct	Item: E6-121	0.999875009	0.999999766	0.999999697	40000.4	5	0.00012	70080729	16.40	1.0000	2.789	9221149	0.0026
In Conduit	Item: E6-122	0.997994901	0.999997428	0.999991686	24413.2	49	0.00201	4364479.	11.22	88.0000	28.222	3394595	0.0728
Insulated	Item: E6-123	0.973653295	0.999976836	0.999976836	2996.3	80	0.02670	328089.9	7.60	0.0000	7.600	328090	0.2029
Cable, AC, 601-15kV	Item: E6-200	0.998623048	0.999998903	0.999985474	568256	783	0.00138	6357495	6.98	4.2034	4.333	298329.1	0.1273
Above Ground	Item: E6-210	0.999462309	0.999999477	0.999998712	526182.7	283	0.00054	16287492	8.52	10.5194	9.605	7458512	0.0113
In Conduit	Item: E6-211	0.999463225	0.999999476	0.999998707	523356.6	281	0.00054	16315315	8.56	41.0000	16.109	12458162	0.0113
In Trays	Item: E6-212	0.997171966	1.000000000	1.000000000	180.1	0	0.00283	3093176	0.00	0.0000	xxx	xxx	0.0000
No Conduit.	Item: E6-214	0.999244433	0.999999655	0.999999655	2646.0	2	0.00076	11589564	4.00	0.0000	0.032	92717	0.0030
Below Ground	Item: E6-220	0.988186203	0.999991725	0.999819915	42072.9	500	0.01188	737117.2	6.1	4.0674	4.131	22937.4	1.5776
In Conduit	Item: E6-221	0.997646877	0.999995779	0.999987126	19525.5	46	0.00236	3718331	15.70	211.0000	41.547	3227231	0.1128
In Duct	Item: E6-222	0.987125021	1.000000000	1.000000000	39.4	0	0.01296	676000	0.00	0.0000	xxx	xxx	0.0000
Insulated	Item: E6-223	0.980031515	0.999988193	0.999674546	22508.1	454	0.02017	434296.5	5.13	4.0000	4.007	12312	2.8510
Cable, Aerial Per 1 Mile	Item:E7-000	0.988381339	0.999997295	0.999997259	37478.5	438	0.01169	749570.9	2.03	0.3529	1.907	695576	0.0240
Cable, Aerial, 0-15kV	Item: E7-100	0.953928762	0.999990218	0.999990218	6593.7	311	0.04717	185725.9	1.82	0.0000	1.817	185726	0.0857
Cable, Aerial >15kV	Item: E7-200	0.995896395	0.999998806	0.999998762	30884.9	127	0.00411	2130325.	2.54	0.0000	2.081	1680443	0.0108
Cable, DC Per 100 ft.	Item: E8-000	0.992748496	0.999998338	0.999998338	412.2	3	0.00728	1203640	2.00	0.0000	0.109	65653	0.0146
Cable, DC, Insulated	Item: E8-100	0.992748496	0.999998338	0.999998338	412.2	3	0.00728	1203640	2.00	0.0000	0.109	65653	0.0146
Cable Connection	Item: E5-000	0.999629261	0.999999968	0.999999968	21574.5	8	0.00037	23624073	0.75	xxx	0.750	23624073	0.0003
Below Ground, Duct													
≤600V, per 1000ft	Item: E5-100	0.999629261	0.999999968	0.999999968	21574.5	8	0.00037	23624073	0.75	xxx	0.0000	23624073	0.0003
Capacitor Bank													
Power Factor Corrector (in kVAR)	Item: E10-000	0.839937440	0.999954142	0.999942075	567.6	99	0.17443	50221.33	2.30	10.0000	2.743	47352	0.5074

* - Time Truncated, Chi Squared, 60% Single Side Confidence Interval

xxx - Data Not Available at Time of Analysis

B-3

Category/Class	Item Number	Reliability	Inherent Availability	Operational Availability	Unit Years	Failures	Failure Rate (Failures/Year)	MTBF	MTTR	MTTM	MDT	MTBM	Hrdt/ Year
Charger, Battery	Item: E11-000	0.992621004	0.999999577	0.999986472	270.0	2	0.00741	1182768	0.50	0.0000	0.133	9816	0.1185
Chiller	Item: H10-000	0.888515818	0.999829779	0.997620632	2021.9	239	0.11820	74109.90	12.62	1.0881	1.164	489	20.843
Absorption	Item: H10-100	0.841986658	0.999769437	0.995132437	430.3	74	0.17199	50932.86	11.74	1.0000	0.653	134	42.639
Centrifugal	Item: H10-200	0.955142622	0.999923928	0.997604888	544.7	25	0.04589	190872.1	14.52	5.2247	5.333	2227	20.981
600 -1000 Tons.	Item: H10-220	0.955142622	0.999923928	0.997604888	544.7	25	0.04589	190872.1	14.52	5.0000	5.333	2227	20.981
Reciprocating	Item: H10-300	0.864557699	0.999799791	0.998898189	948.2	138	0.14554	60190.78	12.05	1.5457	1.837	1667	9.6519
Closed	Item: H10-320	0.879941865	0.999809524	0.998734968	680.2	87	0.12790	68491.3	13.05	1.0000	1.662	1314	11.081
w/Drive, 50-200 T	Item: H10-321	0.879941865	0.999809524	0.998734968	680.2	87	0.12790	68491.3	13.05	1.0000	1.662	1314	11.081
Open,	Item: H10-330	0.826705884	0.999775088	0.999312485	268.0	51	0.19031	46031.1	10.35	3.0000	3.611	5252	6.0226
w/o Drive,50-200T	Item: H10-331	0.826705884	0.999775088	0.999312485	268.0	51	0.19031	46031.1	10.35	3.0000	3.611	5252	6.0226
Rotary	Item: H10-400	0.986993503	0.999964132	0.996197991	76.4	1	0.01309	669120	24.00	6.0723	6.115	1608	33.305
600-1000 Ton	Item: H10-410	0.986993503	0.999964132	0.996197991	76.4	1	0.01309	669120	24.00	6.0000	6.115	1608	33.305
Screw	Item: H10-500	0.956286690	0.999510164	0.996566046	22.4	1	0.04470	195984	96.00	1.0000	1.164	339	30.081
>300 Tons.	Item: H10-520	0.956286690	0.999510164	0.996566046	22.4	1	0.04470	195984	96.00	1.0000	1.164	339	30.081
Circuit Breaker	Item: E12-000	0.999996752	0.999999582	0.999983888	157040.9	52	0.00000	26974078	xxx	1.9167	1.959	121569	0.1411
Fixed (Incl. Mold Case)	Item: E12-200	0.999996551	0.999999899	0.999992732	147880.0	5	0.00000	25400557	xxx	8.2967	8.376	1152516	0.0637
≤600V, 3ph,≤600A	Item: E12-210	0.999949237	0.999999892	0.999994177	59096.5	3	0.00005	172561870	18.667	5.9887	6.065	1041621	0.0510
Normally Closed	Item: E12-211	0.999984307*	1.000000000	0.999997443	32498.7	0	0.00002*	558213637*	0.00	3.0000	3.098	1211442	0.0224
Normally Open	Item: E12-212	0.999887215	0.999999760	0.999990187	26597.8	3	0.00011	77665552	18.67	9.0000	8.727	889300	0.0860
≤600V, 3ph,>600A	Item: E12-220	0.999977474	0.999999904	0.999991770	88783.4	2	0.00002	388871412	37.5	10.1210	10.208	1240419.	0.0721
Normally Closed	Item: E12-221	0.999994218*	1.000000000	0.999992509	88200.2	0	0.00001*	1514968565*	0.00	14.0000	13.618	1817962	0.0656,
Normally Open	Item: E12-222	0.996576534	0.999985320	0.999880051	583.2	2	0.00343	2554428	37.50	3.0000	3.034	25291	1.0507
Metal Clad (Drawout)	Item: E12-400	0.998892235	0.999999605	0.999837990	7217.8	8	0.00111	7903437.	3.13	2.0569	2.059	12706	1.4192
≤600V, ≤600Amp	Item: E12-410	0.999463921	0.999999633	0.999806833	5594.7	3	0.000536	16336496	6	2.0831	2.086	10797.4	1.6921
Normally Closed	Item: E12-411	0.999792091	0.999999858	0.999798004	4809.3	1	0.00021	42129480	6.00	2.0000	2.019	9998	1.7695
Normally Open	Item: E12-412	0.997456731	0.999998256	0.999860901	785.4	2	0.00255	3440004	6.00	3.0000	2.945	21169	1.2185
≤600V, >600Amp	Item: E12-420	0.996924140	0.999999508	0.999945386	1623.1	5	0.00308	2843602	1.4	1.7813	1.777	32535.5	0.4784
Normally Closed	Item: E12-421	0.998150509	0.999999894	0.999954301	1080.4	2	0.00185	4732057.	0.50	1.0000	1.481	32411	0.4003
Normally Open	Item: E12-422	0.994487152	0.999998738	0.999927638	542.7	3	0.00553	1584631.	2.00	2.0000	2.372	32785	0.6339
Vacuum	Item: E12-700	0.980129686	0.999975385	0.999852780	1943.2	39	0.02007	436464	10.74	0.4031	0.480	3263	1.2897
<15kV, <600Amp	Item: E12-710	0.998771968	0.999998878	0.999973208	813.8	1	0.00123	7128984	8.00	0.0728	0.076	2834.6	0.2347

