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An Aging Failure Survey of Light Water Reactor Safety Systems and Components

Babette M. Meale
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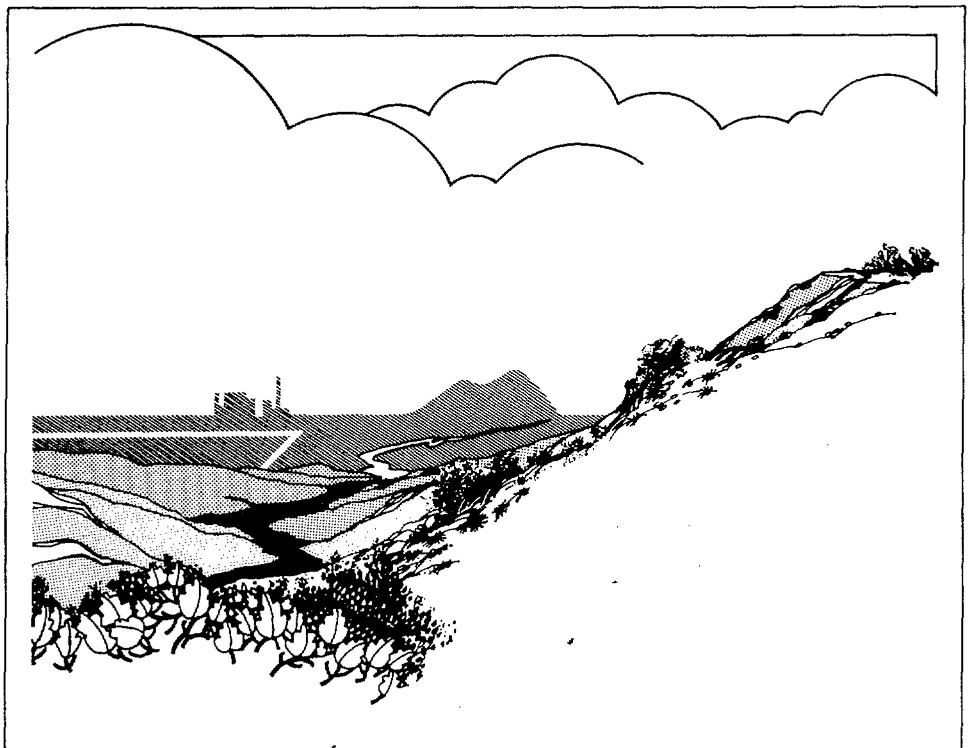

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AN AGING FAILURE SURVEY OF LIGHT WATER REACTOR SAFETY SYSTEMS AND COMPONENTS

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ABSTRACT

This report describes the methods, analyses, results, and conclusions of two different aging studies. The first analysis consists of a survey of light water reactor component failures associated with selected safety and support systems. Tables are presented, indicating the systems and the components within those systems most affected by aging. Also provided are engineering insights drawn from the data. The second analysis consists of identifying and categorizing the reported failure causes of component failures. The systems used in the failure-cause analysis were service water systems and Class 1E electrical power distribution systems for Babcock & Wilcox Company pressurized water reactors and service water systems for boiling water reactors.

FIN No. A6389—Aging Systems Interaction Study:
Component Residual Lifetime Evaluation and
Feasibility Relicensing

EXECUTIVE SUMMARY

This report presents the methods, analyses, results, and conclusions of an aging survey of light water reactor safety system component failures and a detailed aging-related failure-cause analysis of component failure reports. Both studies were performed for the U.S. Nuclear Regulatory Commission (NRC) as a part of the Nuclear Plant Aging Research Program. This report is the first volume of a two-volume set addressing the impact of component aging on selected nuclear power plant safety and support systems. A third document will address the risk importance of time-dependent aging-related failures using the failure cause data reported in Volumes 1 and 2.

The purpose of the analyses presented here is to identify which safety and support systems and their associated components have been affected by aging and, for selected systems, to identify aging-related failures at the reportable cause or mechanism level. The following definition of aging is used in the analyses presented in this report:

> "Aging" is the degradation of a component resulting in the loss of function or reduced performance caused by some time-dependent agent or mechanism. The agent or mechanism can be cyclic, e.g., caused by repeated demand, or continuously acting, e.g., caused by the operational environment. The change in the component failure probability resulting from the degradation will be monotonically increasing with the time of exposure to the agent or mechanism unless the component is refurbished, repaired, or replaced.

The nuclear power plant operational data selected for aging-related failure analysis were from the Nuclear Plant Reliability Data System (NPRDS), a data base of the Institute of Nuclear Power Operations. The NPRDS is considered the best currently accessible data base on which to perform the present work scope of the aging-related data collection and analysis. However, the data source does have significant limitations (detailed in Section 3.2) that should be considered when interpreting or applying the results. The plant-specific NPRDS data are proprietary. Therefore, the data presented in this report have been made generic to enable wider distribution of the results and to ensure that those results cannot be traced to specific plants or manufacturers.

The analyses documented in this report examine the NPRDS data using two unique procedures. An aging survey analysis was performed on the failure reports for nine complete systems, including both pressurized water and boiling water reactors. The purpose of this survey was to identify which systems and which associated components were being most affected by aging phenomena. It is a rather gross analysis but does provide relative magnitudes of aging effects between systems and components. The results of the aging survey will help define future in-depth engineering studies of selected systems and components. The second analysis consisted of a failure-cause determination to identify the aging mechanisms, to the level of resolution available in the failure reports, that caused component failures in two safety and support systems. To determine true root causes of failures for the failed components is beyond the scope of this study. That would require a detailed in-depth engineering evaluation to be performed on the components. Guidelines developed by the Root Causes of Component Failures Program[a] were used in identifying the failure mechanisms. An aging classification procedure was developed to aid the analyst in distinguishing aging-related from non-aging (random) failures. The results of the failure cause study will be used in systems-level aging evaluations using probabilistic risk assessment (PRA) techniques.

Aging Survey Analysis

In the aging survey, failure information for aging-related and non-aging failures was obtained for nine different light water reactor safety and support systems. The information was used to create a computerized data base which was analyzed to identify time-dependent failure contributions of system/component combinations. The failures were grouped into five broad failure categories. Mechanisms of failure were not determined during this analysis; however, several analyses were performed using the failure-category data. Selected groupings of the data were examined to identify systems and components that are susceptible to aging failures. Also, a rudimentary uncertainty

a. D. G. Satterwhite, L. C. Cadwallader, W. E. Vesely, B. M. Meale, *Root Causes of Component Failures Program: Methods and Applications*, NUREG/CR-4616, EGG-2455, December 1986.

analysis was performed to provide an indication of the confidence to be placed in the data analysis results.

The analyses of the data provided several insights into the effect of aging failures. For the systems studied, the failure categories of "aging" and "other" contained the majority of the failures. The contribution to failures in the "human-related" category was very minimal. Approximately 31% of the failures reported were attributed to aging, and 50% of the failures reported were categorized as "other." The "other" category consists of failures for which the cause was not determined or could not be assigned to another category. The size of the "other" category is indicative of both the difficulty in determining the cause of failure for certain components and the practice of replacing a component or piece part without establishing the reason for failure; therefore, a reasonable but unknown fraction of the failures in the "other" category is also probably due to aging mechanisms. While it is recognized that the aging category could also contain an unknown number of misclassified failures, comparison to the failure-cause study indicates that this misclassification is probably minimized.

Results of the aging survey indicate that, in general, a system's operational mode is a factor influencing aging-related component failures. The normally operating fluid systems, such as the service water systems, main feedwater systems, and component cooling water systems, exhibited the highest aging failure fractions, with pumps and valves being the components most affected. However, there are significant exceptions to this observation concerning a system's operational mode. Components in some standby systems also display high aging fractions, e.g., pumps in the standby liquid control systems and valves and pumps in the diesel subsystems of the Class 1E electrical power distribution systems. A limited analysis of these systems indicates that the standby components are adversely affected by their operational environment.

Aggregation and evaluation of the data at the system level to determine system effects indicated that only a small fraction of the failures caused "loss of system function." There was no dominant system effect category.

Examination of the component aging-fraction data indicates that the system/component combinations impacted by aging phenomena are identifiable. The system/component combinations most affected by aging are (a) valves and pumps in normally operating systems, (b) Class 1E diesel subsystem components, (c) heat exchangers in the main feedwater system, and (d) standby liquid control system pumps.

Reported Failure Cause Analysis

The failure-cause analysis of component failures used a cause categorization scheme to identify and characterize the reported cause-of-failure information for aging-related and non-aging failures for selected light water reactor systems. The systems chosen for this analysis were service water systems and Class 1E electrical power distribution systems. The cause identification information provides insights into the effects of aging versus non-aging failures on system performance. Other light water reactor safety and support systems will be studied in the future.

Eight-hundred-and-fifty component failures were evaluated. Results of the analysis indicate that two components in the service water system and one component in the Class 1E electrical power distribution system dominated the failure contributions. Motor-operated valves and motor-driven pumps contributed the largest number of failures within the service water system. These components exhibited relatively high aging-related failure fractions (fraction of total component failures attributable to aging). Aging-related failure fractions calculated in percentages for motor-operated valves were a lower-bound of 39% and an upper-bound of 84%. Fractions for motor-driven pumps are 77% and 84%, respectively. The dominant aging failure cause for these two components was "wear." Within the service water system, check valves (87% to 90%) and strainers (81% to 86%) exhibited the highest aging fractions with "wear" and "corrosion" being the dominant mechanism reported. The diesel generators dominated the Class 1E electrical power distribution system failures with a lower-bound aging-related percentage of 49% and an upper-bound of 66%. Components within the Class 1E electrical power distribution systems exhibiting the highest aging fraction were battery chargers (51% to 97%). The dominant aging cause for the Class 1E electrical power distribution systems was "wear."

FOREWORD

This report is the first volume of a two-volume set addressing the impact of component aging on selected nuclear power plant safety and support systems. A future document using the results presented in Volumes 1 and 2 will address the risk importance of time-dependent, aging-related failures using reported failure-cause data. The work was performed for the U.S. Nuclear Regulatory Commission as part of the Nuclear Plant Aging Research Program. Data selected for these analyses were from the Nuclear Plant Reliability Data System, a data base of the Institute of Nuclear Power Operations.

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CONTENTS

FIGURES

TABLES

ACRONYMS

AFW	auxiliary feedwater system
B&W	Babcock & Wilcox
CCW	component cooling water system
GE	General Electric Company
HPIS	high-pressure injection system
INEL	Idaho National Engineering Laboratory
INPO	Institute of Nuclear Power Operations
LER	licensee event report
LWR	light water reactor
MFW	main feedwater system
NPAR	Nuclear Plant Aging Research
NPRDS	Nuclear Plant Reliability Data System
NRC	U.S. Nuclear Regulatory Commission
NSSS	nuclear steam system supplier
PRA	probabilistic risk assessment
RHR	residual heat removal system
RPS	reactor protection trip system
SBL	standby liquid control system
SWS	service water system
1E	Class 1E electrical power distribution system

AN AGING FAILURE SURVEY OF LIGHT WATER REACTOR SAFETY SYSTEMS AND COMPONENTS

1. INTRODUCTION

Problems caused by time- or cyclic-dependent degradation (aging) mechanisms, such as wear, corrosion, and fatigue, have occurred at some U.S. nuclear power plant reactors. These problems have raised questions about the age-dependent degradation of safety equipment at the plants. Many of these issues have been, and are being, addressed by the nuclear industry through research, improved designs, standards development, and, especially, improved operational and maintenance practices. Nevertheless, aging and degradation of plant safety systems and components will continue, and currently unrecognized degradation effects are likely as the U.S. light water reactor (LWR) population ages. Collection and evaluation of operating experience data are necessary to study the effects of aging and degradation on the safety of operating nuclear power plants during their normal design life and any extended life.

Therefore, an important part of the U.S. Nuclear Regulatory Commission (NRC) research effort is the Nuclear Plant Aging Research (NPAR) Program[1] which is being conducted at several national laboratories, including the Idaho National Engineering Laboratory (INEL). One of the NPAR Program tasks at INEL is to evaluate the extent to which aging has affected the performance of light water reactor safety and support systems. This study uses data from Licensee Event Reports (LER) and the Nuclear Plant Reliability Data System (NPRDS) of the Institute of Nuclear Power Operations (INPO). Specific objectives include: (a) identifying which light water reactor safety or support systems and components have been significantly affected by aging, (b) identifying specific aging failure causes for a few selected systems and components, (c) calculating aging contributions to system and component unavailabilities, and (d) developing quantitative relationships between aging failure data and risk.

This report is the first volume of a two-volume set addressing the impact of component aging on selected nuclear power plant safety and support systems. A future document using the results presented in Volumes 1 and 2 will address the risk importance of time-dependent, aging-related failures using reported failure-cause data. The specific objectives of the analyses reported herein center around the first and second program objectives.

The analyses documented in this report address these two objectives using two unique procedures to analyze NPRDS data. The first, an aging survey analysis, was performed on the failure reports for nine light water reactor safety, support, and power conversion systems, including both pressurized water and boiling water reactors. The purpose of this survey was to identify which systems and associated components were being most affected by aging phenomena. It is a rather gross analysis but provides relative magnitudes of aging effects between systems and components. The second analysis consisted of a failure cause determination to identify the aging mechanisms that caused component failures associated with the service water and Class 1E power distribution systems. The depth of this analysis was limited to the level of resolution available in the failure reports. To determine true root causes of failures for the failed components is beyond the scope of this study. Such a determination would require a detailed in-depth engineering evaluation to be performed on the components. Guidelines developed by the Root Causes of Component Failures Program[2] were used in identifying the failure mechanisms. An aging classification procedure was developed to aid the analyst in distinguishing aging-related from non-aging (random) failures.

The failure-cause information is useful in the evaluation of the influence of aging on plant risk using probabilistic risk assessment (PRA) techniques. In this application, the absolute magnitude of the aging effects is not essential. Relative impacts are useful for the modification of the PRA failure rate data.

In the aging survey, NPRDS failure data were compiled for pressurized water reactor and boiling water reactor systems and their major subsystems. The vendors represented in this survey were Westinghouse Electric Corporation (Westinghouse), Babcock & Wilcox Company (B&W), and General Electric Company (GE). It is recognized that several of these systems are designed by the architect/engineering firm and are not vendor specific. However, the NPRDS is structured to supply system information by reactor vendor only. A breakdown of systems surveyed is presented below:

- Class 1E electrical power distribution systems (1E)—Westinghouse, B&W, GE;
- Auxiliary feedwater systems (AFW)—Westinghouse, B&W;
- Component cooling water systems (CCW)—B&W, GE;
- High-pressure injection systems (HPIS)—Westinghouse, B&W;
- Main feedwater systems (MFW)—B&W, GE;
- Reactor protection trip systems (RPS)—Westinghouse, GE;
- Residual heat removal systems (RHR)—GE;
- Service water systems (SWS)—Westinghouse, B&W, GE;
- Standby liquid control systems (SBL)—GE.

The information contained in the survey data is specific to the nuclear steam system supplier, system, and component. The NPRDS component failure records were utilized to create a data base. This data base was used to classify the NPRDS cause-category/cause-code combinations and assign them to one of five major failure categories (see Section 2). There was no examination of the NPRDS failure records during this study. The in-service age of the component and the system effect associated with the individual failures also were evaluated.

The purpose of the failure-cause analysis described in this report was to identify aging-related failures at the reported failure cause level for (a) boiling water reactor service water systems, (b) B&W service water systems, and (c) B&W Class 1E electrical power distribution systems. Reported cause-of-failure information was obtained for the systems using the techniques developed in the NRC-sponsored Root Causes of Component Failures Program.[2] The cause identification provides insights into the effects of aging failures on system performance.

The service water systems and Class 1E electrical power distribution systems were selected for the initial aging-cause study for the following reasons:

- Probabilistic risk assessments indicate that support systems (those supplying power or cooling to the front-line preventive or mitigative systems) tend to dominate risk in many plants.
- Corresponding systems exist in all nuclear plants.
- Significant amounts of data have been gathered on failures in these systems.

Future aging-cause analyses will include investigating and evaluating the impact of aging on systems such as the high-pressure injection and auxiliary feedwater systems.

Other work related to the system studies described in this report has involved investigating aging of components within the systems. Major components included in those studies are motor-operated valves,[3] electric motors,[4] containment purge valves,[5] and diesel generators.[6] While those studies provide very specific information related to the given components, they do not address the systems in which the components reside. An additional aging study[7] provides insight into aging-related failures and system effects of failures in reactor protection systems. The information for this study was obtained both from the available failure event data (NPRDS, Nuclear Power Experience, Inc., and LERs) and utility records. Of the two, the utility records yielded significantly more detailed information relating to aging failures.

Section 2 of this report discusses the definitions of the terms used in the two analyses. Section 3 defines "aging" and describes the methodology. Section 4 presents the results of the aging survey and failure cause identification analysis. The conclusions are discussed in Section 5.

2. DEFINITIONS

Definitions of the parameters used in the analyses are presented in this section. The definition of aging as used in this report is presented in the next section.

- *Age*—The intent of the aging survey was to produce a time-dependent failure data base for various component failures. Therefore, for the current usage, the age of the component in years at the time of the failure was calculated from the in-service date recorded in the NPRDS component engineering record. The data were placed into the following four age divisions: 0 to 4.9, 5 to 9.9, 10 to 14.9, and 15 to 20 years. No attempt was made to identify how many times a given component failed. The time-dependent data would reflect replacement but not repair.

- *Cause Categories*—The cause categories refer to the nine failure categories used by NPRDS to classify a failure; e.g., design/engineering, incorrect procedure, and wearout. Appendix A (Table A-1) contains additional information concerning this categorization.

- *Cause Codes*—The cause codes refer to the codes used by NPRDS to identify the cause of, or factors contributing to, the failure; e.g., normal/abnormal wear, dirt, mechanical damage/binding, and loose parts.

- *Components*—The component designations in the NPRDS records are generic names, sometimes referring to more than one specific component. The failure category data are presented using these designations. Appendix A (Table A-2) defines the NPRDS component acronyms.

- *Engineering Parameters*—Engineering parameters indicate a variety of engineering information regarding the component. This information includes type, application, ratings, construction materials, and engineering values (such as temperature, revolutions per minute, and horsepower) with their corresponding units.

- *Failure*—A reduced functional efficiency or effectiveness of the component of interest or the loss of ability of the component to perform its intended function.

- *Failure Categories*—The failure categories are broad generic categories used to classify the specific failure information. These categories are defined as follows:

  1. *Aging (A)*—Failures that are the consequence of expected, time-dependent wear or degradation.

  2. *Design and Installation (D)*—Includes failures attributable to (a) inadequate design of the responsible component or system, (b) inadequate assembly or initial quality of the responsible component or system, and (c) improper installation of equipment.

  3. *Human Related (H)*—Includes failures attributable to incorrect procedures that were followed correctly and to failures caused or aggravated by personnel errors, including failure to follow procedures correctly.

  4. *Other/Unknown (O)*—Includes failures attributable to failure or misoperation of another component or system and to failures in which the cause cannot be assigned to any of the other categories.

  5. *Testing and Maintenance (T)*—Failures resulting from improper maintenance, lack of maintenance, or personnel error that occur during maintenance or testing activities performed on the responsible component or system.

- *Failure Mode*—The failure mode of a component is used in PRA analyses to refer to an action that a component fails to perform. For example, a valve that will not open when required is categorized in the "fails to open" failure mode.

- *Family Significance Level*—If no components have significant between-system differences, one can expect 5% of the components to show significance.

- *Reported Failure Cause*—An underlying or initiating event or condition that produces the failure of a component. This cause is identifiable only to the level of detail present in the event report.

- *Significance Level*—The probability that test-indicated differences in aging effects exist, when in fact there are no differences for the given component between systems.

- *System*—Systems are defined in the aging survey in the same manner as in the NPRDS. There is some concern that the utility definitions of systems differ somewhat from those used in the NPRDS. However, this is not considered significant, due to the relative nature of the data obtained in these analyses. Systems are defined in the failure-cause analysis in the manner developed for use in the Root Causes of Component Failure Program.[2]

- *System Effect*—The system effect code identifies the effect on the system caused by the component failure. The codes were taken directly from the NPRDS failure records. The NPRDS has five system effect categories. Appendix A (Table A-3) lists the system effect codes and their corresponding descriptions.

3. METHODOLOGY

This section describes the methodology used in the aging survey and the failure-cause analyses. "Aging" is defined and its identification through a classification procedure is discussed. The acceptability of the NPRDS for these types of analyses is also discussed.

3.1 Aging Definition and Classification

The definition of aging as used in the analysis presented in this report is:

> "Aging" is the degradation of a component resulting in the loss of function or reduced performance caused by a time-dependent agent or mechanism. The agent or mechanism can be cyclic, e.g., caused by repeated demand, or continuously acting, e.g. caused by the operational environment. The change in the component failure probability resulting from the degradation will be monotonically increasing with the time of exposure to the agent or mechanism unless the component is refurbished, repaired, or replaced.

Different types of aging agents or mechanisms affect a component's performance during its operational life. Environmental effects, such as normal wear of component parts, erosion, corrosion, cyclic fatigue, etc., tend to affect the component in a continuous fashion with rather low aging rates. Other types of aging stem from activities affecting the component through a random event. An example of the latter type is a random maintenance error which causes the component to experience significantly accelerated aging through a mechanism, such as binding, resulting in wear. Random maintenance errors will usually not be identified in a failure report. There are other cases where a mechanism identified as causing a failure could be considered aging or random, depending upon the circumstances under which the failure occurred. It is difficult to distinguish aging-related failures from random failures solely on the basis of a failure description or reported failure causes. Therefore, the practical application of this definition leads to a certain amount of uncertainty. Engineering evaluations of the failed components and knowledge of the component maintenance histories are sometimes necessary to accurately identify aging-related failures.

The analyses of component failures presented in this report attempt to identify aging-related failures through two different techniques. The aging survey analysis uses computer sorting techniques to classify the aging-related failures. This analysis relies on the failure category codes assigned by the utility personnel when reporting the failure. The failure-cause analysis attempts a more detailed and accurate determination of aging classification by physical examination of the failure report descriptions. The aging-related failures were identified on the basis of a classification procedure developed for the analysis. These techniques are described in Section 3.4.

3.2 Failure Event Data Source

Licensee event reports were considered as a data source but were rejected due to the nature of the data collection system. The LER system acts as a reporting agent to the NRC and is concerned with the failure effects on systems and safety functions. As such, LERs do not generally go into detail about specific component failure mechanisms, causes, or required repair actions. Additionally, the current LER guidelines do not require the reporting of certain single failures of safety-related equipment. Since most aging-related failures are single failures, this current reporting requirement further reduces the utility of the LER system for identifying aging-related failures.

Specific plant data are the most desirable because of the availability of maintenance histories associated with the failed components. An additional feature of plant-specific data is the ability to identify plant-environmental and human contributors to aging-related failures. These are essentially averaged out when analyses are performed using the generic data bases, such as the NPRDS and LER systems. However, individual plants have relatively small failure populations, and access to the plant data records is very limited. Gaining access to specific plant records and the resultant collection and analysis process was beyond the scope of the current analysis.