* - Time Truncated, Chi Squared, 60% Single Side Confidence Interval

xxx - Data Not Available at Time of Analysis

B-4

Category/Class	Item Number	Reliability	Inherent Availability	Operational Availability	Unit Years	Failures	Failure Rate (Failures/Year)	MTBF	MTTR	MTTM	MDT	MTBM	Hrdt/ Year
Normally Closed	Item: E12-711	0.997191564	0.999997432	0.999960511	355.6	1	0.00281	3114792	8.00	0.0000	0.050	1257	0.3459
Normally Open	Item: E12-712	0.998887668*	1.000000000	0.999983060	458.2	0	0.00111*	7870964*	0.00	2.0000	1.838	108492	0.1484
<15kV, >600Amp	Item: E12-720	0.966912133	0.999958456	0.999765999	1129.4	38	0.03365	260345.1	10.82	0.7150	0.857	3662.8	2.0499
Normally Closed	Item: E12-721	0.976752059	0.999960259	0.999619774	425.1	10	0.02352	372410.4	14.80	1.0000	1.620	4261	3.3308
Normally Open	Item: E12-722	0.961020019	0.999957368	0.999854272	704.2	28	0.03976	220321.7	9.39	0.0000	0.492	3377	1.2766
Compressor, Refrigerant	Item: H11-000	0.986548811	0.999986587	0.999865676	1255.3	17	0.01354	646853.6	8.68	0.9208	1.011	7527	1.1767
>1 Ton	Item: H11-020	0.995193627	0.999998075	0.999907183	1037.8	5	0.00482	1818196.	3.50	1.0000	0.925	9968	0.8131
Screw Type	Item: H11-100	0.946328222	0.999931777	0.999667651	217.5	12	0.05517	158794	10.83	1.0000	1.154	3471	2.9114
Condensers	Item: H12-000	0.900083857	0.999913810	0.999583534	1102.0	116	0.10527	83216.68	7.17	4.0979	4.497	10798	3.6482
Double Tube	Item: H12-100	0.973573588	0.999992357	0.999758971	298.7	8	0.02678	327087	2.50	3.0000	2.628	10903	2.1114
Propeller Type Fans With Coils DX: Direct Expansion	Item: H12-200	0.733621551	0.999734138	0.999393134	348.7	108	0.30976	28279.77	7.52	3.0000	4.165	6863	5.3161
Shell and Tube	Item: H12-300	0.998878743	1.000000000	0.999614286	454.6	0	0.00112	7808282.	xxx	7.0000	7.349	19054	3.3789
Control Panel	Item: C4-000	0.994698171	0.999998908	0.999800824	5643.4	30	0.00532	1647876.	1.80	4.4410	4.406	22119	1.7448
Generator, w/o Switchgear	Item: C4-100	0.988952766	0.999997330	0.999980962	1710.4	19	0.01111	788570.5	2.11	1.0000	0.635	33369	0.1668
HVAC/Chillers/AHUs w/o Switchgear.	Item: C4-200	0.999848787	1.000000000	0.999982209	3372.5	0	0.00015	57926964	xxx	1.0000	1.045	58733	0.1559
Switchgear	Item: C4-300	0.980568763	0.999997149	0.998160003	560.6	11	0.01962	446426.1	1.27	7.0000	7.043	3828	16.118
Convectors	Item: H13-000	0.999913016	1.000000000	0.999998481	5862.9	0	0.00009	10070423	xxx	0.0149	0.015	9830	0.0133
Fin Tube Baseboard	Item: H13-100	0.999913016	1.000000000	0.999998481	5862.9	0	0.00009	10070423	xxx	0.0149	0.015	9830	0.0133
Electric.	Item: H13-110	0.999582861*	1.000000000	0.999999626	1222.4	0	0.00042*	20995811*	0.00	0.0000	0.005	12702	0.0033
Steam/Hot Water	Item: H13-120	0.999890105*	1.000000000	0.999998180	4640.6	0	0.00011*	79708423*	0.00	0.0000	0.017	9277	0.0159
Cooling Tower	Item: H14-000	0.968333522	0.999702865	0.997170520	839.1	27	0.03218	272229.7	80.89	1.0681	1.192	421	24.786
Atmospheric Type w/o Fans, Motors, Pumps, Valves, etc.	Item: H14-100	0.928543791	0.999247479	0.994184363	323.7	24	0.07414	118158.5	88.92	1.0000	1.137	196	50.945
Evaporative Type w/o Fans, Motors, Pumps, Valves, etc.	Item: H14-200	0.994195540	0.999988924	0.999046330	515.3	3	0.00582	1504800	16.67	1.0000	1.458	1529	8.3542
Damper Assembly	Item: H15-000	0.999971953	0.999999975	0.999990131	18183.5	2	0.00003	31232804	xxx	0.0540	0.054	5486	0.0865

* - Time Truncated, Chi Squared, 60% Single Side Confidence Interval

xxx - Data Not Available at Time of Analysis

Category/Class	Item Number	Reliability	Inherent Availability	Operational Availability	Unit Years	Failures	Failure Rate (Failures/Year)	MTBF	MTTR	MTTM	MDT	MTBM	Hrdt/ Year
Motor Operated	Item: H15-100	0.999966919	1.000000000	0.999989337	15416.3	0	0.00003	264797694	xxx	0.0000	0.050	4656	0.0934
Pneumatic	Item: H15-200	0.999277503	0.999999835	0.999994555	2767.2	2	0.00072	12120240	2.00	4.0000	3.882	712955	0.0477
Generator, Diesel Engine	Item: E18-000	0.589772164	0.998540049	0.993985981	1354.1	715	0.52802	16590.31	24.22	2.0554	2.642	439	52.682
Packaged	Item: E18-100	0.775917369	0.999329810	0.997272882	938.1	238	0.25371	34527.71	23.14	1.1483	1.498	549.4	23.890
250kW-1.5MW	Item: E18-120	0.775917369	0.999329810	0.997272882	938.1	238	0.25371	34527.71	23.14	1.1483	1.498	549.4	23.890
Continuous	Item: E18-121	0.558396351	0.998287624	0.996927250	266.0	155	0.58269	15033.8	25.74	1.0000	1.149	374	26.917
Standby	Item: E18-122	0.883822868	0.999742312	0.997409685	672.1	83	0.12350	70932	18.28	2.0000	1.748	675	22.691
Unpackaged	Item: E18-200	0.317735957	0.996759289	0.986574653	416.0	477	1.14653	7640.415	24.76	3.2103	4.064	303	117.60
750kW-7MW	Item: E18-210	0.317735957	0.996759289	0.986574653	416.0	477	1.14653	7640.415	24.76	3.2103	4.064	303	117.60
Continuous	Item: E18-211	0.162719469	0.994801067	0.980739869	180.6	328	1.81573	4824.5	25.08	4.0000	4.997	259	168.71
Standby	Item: E18-212	0.531004159	0.998262059	0.991052357	235.4	149	0.63299	13839.2	24.05	3.0000	3.106	347	78.381
Drive	Item: E14-000	0.978172315	0.999958316	0.999925947	2990.6	66	0.02207	396929.0	16.55	3.4472	6.218	83966	0.6487
Adjustable Speed	Item: E14-100	0.978172315	0.999958316	0.999925947	2990.6	66	0.02207	396929.0	16.55	3.0000	6.218	83966	0.6487
Evaporator	Item: H18-000	0.995968933	0.999993228	0.999908962	7922.3	32	0.00404	2168739	14.69	0.2565	0.277	3040	0.7975
Direct Expansion	Item: H18-100	0.995812835	0.999992633	0.999899263	6911.4	29	0.00420	2087724.	15.38	0.2689	0.290	2876	0.8825
Coil	Item: H18-110	0.995812835	0.999992633	0.999899263	6911.4	29	0.00420	2087724.	15.38	0.0000	0.290	2876	0.8825
Shell Tube	Item: H18-120	0.997036799	0.999997290	0.999975270	1010.9	3	0.00297	2951880	8.00	0.0000	0.123	4972	0.2166
Fan	Item: H19-000	0.987559807	0.999971610	0.999351118	2396.5	30	0.01252	699780	19.87	4.2211	4.372	6737	5.6842
Centrifugal	Item: H19-100	0.981021428	0.999946483	0.999770440	782.8	15	0.01916	457179.2	24.47	2.0000	2.061	8976	2.0109
Propeller/Disc	Item: H19-200	0.989640193	0.999957798	0.999093547	384.1	4	0.01041	841188	35.50	2.0000	1.954	2156	7.9405
Tube axial	Item: H19-300	0.989938879	0.999990870	0.999055744	1087.8	11	0.01011	866290.9	7.91	11.0000	11.375	12047	8.2717
Vane axial	Item: H19-400	0.996408668*	1.000000000	1.000000000	141.8	0	0.00360*	2434823.*	0.00	0.0000	xxx	xxx	0.0000
Filter, Electrical	Item: E16-000	0.999898973	1.000000000	0.999903911	5047.9	0	0.00010	86704894	xxx	0.2894	0.289	3012	0.8417
Tempest	Item: E16-200	0.998510134*	1.000000000	1.000000000	342.1	0	0.00149*	5875341*	0.00	0.0000	0.000	2996424	0.0000
Filter, Mechanical	Item: H20-000	0.999891630	1.000000000	0.999896927	4705.8	0	0.00011	80829552	xxx	0.2894	0.289	2808	0.9029
Air Regulator Set.	Item: H20-100	0.999840000*	1.000000000	0.999981949	3187.2	0	0.00016*	54745647*	0.00	0.0000	0.044	2464	0.1581
Fuel Oil	Item: H20-200	0.999271146*	1.000000000	0.999910729	699.5	0	0.00073*	12014494*	0.00	0.0000	0.486	5442	0.7820
Lube Oil	Item: H20-300	0.999377566*	1.000000000	0.999554311	819.1	0	0.00062*	14069411*	0.00	1.0000	1.439	3229	3.9042
Fuse	Item: E17-000	0.997969725	1.000000000	1.000000000	1145.4	0	0.00087	10033704	xxx	xxx	xxx	xxx	0.0000
>5kV≤15kV	Item: E17-200	0.999341365*	1.000000000	1.000000000	774.1	0	0.00066*	13295858*	0.00	0.0000	xxx	xxx	0.0000