The component-failure data selected for analysis were obtained from the NPRDS. NPRDS is a component-failure data system owned by INPO and generated on a voluntary basis by the INPO member utilities. The data for each failure are sent to INPO for processing and input into the computerized data base. INPO distributes these data to other member organizations and to NRC upon request. The plant-specific NPRDS data are proprietary. Therefore, the data presented in this report have been made generic so events cannot be traced to specific plants or manufacturers.

The NPRDS data source has several strengths and limitations that reflect on the quality of the data and its applicability to certain uses and interpretations. Some strengths are:

- The NPRDS is a large, computerized nuclear power plant component failure data base containing multiple entries for all the safety-significant systems and components. Many utilities contribute to the data base.

- Many of the equipment failures reported to NPRDS are not reportable in LERs.

- Component engineering data are supplied with the failure records. These data supply items such as capacities or ratings and equipment types. The in-service data of the component are also provided in the engineering data.

- The component failure records provide a categorization of the failure by the utility personnel and a failure description. Event dates, discovery methods, plant conditions, and corrective actions are also provided.

- The data base contains sufficient information to allow a reasonable determination of the relative number of failures attributable to various mechanisms. Only 14% of the 850 NPRDS records examined for the failure-cause analysis were unclassifiable into one of the cause or effect codes.

Some of the limitations are:

- Not all utilities report to the NPRDS, but the number and quality of reporting has been increasing.

- Incipient failures are not reportable under NPRDS reporting requirements.

- Complete maintenance histories of failed components are not available, and the effects of test and maintenance activities on aging-related failures are masked.

- The analyses results presented in this report, using the wide spectrum of NPRDS data, represent an average. Therefore, plant-specific effects of maintenance or environment are masked.

- Many failure reports in the data base do not contain a true failure date but rather a discovery date. This is particularly true for reports concerned with mechanical or electrical set point drift where an entire system was checked at one time and all those found out of specification were reported. While these failures represent aging phenomena, establishing either an exposure time or degradation versus time is impossible.

- For some utilities, the in-service date given in the component engineering record is not the date the component became operational, but rather the date the system or plant became operational.

- Approximately 50% of the NPRDS data is placed in the "unknown" or "other devices" failure categories. This reflects the practice of replacing a component or piece part without establishing the reason for failure.

- NPRDS failure descriptions use ambiguous wording, making a determination of the failure cause or aging classification difficult.

In view of the above strengths and weaknesses, the NPRDS data can supply only relative information regarding which LWR safety systems and components have been significantly affected by aging and the underlying cause of that aging. Accurate determinations require analysis of plant records, which is beyond the scope of this study. However, for use in aging evaluations that rely on PRA techniques, only relative information is needed to modify the existing PRA information.

3.3 Aging Survey Analysis

The NPRDS data were utilized to create a data base, which contains information about component failures, identifying the nuclear steam system supplier, utility (not reported herein), system, component, in-service date, and the components engineering parameters. The components engineering parameters allowed collecting failure data that are specific to a particular component type, size, or capacity. Furthermore, the data base contains the failure event date, system effect produced by the failure, cause category, and cause codes.

The failure reports in the NPRDS are organized into nine categories referred to as cause categories. These major categories refer to general causes, such as engineering/design, installation error, wearout, etc. A reported failure is then further characterized by the addition of a cause code identifying the cause of, or contributing factors to, the failure. These codes refer to mechanical, electrical, or human-related causes of failure.

A relationship between the nine NPRDS cause categories and the five general failure categories (as defined in Section 2) was developed so that generic issues could be examined. Figure 1 illustrates the correlation between the nine NPRDS cause categories and the five aging survey failure categories. Appendix A (Table A-1) presents the NPRDS cause-category cause-code grouped into these five failure categories. In practice, examination of the cause code is not necessary to group the failures into the five categories. Minimal error is introduced by using only the NPRDS cause category. The resulting aging-survey data base contains the number of failures, also called counts, specific to NSSS/system/component combinations grouped into the five failure categories. Associated with each failure count are the system effect of the failure and the component age at the time of failure.

For each system, failure fractions were calculated for both the five broad failure categories and the system effect categories. These fractions represent an aggregation of all components within a system. Failure fractions within a given system were calculated by dividing the total counts for a failure category by the total failure counts for that system. System effect fractions were calculated in a similar manner. Component/failure-category fractions were calculated by dividing the total failure counts per component/failure-category by the total failure counts per component within the appropriate system.

Using the component/aging-failure-category fractions, a rudimentary uncertainty study was performed using contingency table analyses. This study addressed the question of whether similar components are more susceptible to failure due to aging, depending upon the system in which they reside. A standard statistical hypothesis test was performed for each component to make this determination. The hypothesis chosen for the test was that no differences in aging fraction existed for similar components placed in different systems. The tests were performed at a family significance level of 0.05. The significance level is defined as the probability that test-indicated differences in aging effects exist, when in fact there are no differences for the given component between systems. Family significance level means that if no components have significant between-system differences, one can expect 5% of the components to show significance. When the analysis showed no statistically significant difference in aging effects for the given component between systems, the component failure counts for the component from all involved systems were combined to calculate an overall aging fraction irrespective of system. A 95% confidence interval was calculated for the composite fraction.

Aging-effect differences were found to be statistically significant for some components in different systems. The data were examined to develop two groups of systems where it was assumed that aging differences did not exist within each group. This procedure resulted in two groups of systems. One group contained the systems that indicated high aging effects, and one group contained the systems that indicated low aging effects. Each group could then be characterized by estimating a composite aging fraction based upon a larger data population base. In addition to aging fractions, 95% confidence intervals were calculated for each group. These confidence intervals for the proportion of faiures due to aging were calculated according to the method described in Reference 8, page 58.

To determine if aging failures increase over time, a time-dependent study was performed on aging versus non-aging failures. The aging failures were tallied for each system/component combination in the four age divisions. Aging fractions for the four age divisions were calculated for the system/component combination by dividing the total failures per system/component/age-division combination by the total failures per system/component combination.

3.4 Reported Failure Cause Analysis and Aging Classification

The methods used in the reported-failure-cause identification and aging classification study are similar to those used in previous work performed at

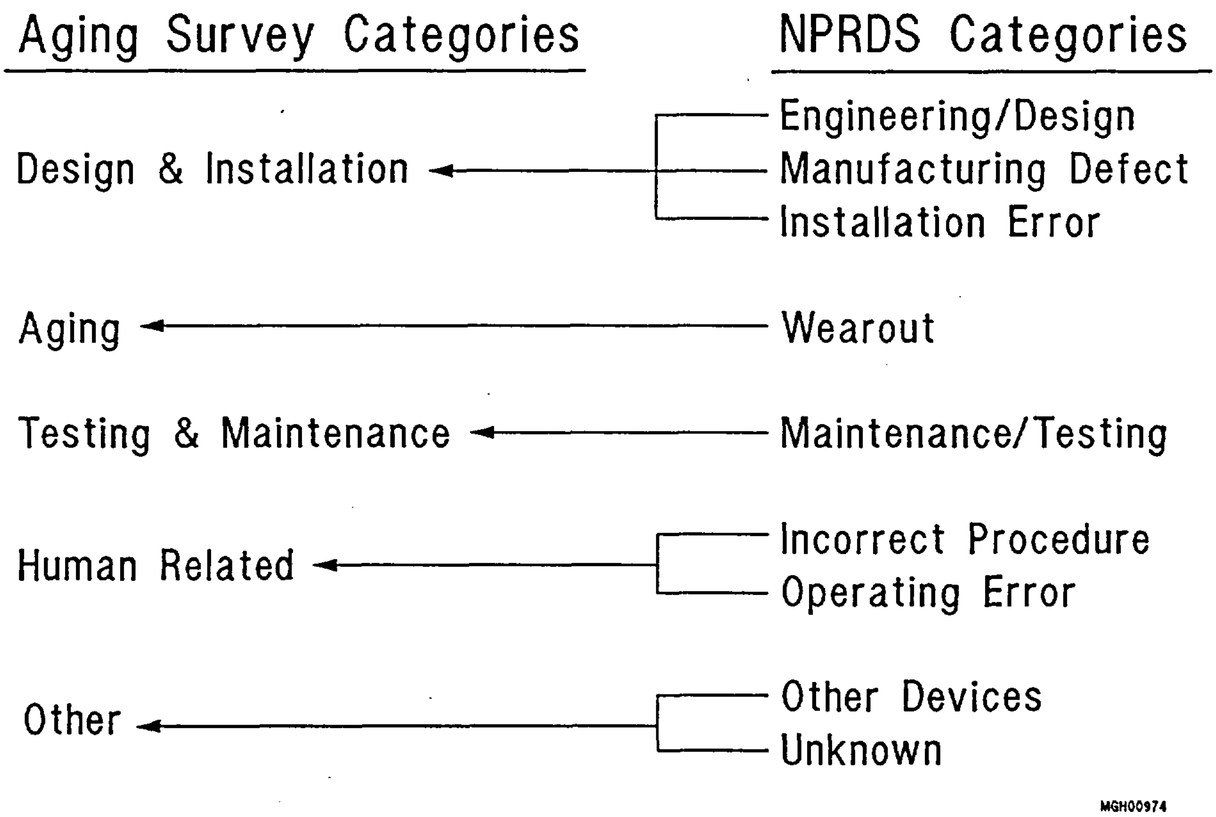

Figure 1. Relationship of the NPRDS cause categories and the aging survey failure categories.

INEL for the Root Causes of Component Failures Program.[2] This section expands on the different aspects of the methodology utilized in this failure cause identification effort.

"Failure cause" is defined as the underlying discernable cause of failure contained in the failure report for a component. The NPRDS data base codes provide some information about the underlying causes of the component failures. However, failure cause identification and aging classification requires a manual examination of failure records. It includes compiling and organizing specific information concerning the component and its failure. The reported causes of failures were categorized and assigned cause codes in accordance with the failure cause categorization scheme presented in Appendix B (Table B-2). Aging classification is done in accordance with the guidelines given in the same table.

The detail and depth of the information in the NPRDS records is different for different components, systems, and plants. To accommodate these differences, the failure cause categorization scheme (or list) consists of three levels. Table 1 presents a portion of the root cause categorization scheme to show the general structure. This table shows the full-depth level of detail for the first general category. The entire categorization scheme is presented in Appendix B, along with the cause-coding form used to compile the data. A description of the cause coding form and the correlation between NPRDS records and the data fields on the form are also provided in Appendix B.

The "unclassifiable cause" codes were used when the NPRDS records did not provide sufficient information to accurately determine the cause of the component failure. Subjective interpretations of the NPRDS narrative were not made. The "unclassifiable cause" category is resolved into second- and third-level codes. However, the third-level resolution of the codes indicates the effect of the failure rather than the actual cause.

Using the definition in Section 3.1, the aging classification scheme was developed to allow a procedural approach to be taken in the identification of aging failures. The procedure for classifying failures is presented in Appendix B. Each failure cause code is assigned one of three aging classifications: non-aging, conditional aging, or aging. Aging-related failure cause codes are codes that always relate to time-dependent effects. Examples of these time-dependent codes are "erosion," "corrosion," and

Table 1. Example of the root cause categorization scheme (full depth)

D	Design/manufacturing/construction/quality assurance inadequacy	
	DC	Construction error or inadequacy
	DCI	Initial construction activity
	DCR	Retrofit construction activity
	DE	Design error or inadequacy
	DEI	Initial design activity
	DER	Retrofit design activity
	DM	Manufacturing error or inadequacy
	DQ	Quality assurance error or inadequacy
	DQD	Initial design quality assurance activity
	DQE	Retrofit design quality assurance activity
	DQI	Initial construction quality assurance activity
	DQM	Manufacturer quality assurance activity
	DQR	Retrofit construction quality assurance activity
	DR	Plant definition requirements inadequacy
	DRI	Initial definition activity
	DRR	Retrofit definition activity

"wear." Non-aging-related failure cause codes are used for random events that cause immediate failure of the component. Examples of these types of failure causes are "fire/smoke," "impact loads," and "electromagnetic interference." Conditional aging failures are classified as aging-related if information in the failure report indicates some aging-related effect code (from the categorization scheme) or some keyword that indicates that a time-dependent process is present. A failure categorized with a conditional aging code is classified non-aging if the failure description indicates that a random event caused an immediate failure. In some instances, a failure description contains enough information to allow categorization with a conditional code but gives no indication as to whether the failure was random or aging-related in nature. In this case, the failure will be assigned an "unknown" classification.

This failure cause identification study was oriented towards analyzing component failures of complete systems. The system configurations used in the failure-cause analysis were developed for use in the Root Causes of Component Failure Program.[2] The component boundaries utilized are listed in Appendix C, along with examples of subcomponents and piece parts of each component.

The failure modes, and definitions thereof, used in the failure cause identification are given in Appendix D. The failure modes are, in general, directly related to the failure modes used in PRA analysis. Whenever the PRA failure mode definitions did not encompass the type of failures reportable under the NPRDS guidelines, certain failure modes were chosen and defined to represent the failure descriptions actually encountered in the NPRDS data. For example, the "no failure" failure mode used for diesel generators was developed to indicate when the diesel generator remained operable, but a failure was reported for a subcomponent of the diesel generator. This failure could have resulted in the inoperability of a redundant diesel generator subsystem.

The failure cause fractions, as used in this analysis, were derived for use in a probablistic risk analysis and are therefore specific to component and failure mode. Manipulation of the reported-failure-cause data base allowed the calculation of cause fractions and aging fractions for the various component/failure-mode/failure-cause combinations for each system. During this process, the number of failures, or counts, was obtained for each component/failure-mode combination, individual failure cause, and aging-classification/failure-cause combination. The failure cause fraction for each component/failure-mode combination was calculated by taking the number of component failures in a specified failure mode which are due to a given failure cause and dividing by the total number of failures in that failure mode, excluding the unclassified causes. The aging failure cause fractions were calculated in the same manner. Failure cause and aging failure cause fractions were calculated for each system/component combination.

The aging-related cause fraction data presented in this study reflect upper and lower bounds derived from the operational data source. These bounds are developed on the uncertainty encountered in accurate identification of aging-related causes on the basis of the component failure descriptions. The categorization scheme defines when a failure should be classified as related to aging or non-aging. When insufficient information is contained in the failure description, the aging classification is "unknown." These failures are then used to establish the upper and lower bounds for the aging-related cause fractions. The upper bounds contain the failures classified as "unknown" as aging-related failures, while the lower bounds contain them as non-aging-related failures.

4. RESULTS

This section describes the results of the aging survey and the failure cause analysis. Engineering insights are also presented.

4.1 Aging Survey Analysis

Data resulting from the survey of the failure category data base are presented in Appendix E. The information is organized by specific system (auxiliary feedwater, component cooling water, etc.). Also provided in Appendix E are (a) definitions of the data fields and other information presented in the tables and (b) summary tables for system/failure-category, system/system-effect-categories, and system/component/failure-category fractions. These data constitute a rollup of the information presented in the detailed aging survey tables, which tabulate an extensive amount of data and have been microfiched for the purpose of this publication.

Table 2 is an illustration of the format of these tables. Some components were broken down only to the major NPRDS components designation, as shown by the "SUPORT" data. For other components, the component engineering data were utilized to provide a more detailed breakdown, as shown in Table 2 for the NPRDS major category "VALVE." The detailed breakdown using the component engineering data depended on the possible safety importance of the component and the amount of data available in the NPRDS. In all nine systems, valves were broken down because they are an important component in PRA analysis. Instrumentation components were only broken down in the reactor protection trip system because in that system, the amount of data for instrumentation components is extensive.

The fractions in percent (by system) for the five major failure categories are shown in Figure 2. As illustrated, the dominant failure categories are "aging" (31%) and "other" (50%). Human-related failures only contribute about 1.5% to the total of failures reported. Failures in the "testing and maintenance" and "design and installation" categories are responsible for approximately 7.5% and 10%, respectively.

The "other" category consists of failures for which the cause of failure was not determined or could not be assigned to another category. The size of the "other" category is indicative of the difficulties encountered in determining the cause of failure for certain components and the practice of replacing a component or piece part without establishing the reason for failure. Therefore, it is likely that some of the failures recorded in the "other" category were caused by unidentified aging mechanisms. It is recognized that this concern could also apply to the aging category. However, examination of the failure-cause study, where the number of unclassified failures is significantly smaller, indicates generally higher component aging fractions and tends to support the conclusion about the "other" category.

Figure 2 also indicates that normally operating fluid systems, such as the service water, main feedwater, and component cooling water systems, exhibit relatively high aging fractions; while standby safety fluid systems, such as the high-pressure injection, residual heat removal, and standby liquid control systems, exhibit lower aging fractions. The aging fractions for the reactor protection trip and Class 1E electrical power distribution systems fall between the higher values of the active fluid systems and lower values of the standby fluid systems due to the mixture of components involved and their operational modes.

The relationship of failures to reported system effects is presented in Figure 3. Examination of this figure indicates that, although the fractions in the "system function unaffected" category are slightly higher, there was no clearly dominant system effect category. It is noteworthy, however, that very few failures caused "loss of system function."

Figures 4 and 5 illustrate the relationship of aging fractions for selected components in different systems. These figures represent only a subset of the data presented in Appendix E. The components selected for Figure 4 were chosen because they tend to have high aging fractions in some systems. The four instrumentation components illustrated in Figure 5 were selected because they appeared in all nine systems and exhibited some aging failures; therefore some comparison could be made. The numbers shown with each bar are the number of failures associated with that component in that system.

A rudimentary uncertainty study was performed on the system/component aging fractions to identify which components exhibit a system-dependent aging relationship. The results of this study are presented in Tables 3 and 4. The components were divided into two groups. Table 3 contains components for which the systems exhibited no statistical dependency related to aging effect. Table 4 contains components for which system dependency of aging

Table 2. Example of detailed aging survey tables

NSSS	System	Component	Failure Total	Sys Eff No.	Sys Eff Co.[b]	Age of Component and Failure Category[a]																			
						0-4.9 Years					5-9.9 Years					10-14.9 Years					15-20 Years				
						D	A	T	H	O	D	A	T	H	O	D	A	T	H	O	D	A	T	H	O
C	CFA	SUPORT																							
		Support/ Snubbers	101		A																				
				11	B	1				1	1	1			2	2	3								
				3	C											1		1		1					
				5	D			1						2	2										
				82	E	6	2	1	1	19	1	6	1		44			1							
C	CFA	VALVE																							
		Check Valve	29		A																				
				11	B	1	3			3	1	3													
				6	C					1	1	3			1										
				4	D		3					1													
				8	E	1				1		1			4					1					
		Manual Valve	25		A																				
				5	B	1		1	1	1		1													
				4	C		2					2													
				3	D					1		1	1												
				13	E							3			7		3								
		Mechanical Valve	20		A																				
				2	B		2																		
				2	C										1	1									
				8	D							8													
				8	E		1			1					2					4					
		Motor-Operated Valve	155	2	A					1		1													
				25	B		5		1	6	5	4	1		1	1				1					
				25	C	1	1		1	2		8			5	1	2	2	1	1					
				43	D	1	8			2	1	16	2		4		8			1					
				60	E		3	1		6	2	10	4		28	1	3			2					

a. Failure categories are: D—design and installation; A—aging; T—testing and maintenance; H—human related; and O—other.

b. System effect categories are: A—loss of system function; B—degraded system operation; C—loss of redundancy; D—loss of subsystem/channel; and E—system function unaffected.

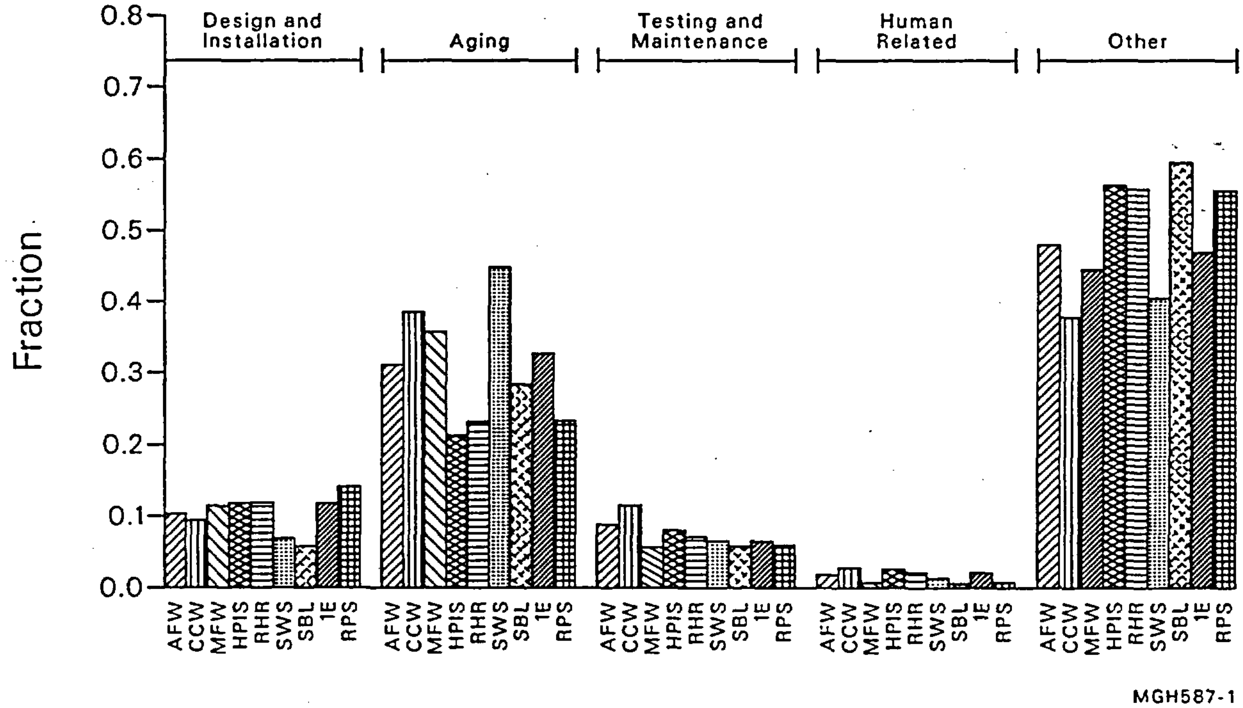

Figure 2. Relationship of the failure category fractions by system.