* - Time Truncated, Chi Squared, 60% Single Side Confidence Interval

xxx - Data Not Available at Time of Analysis

B-6

Category/Class	Item Number	Reliability	Inherent Availability	Operational Availability	Unit Years	Failures	Failure Rate (Failures/Year)	MTBF	MTTR	MTTM	MDT	MTBM	Hrdt/ Year
0-5kV	Item: E17-100	0.998627456*	1.000000000	1.000000000	371.3	0	0.00137*	6377929*	0.00	0.0000	xxx	xxx	0.0000
Generator, Gas Turbine	Item: E19-000	0.647849145	0.998890863	0.990692798	921.5	400	0.43410	20179.80	22.38	2.1583	2.419	260	81.531
Packaged	Item: E19-100	0.587787144	0.998689955	0.989043771	750.9	399	0.53139	16485.05	21.60	2.1103	2.366	216	95.976
750kW-7MW	Item: E19-110	0.587787144	0.998689955	0.989043771	750.9	399	0.53139	16485.05	21.60	2.1103	2.366	216	95.976
Continuous	Item: E19-111	0.177710554	0.994598022	0.983584136	167.9	290	1.72760	5070.6	27.39	1.0000	1.225	75	143.80
Standby	Item: E19-112	0.829472916	0.999868149	0.990615770	583.0	109	0.18696	46853.7	6.18	4.0000	4.453	475	82.205
Unpackaged	Item: E19-200	0.994155201	0.999775158	0.997950995	170.6	1	0.00586	1494384	336.00	4.5892	5.146	2512	17.949
750kW-7MW	Item: E19-210	0.994155201	0.999775158	0.997950995	170.6	1	0.00586	1494384	336.00	4.5892	5.146	2512	17.949
Continuous	Item: E19-211	0.994155201	0.999775158	0.997950995	170.6	1	0.00586	1494384	336.00	5.0000	5.146	2512	17.949
Gauge	Item: C5-000	0.999042094	1.000000000	0.999999785	532.2	0	0.00096	9140564.	xxx	xxx	xxx	xxx	0.0019
Fluid level	Item: C5-100	0.999042094*	1.000000000	0.999999785	532.2	0	0.00096*	9140564*	0.00	0.0000	xxx	xxx	0.0019
Heat Exchanger	Item: H21-000	0.988170294	0.999985962	0.999515055	1512.6	18	0.011900	736120	10.33	0.95	0.976	2012	4.2481
Boiler System	Item: H21-100	0.971835048	0.999998369	0.997231137	210.0	6	0.02857	306624	0.50	29.0000	28.300	10221	24.255
Lube Oil	Item: H21-200	0.996596565	0.999995330	0.999740960	293.3	1	0.00341	2569488	12.00	7.0000	6.590	25440	2.2692
Radiators	Item: H21-300	0.987545587	0.999977760	0.999934189	877.7	11	0.012533	698976	15.55	0.0999	0.150	2285	0.5765
Small Tube	Item: H21-310	0.987545587	0.999977760	0.999934189	877.7	11	0.012533	698976	15.55	0.0999	0.150	2285	0.5765
Water to Water	Item: H21-400	0.996130029*	1.000000000	0.999861134	131.5	0	0.00388*	2259200*	0.00	0.0000	0.054	392	1.2165
Heater	Item: E24-000	0.947826981	0.999984168	0.994164558	317.3	17	0.05358	163483.7	2.59	1.2053	1.207	207	51.118
Lube-Fuel Oil/Jkt water	Item: E24-100	0.947826981	0.999984168	0.994164558	317.3	17	0.05358	163483.7	2.59	1.2053	1.207	207	51.118
Electric	Item: E24-110	0.947826981	0.999984168	0.994164558	317.3	17	0.05358	163483.8	2.59	1.0000	1.207	207	51.118
Humistat Assembly	Item: H24-000	0.984575905	0.999998226	0.999998226	643.3	10	0.01554	563551.2	1.00	0.0000	0.043	24083	0.0155
Inverters All Types	Item: E25-000	0.995190512	0.999985691	0.999598793	414.8	2	0.00482	1817016	26.00	5.0000	5.321	13263	3.5146
Meter	Item: C6-000	0.998913484	0.999993988	0.999993961	16557.7	18	0.00109	8058086.	48.44	0.0055	1.182	195743	0.0529
Electric	Item: C6-100	0.999635167	0.999999958	0.999999958	13702.4	5	0.00036	24006614	1.00	0.0000	0.025	606228	0.0004
Fuel	Item: C6-200	0.946014073	0.999543853	0.999543853	216.2	12	0.05550	157844	72.00	0.0000	72.000	157844	3.9958
Water	Item: C6-300	0.999621152	0.999999870	0.999999697	2639.1	1	0.00038	23118360	3.00	0.0000	0.013	43537	0.0027
Motor Generator Set	Item: E27-000	0.975052652	0.999978501	0.993070544	435.4	11	0.02526	346741.0	7.45	0.8368	0.839	121	60.702
3 Phase	Item: E27-100	0.975052652	0.999978501	0.993070544	435.4	11	0.02526	346741.0	7.45	0.8368	0.839	121	60.702
400Hz,	Item: E27-120	0.995075131	0.999995491	0.999628032	202.6	1	0.00494	1774344	8.00	3.0000	2.895	7782	3.2584
60Hz	Item: E27-110	0.957963867	0.999963722	0.987366458	232.9	10	0.04295	203980.8	7.40	1.0000	0.824	65	110.66

* - Time Truncated, Chi Squared, 60% Single Side Confidence Interval

xxx - Data Not Available at Time of Analysis

Category/Class	Item Number	Reliability	Inherent Availability	Operational Availability	Unit Years	Failures	Failure Rate (Failures/Year)	MTBF	MTTR	MTTM	MDT	MTBM	Hrdt/ Year
Motor Starter	Item: E28-000	0.999147052	0.999995416	0.999944527	597.7	1	0.00085	10265882	xxx	0.2442	0.266	4795	0.4859
≤600V	Item: E28-100	0.998167781*	1.000000000	0.999984223	278.1	0	0.00183*	4776705*	0.00	0.0000	0.081	5161	0.1382
>600V	Item: E28-200	0.996875738	0.999991427	0.999909983	319.6	1	0.00313	2799480	24.00	0.0000	0.406	4515	0.7885
Motor, Electric	Item: E29-000	0.999032041	0.999973300	0.999930849	27880.2	27	0.00097	9045589.	241.52	0.5662	0.921	13318	0.6058
DC	Item: E29-100	0.985531708	0.999031729	0.998182336	754.8	11	0.01457	601071.2	582.00	0.4228	0.904	497	15.922
Induction	Item: E29-200	0.981918899	0.999992950	0.999724259	712.5	13	0.01825	480090.4	3.38	2.9576	2.967	10761	2.4155
≤600Volts	Item: E29-210	0.988992708	0.999998736	0.999957372	361.4	4	0.01107	791448	1.00	1.0000	1.336	31344	0.3734
>600Volts	Item: E29-220	0.974689985	0.999986993	0.999484292	351.1	9	0.02564	341709.3	4.44	3.0000	3.311	6420	4.5176
Single Phase	Item: E29-300	0.999980411	0.999999987	0.999988267	26034.5	1	0.00002	44718136	xxx	0.6247	0.625	53286	0.1028
≤5 Amp	Item: E29-310	0.999979878*	1.000000000	0.999996192	25345.3	0	0.00002*	435342400*	0.00	0.0000	0.491	128934	0.0334
>5 Amp	Item: E29-320	0.998550210	0.999999503	0.999696847	689.3	1	0.00145	6037872	3.00	1.0000	0.716	2360	2.6556
Synchronous	Item: E29-400	0.998653401	0.999978284	0.999857033	378.5	2	0.00135	6500894	xxx	2.2088	2.576	18019	1.2524
≤600Volts	Item: E29-410	0.996555656*	1.000000000	0.999777580	147.8	0	0.00345*	2538917*	0.00	2.0000	2.000	8992	1.9484
>600Volts	Item: E29-420	0.991366824	0.999964367	0.999907948	230.7	2	0.00867	1010304	36.00	3.0000	4.650	50515	0.8064
Engine	Item: E15-000	0.195448823	0.999809717	0.998810724	1154.7	1885	1.63246	5366.145	1.02	2.8441	2.212	1860	10.418
Diesel	Item: E15-100	0.904562026	0.999953538	0.991433654	129.6	13	0.10030	87334.15	4.06	3.0000	3.253	380	75.041
Gas	Item: E15-200	0.161029030	0.999791533	0.999743425	1025.1	1872	1.82617	4796.923	1.00	1.0000	0.941	3668	2.2476
Pipe	Item: H25-000	0.998585822	0.999998644	0.999685368	13425.9	19	0.00142	6190032	8.39	7.7161	7.719	24533	2.7562
Flex	Item: H25-100	0.981888041	0.999994337	0.999991952	383.0	7	0.01828	479265	2.71	4.0000	3.000	372762	0.0705
Non-Reinforced	Item: H25-110	0.985560776	0.999994466	0.999990038	206.3	3	0.01454	602290.2	3.33	4.0000	3.600	361374	0.0873
>4".	Item: H25-112	0.985560776	0.999994466	0.999990038	206.3	3	0.01454	602290.2	3.33	4.0000	3.600	361374	0.0873
Reinforced	Item: H25-120	0.977618384	0.999994186	0.999994186	176.7	4	0.02264	386996.1	2.25	0.0000	2.250	386996	0.0509
>4"	Item: H25-122	0.977618384	0.999994186	0.999994186	176.7	4	0.02264	386996.1	2.25	0.0000	2.250	386996	0.0509
Refrigerant	Item: H25-300	0.999954550	0.999999430	0.999990919	11221.0	6	0.00005	19273661	xxx	3.0645	3.199	352314	0.0795
<1 inch, Per 100ft.	Item: H25-310	0.999925556*	1.000000000	0.999993884	6850.6	0	0.00007*	117668376*	0.00	4.0000	3.670	600109	0.0536
1-3 inch, Per 100ft.	Item: H25-320	0.998628073	0.999998537	0.999986271	4370.4	6	0.001373	6380800	9.3333	3.0000	2.936	213882	0.1203
Water	Item: H25-400	0.999720116	0.999994706	0.997739077	1821.9	6	0.00028	31294258	xxx	xxx	8.008	3542	19.805
≤2 inch Per 100ft.	Item: H25-410	0.998834378*	1.000000000	1.000000000	437.3	0	0.00117*	7510917*	0.00	0.0000	xxx	xxx	0.0000
>12", Per 100ft.	Item: H25-450	0.939385452*	1.000000000	1.000000000	8.2	0	0.06253*	140094.1*	0.00	0.0000	xxx	xxx	0.0000
>2 ≤4 inch, Per 100ft.	Item: H25-420	0.979679275	0.999966994	0.999966994	292.3	6	0.02053	426692	14.08	0.0000	14.083	426692	0.2891
>4≤8 inch, Per 100ft.	Item: H25-430	0.998103531*	1.000000000	1.000000000	268.7	0	0.00190*	4614729*	0.00	0.0000	xxx	xxx	0.0000

* - Time Truncated, Chi Squared, 60% Single Side Confidence Interval

xxx - Data Not Available at Time of Analysis

B-8

Category/Class	Item Number	Reliability	Inherent Availability	Operational Availability	Unit Years	Failures	Failure Rate (Failures/Year)	MTBF	MTTR	MTTM	MDT	MTBM	Hrdt/ Year
>8≤12 inch, Per 100ft	Item: H25-440	0.999374866*	1.000000000	0.994961083	815.6	0	0.00063*	14008611*	0.00	8.0000	8.000	1588	44.140
Pressure Control Assembly	Item: C8-000	0.993091820	0.999995568	0.999938101	721.3	5	0.00693	1263676.	5.60	3.0000	3.492	56414	0.5422
Pressure Regulator	Item: C9-000	0.999163441	1.000000000	0.999993069	609.4	0	0.00084	10467090	xxx	0.5000	0.500	72138	0.0607
Hot Gas	Item: C9-100	0.999163441*	1.000000000	0.999993069	609.4	0	0.00084*	10467090*	0.00	0.0000	0.500	72138	0.0607
Pump	Item: H26-000	0.993705867	0.999994889	0.999826613	1742.2	11	0.00631	1387387.	7.09	0.4204	0.432	2494	1.5189
Centrifugal	Item: H26-100	0.994206434	0.999995523	0.999903450	1376.8	8	0.00581	1507638	6.75	0.3372	0.353	3654	0.8458
Integral Drive	Item: H26-110	0.992515450	0.999993654	0.999897429	665.5	5	0.00751	1166025.	7.40	1.0000	0.599	5836	0.8985
Without Drive	Item: H26-120	0.995791244	0.999997272	0.999909083	711.3	3	0.00422	2076992	5.67	0.0000	0.246	2707	0.7964
Positive Displacement	Item: H26-200	0.991821538	0.999992500	0.999537023	365.3	3	0.00821	1066720	8.00	1.0000	0.526	1135	4.0557
Rectifiers, All Types	Item: E32-000	0.995540658	0.999991837	0.998972976	447.5	2	0.00447	1960032	16.00	3.4491	3.471	3379	8.9967
Sending Unit	Item: C13-000	0.999566658	0.999999536	0.999999258	36914.4	16	0.00043	20210622	9.38	0.0170	0.045	60956	0.0065
Air Velocity	Item: C13-100	0.998867884	0.999998707	0.999997599	6179.6	7	0.00113	7733345.	10.00	0.0000	0.034	14050	0.0210
Pressure	Item: C13-200	0.997916028	0.999997883	0.999997089	4314.2	9	0.00209	4199130	8.89	0.0000	0.076	26028	0.0255
Temperature	Item: C13-300	0.999980697*	1.000000000	1.000000000	26420.6	0	0.00002*	453812471*	0.00	0.0000	xxx	xxx	0.0000
Control System	Item: C12-000	0.642221250	0.999854564	0.999658784	551.0	244	0.44282	19782.19	2.88	0.5615	0.855	2505	2.9891
≤1k Acquisition Points	Item: C12-100	0.777690112	0.999954199	0.999888246	373.9	94	0.25143	34841.10	1.60	1.0000	1.376	12312	0.9790
>1k Acquisition Points	Item: C12-200	0.428800729	0.999644282	0.999174503	177.1	150	0.84676	10345.28	3.68	0.0000	0.771	934	7.2314
Strainer	Item: H27-000	0.999943310	1.000000000	0.999916767	8996.1	0	0.00006	15452150	xxx	0.3084	0.308	3705	0.7291
Liquid	Item: H27-200	0.999943310	1.000000000	0.999916767	8996.1	0	0.00006	15452150	xxx	0.3084	0.308	3705	0.7291
Coolant	Item: H27-210	0.998861684*	1.000000000	0.999333463	447.8	0	0.00114*	7691200*	0.00	2.0000	1.629	2444	5.8389
Duplex Fuel/Lube Oil	Item: H27-220	0.995679886*	1.000000000	0.999861421	117.8	0	0.00433*	2023341*	0.00	1.0000	0.861	6216	1.2140
Fuel Oil	Item: H27-230	0.998766615*	1.000000000	0.999924447	413.2	0	0.00123Z*	7098023*	0.00	2.0000	1.709	22625	0.6618
Lube Oil	Item: H27-240	0.999529759*	1.000000000	0.999881981	1084.3	0	0.00047*	18624376*	0.00	2.0000	1.738	14726	1.0339
Water	Item: H27-250	0.999926442	1.000000000	0.999960363	6933.0	0	0.00007	11908456	xxx	0.1288	0.129	3249	0.3472
≤4 inch	Item: H27-251	0.999920044*	1.000000000	0.999999893	6378.3	0	0.00008*	109556141*	0.00	0.0000	0.000	3116	0.0009
>4 inch	Item: H27-252	0.999081068*	1.000000000	0.999505864	554.7	0	0.00092*	9528423*	0.00	3.0000	3.168	6411	4.3286
Switch	Item: E34-000	0.993744427	0.999996988	0.999960651	9720.8	61	0.00628	1395966.	4.20	1.5333	1.612	40959	0.3447
Automatic Transfer	Item: E34-100	0.950118163	0.999976051	0.999857315	1074.9	55	0.05117	171197.6	4.10	7.3553	6.490	45487	1.2499
>600 Amp, ≤600V	Item: E34-110	0.968631015	0.999994046	0.999809981	690.3	22	0.03187	274853.5	1.64	34.0000	20.891	109941	1.6646