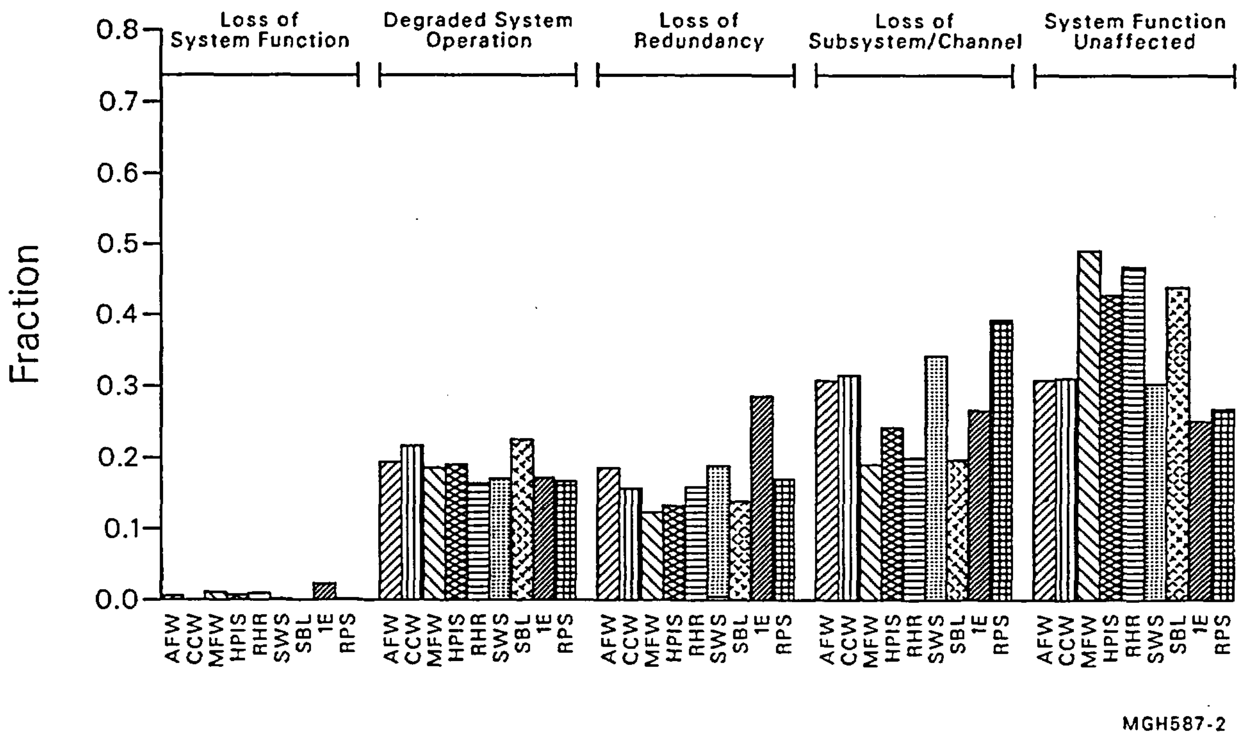

Figure 3. Relationship of the system effect fractions by system.

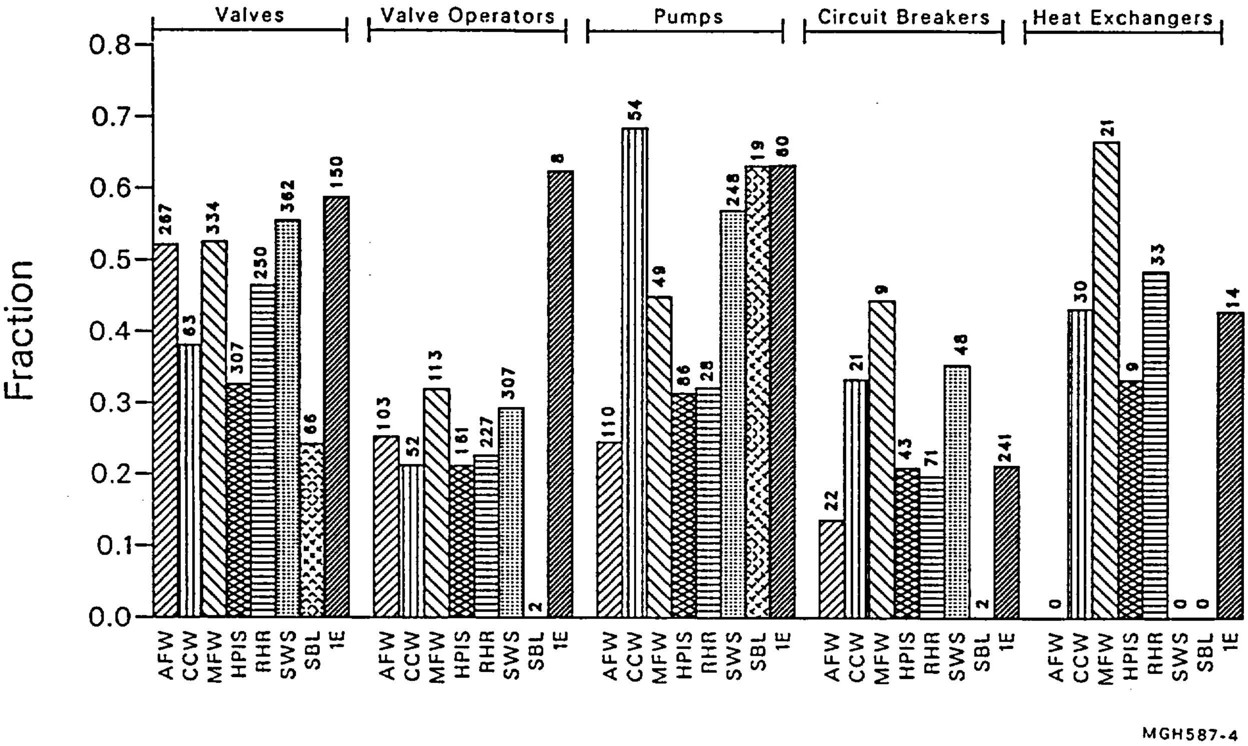

Figure 4. Relationship of the component aging fractions by system.

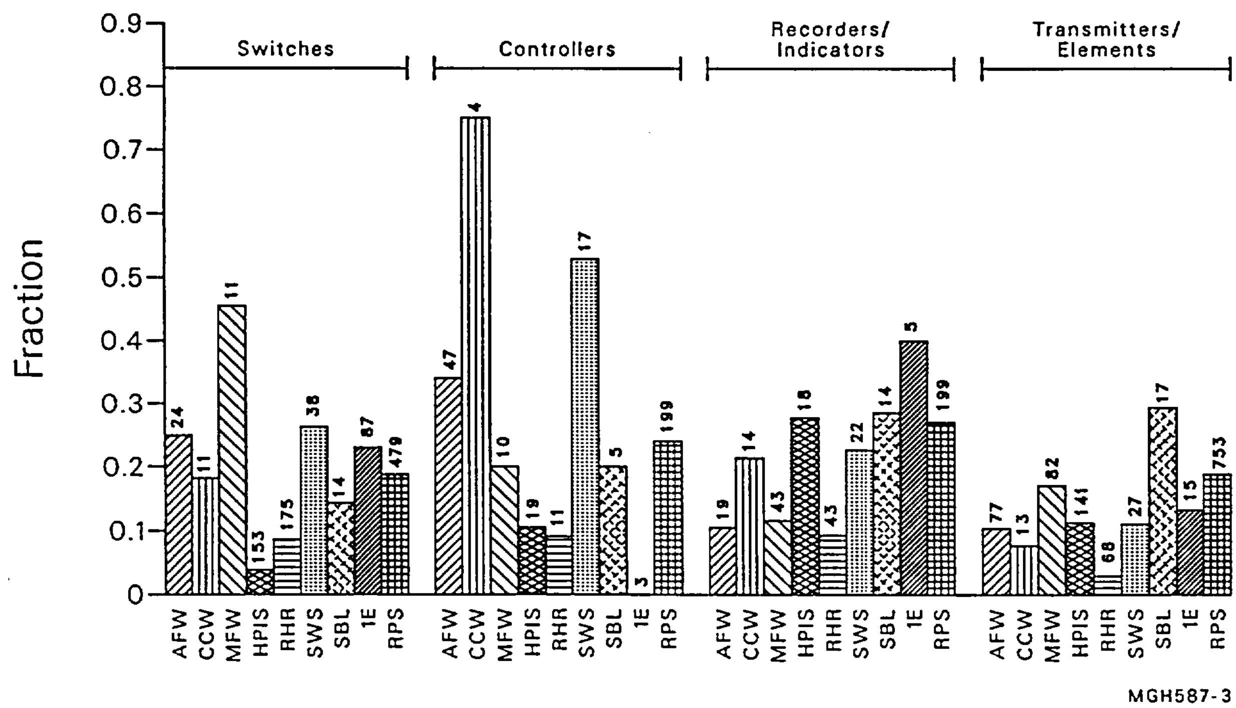

Figure 5. Relationship of the instrumentation component aging fractions by system.

Table 3. Uncertainty study: no statistical system dependency related to aging

Component	Aging Fraction	95% Confidence Interval
Accumulator[a]	0.21	(0.06, 0.46)
Air dry[b]	0.50	(0.07, 0.93)
Annunciator[a]	0.40	(0.05, 0.85)
Battery charging unit[b]	0.33	(0.27, 0.39)
Blower-compressor[b]	0.62	(0.55, 0.69)
Circuit breaker[c]	0.23	(0.19, 0.27)
Electrical conductor	0.10	(0.03, 0.24)
Electronic power supply[d]	0.25	(0.20, 0.31)
Engine[d]	0.26	(0.22, 0.30)
Filter[d]	0.57	(0.47, 0.67)
Generator/alternator/inverter[d]	0.24	(0.19, 0.28)
Heat exchangers	0.50	(0.40, 0.60)
Heater[d]	0.11	(0.03, 0.26)
Instrumentation-computation module[c]	0.28	(0.25, 0.31)
Instrumentation-controller[c]	0.25	(0.20, 0.31)
Instrumentation-indicator/recorder[d]	0.22	(0.18, 0.27)
Instrumentation-isolation device[d]	0.37	(0.20, 0.56)
Mechanical function unit[d]	0.25	(0.15, 0.39)
Motor[c]	0.47	(0.37, 0.57)
Pipe[d]	0.56	(0.31, 0.78)
Relay[d]	0.23	(0.19, 0.27)
Transformer[b]	0.13	(0.04, 0.31)
Turbine[d]	0.13	(0.06, 0.25)
Valve operator[c]	0.26	(0.23, 0.29)

a. The deletion of systems with expected cell count less than 4.7 led to deletion of all systems. Therefore, all data were used to estimate aging fraction and confidence interval.

b. One system/component combination (and no difference test).

c. Systems with expected cell count of less than 4.7 were deleted. The remaining system/component data were used to calculate the aging fraction and confidence interval.

d. The deletion of systems with expected cell count less than 4.7 led to one system/component combination (and no difference test).

effects could be statistically determined. Only five components demonstrated any statistically significant differences between aging fractions across systems. These components are switches, transmitters, pumps, supports, and valves.

Comparing the aging fractions illustrated in Figures 4 and 5 and the results of the uncertainty study on the system/component aging fractions leads to several observations. Figures 4 and 5 clearly indicate which system/component combinations are being impacted by aging phenomena. The uncertainty study further supports these results. Figure 4 indicates that in normally operating systems, valve and pump performance is strongly affected by aging. Furthermore, valves and pumps associated with the diesel engine auxiliary systems in the Class 1E electrical power distribution systems are strongly affected by aging. These components usually reside in highly vibrational environments. It is suspected that this type of environment causes the high numbers of failures. The pumps in the standby liquid control system display a very high aging fraction for a standby safety system. This observation is supported by the fact that the standby liquid control system is a boric acid injection system, and the boric acid environment can be very damaging to pump

Table 4. Uncertainty study: statistical system dependency related to aging

Component	Aging Fraction	95% Confidence Interval	Systems
Instrumentation-switch[a]	0.06	(0.04, 0.10)	RHR, HPIS
	0.20	(0.17, 0.23)	SWS, RPS, 1E
Instrumentation-transmitter[a]	0.55	(0.49, 0.60)	RPS, MFW
	0.03	(0.02, 0.05)	AFW, HPIS, RHR
Pump	0.60	(0.55, 0.65)	SBL, CCW, 1E, SWS
	0.31	(0.26, 0.37)	MFW, RHR, HPIS, AFW
Supports[a]	0.37	(0.21, 0.56)	HPIS
	0.12	(0.07, 0.18)	MFW, RHR
Valve	0.54	(0.52, 0.57)	1E, SWS, MFW, AFW
	0.37	(0.34, 0.41)	RHR, CCW, HPIS, SBL

a. Systems with expected cell count of less than 4.7 were deleted. The remaining system/component data were used to calculate the aging fraction and confidence interval.

seals. The uncertainty study supports these observations—both valves and pumps showed statistically significant differences between aging fractions across the nine systems. The study indicated a higher composite aging fraction (0.60) for pumps in the component cooling water and service water systems (normally operating fluid systems) and the standby liquid control and Class 1E electrical power diesel auxiliary systems (severe operational environment) than for pumps in the main feedwater, residual heat removal, high-pressure injection, and auxiliary feedwater systems (aging fraction of 0.31). Valves displayed similar results, indicating a higher composite aging fraction (0.54) in the service water, main feedwater, and auxiliary feedwater systems (normally operating fluid systems) and Class 1E electrical power diesel auxiliary systems (severe operational environment) than in the residual heat removal, component cooling water, high-pressure injection, and standby liquid control systems (aging fraction of 0.37).

Valve operators in the diesel engine auxiliary subsystems of the Class 1E electrical power distribution systems reside in a highly vibrational environment. Figure 4 shows that these valve operators are significantly affected by aging compared with valve operators in the other eight systems. However, this observation is not supported by the uncertainty study.

Figure 4 also indicates that failures of the heat exchangers in the main feedwater systems are frequently due to aging. These heat exchangers are used as feedwater heaters and are located downstream of the turbine exhaust. It is suspected that the steam environment accelerates the degradation process. While the figure implies that heat exchanger aging is significantly more important in the main feedwater systems, the uncertainty study indicated no statistically significant differences for heat exchangers across the nine systems.

Figure 5 indicates that the aging fractions for solid-state instrumentation components do not vary greatly from system to system. The uncertainty study supports this observation and further illustrates (on the basis of composite aging fractions) that the effect of aging on solid-state component failures is minimal relative to other components. Furthermore, the only instrumentation components showing statistically significant differences across the systems were switches and transmitters.

Table 5 presents the time-dependent aging fractions for system/component combinations having at least 50 failure counts. While the data exhibit definite time dependencies in aging-related failures, there is no apparent pattern to the aging fraction results. In numerous cases, the aging fractions were higher in the 5-to-9.9 year division; while the aging fractions in the 15-to-20 year division were virtually

Table 5. System/component combination time-dependent aging fractions

System	Component	Total Failures	Fraction 0-4.9 yr	5-9.9 yr	10-14.9 yr	15-20 yr
1E	Battery/battery charging unit	243	0.107	0.160	0.053	0.004
1E	Blower	217	0.147	0.304	0.166	0.005
1E	Circuit breaker	247	0.081	0.057	0.057	0.012
RHR	Circuit breaker	72	0.083	0.014	0.083	0.014
1E	Engine	512	0.059	0.074	0.121	0.000
SWS	Filter	101	0.248	0.287	0.030	0.000
1E	Generator/alternator/inverter	87	0.069	0.092	0.069	0.000
HPIS	Instrumentation: switch	154	0.026	0.013	0.000	0.000
RHR	Instrumentation: switch	179	0.022	0.050	0.017	0.000
RPS	Instrumentation: switch	480	0.081	0.062	0.037	0.008
RPS	Instrumentation: controller	201	0.114	0.040	0.070	0.015
RPS	Instrumentation: recorder	204	0.029	0.088	0.088	0.059
RPS	Instrumentation: computation module	865	0.110	0.105	0.047	0.012
RPS	Electronic power supply	256	0.082	0.129	0.023	0.016
AFW	Instrumentation: transmitter	78	0.013	0.077	0.013	0.000
HPIS	Instrumentation: transmitter	142	0.070	0.028	0.014	0.000
MFW	Instrumentation: transmitter	82	0.061	0.098	0.012	0.000
RHR	Instrumentation: transmitter	70	0.000	0.014	0.014	0.000
RPS	Instrumentation: transmitter	766	0.093	0.050	0.040	0.005
1E	Mechanical function unit	55	0.036	0.145	0.073	0.000
SWS	Motor	66	0.091	0.121	0.167	0.000

Table 5. (continued)

System	Component	Total Failures	Fraction 0-4.9 yr	5-9.9 yr	10-14.9 yr	15-20 yr
1E	Pump	61	0.197	0.246	0.180	0.000
AFW	Pump	111	0.063	0.027	0.153	0.000
CCW	Pump	56	0.089	0.321	0.250	0.000
HPIS	Pump	86	0.070	0.070	0.174	0.000
SWS	Pump	252	0.159	0.198	0.198	0.004
1E	Relay	89	0.067	0.067	0.101	0.011
RPS	Relay	339	0.056	0.071	0.100	0.000
MFW	Support	55	0.036	0.091	0.000	0.000
RHR	Support	102	0.020	0.069	0.029	0.000
AFW	Turbine	60	0.050	0.050	0.017	0.017
1E	Valve	165	0.236	0.188	0.139	0.006
AFW	Valve	276	0.261	0.159	0.091	0.000
CCW	Valve	63	0.063	0.270	0.048	0.000
HPIS	Valve	312	0.058	0.167	0.093	0.003
MFW	Valve	335	0.104	0.284	0.122	0.012
RHR	Valve	252	0.123	0.274	0.067	0.000
SBL	Valve	69	0.058	0.072	0.101	0.000
SWS	Valve	369	0.182	0.252	0.114	0.003
AFW	Valve operator	105	0.133	0.086	0.029	0.000
CCW	Valve operator	52	0.019	0.135	0.058	0.000
HPIS	Valve operator	165	0.042	0.073	0.091	0.000
MFW	Valve operator	115	0.087	0.122	0.096	0.009
RHR	Valve operator	228	0.075	0.127	0.026	0.000
SWS	Valve operator	311	0.122	0.122	0.045	0.000

zero. (Very few components have experienced an exposure time this long.) It is expected that the pattern would show an increase in aging failures with the increase in the age of the component up to the useful lifetime of the component. It is not reasonable to expect that the components studied have useful lifetimes only in the range of 5 to 10 years. This is especially true of the component piece parts or internals that age more rapidly than component structural parts. Additionally, the data utilized in this study are impacted by variables such as plant maintenance practices and the age of the plant. Plant maintenance often results in the complete rejuvenation of a component; however, occasionally, plant maintenance results in accelerated component degradation. The impact of these variables cannot be assessed from the data contained in the NPRDS data base. To address the effectiveness of maintenance on controlling aging, plant-specific component maintenance histories would have to be studied. This type of analysis was beyond the scope of the current study.

4.2 Reported Failure Cause Analysis

Table 6 summarizes the service water and Class 1E electrical power distribution systems failure information obtained in the failure-cause study. The complete reported cause of failure data are presented in Appendix F. The data presented in Table 6 consist of the total failures, lower bound aging total, upper bound aging total, lower bound aging fraction, and upper bound aging fraction for those components having five or more failure counts. The data presented are a rollup of the specific component/failure-mode cause fractions for those components having five or more failure counts. From the information presented, it can be seen that the service

Table 6. Table of SWS and Class 1E component failures and aging fractions as determined by the reported causes of failure study

Components[a]	Total Failures	Lower Bound Aging Total	Upper Bound Aging Total	Lower Bound Aging Fraction	Upper Bound Aging Fraction
		Service Water System			
Check valves[b]	31	27	28	0.87	0.90
Strainers	21	17	18	0.81	0.86
Motor-driven pumps[b]	167	129	140	0.77	0.84
Pneumatic-operated valves	47	36	45	0.77	0.96
Hand control valves	17	11	12	0.65	0.71
Circuit breakers[b]	17	9	12	0.53	0.71
Motor-operated valves[b]	111	43	93	0.39	0.84
Total	411	272	348		
System aging fraction				0.66	0.85
		Class 1E Electrical Power Distribution System			
Battery chargers[b]	35	18	34	0.51	0.97
Batteries[b]	10	5	10	0.50	1.00
Diesel generators[b]	113	55	75	0.49	0.66
Circuit breakers[b]	10	3	6	0.30	0.60
Inverters[b]	63	18	38	0.29	0.60
Total	231	99	163		
System aging fraction				0.43	0.71

a. Components have been ordered by lower bound aging fractions.

b. In-depth engineering studies of these components have been implemented as part of the Nuclear Plant Aging Research Program (Reference 1).

water system has a lower bound fraction expressed in percent of 66% and an upper bound of 85% for aging-related failures; the Class 1E power distribution system exhibited 43% and 71%, respectively.

Table 7 summarizes the failure data from this study for selected systems and components, including failure mode and dominant failure causes for the respective failure mode. The data are presented for those component/failure-mode/failure-cause combinations that had five or more documented events per failure cause; therefore, only the major categories of failure causes are presented.

Examination of Tables 6 and 7 indicates that the service water system component having the highest potential system impact due to aging failures is the motor-driven pump. There were 91 failures coded for the failure mode "fails to run," and 64 failures coded for the "external leakage" failure mode. "Wear" and "foreign materials intrusion" are the dominant reported failure causes of these two failure modes. The dominant aging-related failure cause is "wear," with aging-related failures comprising 77% to 84% of the total pump failures (Table 6).

An inspection of the failure records pertinent to service water system motor-driven pumps shows that the failures coded under the failure mode "external leakage" were caused by the wear of the pump seals and pump packing or foreign material intrusion into the pump seals. The foreign material intrusion related primarily to sand and other particulates sometimes found in the influent water.

The wear mechanism for the motor driven pump failures coded under the failure mode "failure to run" is associated with the pump itself, not just the seals and packing. The wear mechanism is also associated with the motor of the motor-driven pump. Sand and other particulates found in the influent water are the dominant cause of the failures coded as "foreign material intrusion."

The service water system components with the second highest potential for aging impacts on system operation are motor-operated valves. The resulting potential aging fraction range (in percent) is 39% to 84%. Although its importance is somewhat reduced due to the relatively small number of failures, the largest aging-related failure cause fraction associated with service water system motor-operated valves is for "wear" and the failure mode of "external leakage." The piece part most affected by "wear" is packing. The largest number of failures occurred for the failure mode "fails to close." Inspection of the failure records indicates that dominant aging failure cause "wear" often caused the failure of the valve stem connection to the valve operator. Table 7 further indicates that the failure cause of "out of adjustment" for motor-operated valves displays a potentially high aging contribution for the failure modes of "fails to close," "fails to open," and "fails to operate as required." Examination of the failure records reveals that "out of adjustment" is associated with the valve operator and the time requirement for actuation of the valve movement.

Service water system check valves are significantly affected by aging. The largest potential aging fraction was calculated for service water system check valves (Table 6, 0.87 to 0.90). The dominant failure mode is "internal leakage," with the dominant aging failure causes of "wear" and "corrosion." Examination of the failure records indicates that the piece parts most affected by wear are the valve seat and valve disc, as would be expected. Failures of the valve body and the valve internals are attributable to corrosion.

Service water system strainers exhibit the second highest potential aging-related failure fraction (Table 6, 0.81 to 0.86). Inspection of the failure records indicates that packing wear and plugging due to foreign material in the influent water are the dominant contributors to failure.

The diesel generators are the largest single contributor of failures for the Class 1E systems. This is, in part, because of the component boundaries developed for the diesel generator for the failure cause study. Aging-related failures comprise 49% to 66% of the total failures, and the largest single aging diesel generator failure cause is "wear." The failure records and data indicate that the wear failures are distributed over four diesel generator subsystems: diesel cooling water, diesel fuel oil, diesel lube oil, and diesel starting air. The components most affected are valves and pumps.

Inverters in the instrument and uninterruptible power systems of the Class 1E system also account for a relatively large failure count. These failures are dominated by electrical failures. Examination of the NPRDS failure records indicates that the major contributors to these electrical failures are blown fuses, defective fuses, and defective solid-state components. There were few aging-related failures found for this component.