* - Time Truncated, Chi Squared, 60% Single Side Confidence Interval

xxx - Data Not Available at Time of Analysis

Category/Class	Item Number	Reliability	Inherent Availability	Operational Availability	Unit Years	Failures	Failure Rate (Failures/Year)	MTBF	MTTR	MTTM	MDT	MTBM	Hrdt/ Year
0-600 Amp., ≤600V	Item: E34-120	0.917774618	0.999943753	0.999942269	384.6	33	0.08580	102093.8	5.74	0.0000	1.280	22165	0.5057
Disconnect	Item: E34-200	0.999846881	0.999999966	0.999961037	3330.5	1	0.00015	57205889	xxx	1.5473	1.547	39694	0.3413
Enclosed	Item: E34-210	0.999398941	0.999999931	0.999928002	1663.2	1	0.00060	14569899	1.00	1.9055	1.904	26442	0.6307
≤600V	Item: E34-211	0.999394569*	1.000000000	0.999938186	842.1	0	0.00061*	14464658*	0.00	2.0000	1.991	32214	0.5415
>600V ≤5kV	Item: E34-212	0.997942528	1.000000000	0.999867230	247.6	0	0.00206	4253270	0.00	2.0000	2.400	18076	1.1631
>5kV	Item: E34-213	0.998257804	0.999999801	0.999939288	573.5	1	0.00174*	5023755*	1.00	2.0000	1.510	24870	0.5318
Fused, DC	Item: E34-220	0.999694154	1.000000000	0.999993992	1667.25	0	0.00031	28637459	xxx	0.4769	0.477	79376	0.0526
>600 amp, ≤600V	Item: E34-222	0.999408178*	1.000000000	1.000000000	861.5	0	0.00059*	14797364*	0.00	0.0000	0.000	314444	0.0000
0-600 amp, ≤600V	Item: E34-221	0.999367257*	1.000000000	0.999987568	805.8	0	0.00063*	13840094*	0.00	1.0000	0.548	44115	0.1089
Electric, On/Off Breaker Type, Non-knife	Item: E34-300	0.999358198	0.999999927	0.999999780	3115.2	2	0.00064	13644684	1.00	0.0093	0.014	63170	0.0019
≤600V	Item: E34-310	0.999358198	0.999999927	0.999999780	3115.2	2	0.00064	13644684	1.00	0.0000	0.014	63170	0.0019
Float, Electric	Item: E34-400	0.997716932	0.999999478	0.999985388	437.5	1	0.00229	3832560	2.00	0.1869	0.193	13216	0.1280
Manual Transfer	Item: E34-500	0.999129111	1.000000000	0.999966262	585.4	0	0.00087	10054305	xxx	1.4786	1.479	43826	0.2955
≤600 Amp, ≤600V	Item: E34-510	0.997919138*	1.000000000	0.999952908	244.8	0	0.00208*	4205411*	0.00	1.0000	1.098	23313	0.4125
>600 Amp, ≤600V	Item: E34-520	0.998503402*	1.000000000	0.999975863	340.5	0	0.00150*	5848894*	0.00	3.0000	2.880	119317	0.2114
Oil Filled	Item: E34-600	0.998241979	1.000000000	0.999996849	289.8	0	0.00176	4978494.	xxx	8.0000	8.000	2539032	0.0276
≥5kV	Item: E34-610	0.998241979*	1.000000000	0.999996849	289.8	0	0.00176*	4978494*	0.00	8.0000	8.000	2539032	0.0276
Static	Item: E34-800	0.997748999	0.999996656	0.999919287	887.5	2	0.00225	3887220	13.00	2.0390	2.113	26177	0.7070
>1000 Amp,≤600V	Item: E34-830	0.996326697	0.999989918	0.999739539	271.7	1	0.00368	2380392	24.00	3.0000	3.584	13759	2.2816
>600≤1000Amp,≤600V	Item: E34-820	0.992336720	0.999998244	0.999994731	130.0	1	0.00769	1138728	2.00	0.0000	0.078	14789	0.0462
0-600 Amp,≤600V	Item:E34-810	0.998950665*	1.000000000	0.999999648	485.8	0	0.00105*	8343764*	0.00	0.0000	0.032	90539	0.0031
Switchgear	Item: E36-000	0.991916417	0.999974462	0.999585725	4558.7	37	0.00812	1079291.	27.56	3.4490	3.646	8800	3.6291
Bare Bus	Item: E36-100	0.989863408	0.999968286	0.999579123	3239.0	33	0.01019	859808.3	27.27	3.7329	3.993	9486	3.6869
≤600V, Bkrs. Not Incl.	Item: E36-110	0.990554799	0.999992098	0.999455269	1791.3	17	0.00949	923068.2	7.29	4.0000	4.308	7909	4.7718
>5kV Bkrs. Not Incl.	Item: E36-130	0.982216877	0.999995342	0.999839597	780.2	14	0.01794	488208.8	2.27	1.0000	1.296	8079	1.4051
>600V≤5kV Breakers Not Incl.	Item: E36-120	0.997007868	0.999872746	0.999607036	667.4	2	0.00300	2923296	372.00	10.0000	14.270	36314	3.4424
Insulated Bus	Item: E36-200	0.999613608	0.999989619	0.999601929	1319.6	4	0.00039	22666917	xxx	2.9046	2.975	7473	3.4871
≤600V Bkrs Not Incl.	Item: E36-210	0.998420947*	1.000000000	0.999468794	322.7	0	0.00158*	5543247*	0.00	3.0000	3.182	5990	4.6534
>5kV Bkrs. Not Incl.	Item: E36-230	0.995913049	0.999982547	0.999626621	732.5	3	0.00410	2139024	37.33	14.0000	14.434	38657	3.2708

* - Time Truncated, Chi Squared, 60% Single Side Confidence Interval

xxx - Data Not Available at Time of Analysis

B-10

Category/Class	Item Number	Reliability	Inherent Availability	Operational Availability	Unit Years	Failures	Failure Rate (Failures/Year)	MTBF	MTTR	MTTM	MDT	MTBM	Hrdt/ Year
>600V≤5kV, Bkrs. Not Incl.	Item: E36-220	0.996224761	0.999996546	0.999696028	264.4	1	0.00378	2316000	8.00	1.0000	0.774	2548	2.6628
Tank	Item: E37-000	0.995965564	0.999991636	0.999971186	1978.9	8	0.00404	2166924	18.13	0.1221	0.172	5955	0.2524
Air	Item: E37-100	0.997280535	0.999997824	0.999996891	734.4	2	0.00272	3216840	7.00	0.0029	0.010	3078	0.0272
Receiver	Item: E37-110	0.997280535	0.999997824	0.999996891	734.4	2	0.00272	3216840	7.00	0.0000	0.010	3078	0.0272
Liquid	Item: E37-200	0.995190343	0.999987984	0.999956016	1244.5	6	0.00482	1816952	21.83	0.4276	0.584	13279	0.3853
Day	Item: E37-210	0.994810377	0.999997030	0.999974756	384.4	2	0.00520	1683600	5.00	0.0000	0.346	13688	0.2211
Fuel	Item: E37-220	0.993549151	0.999955673	0.999872929	309.0	2	0.00647	1353576	60.00	1.0000	1.911	15040	1.1131
Water	Item: E37-230	0.996377265	0.999999793	0.999989539	551.1	2	0.00363	2413680	0.50	0.0000	0.128	12221	0.0916
Thermostat	Item: C15-000	0.998319168	0.999999398	0.999997565	6538.9	11	0.00168	5207323.	3.14	0.7895	0.969	397782	0.0213
Radiator	Item: C15-100	0.998319168	0.999999398	0.999997565	6538.9	11	0.00168	5207323.	3.14	1.0000	0.969	397782	0.0213
Transducer	Item: C16-000	0.999978470	0.999999933	0.999998552	23687.4	42	0.00002	40686583	xxx	0.0183	0.019	13235	0.0127
Flow	Item: C16-100	0.996713345*	1.000000000	0.999986736	154.9	0	0.00329*	2660941*	0.00	0.0000	0.360	27142	0.1162
Pressure	Item: C16-200	0.997477750	0.999999423	0.999987243	791.9	2	0.00253	3468708	2.00	1.0000	0.720	56402	0.1118
Temperature	Item: C16-300	0.998242572	0.999999950	0.999999026	22740.5	40	0.00176	4980177	0.25	0.0000	0.013	12848	0.0085
Transformer, Dry	Item: E38-100	0.999953743	0.999995817	0.999971899	11025.1	19	0.00005	18937280	xxx	3.2263	3.693	131402	0.2462
Air Cooled	Item: E38-110	0.999882198	1.000000000	0.999944571	4329.0	0	0.00012	74357512	xxx	4.2724	4.272	77078	0.4856
≤500kVA	Item: E38-111	0.999775100*	1.000000000	0.999995570	2267.4	0	0.00022*	38946258*	0.00	4.0000	3.826	863591	0.0388
>1500kVA ≤ 3000kVA	Item: E38-113	0.999393210*	1.000000000	0.999745124	840.2	0	0.00061*	14432242*	0.00	4.0000	4.206	16503	2.2327
>500kVA ≤ 1500kVA	Item: E38-112	0.999582527*	1.000000000	0.999987102	1221.4	0	0.00042*	20979011*	0.00	6.0000	6.000	465187	0.1130
Dry, Isolation	Item: E38-120	0.997166548	0.999993113	0.999989567	6696.1	19	0.00284	3087252.	21.26	0.9286	2.519	241390	0.0914
Delta Wye, <600V	Item: E38-121	0.997166548	0.999993113	0.999989567	6696.1	19	0.00284	3087252.	21.26	1.0000	2.519	241390	0.0914
Transformer, Liquid	Item: E38-200	0.994797669	0.999950735	0.998990580	8819.2	46	0.00522	1679476.	82.74	16.9047	17.588	17424	8.8425
Forced Air	Item: E38-210	0.989259891	0.999836759	0.996601877	2593.0	28	0.01080	811246.2	132.43	21.1758	22.066	6494	29.767
≤10,000 kVA	Item: E38-212	0.992879584	0.999797696	0.990915913	419.8	3	0.00715	1225880	248.00	23.0000	23.677	2606	79.576
≤5,000kVA	Item: E38-211	0.987452327	0.999994736	0.999987215	1821.5	23	0.01263	693748.2	3.65	1.0000	0.976	76345	0.1120
>10,000kVA ≤50,000kVA	Item: E38-213	0.994329760	0.999065253	0.985856760	351.7	2	0.00569	1540524	1440.0	22.0000	23.203	1641	123.89
Non-Forced Air	Item: E38-220	0.997113141	0.999998203	0.999985412	6226.1	18	0.00289	3030057.	5.44	0.7600	0.850	58270	0.1278
≤3000kVA	Item: E38-221	0.998891114	0.999999367	0.999996102	5407.8	6	0.00111	7895436	5.00	10.0000	8.394	2153301	0.0341