Table 7. Reported failure cause identification summary

System/Components	Failure Mode	Total Counts	Dominant Failure Cause	Fraction: Failure Cause	Fraction: Lower Bound Aging	Fraction: Upper Bound Aging
Essential service water						
Check valves	Internal leakage	25	Wear	0.480	0.480	0.480
			Corrosion	0.240	0.240	0.240
Motor-operated valves	External leakage	7	Wear	0.714	0.714	0.714
	Fails to open	27	Binding/out of adjustment	0.296	0.037	0.222
	Fails to close	43	Wear	0.140	0.140	0.140
			Binding/out of adjustment	0.535	0.000	0.488
	Fails to operate as required	17	Binding/out of adjustment	0.294	0.059	0.235
Pneumatic-operated valves	External leakage	5	Wear	1.000	1.000	1.000
	Fails to close	15	Wear	0.333	0.333	0.333
	Fails to operate as required	13	Wear	0.385	0.385	0.385
Motor-driven pumps	Fails to run	91	Wear	0.319	0.319	0.319
			Binding/out of adjustment	0.110	0.011	0.066
			Foreign materials intrusion	0.253	0.176	0.176
	External leakage	64	Wear	0.703	0.703	0.703
			Foreign materials intrusion	0.141	0.125	0.125
Strainers	Loss of function	13	Wear	0.615	0.615	0.615
	Plugged	8	Foreign materials intrusion	0.750	0.500	0.500
Instrument and uninterruptible power supply system—Class 1E						
Inverters	Loss of function	63	Design error or inadequacy	0.079	0.000	0.016
			Wear	0.079	0.079	0.076
			Electrical overload	0.143	0.000	0.016
			Faulty module	0.286	0.079	0.222
			Short circuit	0.127	0.016	0.079

Table 7. (continued)

System/Components	Failure Mode	Total Counts	Dominant Failure Cause	Fraction		
				Failure Cause	Lower Bound Aging	Upper Bound Aging
DC power supply system—Class 1E						
Battery chargers	Loss of function	35	Faulty module	0.657	0.400	0.657
Emergency on-site power supply system						
Diesel generator	Fails to run	46	Wear	0.304	0.304	0.304
	No failure	49	Water intrusion	0.184	0.041	0.061
			Wear	0.122	0.122	0.122
			Cyclic fatigue	0.102	0.102	0.102

5. CONCLUSIONS

This section discusses the conclusions drawn from the aging survey and reported failure-cause analyses.

5.1 Aging Survey Analysis

A data base consisting of operational events recorded in the NPRDS has been generated for selected LWR safety and support systems. Analyses performed on the data provided several insights concerning the effect of aging failures on the selected systems. It was determined that for the systems in general many nuclear power plant component failures are due to aging, while failures categorized as "human related" were few. The "other" category is the largest failure category. It consists of failures for which the cause either was not determined or could not be assigned to another category. The size of this category is indicative of the difficulties encountered in determining the cause of failure for certain components and the practice of replacing a component or piece part without establishing the reason for failure.

The analysis established that normally operating fluid systems, such as the service water, main feedwater, and component cooling water systems, exhibit the highest aging failure fractions, with pumps and valves being the components most affected. However, there are significant exceptions to this finding concerning operational mode. Components in some standby systems (such as pumps in the standby liquid control system and valves and pumps in the diesel subsystems of the Class 1E electrical power distribution systems) also display high aging fractions. It is suspected, as a result of a minimal systems analysis, that these standby system components are adversely affected by their operational environment.

While the data exhibit a variety of time dependencies of the aging-related failures, the time-dependent aging analysis did not yield any definitive results in terms of component- or system-specific aging patterns. The data utilized in this study are impacted by variables such as plant maintenance practices and the age of the plant. Some of the information necessary to assess the impact of these variables on aging is not available from the NPRDS source data.

5.2 Reported Failure Cause Analysis

The failure cause identification analysis has provided insights into the effects of aging-related failures in service water and Class 1E electrical power distribution systems. The analysis established that the service water system, a normally operating fluid system, is significantly affected by aging (lower bound system aging fraction of 0.66 and upper bound system aging fraction of 0.85); the Class 1E electrical power distribution systems, however, are somewhat less affected by aging (lower bound system aging fraction of 0.43 and upper bound system aging fraction of 0.71).

The specific service water system components that exhibit significant aging-related failures are check valves (87% to 90%), strainers (81% to 86%), motor-driven pumps (77% to 84%), and motor-operated valves (39% to 84%). "Wear" was the significant aging mechanism affecting the valves. Motor-driven pump and strainer failures were dominated by "wear" and "foreign material intrusion." These aging mechanisms are prominent in the service water system due to sand and other particulates normally present in the influent water.

Failures of the diesel generators dominated the Class 1E electrical power distribution system and exhibited an aging fraction of 0.49 to 0.66. The aging mechanism most prominent for the diesel generator was "wear," which comprised 30% of the aging-related failures. The subcomponents failing due to "wear" were the valves and pumps located in the cooling water, fuel oil, lube oil, and starting air subsystems of the diesel generator.

In conclusion, while it can be easily seen that aging failures contribute approximately 31% to the recorded failures in the systems examined, a quantitative statement about risk or safety requires the use of PRA methods.

6. REFERENCES

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APPENDIX A

ACRONYMS AND CODES FOR THE AGING FAILURE SURVEY

APPENDIX A

ACRONYMS AND CODES FOR THE AGING FAILURE SURVEY

Table A-1. Failure category assignments for NPRDS codes

Design & Installation (D)			
NPRDS Cause Categories:	A	-	Engineering/Design
	C	-	Manufacturing Defect
	D	-	Installation Error
NPRDS Causes:	AB		Foreign/Incorrect Material
	AC		Particulate Contamination
	AF		Weld Related
	AG		Abnormal Stress
	AY		Electrical Overload
	AZ		Material Defect
	BC		Out of Mechanical Adjustment
	BE		Dirty
	BF		Blocked/Obstructed
Aging (A)			
NPRDS Cause Categories:	H	-	Wearout
NPRDS Causes:	AC		Particulate Contamination
	AD		Normal/Abnormal Wear
	AE		Lubrication Problem
	AG		Abnormal Stress
	AL		Set Point Drift
	AR		Insulation Breakdown
	AS		Short/Grounded
	AT		Open Circuit
	AU		Contacts Burned/Pitted/Corroded
	AV		Connection Defective/Loose Parts
	AW		Circuit Defective
	AX		Burned/Burned Out
	AY		Electrical Overload
	AZ		Material Defect
	BB		Mechanical Damage/Binding
	BC		Out of Mechanical Adjustment
	BD		Aging/Cyclic Fatigue
	BE		Dirty
	BF		Blocked/Obstructed
	BG		Corrosion
	BH		Out of Calibration
Testing & Maintenance (T)			
NPRDS Cause Categories:	F	-	Maintenance/Testing
NPRDS Causes:	AG		Abnormal Stress
	AN		Incorrect Procedure
	AR		Insulation Breakdown
	AW		Circuit Defective
	AY		Electrical Overload
	BC		Out of Mechanical Adjustment
	BJ		Incorrect Action

Table A-1. (continued)

Human Related (H)		
NPRDS Cause Categories:	B -	Incorrect Procedure
	E -	Operating Error
NPRDS Causes:	AA	Foreign/Wrong Part
	AE	Lubrication Problem
	AL	Set Point Drift
	AM	Previous Repair/Installation Status
	AN	Incorrect Procedure
	AV	Connection Defective/Loose Parts
	AW	Circuit Defective
	AY	Electrical Overload
	BC	Out of Mechanical Adjustment
	BJ	Incorrect Action
Other/Unknown (O)		
NPRDS Cause Categories:	J -	Other
	K -	Unknown
NPRDS Causes:		Any of the causes apply as long as the cause categories are the two listed above.

Table A-2. NPRDS component acronyms

ACCUMU	- Accumulators
AIRDRY	- Air/Gas Dryers
ANNUNC	- Annunciator Modules
BATTRY	- Batteries and Chargers
BLOWER	- Blowers (Compressors)
CKTBRK	- Circuit Closers/Interrupters
ELECON	- Electrical Conductors
ENGINE	- Engines, Internal Combustion
FILTER	- Filters/Strainers
GENERA	- Generators/Inverters/Alternators
HEATER	- Heaters, Electric
HTEXCH	- Heat Exchangers
IBISSW	- Instrumentation, Bistable/Switch
ICNTRL	- Instrumentation, Controllers
INDREC	- Instrumentation, Indicators/Recorders
INTCPM	- Instrumentation, Integrator/Computation Module
IPWSUP	- Instrumentation, Electronic Power Supply
ISODEV	- Instrumentation, Isolation Device
IXMITR	- Instrumentation, Transmitter/Element
MECFUN	- Mechanical Function Units
MOTOR	- Motors
PIPE	- Pipe, Fittings
PUMP	- Pumps
RELAY	- Relays
SUPORT	- Shock Suppressors and Supports
TRANSF	- Transformers
TURBIN	- Turbines
VALVE	- Valves and Dampers
VALVOP	- Valve Operators

Table A-3. NPRDS system effect descriptions

A -	Loss of System Function - A component failure that, by itself, results in the system being unable to perform its intended function (i.e., all trains, channels, etc., inoperable).
B -	Degraded System Operation - The system is capable of fulfilling its intended function, but some feature of the system is impaired.
C -	Loss of Redundancy - Loss of one system functional path.
D -	Loss of Subsystem/Channel - A partial loss of system functional path.
E -	System Function Unaffected - Failure did not affect the operation of the system.

APPENDIX B

REPORTED FAILURE CAUSE IDENTIFICATION INFORMATION

APPENDIX B

REPORTED FAILURE CAUSE IDENTIFICATION INFORMATION

Failure Cause Coding

This appendix contains information concerning the failure cause coding form (Figure B-1) used to compile the analysis data. The data fields of the coding form were developed such that necessary information could be gathered in a concise manner amenable to constructing a failure cause data base. Many of the fields were obtained directly from the Nuclear Plant Reliability Data System (NPRDS) record format. Table B-1 shows those fields having one-to-one correspondence.

The failure cause coding form used for this study is a modification of the form used in the Root Causes of Component Failures Program. The following new fields were added: System Initial Conditions, System Effect, Event Date, In-Service Date, Age, and Out of Service. The latter four fields are discussed in the footnotes of Figure B-1. A field called "Aging" was also added to indicate if the failure was considered to be age-related. This was necessary to tabulate the aging failures, since many causes of failure may or may not be age-related. A field for the report number was included to relate the coding form to the specific NPRDS record. Two fields (Secondary Failure Mode-Component and Secondary Failure Mode-Subcomponent) were also added. These fields provide more detail about how the component itself and its piece parts failed.

Additional information concerning the failure cause coding can be found in *Root Causes of Component Failures Program: Methods and Applications*, NUREG/CR-4616, EGG-2455, December 1986.

Failure Cause/Aging Categorization Scheme

The failure cause categorization scheme and guidelines for aging failure classification are presented in this Appendix. This categorization scheme is based upon the failure cause categorization developed for use in the Root Causes of Components Failures Program and provides a means of identifying and collecting reportable mechanisms of failure for components contained in reactor systems. For use in the NRC Nuclear Plant Aging Research (NPAR) Program, the scheme has been expanded to provide guidelines for identifying aging-related failures to the degree of certainty allowable by the event data source. This entails identification of aging-related failures on the basis of certain causes or effects described in the failure record narratives.

The categorization scheme consists of three levels. The first, and most general, level of failure cause categorization is represented by a one-character code. It is comprised of five categories: design/manufacturing/construction/quality assurance inadequacy (D), environmental stress (E), human actions (H), supervision/management inadequacy (S), and unclassifiable cause (U).

The second level of categorization is a further resolution of the first level. For example, supervision/management inadequacy (S) is divided into the following second-level headings: contractor/other personnel inadequacy (SC), inadequate human environment (SH), procedures inadequacy (SP), and training inadequacy (ST). All second-level failure causes are designated by 2-character codes.

The third level of cause resolution is the finest available for use and is designated by a 3-character code. For example, the second-level entry for procedures inadequacy (SP) is divided into the following third-level causes: calibration procedures (SPC), maintenance procedures (SPM), operational procedures (SPO), quality assurance procedures (SPQ), and testing/surveillance procedures (SPT). It should be noted that for the purpose of aging-related failure determination, many of the third level causes tend to be more related to failure effect codes than true failure causes that would be determinable by component engineering studies.

Although the unclassifiable cause (U) category is broken down into second and third levels, the third-level codes indicate the effect of the failure and are not considered to be true failure causes. These third-level entries are used because the failure causes are unidentifiable from the failure report.

Using the definition in Section 3.1, the aging classification scheme was developed to allow a procedural approach to be taken in the identification of aging failures. Each failure cause code is

Plant ID:

Docket Number:

Report Type: NPRDS

Report Number:

Plant Type:

Plant Group:

Manufacturer:[b]

Model Number:[d]

Util. Component ID:

Safety Class:

PC Record Number: ____________

	Person	Date
Coding:		
Quality Assurance:		

Failure Sequences: ____________

Sequences this page : ____________

CCF: ____________

Event Date:[a] ____________

In-Service Date:[c] ____________

Age:[e] ____________

Out-of-Service: YES/NO

Out-of-Service (replacement) Date:[f] ____

	CODE	DESCRIPTION
FAILURE CAUSE		
Supplemental Cause		
Agree w/NPRDS	YES/NO	
Aging	YES/NO/UNK	
COMPONENT		
Subcomponent		
FAILURE MODE: COMPONENT		
Subcomponent		
SECONDARY FAILURE MODE: COMPONENT		
Subcomponent		
SYSTEM		
System Initial Conditions		
System Effect		
INTERFACING SYSTEM		
METHOD OF DISCOVERY		
UNIT: INITIAL CONDITIONS		
Unit Effect		

	Testing Performed	Frequency/Interval	Hours OOS
TESTING	Check Testing		
INTERVAL	Functional Testing		
	Calibration Testing		

Reference Reports:[g]
Pertinent Information:
Comments:
Failure Cause Key Phrases:

Figure B-1. Failure cause coding form.

EXPLANATION OF FOOTNOTES

a. Event Date (or date failure occurred)--The date or estimated date that the system or component first became unable to operate at an acceptable level.

b. Manufacturer--The company that manufactured the component.

c. In-Service Date--The actual date the system or component went into service.

d. Model Number--The number used by the manufacturer to identify the component.

e. Age--This is the time to failure based on elapsed time from in-service date to event date.

f. Out-of-Service Date--(a) If the out-of-service date is given in the NPRDS 2C-Component Engineering Report, use of this date as the out-of-service date shows the date that the old component was replaced with an identical component, or equivalent. (b) If no out-of-service date is given in the 2C report, use the Event Date (EDATE) given in the 4C-Component Failure Report if there was an indication that the component was repaired.

g. Reference Reports--If a Licensee Event Report (LER) was indicated, used the actual LER number. If the record stated that an LER was submitted, the analyst stated "LER submitted." Also, utility document numbers concerning analysis of a failure were recorded.

Figure B-1 (continued)

Table B-1. Cross-reference fields between the NPRDS records and the failure cause coding form

NPRDS		
Report	Field	Failure Cause Coding Form Field
2C-Component Engineering Report	—	Plant Identification[a]
		Docket Number
		Report Type
		Report Number[b]
	UNITID	Plant Group[b]
	SYSTEM	System[b]
	UTILITY COMPONENT ID	Utility Component Identification[b]
	NSSS	Plant Type[c]
	—	Age
	ISDATE[d]	In-Service Date
	OSDATE[d]	Out-Of-Service Date (if specified)
	SCLASS[d]	Safety Class
	MFG[d]	Manufacturer
	MFG MODEL NO[d]	Model Number
	CTFREQ[d]	Check-Testing Frequency
	CTHRS[d]	Check-Testing Out-Of-Service Hours
	FFREG[d]	Functional Testing Frequency
	FCODE[d]	Functional Testing Interval Code
	FHRS[d]	Functional Testing Out-of-Service Hours
	CALFREQ[d]	Calibration Testing Frequency
	CALCODE[d]	Calibration Testing Interval Code
	CALHRS[d]	Calibration Testing Out-Of-Service Hours
4C-Component Failure Report	SDATE[d]	Event Date[b]
	STATUS[d]	System Initial Conditions[d]
	DETECT[d]	Method of Discovery
	FAILURE DESCRIPTION	Method of Discovery
		Failure Mode—Component
		Reference Reports
	CAUSE CAT	Root Cause
	CAUSE	Root Cause
	SYS EFF[d]	System Effect[d]
	PL EFF[d]	Unit Effect[d]
	CAUSE OF FAILURE	Subcomponent
		Root Cause
		Root Cause Key Phrases
	CORRECTIVE ACTION	Comments

a. Plant ID is the fourth to seventh digit from UNITID field.

b. Necessary fields to retrieve NPRDS record.

c. Plant group: A - B&W for PWRs and C - GE for BWRs.

d. Taken directly from the NPRDS records.

assigned one of three aging classifications: non-aging, conditional aging, or aging. Aging-related failure cause codes are codes that always relate to time-dependent effects. Examples of these time-dependent codes are "erosion," "corrosion," and "wear." Non-aging-related failure cause codes are used for random events that cause immediate failure of the component. Examples of these types of failure causes are "fire/smoke," "impact loads," and "electromagnetic interference." Conditional aging failures are classified as aging-related if information in the failure report indicates some aging-related effect code (from the categorization scheme) or some keyword that indicates that a time-dependent process is present. A failure categorized with a conditional aging code is classified non-aging if the failure description indicates that a random event caused an immediate failure. In some instances, a failure description contains enough information to allow categorization with a conditional code but gives no indication as to whether the failure was random or aging-related in nature. In this latter case, the failure will be assigned an "unknown" classification.

Table B-2 presents the failure cause categorization and aging classification scheme. It is followed by the definitions of the failure causes and guidelines for establishing the aging classification.

Table B-2. Failure cause categorization and aging classification scheme

D Design/manufacturing/construction/quality assurance inadequacy

- DC Construction error or inadequacy - conditional aging-related
  - DCI Initial construction activity
  - DCR Retrofit construction activity
- DE Design error or inadequacy - conditional aging-related
  - DEI Initial design activity
  - DER Retrofit design activity
- DM Manufacturing error or inadequacy - conditional aging-related
- DQ Quality assurance error or inadequacy - non-aging-related
  - DQD Initial design quality assurance activity
  - DQE Retrofit design quality assurance activity
  - DQI Initial construction quality assurance activity
  - DQM Manufacturer quality assurance activity
  - DQR Retrofit construction quality assurance activity
- DR Plant definition requirements inadequacy - conditional aging-related
  - DRI Initial definition activity
  - DRR Retrofit definition activity

Table B-2. (continued)

E Environmental stress

EA Animate causes

EAB Metal-sheathed bacteria - aging-related

EAE Animal encroachment - conditional aging-related

EAO Aquatic organisms - conditional aging-related

EB Materials interaction

EBB Embrittlement - aging-related

EBC Cavitation - conditional aging-related

EBE Erosion - aging-related

EBF Cyclic fatigue - aging-related

EBM Materials defect - conditional aging-related

EBR Wear - aging-related

EBS Steam impingement - non-aging-related

EBW Weld-related flaw - conditional aging-related

EC Chemical reactions

ECC Corrosion - aging-related

ECE Electrolysis - aging-related

ECF Foaming - non-aging-related

ECS Stratification - conditional aging-related

ED Mechanical failure

EDB Binding/out of adjustment - conditional aging-related

EDF Friction - non-aging-related

EDI Foreign materials intrusion - conditional aging-related

EDL Improper level - non-aging-related

EDO Mechanical overload - conditional aging-related

EDS Set point drift - aging-related

EDT Out of calibration - conditional aging-related

EDU Improper lubrication - conditional aging-related

EDW Improper flow - non-aging-related

Table B-2. (continued)

EE Electromagnetic interference - non-aging-related

- EEI Inadvertent electrical energy exposure
- EEM Magnetic field exposure
- EEN Noise

EF Fire/smoke - non-aging-related

EH Human-caused event - non-aging-related

- EHD Deliberate acts
- EHU Unintentional acts

EI Impact loads - non-aging-related

EL Electrical failure

- ELA Arcing - conditional aging-related
- ELC Over/under current - conditional aging-related
- ELD Set point drift - aging-related
- ELE Electrical overload - conditional aging-related
- ELF Faulty module - conditional aging-related
- ELG Abnormal specific gravity - conditional aging-related
- ELH Abnormal resistance - aging-related
- ELI Insulation breakdown - conditional aging-related
- ELK Contact failure - conditional aging-related
- ELL End of life - aging-related
- ELO Open circuit - conditional aging-related
- ELR Erroneous/spurious signal - non-aging-related
- ELS Short circuit - conditional aging-related
- ELT Out of calibration - conditional aging-related
- ELV Over/under voltage - conditional aging-related
- ELW Winding/coil failure - conditional aging-related

EM Moisture

- EMH High humidity - conditional aging-related
- EMI Icing - non-aging-related

Table B-2. (continued)

EML Low humidity - non-aging-related

EMW Water intrusion - conditional aging-related

EN Acts of nature

ENA Atmospheric conditions - conditional aging-related

ENG Geological/geographic conditions - non-aging-related

ENM Meteorological conditions - non-aging-related

EP Pressure - non-aging-related

EPF Fluctuating pressure

EPH High pressure

EPI Improper differential pressure

EPL Low pressure

ER Radiation - aging-related

ERH High-level radiation

ERL Low-level radiation

ET Temperature - conditional aging-related

ETF Fluctuating temperature

ETH High temperature

ETI Improper differential temperature

ETL Low temperature

EV Vibration loads - conditional aging-related

EVF Flow-induced vibration

EVM Mechanical vibration

H Human actions

HA Accidental action - non-aging-related

HAC Calibration activity

HAM Maintenance activity

HAO Operations activity

HAQ Quality assurance activity

HAT Testing/surveillance activity

Table B-2. (continued)

- HC Communication problem - non-aging-related
  - HCC Calibration activity
  - HCM Maintenance activity
  - HCO Operations activity
  - HCQ Quality assurance activity
  - HCT Testing/surveillance activity
- HE Human error (practices) - conditional aging-related
  - HEC Calibration activity
  - HEM Maintenance activity
  - HEO Operations activity
  - HEQ Quality assurance activity
  - HET Testing/surveillance activity
- HM Misdiagnosis - conditional aging-related
  - HMC Calibration activity
  - HMM Maintenance activity
  - HMO Operations activity
  - HMQ Quality assurance activity
  - HMT Testing/surveillance activity
- HP Failure to follow procedures - conditional aging-related
  - HPC Calibration activity
  - HPM Maintenance activity
  - HPO Operations activity
  - HPQ Quality assurance activity
  - HPT Testing/surveillance activity

S Supervision/management inadequacy

- SC Contractor/other personnel inadequacy - non-aging-related
- SH Inadequate human environment (hazardous) - non-aging-related
  - SHC Calibration activity
  - SHM Maintenance activity

Table B-2. (continued)

		SHO	Operations activity
		SHQ	Quality assurance activity
		SHT	Testing/surveillance activity
	SP	Procedures inadequacy - conditional aging-related	
		SPC	Calibration procedures
		SPM	Maintenance procedures
		SPO	Operational procedures
		SPQ	Quality assurance procedures
		SPT	Testing/surveillance procedures
	ST	Training inadequacy - conditional aging-related	
		STC	Calibration activity
		STM	Maintenance activity
		STO	Operations activity
		STQ	Quality assurance activity
		STT	Testing/surveillance activity
U	Unclassifiable cause - conditional aging-related		
	UA	Aging/wearout - aging-related	
	UE	Effects displayed - conditional aging-related	
		UEB	Burned out
		UEC	Closed
		UEE	Bent/overstressed
		UEF	Computer malfunction
		UEK	Broken
		UEL	Leakage
		UEM	Missing/misplaced
		UEO	Open
		UES	Loose
		UET	Tight
	UN	No effects displayed - conditional aging-related	

Definitions

The definitions for each of the entries in the failure cause categorization scheme are presented in this section.

D *Design/Manufacturing/Construction/Quality Assurance Inadequacy*

This is the group of causes associated with decisions or events that generally take place before the plant is operational. These causes are usually outside the purview of operations personnel.

DC *Construction Error or Inadequacy*

The DC code is used when the constructors do not follow instructions, abuse equipment, or use poor practices in matters normally left to the judgment of the installers.

Aging Classification: Conditional aging - Errors or inadequacies associated with these causes can cause accelerated aging. In order for a failure to be classified as aging-related when using one of these codes, the failure description must also contain an aging-related environmental stress effect or failure cause (described under the environmental codes) resulting from the error or inadequacy.

DCI *Initial Construction Activity*

DCR *Retrofit Construction Activity*

DE *Design Error or Inadequacy*

This code is applied where the designer uses a wrong table or equation, errs in making a calculation, allows inadequate margin, misapplies equipment, or fails to provide error-free drawings and specifications to manufacturing.

Aging Classification: Conditional aging - Errors or inadequacies associated with these causes can cause accelerated aging. In order for a failure to be classified as aging-related when using one of these codes, the failure description must also contain an aging-related environmental stress effect or failure cause (described under the environmental codes) resulting from the error or inadequacy.

DEI *Initial Design Activity*

DER *Retrofit Design Activity*

DM *Manufacturing Error or Inadequacy*

The DM code is applied when manufacturing personnel do not follow the designer's instructions, allow manufacturing processes to go out of control, or allow damage to occur to the manufactured items while in storage.

Aging Classification: Conditional aging - Errors or inadequacies associated with these causes can cause accelerated aging. In order for a failure to be classified as aging-related when using one of these codes, the failure description must also contain an aging-related environmental stress effect or failure cause (described under the environmental codes) resulting from the error or inadequacy.

DQ *Quality Assurance Error or Inadequacy*

This code is applied when design, construction, or manufacturing personnel do not properly perform quality assurance on this work.

Aging Classification: Non-aging - failures resulting from accelerated aging caused by design, construction, or manufacturing activities would be coded under those failure codes, not quality assurance codes.

DQD *Initial Design Quality Assurance Activity*

DQE *Retrofit Design Quality Assurance Activity*

DQI *Initial Construction Quality Assurance Activity*

DQM *Manufacturer Quality Assurance Activity*

DQR *Retrofit Construction Quality Assurance Activity*

DR *Plant Definition Requirements Inadequacy*

This is the most basic design-related inadequacy—the failure to provide the proper set of design requirements for the component. For example, the design requirements call for an ambient temperature of 100°F, whereas the actual temperature frequently exceeds 115°F.

Aging Classification: Conditional aging - Inadequacies associated with these causes can cause accelerated aging. In order for a failure to be classified as aging-related when using one of these codes, the failure description must also contain an aging-related environmental stress effect or failure cause (described under the environmental codes) resulting from the inadequacy.

DRI *Initial Definition Activity*

DRR *Retrofit Definition Activity*

E *Environmental Stress*

The following cause codes represent actual causes of failures. In many cases, the codes stand for the effects produced by mechanisms that may not be identified by the failure descriptions. Therefore, for the purpose of categorization, the terms "effect" and "cause" can be used interchangeably. These cause codes apply to environmental stresses that may be either the sole cause or one of two or more causes that together are the cause of a component failure. Generally, an abnormal stress may be a sole cause, whereas an ambient stress usually acts in conjunction with another cause. With the exception of the "acts of nature" and "human caused events," the stresses are considered to be induced by the plant environment.

EA *Animate Causes*

This cause code relates to failures involving nonhuman animate causes.

EAB *Metal Sheathed Bacteria*

This cause code refers to growth of bacteria that attack pipe walls.

Aging classification: Aging - The process of bacterial attack on piping walls results in a degradation that is time-dependent.

EAE *Animal Encroachment*

Code refers to invasion by animals, such as rats, field mice, and birds.

Aging Classification: Conditional aging - The occurrence of animal encroachment is not generally considered aging-related, since the action would result in an immediate equipment failure particularly in items such as electrical cabinets. The gradual accumulation of animal debris, causing degradation of electrical equipment in a panel, is considered to be aging-related.

EAO *Aquatic Organisms*

This includes invasion by aquatic organisms such as fish and snails.

Aging Classification: Conditional aging - In general, failures resulting from the intrusion of aquatic animals are not considered aging-related. However, buildup of organisms such as algae, etc., constitute a time-dependent process and as such are considered aging-related. Failures resulting from the latter would normally contain indications of foreign material intrusion, and gradual accumulation, in the failure description.

EB *Materials Interaction*

This category includes causes arising from the interaction or interfacing of materials in components, between components, or between solids and liquids.

EBB *Embrittlement*

The EBB code represents a materials problem brought about by the environment a component is in, such as high-temperature effects on seals or high-level radiation exposure. Embrittlement may lead to cracking.

Aging Classification: Aging - Embrittlement is a time-dependent degradation of material properties.

EBC *Cavitation*

Cavitation is a hydraulic phenomenon of a liquid changing into a gaseous phase in a region of low liquid pressure. The vapor bubbles can later collapse, causing shock waves and damage to chamber walls.

Aging Classification: Conditional aging - Cavitation results from system conditions resulting from random events, poor design, or misapplication of hydraulic equipment. Cavitation will generally produce an immediate degradation of the system or equipment such as pumps. In this situation, cavitation is considered non-aging. The code is considered to be aging-related if the cavitation has caused erosion, such as in thinning of pipe walls or pitting and eroding pump impellers.

EBE *Erosion*

Erosion refers to processes where the surfaces of a component are gradually diminished. These processes are caused by a flowing medium, such as a liquid, gas, or slurry, impinging on the component.

Aging Classification: Aging - Erosion is the time-dependent removal of material by some active agent.

EBF *Cyclic Fatigue*

This is a failure cause in metals and some plastics where repeated or cyclic loading yields cracking or fracture.

Aging Classification: Aging - Cyclic fatigue is a time-dependent degradation of material properties.

EBM *Materials Defect*

This cause code includes pores and voids.

Aging Classification: Conditional aging - Defective or weakened materials can result in the effective accelerated aging of a component operating in its design environment. In this situation, the cause (or effect) is classified as aging. Material defects can also cause component failure once placed in operation. In the latter situation, the code is not considered aging because an immediate failure occurs.

EBR *Wear*

This refers to the process of relative movement between parts of a component gradually deteriorating the contact surfaces. The EBR code includes abrasion, galling, and fretting.

Aging Classification: Aging - Degradation from this cause (or effect) is time-dependent in nature.

EBS *Steam Impingement*

This cause code refers to high temperature and high humidity events.

Aging Classification: Non-aging - This cause (or effect) refers to immediate failure due to a random event causing high temperature or humidity.

EBW *Weld Related Flaw*

The EBW code includes any materials problems, such as cracking, which occur in welds or in the heat-affected zone.

Aging Classification: Conditional aging - Defective or weakened welds can result in the effective accelerated aging of a component operating in its design environment. In this situation, the cause (or effect) is classified as aging. Weld defects can also cause component failure when first placed in operation. In the latter situation, the code is not considered aging because the failure will be immediate.

EC *Chemical Reactions*

This cause code applies to chemical reactions between the component and chemicals in the process or in the environment that cause corrosion, foaming, or electrolysis.

ECC *Corrosion*

This cause has several forms: corrosive agent exposure, galvanic corrosion, oxidation corrosion, stress corrosion/intergranular stress corrosion cracking (IGSCC).

Aging Classification: Aging - All forms of corrosion entail the time-dependent degradation by some agent.

ECE *Electrolysis*

The ECE code refers to the decomposition of a substance by electric current.

Aging Classification: Aging - The decomposition of a substance through electrolysis is a time-dependent process. Therefore, any failures attributable to this cause are considered aging-related.

ECF *Foaming*

This code refers to a frothing that is caused by chemical impurities.

Aging Classification: Non-aging - Chemical impurities entering a system in concentrations high enough to cause frothing would result in the immediate degradation of the system or component performance.

ECS *Stratification*

The ECS code refers to a condition where a formerly mixed chemical substance separates and forms layers of constituent elements.

Aging Classification: Conditional aging - Stratification of chemicals is a time-dependent process usually occurring in battery chemicals. Particularly in the case of battery power degradation, the cause (or effect) is considered to be aging. This code is considered to be conditional aging so as not to preclude immediate performance degradations in other systems where chemicals are mixed.

ED *Mechanical Failures*

This cause category applies to all failures found in mechanisms, machines, and mechanical devices. This includes valve operators and circuit breaker mechanisms.

EDB *Binding/Out of Adjustment*

This applies mainly to shafts, but can be used for other failures as well. It should not be used for a component that is out of calibration.

Aging Classification: Conditional aging - Binding/out of adjustment due to a maintenance activity or thermal stress on the system usually results in the immediate failure of the component and is considered to be non-aging. However, cases occur where the problem is not serious enough to cause immediate failure. In this situation, accelerated aging can occur. The failure would be classified aging only if information exists in the failure description linking an aging failure cause (or effect) with the binding/out of adjustment condition.

EDF *Friction*

The EDF code is mainly intended to describe the process where heat is produced by excessive contact of moving parts; but it can have other applications, such as flow friction.

Aging Classification: Non-aging - This code is primarily an effect code resulting from items such as loss of or improper lubrication, binding/out of adjustment, etc. Therefore, the aging classification is assigned to the cause of the friction.

EDI *Foreign Materials Intrusion*

This code includes blockage/obstruction, dirt, and particulate contamination.

Aging Classification: Conditional aging - Situations where equipment failures occur due to the build up of some material resulting from the action of a time-dependent agent are classified as aging. Blockages due to random events are non-aging.

EDL *Improper Level*

The EDL cause code includes high/low level and fluctuating level.

Aging Classification: Non-aging - This code represents an immediately detectable system condition due to an event consisting of either a random or aging-related failure of some component. The aging classification would be assigned to the failure cause of the component. This code should not be used for lubrication incidents.

EDO *Mechanical Overload*

The EDO code refers to force or stress greater than design capabilities, either demanded or received from a machine or mechanism.

Aging Classification: Conditional aging - In general, this cause (or effect) applies to events where an overload condition caused by some other event leads to an immediate failure. Since the continual application of overload conditions will lead to degradation of equipment, the cause (or effect) is considered to be aging-related if the failure description indicates that the condition has existed for some period of time.

EDS *Set Point Drift*

This cause code refers to mechanical set points that change over time, such as spring tension in relief valves.

Aging Classification: Aging - The drift of mechanical set points requires the time-dependent change of material properties.

EDT *Out of Calibration*

The EDT cause code refers to mechanical items that fall out of calibration and do not perform as required. This code should only be used when no better information is available. For example: cable drive slips on a strip-chart recorder so the pen does not mark at the true indication. "Zero adjustment" faults are also included here.

Aging Classification: Conditional aging - This cause (or effect) code may be the result of random actions that disturb the equipment. A common example would be maintenance errors. This code is analogous to drift when a time-dependent aging phenomenon is involved. In order for this code to be classified as aging, some indication of a time dependence must be present in the failure description.

EDU *Improper Lubrication*

This cause code applies to loss-of-lubrication incidents. Other lubrication problems should be covered by personnel codes.

Aging Classification: Conditional aging - Improper lubrication can cause accelerated aging when not detected. To classify a failure, using this code, as aging, there must be an aging effect code identifiable in the failure description.

EDW *Improper Flow*

The EDW cause code includes high/low flow, no flow, and pulsating flow.

Aging Classification: Non-aging - This code represents an immediately detectable system condition due to either a random or aging-related failure of some component. The aging classification would be assigned to the failure cause of the component.

EE *Electromagnetic Interference*

This cause code applies to all electromagnetic interferences generated by equipment in or around the plant. It does not include lightning, an "act of nature."

Aging Classification: Non-aging - Electrical failures resulting from these causes (or effects) are considered to be random.

EEI *Inadvertent Electrical Energy Exposure*

The EEI code includes static charge buildup.

EEM *Magnetic Field Exposure*

This cause code includes magnetization of ferritic components.

EEN *Noise*

Noise is the generation of random electrical impulses that are transmitted with signals.

EF *Fire/Smoke*

This cause code applies to fire or any form of combustion. This stress may be due to heat or the combustion products. This could be inside or outside the plant.

Aging Classification: Non-aging - Fires result in immediate dagradation of equipment performance.

EH *Human Caused Event*

This code refers to human actions that are outside normal operation of the plant (i.e., the personnel involved, if they are plant employees, caused a failure doing something other than the performance of their jobs). Nonplant personnel may be antagonistic and/or violent.

Aging Classification: Non-aging - Failures resulting from human actions are random events.

EHD *Deliberate Acts*

This code includes malicious mischief.

EHU *Unintentional Acts*

The EHU code includes transportation accidents and industrial accidents.

EI *Impact Loads*

This cause code applies to impact loads imposed on a component. Examples are component damage by a falling body or distortion of a check valve caused by water hammer. These could affect the component either internally or externally.

Aging Classification: Non-aging - Failures resulting from impacts are random events. Events such as water hammer are precluded by operational procedures. Should continuing water hammer events degrade a system, the failure would be classified aging under a procedural cause code.

EL *Electrical Failure*

This cause code is used for electrical items where more detailed information is not obtainable. These causes interfere with the function of electrical components.

ELA *Arcing*

Arcing is a condition of electric current breaking down air and spanning a gap between open contacts.

Aging Classification: Conditional aging - In general, this cause (or effect) would result in immediate failure of the electrical component. However, in the case of contacts eroding or wearing via multiple switch or relay opening and closure, the cause would be considered aging.

ELC *Over/Under Current*

This code refers to a condition of too high or too low current.

Aging Classification: Conditional aging - In general, this cause (or effect) applies to events where over/under current conditions caused by some other event lead to an immediate failure. Since the continual application of over/under current conditions will lead to degradation of equipment, the cause (or effect) is considered to be aging-related if the failure description indicates that the condition has existed for some period of time, such as longer than a maintenance interval.

ELD *Set Point Drift*

This code refers to electrical equipment varying from a fixed setting for starting a process, stopping a process, or modifying a process.

Aging Classification: Aging - Set point drift of electrical components requires the time-dependent degradation of the material electrical properties.

ELE *Electrical Overload*

The ELE code refers to more power demanded or delivered than the component is designed for.

Aging Classification: Conditional aging - In general, this cause (or effect) applies to events where an overload condition caused by some other event leads to an immediate failure. Since the continual application of overload conditions will lead to degradation of equipment, the cause (or effect) is considered to be aging-related if the failure description indicates that the condition has existed for some period of time, such as longer than a maintenance interval.

ELF *Faulty Module*

Faulty module refers to a condition where an electrical unit composed of more than one solid-state component (such as an amplifier, circuit board, integrated circuit, etc.) does not perform its function. The cause for failure to perform is likely to be undetermined.

Aging Classification: Conditional aging - In general, the cause will be aging-related because a component in the module failed due to continued operation at stressful conditions, such as abnormal temperature, excessive vibration, or electrical overload. Some cases will exist where the failure is due to mishandling or a single event; in those cases, the failure is non-aging.

ELG *Abnormal Specific Gravity*

Abnormal specific gravity refers to a condition of the electrolyte in a lead-acid storage battery. Specific gravity is an indicator of the charge of a battery. Low specific gravity indicates a low state of charge. Abnormal specific gravity is usually low, but some situations can cause the measured specific gravity to be high.

Aging Classification: Conditional aging - When the failure description indicates that the abnormal specific gravity is related to an aged battery that can no longer be successfully charged, the failure is age-related. In some cases, the specific gravity will be low because the battery had not been charged or because water had been recently added; the failure cause is then non-age-related.

ELH *Abnormal Resistance*

Abnormal resistance refers to a condition in which the resistance is not as expected but is neither a short circuit or an open circuit. Windings, coils, and contacts in switches, relays, or connectors can have an abnormal resistance that prevents proper operation.

Aging Classification: Aging-related - Abnormal resistance is caused by corrosion, insulation breakdown, or other time-related effects that either increase or decrease the resistance of the circuit.

ELI *Insulation Breakdown*

The ELI code refers to a degraded condition of electrical insulation that allows current to seek a path through the insulation.

Aging Classification: Conditional aging - In general, the cause (or effect) will be aging-related since the decomposition of insulation is a time-dependent process. Cases will exist, however, where the insulation was damaged by an random event, such as impact. In the latter situ-

ELK *Contact Failure*

Contact failure refers to a condition of a relay when the failure is known to be at the contact rather than the coil but additional information is not provided. The event could be a failure of the contact to close, to open, or to make proper electrical contact even though it mechanically operated, such as would happen with corroded contacts.

Aging Classification: Conditional aging - If the failure description indicated the existence of time-related factors, the failure is age-related. If the failure is caused by a single event, such as over-current damaging the contacts, the failure is non-age-related.

ELL *End of Life*

End of life is a condition in which the failure is attributed to the component being old or having reached its natural end of life without providing more detailed information.

Aging Classification: Aging-related - The stated condition is end of life.

ELO *Open Circuit*

Open circuit is a condition where the resistance between two conductors of a electrical circuit is very large. Examples include broken wires, wires coming loose from terminals, connectors becoming loose, and excessive corrosion at connections.

Aging Classification: Conditional aging - In general, this condition would result in immediate failure of the circuit to perform its intended function. However, in the case of connections corroding or wires breaking due to continual flexing or frequent handling, the cause would be considered aging.

ELR *Erroneous/Spurious Signal*

The ELR code refers to a signal that is unwanted or unneeded, sometimes generated by electrical noise.

Aging Classification: Non-aging - This cause (or effect) is considered a random event.

ELS *Short Circuit*

Short circuit refers to a condition is which the resistance between two conductors or between a conductor and ground is very small and much less than normal for that particular circuit.

Aging Classification: Conditional aging - Often this condition will be age-related, since short circuits usually result from a breakdown in insulation which is a time-dependent process. Cases will exist where the short circuit is a result of damaged insulation or some event that causes a mechanical connection of the two conductors. In the latter situation, the failure is non-aging-related.

ELT *Out of Calibration*

The ELT code refers to a component being out of calibration and not performing as required. Sending a signal at an incorrect voltage is an example of out of calibration.

Aging Classification: Conditional aging - This cause (or effect) code may be the result of random actions that disturb the equipment. A common example would be maintenance errors. This code is analogous to drift when a time-dependent aging phenomenon is involved. In order for this code to be classified as aging, some indication of a time dependence must be present in the failure description.

ELV *Over/Under Voltage*

This code refers to a condition of too high or too low voltage.

Aging Classification: Conditional aging - In general, this cause (or effect) applies to events where over/under voltage conditions caused by some other event lead to an immediate failure. But since the continual application of over/under voltage conditions will lead to degradation of equipment, the cause (or effect) is considered to be aging-related if the failure description indicates that the condition has existed for some period of time, such as longer than a maintenance interval.

ELW *Winding/Coil Failure*

Winding/coil failure is a condition in which a winding/coil in a motor, solenoid, relay, switch, etc. has failed (often burned out) but the cause of the failure is not defined. Causes could be a result of a failure within the winding/coil or a result of some adverse condition that was applied.

Aging Classification: Conditional aging - Failures as a result of insulation breakdown or continued operation at elevated temperature or in a high humidity environment would be aging-related. Failures as a result of a single event would be non-aging-related.

EM *Moisture*

This cause code is applied to ice, water, or water vapor in the environment that causes a component failure. Spray and flood are two examples.

EMH *High Humidity*

The EMH code refers to high humidity inside the power plant.

Aging Classification: Conditional aging - The presence of moisture in high concentrations has degrading effects on equipment and is addressed by equipment qualification standards. A failure that can be categorized using this code is classified as aging-related if the failure reports contain indications of other aging-related effects, such as corrosion.

EMI *Icing*

The EMI code refers to icing inside the plant, such as in ice condenser units.

Aging Classification: Non-aging - Icing of equipment will result in the immediate failure of the affected equipment.

EML *Low Humidity*

This refers to lower-than-normal humidity inside the power plant.

Aging Classification: Non-aging - Equipment qualification standards do not consider low humidity a concern to component operational life.

EMW *Water Intrusion*

The EMW code refers to water entering the plant from outside or for water intruding from area to area inside the plant.

Aging Classification: Conditional aging - In general, the intrusion of water is a random event and will cause immediate equipment failure. Undetected and uncorrected water intrusion can cause accelerated aging. For this situation, the failure description must also identify aging-related effects to be classified as aging.

EN *Acts of Nature*

This cause code applies very selectively to those causes that are in no way induced by the plant itself, such as earthquakes, tornadoes, floods, lightning, and precipitation.

ENA *Atmospheric Conditions*

The ENA code is used for conditions that are more or less stable and originate due to climate or other location-dependent conditions. This includes high or low barometric pressure, high or low atmospheric temperature, and saline atmosphere.

Aging Classification - Conditional aging - Equipment failures attributable to atmospheric conditions would be considered aging-related if other effect or failure causes such as corrosion or foreign materials intrusion were present in the failure description. These types of effects could result from atmospheric conditions, such as high saline content or winds with high dust content.

ENG *Geological/Geographic Conditions*

This includes avalanche, landslide/mudslide, and seismic activity.

Aging Classification - Non-aging - These types of conditions or events result in immediate equipment failure.

ENM *Meteorological Conditions*

This includes weather conditions, such as electrical storm, high wind, hurricane, lightning, tornado, tsunami, rain or freezing rain, hail, and snow.

Aging Classification - Non-aging - This code is used where these types of conditions or events result in immediate equipment failure.

EP *Pressure*

This code is applied to liquid and gas system pressure problems. It does not include barometric pressure (code ENA).

Aging Classification: Non-aging - Plant design and operations are established to control pressure. Therefore, failures related to pressure would result from procedural or equipment failures. Aging classification would be reserved for the failures causing the pressure transient.

EPF *Fluctuating Pressure*

EPH *High Pressure*

EPI *Improper Differential Pressure*

EPL *Low Pressure*

ER *Radiation*

This cause code applies to damage due to radiation (i.e., alpha, beta, gamma, neutrons, or combinations thereof).

Aging Classification: Aging - Material property degradation due to radiation is considered to be aging-related.

ERH *High Level Radiation*

ERL *Low Level Radiation*

ET *Temperature*

The ET cause code applies to the stress caused by abnormal temperatures within the plant.

Aging Classification: Conditional aging - Temperature effects can cause embrittlement or other material degradation, such as loss of plasticity or degradation of electrical equipment. Improper differential temperatures can cause binding or wear so as to eventually degrade a component. These effects are time-dependent, and failures labeled with these codes are classified as aging if the failure description identifies the presence of aging-related effects.

ETF *Fluctuating Temperature*

ETH *High Temperature*

ETI *Improper Differential Temperature*

ETL *Low Temperature*

EV *Vibration Loads*

This cause code applies to vibration-induced loads imposed on a component from sources within the plant. For example, vibration from rotating machinery causes the loosening of screws within a circuit breaker.