* - Time Truncated, Chi Squared, 60% Single Side Confidence Interval

xxx - Data Not Available at Time of Analysis

Category/Class	Item Number	Reliability	Inherent Availability	Operational Availability	Unit Years	Failures	Failure Rate (Failures/Year)	MTBF	MTTR	MTTM	MDT	MTBM	Hrdt/ Year
>3000kVA ≤10000kVA	Item: E38-222	0.994771048	0.999999402	0.999985038	190.7	1	0.00524	1670904	1.00	3.0000	2.500	167090	0.1311
>10000kVA≤50000kVA	Item:E38-223	0.982624792	0.999987813	0.999893406	627.6	11	0.01753	499773.8	6.09	1.0000	0.648	6081	0.9338
UPS: Uninterruptible Power Supply	Item: E39-000	0.999078297	0.999998349	0.999951289	553.1	4	0.00092	9499764.	xxx	3.8000	3.688	75701	0.4267
Rotary	Item: E39-100	0.995983397*	1.000000000	0.999895500	126.7	0	0.00402*	2176564*	0.00	6.0000	6.105	58424	0.9154
Small Computer Room Floor	Item: E39-200	0.990661925	0.999997858	0.999967870	426.4	4	0.00938	933708	2.00	3.0000	2.667	82996	0.2815
Valve	Item: H28-000	0.999995192	0.999999568	0.999977752	106073.6	183	0.00000	18219692	xxx	0.7962	0.806	36233	0.1949
3-way	Item: H28-100	0.999727982	1.000000000	0.999987577	1874.6	0	0.00027	32199388	xxx	0.5165	0.516	41574	0.1088
Diverting/Sequencing	Item: H28-110	0.999257278*	1.000000000	0.999999501	686.4	0	0.00074*	11790070*	0.00	0.0000	0.015	30368	0.0044
Mixing Control	Item: H28-120	0.999570876*	1.000000000	0.999980689	1188.2	0	0.00043*	20409317*	0.00	1.0000	1.020	52836	0.1692
Ball	Item: H28-300	0.999807822	0.999999957	0.999999204	2653.5	2	0.00019	45578400	xxx	0.1577	0.164	205708	0.0070
Normally Closed	Item: H28-310	0.999516658*	1.000000000	0.999998106	1054.9	0	0.00048*	18119435*	0.00	0.0000	0.192	101548	0.0166
Normally Open	Item: H28-320	0.998749718	0.999999929	0.999999929	1598.6	2	0.00125	7002036	0.50	0.0000	0.045	636549	0.0006
Butterfly	Item: H28-400	0.998692271	0.999999513	0.999995506	17576.2	23	0.00131	6694253.	3.26	0.5539	0.609	135416	0.0394
Normally Closed	Item: H28-410	0.991788585	0.999996931	0.999990199	2789.5	23	0.00825	1062421.	3.26	1.0000	1.288	131375	0.0859
Normally Open	Item: H28-420	0.999965510*	1.000000000	0.999996507	14786.8	0	0.00003*	253984565*	0.00	0.0000	0.476	136206	0.0306
Check	Item: H28-500	0.999742108	0.999999971	0.999980199	3877.1	1	0.00026	33963360	1.00	1.0000	0.914	46146	0.1735
Control	Item: H28-600	0.999937125	0.999999943	0.999996490	15904.0	1	0.00006	13931940	8.00	0.1091	0.111	31599	0.0307
Normally Closed	Item: H28-610	0.999922211	0.999999929	0.999997478	12854.8	1	0.00008	112607808	8.00	0.0000	0.080	31864	0.0221
Normally Open	Item: H28-620	0.999832761*	1.000000000	0.999992325	3049.3	0	0.00017*	52375670*	0.00	0.0000	0.234	30528	0.0672
Expansion	Item: H28-700	0.999742991*	1.000000000	1.000000000	1984.1	0	0.00026*	34080094*	0.00	0.0000	xxx	xxx	0.0000
Gate	Item: H28-800	0.999827547	0.999999888	0.999999642	17394.5	3	0.00017	50792032	5.67	0.8333	1.135	3174502	0.0031
Normally Closed	Item: H28-810	0.999421886	0.999999934	0.999998647	1729.3	1	0.00058	15148344	1.00	1.0000	0.603	445540	0.0119
Normally Open	Item: H28-820	0.999872337	0.999999883	0.999999752	15665.3	2	0.00013	68613876	8.00	2.0000	2.429	9801982	0.0022
Globe	Item: H28-900	0.999980570	1.000000000	0.999921533	26248.0	0	0.00002	45084720	xxx	0.9954	0.995	12685	0.6874
Normally Closed	Item: H28-910	0.999975654*	1.000000000	0.999901776	20947.4	0	0.00002*	359802729*	0.00	1.0000	0.997	10149	0.8604
Normally Open	Item: H28-920	0.999903788*	1.000000000	0.999999612	5300.5	0	0.00010*	91044470*	0.00	0.0000	0.400	1031837	0.0034
Plug	Item: H28-A00	0.990331504	0.999997992	0.999997984	15233.3	148	0.00972	901648.3	1.81	0.0476	1.592	789609	0.0177
Normally Closed	Item: H28-A10	0.986191497	0.999997832	0.999997819	8845.9	123	0.01390	630001.6	1.37	0.0000	1.174	538126	0.0191
Normally Open	Item: H28-A20	0.996093704	0.999998213	0.999998213	6387.4	25	0.00391	2238150.	4.00	0.0000	4.000	2238151	0.0157