Aging Classification: Conditional aging - Vibration will cause accelerated aging to occur. The categorization of a failure using these codes is classified aging if one of the aging effect codes, such as cyclic fatigue or wear, can be identified in the failure description. Vibration would be considered non-aging if, for example, a pump were out of adjustment and began vibrating to the point that it destroyed itself or a piece part of the pump very quickly.

EVF *Flow Induced Vibration*

EVM *Mechanical Vibration*

H *Human Actions*

These are human errors of omission, commission, and accidental human actions committed during plant operation and maintenance. ("Design inadequacies" and "procedure inadequacies" are of human origin also, but are remote from the on-line decisions that must be made by a plant operator.)

HA *Accidental Action*

The HA code is used when the human action is purely accidental. For example, the plant operator is correctly following the appropriate calibration procedure, but the screwdriver slips and short-circuits the signal line.

Aging Classification: Non-aging - These causes refer to immediate equipment failures resulting from accidental actions.

HAC *Calibration Activity*

HAM *Maintenance Activity*

HAO *Operations Activity*

HAQ *Quality Assurance Activity*

HAT *Testing/Surveillance Activity*

HC *Communication Problem*

This cause code is used when personnel encounter a communication discrepancy or problem, either written (such as ambiguous plant orders or memos) or oral (such as poor telephone connections or noise). This code is not used for difficulties with procedures.

Aging Classification: Non-aging - These causes refer to immediate events resulting from poor communications.

HCC *Calibration Activity*

HCM *Maintenance Activity*

HCO *Operations Activity*

HCQ *Quality Assurance Activity*

HCT *Testing/Surveillance Activity*

HE *Human Error*

This HE code is used when personnel perpetrate an error of commission by exceeding an appropriate procedure. An example is when an operator overtorques a valve when directed to close it. These types of errors are usually termed "good practice" errors.

Aging Classification: Conditional aging - Actions associated with these causes can cause accelerated aging. In order for a failure to be classified as aging-related when using one of these codes, the failure description must also contain an aging-related environmental stress effect or failure cause (described under the environmental codes) resulting from the error.

HEC *Calibration Activity*

HEM *Maintenance Activity*

HEO *Operations Activity*

HEQ *Quality Assurance Activity*

HET *Testing/Surveillance Activity*

HM *Misdiagnosis (Followed Wrong Procedures)*

The HM cause code applies when plant personnel, through misdiagnosis, choose the wrong procedure to follow.

Aging Classification: Conditional aging - Actions associated with these causes can cause accelerated aging. In order for a failure to be classified as aging-related when using one of these codes, the failure description must also contain an aging-related environmental stress effect or failure cause (described under the environmental codes) resulting from the error.

HMC *Calibration Activity*

HMM *Maintenance Activity*

HMO *Operations Activity*

HMQ *Quality Assurance Activity*

HMT *Testing/Surveillance Activity*

HP *Failure to Follow Procedures*

This HP code is used when the procedures are correct but plant personnel fail to follow the procedures.

Aging Classification: Conditional aging - Actions associated with these causes can cause accelerated aging. In order for a failure to be classified as aging-related when using one of these codes, the failure description must also contain an aging-related environmental stress effect or failure cause (described under the environmental codes) resulting from the error.

HPC *Calibration Activity*

HPM *Maintenance Activity*

HPO *Operations Activity*

HPQ *Quality Assurance Activity*

HPT *Testing/Surveillance Activity*

S *Supervision/Management Inadequacy*

This group of causes pertains to utility management. It includes failure areas of management or supervision. Management is considered responsible for non-plant personnel working within the plant. Inadequate procedures and inadequate training programs arise from improper managerial control. It is considered an error in supervision to send personnel into a hazardous environment without proper protective clothing.

SC *Contractor/Other Personnel Activity*

The SC code applies to contractors or other non-plant personnel who are working in the plant area, but are not plant employees. This code is used for errors such as a contractor inadvertently tripping a circuit breaker in the work location or incorrectly performing a function so as to cause a component to fail.

Aging Classification: Non-aging - The cause refers to immediate failures resulting from human interaction.

SH *Inadequate Human Environment*

The SH code is used when the working environment is hazardous or extreme, containing such factors as high heat, excess noise, steam leakages, or high radiation.

Aging Classification - Non-aging - These causes refers to immediate failures resulting from human interaction due to environmental stress.

SHC *Calibration Activity*

SHM *Maintenance Activity*

SHO *Operations Activity*

SHQ *Quality Assurance Activity*

SHT *Testing/Surveillance Activity*

SP *Procedures Inadequacy*

This is the group of causes associated with procedures, written or not, that are the prescribed way of operating and maintaining the equipment. Inadequate procedures include ambiguous, incomplete, or erroneous procedures. An ambiguous procedure is one that lacks clarity, or one that can easily be misinterpreted. An incomplete procedure is one that omits an important detail or assumes the operator knows more than is normally expected. An erroneous procedure is one that, if followed exactly, would lead to an undesirable result.

Aging Classification: Conditional aging - Inadequacies associated with these causes can cause accelerated aging. In order for a failure to be classified as aging-related when using one of these codes, the failure description must also contain an aging-related environmental stress effect or failure cause (described under the environmental codes) resulting from the inadequacy.

SPC *Calibration Procedures*

The SPC code applies to procedures on when and how to check for calibration error, and how to recalibrate.

SPM *Maintenance Procedures*

This code applies to procedures on when and how to maintain the plant equipment. It includes schedules and procedures for preventative maintenance, as well as procedures for repairing failed equipment.

SPO *Operational Procedures*

The SPO code applies to procedures on how to operate the plant, as well as procedures that tell operators when and how to start, stop, and make operating adjustments in equipment.

SPQ *Quality Assurance Procedures*

SPQ applies to procedures on how to check and ensure the quality of plant equipment.

SPT *Testing/Surveillance Procedures*

SPT applies to procedures on when and how to test plant equipment and follow surveillance instructions.

ST *Training Inadequacy*

The ST cause codes are used to describe personnel who fail to perform their function properly because of poor or improper training, or because of unfamiliarity with the power plant.

Aging Classification: Conditional aging - Inadequacies associated with these causes can cause accelerated aging. In order for a failure to be classified as aging-related when using one of these codes, the failure description must also contain an aging-related environmental stress effect or failure cause (described under the environmental codes) resulting from the inadequacy.

STC *Calibration Activity*

STM *Maintenance Activity*

STO *Operations Activity*

STQ *Quality Assurance Activity*

STT *Testing/Surveillance Activity*

U *Unclassifiable Cause*

This code should only be used as a last resort. It is used when the cause is simply not stated within the failure report. Often the effect is stated, so the third level was generated to retain and show the effect displayed by the component.

Aging Classification: Conditional aging - Failures categorized with these codes are considered to be conditional aging-related. If the failure description indicates that an unidentifiable, time-dependent process has occurred, the failure would be classified as "unclassifiable aging/wearout." If the failure description indicates an unidentifiable random event or provides no indication of what caused the failure, then the failure would be classified non-aging or unknown and one of the UE codes would be used.

UA *Unclassifiable Aging/Wearout*

UE *Effects Displayed*

UEB *Burned Out*

The UEB cause code is used to indicate a loss of function due to adverse electrical energy exposure.

UEC *Closed*

UEE *Bent*

UEF *Computer Malfunction*

UEF covers computer-oriented problems whose nature is not well explained. Resolution down to hardware or software faults should be covered with the other cause categories (hardware faults—E codes, software faults—D or S codes).

UEK *Broken*

UEL *Leakage*

This code is used for between systems leakage (internal) and for out-of-system leakage (external).

UEM *Missing/Misplaced*

UEO *Open*

UES *Loose*

UET *Tight*

UN *No Effect Displayed*

APPENDIX C

COMPONENT BOUNDARIES FOR THE FAILURE CAUSE IDENTIFICATION STUDY

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COMPONENT BOUNDARIES FOR THE FAILURE CAUSE IDENTIFICATION STUDY

This appendix describes the component boundaries used in the root cause identification study. Examples of subcomponents and piece parts are also given for each of the components.

Battery Chargers

Battery chargers are units composed of transformers and rectifiers. The transformer converts the alternating current (AC) input voltage to a lower AC voltage, and the rectifier converts alternating current to a direct current (DC) voltage which is filtered. Protection electrical devices and monitoring instrumentation also exist to ensure adequate operation (no overcharging, for example). A cooling system is likely to be internal to the battery charger as well. The boundary includes the output breaker between the charger and the battery.

Piece Parts:

- Transformer (with subcomponents)
- Rectifiers (with subcomponents)
- Circuit breaker (with subcomponents)
- Protective electronics
- Monitoring instrumentation
- Wiring
- Connectors
- Switches
- Filters
- Cooling subsystem (fans, for example)

Buses

Buses are bars of conducting material, such as copper or aluminum. These are generally located inside switchgear cabinets. Connectors are used to join cables to buses. The component boundary is around the bar itself and the connectors. Cables are considered separately. Circuit breakers or motor starters that may have a direct mechanical connection are also considered separately.

Cables

Electrical cables consist of one or more conducting material(s), usually strands of copper or aluminum, surrounded by insulated materials. Multiple conductors are individually insulated. Insulating materials are generally rubber, asbestos, enamel coatings, mineral oil impregnated paper, or various plastics.

The boundary is around the cable perimeter. Terminals and connectors are considered separately.

Circuit Breakers

The component boundary is the breaker casing itself, including the internals such as the mechanism that moves the contacts, power lead connectors, and circuitry (such as relays). The control power and line power cables are not considered to be part of the circuit breaker.

Piece Parts:

- Arc suppressor
- Bearing
- Bushing
- Cable
- Casing
- Circuit board
- Coil
- Connector
- Contacts
- Converter
- Drive pawl
- Fuse
- Indicator
- Lockout device
- Latch
- Motor
- Plunger
- Relays
- Solenoid
- Spring
- Switch

Emergency Diesel Generators

The boundary for emergency diesel generators is the diesel engine, generator, and associated subsystems. These subsystems include the lube oil system, fuel system, starting air system, cooling system, and engine exhaust system. The amount and type of subcomponents are numerous. The output power leads out of the generator, up to and including the output circuit breaker, are included in the component boundary. The cooling systems include heat exchangers that provide an interface to the essential service water system, but not the piping associated with the service water.

It should be noted that several types of valves, such as gate or globe valves, may appear in failure reports as part of emergency diesel generator subsystems. This will be treated as a subcomponent of the diesel generator system, and the failure of the diesel generator will be reported.

Components:

Principal System

- Cables
- Circuit breakers
- Diesel engines (with associated components and piece parts)
- Generator (with associated components and piece parts)
- Governors
- Instrumentation and control circuits
- Relays
- Switches
- Voltage regulator

Lube Oil System

- Filters
- Gaskets
- Heat exchangers
- Heaters
- Motors
- Pipes, supports, hangers
- Pumps
- Valves and valve operators
- Dip stick

Fuel System

- Filters
- Gaskets
- Motors
- Pipes, supports, hangers
- Pumps
- Tanks
- Valves and valve operators

Starting Air System

- Air tank
- Compressors
- Filters
- Gaskets
- Piping, supports, hangers
- Valves and valve operators

Cooling Systems

- Heat exchangers
- Heaters
- Motors
- Piping, supports, hangers
- Pumps
- Valves and valve operators
- Tanks
- Indicators (level, temperature, pressure)

Engine Exhaust System

- Piping
- Baffles
- Gaskets
- Covers

Filter/Strainer

A filter is a device containing a porous material through which fluid is passed to remove suspended impurities or to recover solids. The filter resides in a housing, which holds and supports the filter material and also provides a pressure boundary.

Filters range in complexity from a filter material in a housing to self-cleaning or traveling screens. The boundary for the self-cleaning type includes spray nozzles, refuse troughs, a pump, motor, and sometimes a space heater to ensure continuous operation during subfreezing temperature conditions. The boundary for the simple filter encloses the housing and the filter material.

Filter/Strainer (continued)

Piece Parts:

- Filter material
- Housing
- Vent valves
- Drain valves
- Pump
- Motor
- Refuse troughs
- Spray nozzles
- Space heater
- Piping from pump to nozzle

Inverters

Inverters convert DC power into AC power suitable for use for instrumentation. The boundary around the inverter encloses the casing but stops at the input and output leads. An inverter is sometimes referred to as an uninterruptible power supply.

Piece Parts:

- Annunciator control card
- Capacitor
- Choke
- Control card/module
- Cooling fan
- Diode
- Driver board
- Firing circuit
- Frequency board
- Fuse
- Inductor
- Internal power supply
- Oscillator
- Protection card
- Rectifier
- Relay
- Resister
- Switch
- Transformer
- Transistor
- Undervoltage coil
- Undervoltage trip
- Voltage regulator

Measurement System[a]

A measurement system or subsystem consists of one or more measurement devices and any other necessary subsystem elements interconnected to perform a complete measurement from the sensor to the output. A measurement subsystem is divided into general functional groups consisting of primary detector, intermediate means, and the end device. The definitions of these functional groups are as follows:

Primary Detector (sensing element or initial element)—The primary detector is the first subsystem element or group of elements that responds quantitatively to the parameter being measured and performs the initial measurement operation.

Intermediate Means—The intermediate means includes all subsystem elements that are used to perform necessary and distinct operations in the measurement sequence between the primary detector and the end device. It adapts the operational results of the primary detector to the input requirements of the end device.

End Device—An end device is the final subsystem element that responds quantitatively to the parameter being measured and performs the final measurement operation. It performs the final conversion of measurement energy to an indication, record, or the initiation of control.

The components of the measurement subsystem are:

- Pressure indicator
- Flow indicator
- Temperature indicator
- Pressure indicator control
- Temperature indicator control
- Level transmitter
- Inverter
- Position switch
- Pressure switch
- Level switch
- Temperature switch

a. Strictly speaking, a measurement system is a purist concept. In practice, it is altered to fit the conditions of the engineer. For instance, root cause analysis deals with systems containing mechanical subsystems and electrical subsystems. In this case, a measurement system is considered a subsystem.

Measurement System (continued)

Piece Parts (continued):

Pressure differential switch
Timer
Thermowell[a]
Cable

Motor-Driven Pumps

For these pumps, the component boundary is chosen to be the pump unit and the driver. The pump unit description is the same as that for the turbine driver. The pump motor driver boundary is around the driver housing and shaft coupling. Power failures are not considered. Some motor-driven pumps may have a reducing gear for variable speed of the pump shaft. This special coupling is included within the boundary. Any lubrication systems are also included.

Piece Parts:

Electric motor with internals
Housing/stator
Stator windings
Rotor body
Rotor windings
Magnets
Bearings
Motor shaft

Coupling to pump unit
Pump unit
  Casing/housing
  Impeller
  Shaft
  Bearings
  Seals (see information below)
  Suction
Lubrication subsystem

Pump Seals

Pump seal failures will generally be described in pump reports; however, they can be considered separately. Some pumps have complicated seals. A seal is defined as a material "packed" about a shaft (or between metal parts by either compression or mechanical action to hold it in place). Mechanical seals use extremely close gaps so a fluid film forms and keeps leakage acceptably low.

a. A piece of material (e.g., pipe) that protrudes into the system boundary and forms a pressure boundary of the system. The function of the thermowell is to measure the temperature inside the system boundary.

Packing Materials:

Asbestos
Carbon
Graphite
TFE (Tetrafluoroethylene compounds, i.e. Teflons)
Glass fiber
Metals [aluminum, copper, or Babbitt (an antifriction alloy of tin, copper and antimony)]
O and T rings of various elastomers

Mechanical seals:

Generally these are fine tolerance metal parts. Spring loaded rings or injection fluids may be used.

Pipes

Pipes include the following:

Elbows
Tees
Junctions
Unions (flanged or welded connection)
Tubing

Pipes and extruded tubing are in this category. The component boundary is the outer wall of the pipe or tubing. A junction is viewed as a small diameter pipe welded to the side of a larger diameter pipe. In this case, the weld is considered as part of the junction. A union is a connection between two similar diameter pipes, either a flanged and/or welded connection.

Piece Parts:

Pipes
Tubing

Rectifiers

Generally, a rectifier converts alternating current to direct current. It is composed of diodes (usually solid state but may be selenium or mercury valves) that are connected to each other.

The boundary is around the rectifier casing.

Rectifiers (continued)

Piece Parts:

- Connectors
- Casing
- Cooling fan
- Diodes

Relays

The boundary around a relay includes the casing, coil, and contacts. Control or line power faults are outside the boundary.

Piece Parts:

- Solenoid coil
- Contacts
- Wires
- Springs
- Connectors

Supports and Snubbers

These complex devices are used to accommodate thermal movement, hydraulic transient loads, and seismic event loads in piping and components in accordance with American Society of Mechanical Engineers (ASME) code requirements. They include constant supports (CS), variable spring supports (VSS), mechanical snubbers (MS), and hydraulic snubbers (HS). The boundary encompasses the attachment to the pipe or component, the attachment to the beam or other appurtenances, all external auxiliary systems that support the device, and the device per se. The piece parts for these devices are shown in the following matrix (Table C-1).

Table C-1. Supports and snubbers piece parts

	Device			
	CS	VSS	MS	HS
Housing/body/cylinder	X	X	X	X
Wiper				X
Turnbuckle	X			
Reservoir				X
Rod/Hanger		X		
Bleed Plug				X
Welded Attachment	X	X		
Clamp				X
Steal Beam	X			
Filter				X
Valve				X
Travel Scale	X	X		
Spring	X	X	X	
Nut	X	X	X	
Washer	X			
Plate	X			X
Piston				X
Pivot		X		
Shaft			X	X
Bearing		X	X	
Inertia Mass			X	
Torque Trans. Drum			X	
Cylinder End Plug			X	
Telescoping Cylinder			X	
Paddle				X
Head				X

Transformers

The component boundary is the transformer casing itself, including the internals such as the core and wire winding. Cables are not considered as part of the boundary.

Piece Parts:

- Bushings
- Casing (perhaps an oil bath, too)
- Coil windings
- Connectors
- Core
- (some transformers may have a cooling subsystem for an oil bath or cooling fans)

Over-Pressure Protection Valves

This category includes the following:

- Code safety valves
- Power-operated relief valves
- Safety/relief valves

These are specific valves for safety applications. Code safety valves are safety valves that meet the requirements of the ASME Boiler and Pressure Vessel Code. This type of valve uses spring pressure to hold the valve disc shut against the system pressure. It is totally self-activated and is used for quick relief of excessive system pressure. The component boundary is around the valve surface. The welds that join the valve base and outlet to the associated pipes are included with the pipe component.

Power-operated relief valves (PORVs) are controlled either automatically or manually. These valves generally have a pilot tube and solenoid plunger to control the valve disc (closure member) motion. The component boundary is treated the same as that for a code safety valve, with the inclusion of the solenoid and plunger. Power leads are outside the boundary.

A safety/relief valve is another type of pressure relief valve. This valve, like the PORV, can be operated automatically or manually. The component boundary is treated the same as above, with the boundary over the valve surface and welds included in the piping system.

Piece Parts:

Code Safety Valve

- Adjusting screw
- Base
- Bonnet
- Cap
- Disc
- Disc guide
- Packing
- Seat
- Spindle
- Spring

Power-Operated Relief Valve

- Body
- Lever
- Packing
- Pilot valve disc
- Pilot valve seat
- Piston
- Plunger
- Solenoid or other operator
- Spring
- Switch
- Valve disc
- Valve seat

Safety/Relief Valve

- Base
- Compression screw
- Disc
- Drop lever
- Lifting gear
- Operator
- Packing
- Seat
- Spindle
- Spring
- Yoke

Check Valves

Check valves are considered to be simpler than air- or motor-operated valves. The check valve is designed to permit only one-directional flow.

Piece Parts:

- Valve body
- Valve closure member
- Hinge
- Access panel
- Bolts, seals

Motor-Operated Valves

The boundary around a motor-operated valve includes the valve and the motor operator. The valve is defined as the valve body, all internals, and seals. The motor operator is defined as all components inside the motor housing that are necessary to make the valve function correctly. The control power and main power cables are outside the boundary.

Valve Piece Parts:

- Valve stem
- Yoke
- Packing
- Packing follower
- Bonnet
- Closure member
- Flange
- Valve body
- Bolts, nuts
- Valve seat
- Seals

Motor Operator Piece Parts:

- Electric motor with internals
  - Housing/stator
  - Stator windings
  - Rotor body
  - Magnets
  - Bearings
  - Motor shaft
- Gears
- Limit switch
- Torque switch
- Manual operator
- Valve stem connection
- Housing assembly

Air-Operated Valves

The air-operated valve boundary is similar to the motor-operated valve boundary. The valve parts are basically the same, however, the operator is different. Loss of air pressure to the operator is not considered to be a valve or operator fault.

Valve Piece Parts:

- Valve stem
- Yoke
- Packing
- Packing follower
- Bonnet
- Closure member
- Flange
- Valve body
- Bolts, nuts
- Valve seat
- Seals

Air Operator Piece Parts:

- Actuator housing
- Air chamber
- Diaphragm
- Spring
- Actuator shaft, coupling
- Bolts
- Linkages
- Pneumatic positioner unit with internals (this unit is not generic to all valve operator designs.)
- Air flow control valve (solenoid operated).

Manual Valves

The boundary around a manual valve includes the valve body and actuator. The valve body is defined as including all internals and seals.

Valve Piece Parts:

- Valve stem
- Valve stem connection
- Yoke
- Packing
- Packing follower
- Bonnet
- Closure member
- Flange
- Valve body
- Bolts, nuts
- Valve seat
- Seals
- Mechanical stop

Welds

A weld is the joint between two pipes, formed by either heat or pressure or both, as well as the use of a filler material for the gap between pipes. For this definition, the heat-affected zone in the pipe material is included with the weld.

Piece Parts:

- Welds
- Filler material
- Heat-affected zone of piping or tubing

APPENDIX D

FAILURE MODE CODES AND DEFINITIONS

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FAILURE MODE CODES AND DEFINITIONS

Table D-1. Failure mode codes

Component	Code	Description
Battery/Battery Charging Unit	GLF	Loss of function (no output)
Bus	GLF	Loss of function
Cable	GLF	Loss of function
Circuit Breaker	GFP	Fails to operate
	GSO	Opens (premature)
Diesel Generator	GFS	Fails to start
	GFU	Fails to run
	GNF	No failure (only used when diesel generator is still operable despite subcomponent failure)
Filter/Strainer	GLF	Loss of function
	GPL	Plugged
Hanger/Snubber/Support	GLF	Loss of function
Instrumentation	GFP	Fails to operate
	GEE	Erroneous/erratic signal
Inverter	GLF	Loss of function
Motor	GFU	Fails to run
Pipe	GRU	Rupture
	GPL	Plugged
Power Supply, Electric	GLF	Loss of function
Motor-Driven Pump	GFS	Fails to start
	GFU	Fails to run
	GEL	External leakage
Turbine-Driven pump	GFS	Fails to start
	GFU	Fails to run
	GEL	External leakage
Relay	GFC	Fails to close (normally open)
	GFO	Fails to open (normally closed)
	GSH	Short circuit
	GFP	Fails to operate (energize)
Thermowell	GLF	Loss of function

Table D-1. (continued)

Component	Code	Description
Timer	GLF	Loss of function
Transformer	GLF	Loss of function
Valves (general)	GFO	Fails to open
	GFC	Fails to close
	GEL	External leakage
	GFR	Fails to operate as required
	GOC	Fails to open/fails to close
	GPL	Plugged (fails to remain open)
Check Valve	GFO	Fails to open
	GIL	Internal leakage (reverse leakage)
	GEL	External leakage
Motor-Operated Valve	GFO	Fails to open
	GFC	Fails to close
	GEL	External leakage
	GPL	Plugged (fails to remain open)
	GFR	Fails to operate as required
	GOC	Fails to open/fails to close
Pneumatic Valve	GFO	Fails to open
	GFC	Fails to close
	GEL	External leakage
	GPL	Plugged (fails to remain open)
	GFR	Fails to operate as required
	GOC	Fails to open/fails to close
Relief/Safety Valve	GFO	Fails to open
	GSO	Opens (premature)
	GFC	Fails to close (reseat)
Vent Valve	GFO	Fails to open
	GFC	Fails to close
	GEL	External leakage
	GFR	Fails to operate as required
	GOC	Fails to open/fails to close
	GPL	Plugged (fails to remain open)

Table D-2. Failure mode descriptions

Battery/Battery Charging Unit

1. Loss of function—This failure mode is the inability of the charging unit to perform its function to specifications or the lack of specified output from the battery.

Bus

1. Loss of function—This failure mode is the inability of the bus to perform its intended function.

Cable

1. Loss of function—This failure mode is the inability of the cable to transmit the correct signals. An example of this type of failure mode is insulation breakdown around the cable producing a short or ground.

Circuit Breaker

1. Fails to operate—This failure mode describes the circuit breaker that does not function properly. It can either fail to open or fail to close on demand.

2. Opens (Premature)—This failure mode is the opening of the circuit breaker prior to demand.

Diesel Generator

1. Fails to start—Fails to start encompasses diesel generator failures that resulted from the diesel failing to start, failing to reach rated speed and voltage once a start sequence was initiated, and failing to achieve expected loading (kW).

2. Fails to run—Failure to run mode is any failure of an operating diesel generator to supply power to the emergency bus, given that the diesel generator had undergone a successful start. It also includes the spurious stopping of the diesel generator and the inability of the diesel generator to continue to run as demanded.

3. No failure—The diesel generator does not fail when the narrative states that the diesel generator is still operable despite the failure of a subcomponent in one of the diesel generator's subsystems. An example of this is when a cooling pump fails but a back-up pump is available for the diesel generator involved.

Filter/Strainer

1. Loss of function—This is the inability of the filter/strainer to perform its intended function.

2. Plugged—This includes plugging of the filter/strainer.

Hanger/Snubber/Support

1. Loss of function—This is the failure of the component to provide the pipe with the necessary support and it is the inability of a snubber to perform to seismic requirements.

Instrumentation

1. Fails to operate—This failure mode is the inability of the instrument to perform its function.

2. Erroneous/Erratic signal—Erroneous or erratic signals are produced by the instrument.

Table D-2. (continued)

Inverter

1. Loss of function—This is the failure of the inverter to perform its intended function to specified requirements.

Motor

1. Fails to run—This failure mode is the inability of a motor to run as required.

Pipe

1. Rupture—Rupture of a pipe is a break in the pipe that can or does produce leakage of the contained medium.

2. Plugged—Plugging of a pipe is a restriction of flow of the contained medium.

Power Supply, Electric

1. Loss of function—This is the failure of the power supply to provide the required amount of power to the interfacing component.

Pump

1. Fails to start—This failure mode is used to describe faults involving pumps that did not start upon demand or which started and only operated for a brief period of time before tripping off-line.

2. Fails to run—Fails to run indicates that an operating pump was automatically or manually tripped off-line to prevent damage to the pump. It also includes pumps that fail to run to specifications.

3. External leakage—The leakage failure mode describes a fault in which the pump is operational, but is removed from service because of excessive leakage of the pumped medium. A common example of this mode is a packing leak.

Relay

1. Fails to close—Fails to close is the failure of a normally open relay to close upon demand.

2. Fails to open—Fails to open is the failure of a normally closed relay to open upon demand.

3. Short circuit—This failure mode describes short circuit of either a normally open or normally closed relay. This may include the improper operations of the relay.

4. Fails to operate (energize)—This failure mode is the failure of the relay to operate due to lack of an input signal.

Thermowell

1. Loss of function—This failure mode is the inability of the thermowell to perform its function. This includes leaks around the thermowell.

Timer

1. Loss of function—This failure mode is the inability of the timer to perform its function.

Table D-2. (continued)

Transformer

1. Loss of function—This failure mode is the inability of the transformer to continue to function properly.

Valve

1. Fails to open—Valve fails to open fully when demanded.

2. Fails to close—Valve fails to close fully when demanded. This includes safety/relief valves failing to reseat.

3. External leakage—A leak or rupture of the valve that would allow the contained medium to escape from the component boundary. The most common example of this mode is a flange leak.

4. Plugged (fails to remain open)—This failure mode refers to any event that would stop or limit flow through a normally open valve. Valves that fail to open or valves that are either intentionally or unintentionally closed by human action when required open are not considered plugged valves. Two examples of a plugging event are (a) a valve disc that separates from the stem and falls into the closed position and (b) the air supply to an air-operated valve fails, allowing the valve to drift closed.

5. Fails to operate as required—The fails-to-operate-as-required mode is to be used whenever (a) a valve fails to meet specific requirements such as stroke time or (b) a valve loses the ability to control system parameters.

6. Fails to open/fails to close—This failure mode is used when the narrative lacks specific information on whether the valve failed to open or failed to close.

7. Internal leakage (reverse leakage)—Reverse leakage is a mode used to describe internal leakage through a check valve.

8. Opens (premature)—This failure mode applies strictly to relief and safety valves. A relief or safety valve opening prior to its pressure setting is a typical example of this mode; however, the cause of a "premature open" is not always a pressure transient.

APPENDIX E

AGING FAILURE SURVEY INFORMATION

APPENDIX E

AGING FAILURE SURVEY INFORMATION

Appendix E is divided into nine subsections. These subsections contain information pertinent to the nine systems analyzed and appear in the following order:

1. Class 1E electrical power distribution system (1E)
2. Auxiliary feedwater system (AFW)
3. Component cooling water system (CCW)
4. High-pressure injection system (HPIS)
5. Main feedwater system (MFW)
6. Reactor protection trip system (RPS)
7. Residual heat removal system (RHR)
8. Service water system (SWS)
9. Standby liquid control system (SBL).

The following tabular information is provided for each subsection:

1. A listing of the NSSS, system, and component codes and descriptions present in the data for that specific system. This listing is provided for ease of interpreting the codes used in the tables.
2. A table summarizing the total counts per failure category and total counts per system effect category with the corresponding overall fractions per category. These failure fractions were calculated by dividing the total counts within a failure category or system effect category by the total failure counts for that system.
3. A summary table indicating the total counts for the major component divisions and the corresponding fractions for the five major failure categories. These component/failure-category fractions were calculated by dividing the total failure counts per component/failure-category by the total failure counts per component within the appropriate system.
4. Detailed aging tallies tables (on microfiche inside back cover). These tables display the detailed breakdown for the data by component, system effect, failure category, and age of component at time of failure. The information is presented in these tables by NSSS, system or subsystem, and component. For each NSSS/system/component combination, a failure total and system effect breakdown is enumerated. The failure total indicates the total failure counts for that particular NSSS/system/component combination. The system effect number (sys. eff. no.) indicates the total number of failures for that NSSS/system/component that resulted in that system effect.

Table E-1. Class 1E electrical power distribution system

NSSS:	A-BABCOCK & WILCOX C-GENERAL ELECTRIC E-WESTINGHOUSE	
SYSTEM:	A-BABCOCK & WILCOX EBE-PLANT AC POWER EBG-INSTRUMENT AC POWER ECD-DC POWER EEC-EMERGENCY POWER EECDAA-DIESEL STARTING AIR EECDCA-DIESEL COOLING WATER EECFOA-DIESEL FUEL OIL EECLOA-DIESEL LUBE OIL	
	C-GENERAL ELECTRIC EBA-PLANT AC DISTRIBUTION EBJ-INSTRUMENT AC POWER ECB-DC POWER EEA-EMERGENCY POWER EEADAA-DIESEL STARTING AIR EEADCA-DIESEL COOLING WATER EEAFOA-DIESEL FUEL OIL EEALOA-DIESEL LUBE OIL	
	E-WESTINGHOUSE EBF-PLANT AC POWER EBK-INSTRUMENT AC POWER ECC-DC POWER EEB-EMERGENCY POWER EEBDAA-DIESEL STARTING AIR EEBDCA-DIESEL COOLING WATER EEBLOA-DIESEL LUBE OIL	
COMPONENTS:	ACCUMU	INDREC
	AIRDRY	INTCPM
	ANNUNC	IPWSUP
	BATTRY	IXMITR
	BLOWER	MECFUN
	CKTBRK	MOTOR
	ELECON	PIPE
	ENGINE	PUMP
	FILTER	RELAY
	GENERA	TRANSF
	HEATER	TURBIN
	HTEXCH	VALVE
	IBISSW	VALVOP
	ICNTRL	

Table E-2. Class 1E electrical power distribution system totals and fractions

Failure Category Totals		
Design Failures	=	259
Aging Failures	=	716
Test and Maintenance Failures	=	143
Human-Related Failures	=	46
Other Failures	=	1027
Total		2191
Failure Category Fractions		
Design Fraction	=	0.118
Aging Fraction	=	0.327
Test and Maintenance Fraction	=	0.065
Human-Related Fraction	=	0.021
Other Fraction	=	0.469
System Effect Totals		
Loss of System Function	=	51
Degraded System Operation	=	380
Loss of Redundancy	=	627
Loss of Subsystem/Channel	=	582
System Function Unaffected	=	551
Total		2191
System Effect Fractions		
Loss of System Function Fraction	=	0.023
Degraded System Operation Fraction	=	0.173
Loss of Redundancy Fraction	=	0.286
Loss of Subsystem/Channel Fraction	=	0.266
System Function Unaffected Fraction	=	0.251

Table E-3. Class 1E electrical power distribution system component failure category fractions[a]

Component	Total	Design	Aging	Testing	Human	Other
Pipe	3	—	0.667	—	—	0.333
Pump	60	0.067	0.633	0.100	—	0.200
Valve Operator	8	0.125	0.625	—	—	0.250
Blower: Compressor	215	0.005	0.623	0.056	0.005	0.312
Motor	30	0.100	0.600	0.067	—	0.233
Valve	150	0.173	0.587	0.060	0.007	0.173
Electronic Power Supply	2	—	0.500	—	—	0.500
Airdry	4	—	0.500	—	—	0.500
Heat Exchanger	14	—	0.429	—	—	0.571
Instrumentation: Indicators	5	—	0.400	0.200	—	0.400
Heater	11	0.182	0.364	0.091	—	0.364
Battery	242	0.107	0.326	0.045	0.025	0.496
Engine	496	0.131	0.256	0.099	0.028	0.486
Mechanical Function Unit	55	0.109	0.255	0.091	0.055	0.491
Relay	88	0.125	0.250	0.045	0.034	0.545
Generator/Alternator/ Inverter/Dynometer	390	0.115	0.236	0.033	0.015	0.600
Instrumentation: Switch	87	0.069	0.230	0.069	0.011	0.621
Filter	9	0.444	0.222	0.222	—	0.111
Circuit Breaker	241	0.145	0.212	0.058	0.046	0.539
Turbine	5	0.200	0.200	—	—	0.600
Instrumentation: Transmitter	15	0.067	0.133	0.200	—	0.600
Transformer	30	0.233	0.133	0.033	—	0.600
Electrical Conductors	24	0.542	0.083	0.125	—	0.250

Table E-3. (continued)

Component	Total	Design	Aging	Testing	Human	Other
Instrumentation: Computation Module	1	—	—	1.000	—	—
Accumulator	2	—	—	—	—	1.000
Annunciator	1	—	—	—	—	1.000
Instrumentation: Controller	3	0.667	—	—	—	0.333

a. Components ordered by aging fraction.

Table E-4. Auxiliary feedwater system

NSSS:	A-BABCOCK & WILCOX E-WESTINGHOUSE
SYSTEM:	A-BABCOCK & WILCOX HHB-EMERGENCY FEEDWATER
	E-WESTINGHOUSE HHC-AUXILIARY FEEDWATER
COMPONENTS:	ANNUNC CKTBRK ENGINE IBISSW ICNTRL INDREC INTCPM IPWSUP ISODEV IXMITR MECFUN MOTOR PIPE PUMP RELAY SUPORT TURBIN VALVE VALVOP

Table E-5. Auxiliary feedwater system totals and fractions

Failure Category Totals		
Design Failures	=	85
Aging Failures	=	258
Test and Maintenance Failures	=	73
Human-Related Failures	=	15
Other Failures	=	398
Total		829
Failure Category Fractions		
Design Fraction	=	0.103
Aging Fraction	=	0.311
Test and Maintenance Fraction	=	0.088
Human-Related Fraction	=	0.018
Other Fraction	=	0.480
System Effect Totals		
Loss of System Function	=	5
Degraded System Operation	=	161
Loss of Redundancy	=	153
Loss of Subsystem/Channel	=	255
System Function Unaffected	=	255
Total		829
System Effect Fractions		
Loss of System Function Fraction	=	0.006
Degraded System Operation Fraction	=	0.194
Loss of Redundancy Fraction	=	0.185
Loss of Subsystem/Channel Fraction	=	0.308
System Function Unaffected Fraction	=	0.308

Table E-6. Auxiliary feedwater system component failure category fractions[a]

Component	Total	Design	Aging	Testing	Human	Other
Annunciator	1	—	1.000	—	—	—
Valve	267	0.097	0.521	0.082	0.007	0.292
Instrumentation: Isolation Device	2	—	0.500	—	—	0.500
Instrumentation: Computation Module	26	—	0.385	0.115	—	0.500
Instrumentation: Controller	47	0.043	0.340	0.021	—	0.596
Instrumentation: Electrical Power Supply	3	0.333	0.333	—	—	0.333
Relay	12	0.250	0.333	0.167	—	0.250
Valve Operator	103	0.078	0.252	0.107	0.019	0.544
Instrumentation: Switch	24	0.042	0.250	—	—	0.708
Pump	110	0.091	0.245	0.091	0.027	0.545
Pipe	5	0.400	0.200	—	—	0.400
Mechanical Function Unit	16	0.062	0.188	0.250	0.125	0.375
Motor	7	—	0.143	—	—	0.857
Circuit Breaker	22	0.136	0.136	0.227	—	0.500
Turbine	60	0.150	0.133	0.100	0.050	0.567
Instrumentation: Recorder	19	—	0.105	0.105	—	0.789
Instrumentation: Transmitter	77	0.143	0.104	0.026	0.039	0.688
Support	22	0.364	0.045	0.136	—	0.455
Engine	6	—	—	0.333	—	0.667

a. Components ordered by aging fraction.

Table E-7. Component cooling water system

NSSS:	A-BABCOCK & WILCOX C-GENERAL ELECTRIC
SYSTEM:	A-BABCOCK & WILCOX WBB-COMPONENT COOLING WATER C-GENERAL ELECTRIC WBA-REACTOR BLDG. CLOSED COOLING WATER
COMPONENTS:	ACCUMU CKTBRK HTEXCH IBISSW ICNTRL INDREC INTCPM IXMITR MOTOR PIPE PUMP RELAY SUPORT VALVE VALVOP

Table E-8. Component cooling water system totals and fractions

Failure Category Totals		
Design Failures	=	27
Aging Failures	=	110
Test and Maintenance Failures	=	33
Human-Related Failures	=	8
Other Failures	=	108
Total		286
Failure Category Fractions		
Design Fraction	=	0.094
Aging Fraction	=	0.385
Test and Maintenance Fraction	=	0.115
Human-Related Fraction	=	0.028
Other Fraction	=	0.378
System Effect Totals		
Loss of System Function	=	0
Degraded System Operation	=	62
Loss of Redundancy	=	45
Loss of Subsystem/Channel	=	90
System Function Unaffected	=	89
Total		286
System Effect Fractions		
Loss of System Function Fraction	=	0.000
Degraded System Operation Fraction	=	0.217
Loss of Redundancy Fraction	=	0.157
Loss of Subsystem/Channel Fraction	=	0.315
System Function Unaffected Fraction	=	0.311

Table E-9. Component cooling water system component failure category fractions[a]

Component	Total	Design	Aging	Testing	Human	Other
Pipe	1	—	1.000	—	—	—
Instrumentation: Controller	4	—	0.750	0.250	—	—
Pump	54	0.074	0.685	0.056	—	0.185
Motor	13	—	0.538	0.154	—	0.308
Heat Exchanger	30	0.133	0.433	0.033	0.033	0.367
Valve	63	0.048	0.381	0.159	0.032	0.381
Circuit Breaker	21	0.095	0.333	0.048	0.048	0.476
Instrumentation: Recorder	14	—	0.214	0.286	—	0.500
Valve Operator	52	0.173	0.212	0.154	0.038	0.423
Support	5	0.200	0.200	—	—	0.600
Instrumentation: Switch	11	0.091	0.182	0.091	—	0.636
Instrumentation: Transmitter	13	0.154	0.077	0.154	0.077	0.538
Relay	3	0.333	—	—	0.333	0.333
Accumulator	1	—	—	—	—	1.000
Instrumentation: Computation Module	1	—	—	—	—	1.000

a. Components ordered by aging fraction.

Table E-10. High-pressure injection system

NSSS:	A-BABCOCK & WILCOX E-WESTINGHOUSE
SYSTEM:	A-BABCOCK & WILCOX PCB-LETDOWN PURIFICATION AND MAKEUP SFD-HIGH PRESSURE INJECTION E-WESTINGHOUSE SFK-HIGH PRESSURE SAFETY INJECTION SFKUHI-HIGH PRESSURE SAFETY INJECTION - UPPER HEAD INJECTION SUBSYSTEM
COMPONENTS:	ACCUMU CKTBRK FILTER HEATER HTEXCH IBISSW ICNTRL INDREC INTCPM IXMITR MOTOR PIPE PUMP RELAY SUPORT VALVE VALVOP

Table E-11. High-pressure injection system totals and fractions

Failure Category Totals		
Design Failures	=	122
Aging Failures	=	221
Test and Maintenance Failures	=	83
Human-Related Failures	=	27
Other Failures	=	583
Total		1036
Failure Category Fractions		
Design Fraction	=	0.118
Aging Fraction	=	0.213
Test and Maintenance Fraction	=	0.080
Human-Related Fraction	=	0.026
Other Fraction	=	0.563
System Effect Totals		
Loss of System Function	=	7
Degraded System Operation	=	197
Loss of Redundancy	=	138
Loss of Subsystem/Channel	=	251
System Function Unaffected	=	443
Total		1036
System Effect Fractions		
Loss of System Function Fraction	=	0.007
Degraded System Operation Fraction	=	0.190
Loss of Redundancy Fraction	=	0.133
Loss of Subsystem/Channel Fraction	=	0.242
System Function Unaffected Fraction	=	0.428

Table E-12. High-pressure injection system component failure category fractions[a]

Component	Total	Design	Aging	Testing	Human	Other
Relay	1	—	1.000	—	—	—
Support	32	0.156	0.375	0.031	0.031	0.406
Filter	6	—	0.333	0.500	—	0.167
Heat Exchanger	9	0.444	0.333	—	—	0.222
Valve	307	0.127	0.326	0.085	0.020	0.443
Pump	86	0.105	0.314	0.116	0.047	0.419
Instrumentation: Recorder	18	—	0.278	—	—	0.722
Valve Operator	161	0.081	0.211	0.143	0.031	0.534
Circuit Breaker	43	0.163	0.209	0.070	0.047	0.512
Instrumentation: Transmitter	141	0.106	0.113	0.071	0.007	0.702
Heater	36	0.111	0.111	0.111	0.167	0.500
Instrumentation: Controller	19	0.158	0.105	—	—	0.737
Instrumentation: Switch	153	0.124	0.039	0.007	—	0.830
Accumulator	4	—	—	—	0.250	0.750
Motor	9	0.111	—	0.111	0.111	0.667
Pipe	5	0.400	—	0.200	—	0.400
Instrumentation: Computation Module	6	0.167	—	—	—	0.833

a. Components ordered by aging fraction.

Table E-13. Main feedwater system

NSSS:	A-BABCOCK & WILCOX C-GENERAL ELECTRIC
SYSTEM:	A-BABCOCK & WILCOX HHA-FEEDWATER C-GENERAL ELECTRIC CHA-FEEDWATER
COMPONENTS:	CKTBRK FILTER HTEXCH IBISSW ICNTRL INDREC INTCPM IPWSUP ISODEV IXMITR MECFUN MOTOR PIPE PUMP RELAY SUPORT TURBIN VALVE VALVOP

Table E-14. Main feedwater system totals and fractions

Failure Category Totals		
Design Failures	=	94
Aging Failures	=	310
Test and Maintenance Failures	=	49
Human-Related Failures	=	6
Other Failures	=	368
Total		827
Failure Category Fractions		
Design Fraction	=	0.114
Aging Fraction	=	0.375
Test and Maintenance Fraction	=	0.059
Human-Related Fraction	=	0.007
Other Fraction	=	0.445
System Effect Totals		
Loss of System Function	=	9
Degraded System Operation	=	153
Loss of Redundancy	=	102
Loss of Subsystem/Channel	=	157
System Function Unaffected	=	406
Total		827
System Effect Fractions		
Loss of System Function Fraction	=	0.011
Degraded System Operation Fraction	=	0.185
Loss of Redundancy Fraction	=	0.123
Loss of Subsystem/Channel Fraction	=	0.190
System Function Unaffected Fraction	=	0.491

Table E-15. Main feedwater system component failure category fractions[a]

Component	Total	Design	Aging	Testing	Human	Other
Relay	3	—	1.000	—	—	—
Heat Exchanger	21	0.048	0.667	0.048	—	0.238
Valve	334	0.108	0.524	0.042	0.006	0.320
Instrumentation: Electronic Power Supply	2	—	0.500	—	—	0.500
Instrumentation: Switch	11	0.182	0.455	—	—	0.364
Pump	49	0.143	0.449	0.102	0.020	0.286
Circuit Breaker	9	0.111	0.444	—	—	0.444
Valve Operator	113	0.071	0.319	0.106	0.018	0.487
Mechanical Function Unit	15	0.067	0.267	0.067	—	0.600
Pipe	4	0.500	0.250	—	—	0.250
Instrumentation: Computation Module	41	—	0.244	0.024	—	0.732
Turbine	26	0.115	0.231	0.077	—	0.577
Motor	5	0.600	0.200	—	—	0.200
Instrumentation: Controller	10	—	0.200	0.100	—	0.700
Instrumentation: Transmitter	82	0.024	0.171	0.049	—	0.756
Support	55	0.491	0.127	0.055	0.018	0.309
Instrumentation: Recorder	43	0.023	0.116	0.047	—	0.814
Instrumentation: Isolation Device	1	—	—	—	—	1.000
Filter	3	—	—	1.000	—	—

a. Components ordered by aging fraction.