* - Time Truncated, Chi Squared, 60% Single Side Confidence Interval
xxx - Data Not Available at Time of Analysis

Category/Class	Item Number	Reliability	Inherent Availability	Operational Availability	Unit Years	Failures	Failure Rate (Failures/Year)	MTBF	MTTR	MTTM	MDT	MTBM	Hrdt/ Year
Reducing	Item: H28-B00	0.998490771	1.000000000	0.999972616	337.7	0	0.00151	5799905.	xxx	0.4939	0.494	18036	0.2399
Makeup Water	Item: H28-B10	0.998490771*	1.000000000	0.999972616	337.7	0	0.00151*	5799905*	0.00	0.0000	0.494	18036	0.2399
Relief	Item: H28-C00	0.998671145	0.999999696	0.999994763	752.0	1	0.00133	6587760	2.00	0.0000	0.190	36196	0.0459
Suction	Item: H28-D00	0.998214603	0.999998521	0.999994094	2238.4	4	0.00179	4902090	7.25	1.0000	0.698	118123	0.0517
Valve Operator	Item: C17-000	0.992808232	0.999991177	0.999971677	9975.4	72	0.00722	1213674	10.71	1.0564	1.469	51860	0.2481
Electric	Item: C17-100	0.990159307	0.999979209	0.999934083	3640.2	36	0.00989	885794	18.42	1.0000	1.400	21245	0.5774
Hydraulic	Item: C17-200	0.915817948	0.999969884	0.999601804	68.2	6	0.08794	99616	3.00	2.0000	2.204	5534	3.4882
Pneumatic	Item: C17-300	0.995224402	0.999998361	0.999997541	6266.9	30	0.00479	1829941.	3.00	1.0000	1.776	722345	0.0215
Voltage Regulator	Item: E40-000	0.964377637	0.999690405	0.999644857	358.4	13	0.03627	241506.4	74.77	0.3333	2.523	7103	3.1110
Static	Item: E40-100	0.964377637	0.999690405	0.999644857	358.4	13	0.03627	241506.5	74.77	0.0000	2.523	7103	3.1110
Water Cooling Coil	Item: H29-000	0.999577258	0.999999879	0.999993176	4730.0	2	0.00042	20717496	2.50	0.2558	0.260	38084	0.0598
Fan Coil Unit	Item: H29-100	0.999577258	0.999999879	0.999993176	4730.0	2	0.00042	20717496	2.50	0.0000	0.260	38084	0.0598

* - Time Truncated, Chi Squared, 60% Single Side Confidence Interval
xxx - Data Not Available at Time of Analysis

GLOSSARY

-A-

AVAILABILITY, INHERENT (A_i). The instantaneous probability that a component will be up. Ai considers only downtime for repair due to failures. No logistics delay time, preventative maintenance, etc. is included.

AVAILABILITY, OPERATIONAL (A_0). Ao is the instantaneous probability that a component will be up but differs from inherent availability in that it includes ALL downtime. Included is downtime for both corrective maintenance and preventative maintenance, including any logistics delay time

-C-

CORRECTIVE MAINTENANCE (CM): All actions performed as a result of failure, to restore an item to a specified condition. Corrective maintenance can include any or all of the following steps: Localization, Isolation, Disassembly, Interchange, Reassembly, Alignment and Checkout.

-D-

DOWNTIME: That element of time during which an item is in an operational inventory but is not in condition to perform its required function.

-F-

FAILURE (f). The termination of the ability of a component or system to perform a required function.

FAILURE RATE (λ): The mean (arithmetic average, also known as the forced outage rate) number of failures of a component and/or system per unit exposure time. The most common unit in reliability analyses is hours (h).However, some industries use failures per year (f/y) which is denoted by the symbol (λy).

-H-

HOURS DOWN TIME PER YEAR (Hrdt/Year). Average hours the item is expected to be not functional in a one year period, caused by both preventative maintenance and failures. This includes any logistics delay time.

-L-

LOGISTIC DELAY TIME: That element of downtime during which no maintenance is being accomplished on the item because of either supply or administrative delay.

-M-

MAINTENANCE: All actions necessary for retaining an item in or restoring it to a specified condition.

MAINTENANCE DOWN TIME (Mdt). The total downtime for preventative maintenance (including logistics delay time, which includes spare parts availability, crew availability, etc) for a given period, Tp. (hours).

MEAN DOWN TIME (MDT). The average downtime caused by preventative and corrective maintenance, including any logistics delay time. This is synonymous with mean time to restore system (MTTRS) as found in some publications

MEAN TIME BETWEEN FAILURES (MTBF). The mean exposure time between consecutive failures of a component. MTBF is a require measurement used for calculating inherent availability. It can be estimated by dividing the exposure time by the number of failures in that period.

MEAN TIME BETWEEN MAINTENANCE (MTBM). The average time between all maintenance events that cause downtime, both preventative and corrective maintenance, and also includes any associated logistics delay time.

MEAN TIME TO MAINTAIN (MTTM). The average downtime for preventative maintenance. This includes any logistics delay time.

MEAN TIME TO REPAIR (MTTR). The mean time to replace or repair a failed component. Logistics delay time associated with the repair, such as parts acquisitions, crew mobilization, are not included. It can be estimated by dividing the summation of repair times by the number of repairs and, therefore, is practically the average repair time. The most common unit in reliability analyses is hours

-P-

PREVENTATIVE MAINTENANCE (PM): All actions performed in an attempt to retain an item in a specified condition. These actions may or may not result in downtime for the component, and may or may not be performed on a fixed interval

-R-

RELIABILITY (R(t)). The probability that a component can perform its intended function for a specified time interval (t) under stated conditions. This calculation is based on the exponential distribution.

REPAIR DOWNTIME (Rdt). The total downtime for corrective maintenance (excluding logistics delay time) for a given Tp. (hours).

REPAIR LOGISTICS TIME (Rlt). The total logistics delay time for corrective maintenance for a given Tp. (hours).

-T-

TOTAL DOWNTIME EVENTS (Tde): The total number of downtime events (including scheduled maintenance and failures) during the Tp.

TOTAL FAILURES (Tf). The total number of failures during the Tp.

TOTAL PERIOD (Tp). The calendar time over which data for the item was collected.

TOTAL MAINTENANCE ACTIONS (Tma). The total number of preventative maintenance actions which take the component down during the Tp.

-Y-

YEAR (y): The unit of time measurement approximately equal to 8765.81277 hours (h). Any rounding of this value will have adverse effects on analyses depending on the magnitude of that rounding. 8766 is used commonly as it is the result of rounding to 365.25×24 (which accounts for a leap year every 4th year). 8760, which is 365×24, is the most commonly used value in the power reliability field. By convention, 8760 will be used throughout this document

The proponent agency of this publication is the Chief of Engineers, United States Army. Users are invited to send comments and suggested improvements on DA Form 2028 (Recommended Changes to Publications and Blank Forms) directly to HQUSACE, (ATTN: CEMP-OS-P), Washington, DC 20314-1000.

By Order of the Secretary of the Army:

PETER J. SCHOOMAKER
General, United States Army
Chief of Staff

Official:

JOYCE E. MORROW
Administrative Assistant to the
Secretary of the Army

Distribution:

To be distributed in accordance with Initial Distribution Number (IDN) 344817, requirements for non-equipment TM 5-698-5.