Table E-16. Reactor protection trip system

NSSS:	C-GENERAL ELECTRIC E-WESTINGHOUSE
SYSTEM:	C-GENERAL ELECTRIC IBA-REACTOR PROTECTION IBAIAA-REACTOR PROTECTION - NEUTRON MONITORING SUBSYSTEM E-WESTINGHOUSE IBG-REACTOR PROTECTION AND LOGIC IBK-ENGINEERED SAFEGUARDS ACTUATION AND LOGIC
COMPONENTS:	ANNUNC CKTBRK ELECON GENERA IBISSW ICNTRL INDREC INTCPM IPWSUP ISODEV IXMITR RELAY

Table E-17. Reactor protection trip system totals and fractions

Failure Category Totals		
Design Failures	=	448
Aging Failures	=	740
Test and Maintenance Failures	=	189
Human-Related Failures	=	26
Other Failures	=	1761
Total		3170
Failure Category Fractions		
Design Fraction	=	0.141
Aging Fraction	=	0.233
Test and Maintenance Fraction	=	0.060
Human-Related Fraction	=	0.008
Other Fraction	=	0.556
System Effect Totals		
Loss of System Function	=	6
Degraded System Operation	=	529
Loss of Redundancy	=	538
Loss of Subsystem/Channel	=	1247
System Function Unaffected	=	851
Total		3170
System Effect Fractions		
Loss of System Function Fraction	=	0.002
Degraded System Operation Fraction	=	0.167
Loss of Redundancy Fraction	=	0.170
Loss of Subsystem/Channel Fraction	=	0.393
System Function Unaffected Fraction	=	0.268

Table E-18. Reactor protection trip system component failure category fractions[a]

Component	Total	Design	Aging	Testing	Human	Other
Instrumentation: Isolation Device	30	0.033	0.367	—	—	0.600
Annunciator	3	0.333	0.333	—	—	0.333
Generator/Alternator/ Inverter	16	0.250	0.312	0.125	—	0.312
Instrumentation: Computation Module	851	0.063	0.276	0.033	0.009	0.618
Instrumentation: Recorder	199	0.126	0.271	0.060	0.005	0.538
Circuit Breaker	41	0.098	0.268	0.098	—	0.537
Instrumentation: Electronic Power Supply	254	0.075	0.252	0.043	—	0.630
Instrumentation: Controllers	199	0.090	0.241	0.055	—	0.613
Relay	335	0.284	0.230	0.033	0.018	0.436
Electrical Conductors	10	0.100	0.200	—	—	0.700
Instrumentation: Transmitter	753	0.117	0.189	0.106	0.009	0.571
Instrumentation: Switch	479	0.288	0.188	0.063	0.008	0.453

a. Components ordered by aging fraction.

Table E-19. Residual heat removal system

NSSS:	C-GENERAL ELECTRIC
SYSTEM:	CFA-RESIDUAL HEAT REMOVAL/LOW PRESSURE INJECTION
COMPONENTS:	CKTBRK ELECON HTEXCH IBISSW ICNTRL INDREC INTCPM IPWSUP IXMITR MOTOR PIPE PUMP RELAY SUPORT VALVE VALVOP

Table E-20. Residual heat removal system totals and fractions

Failure Category Totals		
Design Failures	=	126
Aging Failures	=	245
Test and Maintenance Failures	=	75
Human-Related Failures	=	22
Other Failures	=	590
Total		1058
Failure Category Fractions		
Design Fraction	=	0.119
Aging Fraction	=	0.232
Test and Maintenance Fraction	=	0.071
Human-Related Fraction	=	0.021
Other Fraction	=	0.558
System Effect Totals		
Loss of System Function	=	10
Degraded System Operation	=	173
Loss of Redundancy	=	168
Loss of Subsystem/Channel	=	212
System Function Unaffected	=	495
Total		1058
System Effect Fractions		
Loss of System Function Fraction	=	0.009
Degraded System Operation Fraction	=	0.164
Loss of Redundancy Fraction	=	0.159
Loss of Subsystem/Channel Fraction	=	0.200
System Function Unaffected Fraction	=	0.468

Table E-21. Residual heat removal system component failure category fractions[a]

Component	Total	Design	Aging	Testing	Human	Other
Heat Exchanger	33	0.121	0.485	0.030	—	0.364
Valve	250	0.076	0.464	0.056	0.016	0.388
Pump	28	0.214	0.321	—	0.107	0.357
Valve Operator	227	0.137	0.225	0.079	0.035	0.524
Circuit Breaker	71	0.183	0.197	0.085	—	0.535
Instrumentation: Computation Module	6	—	0.167	—	—	0.833
Relay	26	0.077	0.154	0.115	—	0.654
Support	101	0.119	0.119	0.050	0.030	0.683
Instrumentation: Recorder	43	0.093	0.093	0.116	—	0.698
Instrumentation: Controller	11	0.182	0.091	0.182	—	0.545
Instrumentation: Switch	175	0.109	0.086	0.051	0.017	0.737
Instrumentation: Transmitter	68	0.059	0.029	0.162	0.015	0.735
Pipe	10	0.800	—	—	—	0.200
Motor	6	0.333	—	0.167	—	0.500
Electrical Conductor	1	—	—	—	—	1.000
Instrumentation: Electrical Power Supply	2	—	—	—	—	1.000

a. Components ordered by aging fraction.

Table E-22. Service water system

NSSS:	A-BABCOCK & WILCOX C-GENERAL ELECTRIC E-WESTINGHOUSE
SYSTEM:	A-BABCOCK & WILCOX WAB-LOW PRESSURE SERVICE WATER C-GENERAL ELECTRIC WAA-ESSENTIAL SERVICE WATER E-WESTINGHOUSE WAD-NUCLEAR SERVICE WATER
COMPONENTS:	CKTBRK ELECON FILTER IBISSW ICNTRL INDREC INTCPM IPWSUP IXMITR MOTOR PIPE PUMP RELAY SUPORT VALVE VALVOP

Table E-23. Service water system totals and fractions

Failure Category Totals		
Design Failures	=	88
Aging Failures	=	570
Test and Maintenance Failures	=	83
Human-Related Failures	=	16
Other Failures	=	515
Total		1272
Failure Category Fractions		
Design Fraction	=	0.069
Aging Fraction	=	0.448
Test and Maintenance Fraction	=	0.065
Human-Related Fraction	=	0.013
Other Fraction	=	0.405
System Effect Totals		
Loss of System Function	=	3
Degraded System Operation	=	216
Loss of Redundancy	=	233
Loss of Subsystem/Channel	=	435
System Function Unaffected	=	385
Total		1272
System Effect Fractions		
Loss of System Function Fraction	=	0.002
Degraded System Operation Fraction	=	0.170
Loss of Redundancy Fraction	=	0.183
Loss of Subsystem/Channel Fraction	=	0.342
System Function Unaffected Fraction	=	0.303

Table E-24. Service water system component failure category fractions[a]

Component	Total	Design	Aging	Testing	Human	Other
Instrumentation: Electronic Power Supply	2	—	1.000	—	—	—
Filter	98	0.102	0.571	0.041	—	0.286
Pump	248	0.044	0.569	0.077	—	0.310
Pipe	18	—	0.556	0.056	—	0.389
Valve	362	0.066	0.555	0.039	0.025	0.315
Instrumentation: Controller	17	0.059	0.529	0.118	—	0.294
Motor	64	0.078	0.391	0.016	0.016	0.500
Circuit Breaker	48	0.062	0.354	0.083	0.042	0.458
Valve Operator	307	0.072	0.293	0.117	0.013	0.505
Instrumentation: Switch	38	0.079	0.263	0.026	—	0.632
Instrumentation: Recorder	22	0.045	0.227	—	—	0.727
Instrumentation: Transmitter	27	0.037	0.111	0.037	—	0.815
Support	10	0.300	0.100	—	—	0.600
Relay	5	0.600	—	—	—	0.400
Electrical Conductor	4	0.250	—	—	—	0.750
Instrumentation: Computation Module	2	—	—	—	—	1.000

a. Components ordered by aging fraction.

Table E-25. Standby liquid control system

NSSS:	C-GENERAL ELECTRIC
SYSTEM:	PCA-STANDBY LIQUID CONTROL
COMPONENTS:	ACCUMU CKTBRK HEATER IBISSW ICNTRL INDREC IPWSUP IXMITR PUMP RELAY SUPORT VALVE VALVOP

Table E-26. Standby liquid control system totals and fractions

Failure Category Totals		
Design Failures	=	10
Aging Failures	=	49
Test and Maintenance Failures	=	10
Human-Related Failures	=	1
Other Failures	=	103
Total		173
Failure Category Fractions		
Design Fraction	=	0.058
Aging Fraction	=	0.283
Test and Maintenance Fraction	=	0.058
Human-Related Fraction	=	0.006
Other Fraction	=	0.595
System Effect Totals		
Loss of System Function	=	0
Degraded System Operation	=	39
Loss of Redundancy	=	24
Loss of Subsystem/Channel	=	34
System Function Unaffected	=	76
Total		173
System Effect Fractions		
Loss of System Function Fraction	=	0.000
Degraded System Operation Fraction	=	0.225
Loss of Redundancy Fraction	=	0.139
Loss of Subsystem/Channel Fraction	=	0.197
System Function Unaffected Fraction	=	0.439

Table E-27. Standby liquid control system component failure category fractions[a]

Component	Total	Design	Aging	Testing	Human	Other
Pump	19	0.053	0.632	—	—	0.316
Relay	2	—	0.500	—	—	0.500
Accumulator	12	0.083	0.333	0.167	—	0.417
Instrumentation: Transmitter	17	0.118	0.294	—	—	0.588
Instrumentation: Recorder	14	—	0.286	—	—	0.714
Instrumentation: Electronic Power Supply	4	—	0.250	—	—	0.750
Valve	66	0.076	0.242	0.091	—	0.591
Instrumentation: Controller	5	—	0.200	0.200	—	0.600
Heater	10	—	0.200	0.100	—	0.700
Support	6	—	0.167	—	—	0.833
Instrumentation: Switch	14	—	0.143	—	—	0.857
Circuit Breaker	2	—	—	—	0.500	0.500
Valve Operator	2	0.500	—	—	—	0.500

a. Components ordered by aging fraction.

APPENDIX F

REPORTED FAILURE CAUSE DATA SUMMARIES

APPENDIX F

REPORTED FAILURE CAUSE DATA SUMMARIES

Specific vendors and plant identifications are maintained in the data base created during this study. To preserve the proprietary nature of the data and yet obtain acceptable data populations, the failure cause data presented in this report are system-specific. Tables F-1 and F-2 summarize the failure cause data. Table F-1 lists components having five or more failure counts, and Table F-2 lists those with less than five failure counts. Tables F-3 through F-19 show the number of failure causes, the failure cause fractions, the upper bound failure cause fraction, and the lower bound failure cause fraction for each failure mode of each component, excluding the unclassified causes. These latter tables do not contain any components having less than five failure counts. The failure causes are presented in alphabetical order in the tables. Table F-20 lists the system, component, failure mode, system effect, and aging classification for all the records coded "unclassifiable."

TABLE F-1. SUMMARY OF DATA ANALYZED DURING THE FAILURE CAUSE IDENTIFICATION ANALYSIS[a]

System	Components[b]	Failure Mode	Failure Mode Code	Counts[c]
Essential Service Water System	Circuit Breaker, AC	Fails to Operate	GFP	11
		Opens (Premature)	GSO	6
	Flow Switch	Erroneous/Erratic Signals	GEE	16
	Check Valve	External Leakage	GEL	2
		Fails to Open	GFO	4
		Internal Leakage	GIL	25
	Flow Indicator	Erroneous/Erratic Signals	GEE	1
		Fails to Operate	GFP	4
	Hand Control Valve	External Leakage	GEL	2
		Fails to Close	GFC	7
		Fails to Open	GFO	1
		Failure to Operate as Required	GFR	6
		Fails to Open/Fails to Close	GOC	1
	Motor-Driven Pump	External Leakage	GEL	64
		Fails to Start	GFS	12
		Fails to Run	GFU	91
	Motor-Operated Valve	External Leakage	GEL	7
		Fails to Close	GFC	43
		Fails to Open	GFO	27
		Failure to Operate as Required	GFR	17
		Fails to Open/Fails to Close	GOC	17
	Pressure Indicator	Erroneous/Erratic Signals	GEE	5
		Fails to Operate	GFP	1
	Pnuematic-Operated Valve	External Leakage	GEL	5
		Fails to Close	GFC	15
		Fails to Open	GFO	9
		Failure to Operate as Required	GFR	13
		Fails to Open/Fails to Close	GOC	5
	Strainer	Loss of Function	GLF	13
		Plugged	GPL	8
Instrumentation & Uninterruptible Power Supply System--Class 1E	Circuit Breaker, AC	Fails to Operate	GFP	5
	Inverter	Loss of Function	GLF	63

TABLE F-1. (continued)

System	Components[b]	Failure Mode	Failure Mode Code	Counts[c]
DC Power System - 1E	Battery	Loss of Function	GLF	10
	Battery Charger	Loss of Function	GLF	35
Emergency On-site Power Supply System	Circuit Breaker, AC	Fails to Operate	GFP	5
	Diesel Generator	Fails to Start	GFS	18
		Fails to Run	GFU	46
		No Failure	GNF	49

a. See Table F-20 for summary of data categorized as unclassifiable.

b. See Table F-2 for those components having less than 5 counts.

c. Total counts: 669.

TABLE F-2. SUMMARY OF COMPONENTS HAVING LESS THAN 5 COUNTS EACH[a]

System	Components	Failure Mode	Failure Mode Code	Counts[b]
Essential Service Water System	Position-Limit Switch	Erroneous/Erratic Signals	GEE	1
	Pressure Switch	Erroneous/Erratic Signals Fails to Operate	GEE GFP	3 1
	Level Switch	Erroneous/Erratic Signals	GEE	1
	DC Overcurrent Relay	Fails to Operate	GFP	1
	Flow Modifier	Erroneous/Erratic Signals	GEE	1
	Electric Power Supply	Loss of Function	GLF	1
	Level Transmitter	Fails to Operate	GFP	1
	Motor	Fails to Run	GFU	3
	Differential Pressure Indicating Switch	Erroneous/Erratic Signals	GEE	4
	Differential Pressure Control Recorder	Erroneous/Erratic Signals Fails to Operate	GEE GFP	1 1
	Pipe	Plugged Rupture	GPL GRU	1 3
	Relay	Fails to Close Fails to Open Short Circuit	GFC GFO GSH	1 1 1
	Relief Valve	Fails to Close	GFC	3
	Snubber	Loss of Function	GLF	4
	Support	Loss of Function	GLF	2
	Safety Relief Valve	Fails to Close	GFC	1
	Temperature Indicator	Erroneous/Erratic Signals Fails to Operate	GEE GFP	1 1
	Temperature Control Indicator	Fails to Operate	GFP	1
	Temperature Switch	Erroneous Output	GEO	1

TABLE F-2. (continued)

System	Components	Failure Mode	Failure Mode Code	Counts[b]
Essential Service Water System (continued)	Thermowell	Loss of Function	GLF	1
	Vent Valve	Fails to Close	GFC	1
		Fails to Open/Fails to Close	GOC	1
	Zone Modifier	Erroneous/Erratic Signals	GEE	1
Medium Voltage Power Supply System--Class 1E	Circuit Breaker, AC	Fails to Operate	GFP	3
		Opens (Premature)	GSO	1
	Cable	Loss of Function	GLF	1
	Transformer	Loss of Function	GLF	4
Low Voltage Power Supply System--Class 1E	Circuit Breaker, AC	Fails to Operate	GFP	3
	Bus	Loss of Function	GLF	1
	Relay	Fails to Operate	GFP	2
		Short Circuit	GSH	1
DC Power System--Class 1E	Circuit Breaker, AC	Fails to Operate	GFP	1
Emergency On-Site Power Supply System	Temperature Indicator	Erroneous/Erratic Signals	GEE	1
	Timer	Erroneous/Erratic Signals	GEE	1

a. Table summary does not contain data for any failure categorized unclassifiable (Table F-20).

b. Total counts: 63.

TABLE F-3. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS CHECK VALVES

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
CHECK VALVES

Failure Mode: EXTERNAL LEAKAGE - GEL

Failure Cause										Totals
Failure Cause Code	EBR	HPM								
Failure Cause Count	1	1								2
Failure Cause Fraction	0.500	0.500								1.000
Aging										
Yes/No/Unknown	1/0/0	0/1/0								1/1/0
Aging Fractions										
Upper Bound	0.500	0.000								0.500
Lower Bound	0.500	0.000								0.500

Failure Mode: FAILS TO OPEN - GFO

Failure Cause										Totals
Failure Cause Code	DCI	EBE	EBR	ECC						
Failure Cause Count	1	1	1	1						4
Failure Cause Fraction	0.250	0.250	0.250	0.250						1.000
Aging										
Yes/No/Unknown	0/1/0	1/0/0	1/0/0	1/0/0						3/1/0
Aging Fractions										
Upper Bound	0.000	0.250	0.250	0.250						0.750
Lower Bound	0.000	0.250	0.250	0.250						0.750

TABLE F-3. (continued)

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
CHECK VALVES

Failure Mode: INTERNAL LEAKAGE - GIL

Failure Cause										Totals
Failure Cause Code	DE	EBE	EBR	ECC	EDB	EDI				
Failure Cause Count	1	3	12	6	1	2				25
Failure Cause Fraction	0.040	0.120	0.480	0.240	0.040	0.080				1.000
Aging										
Yes/No/Unknown	1/0/0	3/0/0	12/0/0	6/0/0	0/0/1	1/1/0				23/1/1
Aging Fractions										
Upper Bound	0.040	0.120	0.480	0.240	0.040	0.040				0.960
Lower Bound	0.040	0.120	0.480	0.240	0.000	0.040				0.920

TABLE F-4. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS HAND CONTROL VALVES

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
HAND CONTROL VALVES

Failure Mode: EXTERNAL LEAKAGE - GEL

Failure Cause			Totals
Failure Cause Code	EBR	ECC	
Failure Cause Count	1	1	2
Failure Cause Fraction	0.500	0.500	1.000
Aging			
Yes/No/Unknown	1/0/0	1/0/0	2/0/0
Aging Fractions			
Upper Bound	0.500	0.500	1.000
Lower Bound	0.500	0.500	1.000

Failure Mode: FAILS TO CLOSE - GFC

Failure Cause					Totals
Failure Cause Code	EBE	EBR	ECC	EDI	
Failure Cause Count	1	2	3	1	7
Failure Cause Fraction	0.143	0.286	0.429	0.143	1.000
Aging					
Yes/No/Unknown	1/0/0	2/0/0	3/0/0	1/0/0	7/0/0
Aging Fractions					
Upper Bound	0.143	0.286	0.429	0.143	1.000
Lower Bound	0.143	0.286	0.429	0.143	1.000

TABLE F-4. (continued)

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
HAND CONTROL VALVES

Failure Mode: FAILS TO OPEN - GFO

Failure Cause										Totals
Failure Cause Code	HEO									
Failure Cause Count	1									1
Failure Cause Fraction	1.000									1.000
Aging										
Yes/No/Unknown	0/1/0									0/1/0
Aging Fractions										
Upper Bound	0.000									0.000
Lower Bound	0.000									0.000

Failure Mode: FAILURE TO OPERATE AS REQUIRED - GFR

Failure Cause										Totals
Failure Cause Code	ECC	EDB	HEM	HEO						
Failure Cause Count	1	1	1	3						6
Failure Cause Fraction	0.167	0.167	0.167	0.500						1.000
Aging										
Yes/No/Unknown	1/0/0	0/0/1	0/1/0	0/3/0						1/4/1
Aging Fractions										
Upper Bound	0.167	0.167	0.000	0.000						0.334
Lower Bound	0.167	0.000	0.000	0.000						0.167

TABLE F-4. (continued)

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
HAND CONTROL VALVES

Failure Mode: FAILS TO OPEN/FAILS TO CLOSE - GOC

										Totals
Failure Cause										
Failure Cause Code	EDB									
Failure Cause Count	1									1
Failure Cause Fraction	1.000									1.000
Aging										
Yes/No/Unknown	1/0/0									1/0/0
Aging Fractions										
Upper Bound	1.000									1.000
Lower Bound	1.000									1.000

TABLE F-5. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS MOTOR-OPERATED VALVES

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
MOTOR-OPERATED VALVES

Failure Mode: FAILS TO CLOSE - GFC

Failure Cause										Totals
Failure Cause Code	DCI	EBE	EBR	ECC	EDB	EDI	ELO	ELR	ELS	
Failure Cause Count	1	3	6	2	23	3	1	1	1	
Failure Cause Fraction	0.023	0.070	0.140	0.047	0.535	0.070	0.023	0.023	0.023	
Aging										
Yes/No/Unknown	0/1/0	3/0/0	6/0/0	2/0/0	0/2/21	3/0/0	0/0/1	1/0/0	0/0/1	
Aging Fractions										
Upper Bound	0.000	0.070	0.140	0.047	0.488	0.070	0.023	0.023	0.023	
Lower Bound	0.000	0.070	0.140	0.047	0.000	0.070	0.000	0.023	0.000	

Failure Mode: FAILS TO CLOSE - GFC(continued)

Failure Cause										Totals
Failure Cause Code	HEM	HEO								
Failure Cause Count	1	1								43
Failure Cause Fraction	0.023	0.023								1.000
Aging										
Yes/No/Unknown	0/1/0	0/1/0								15/5/23
Aging Fractions										
Upper Bound	0.000	0.000								0.884
Lower Bound	0.000	0.000								0.350

TABLE F-5. (continued)

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
MOTOR-OPERATED VALVES

Failure Mode: FAILS TO OPEN - GFO

Failure Cause										Totals
Failure Cause Code	DM	EBF	EBR	EDB	EDI	EDU	EL	ELK	ELO	
Failure Cause Count	1	1	3	8	2	2	2	1	3	
Failure Cause Fraction	0.037	0.037	0.111	0.296	0.074	0.074	0.074	0.037	0.111	
Aging										
Yes/No/Unknown	0/0/1	1/0/0	3/0/0	1/2/5	1/0/1	0/1/1	0/0/2	0/0/1	0/0/3	
Aging Fractions										
Upper Bound	0.037	0.037	0.111	0.222	0.074	0.037	0.074	0.037	0.111	
Lower Bound	0.000	0.037	0.111	0.037	0.037	0.000	0.000	0.000	0.000	

Failure Mode: FAILS TO OPEN - GFO(continued)

Failure Cause										Totals
Failure Cause Code	ELS	ELT	HEM	HEO						
Failure Cause Count	1	1	1	1						27
Failure Cause Fraction	0.037	0.037	0.037	0.037						1.000
Aging										
Yes/No/Unknown	0/0/1	1/0/0	0/1/0	0/1/0						7/5/15
Aging Fractions										
Upper Bound	0.037	0.037	0.000	0.000						0.814
Lower Bound	0.000	0.037	0.000	0.000						0.259

TABLE F-5. (continued)

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
MOTOR-OPERATED VALVES

Failure Mode: FAILURE TO OPERATE AS REQUIRED - GFR

Failure Cause										Totals
Failure Cause Code	DEI	EBE	EBR	ECC	EDB	EL	ELO	EVM	HPM	
Failure Cause Count	1	2	3	1	5	1	1	2	1	17
Failure Cause Fraction	0.059	0.118	0.176	0.059	0.294	0.059	0.059	0.118	0.059	1.000
Aging										
Yes/No/Unknown	0/1/0	2/0/0	3/0/0	1/0/0	1/1/3	0/0/1	0/0/1	2/0/0	0/1/0	9/3/5
Aging Fractions										
Upper Bound	0.000	0.118	0.176	0.059	0.235	0.059	0.059	0.118	0.000	0.824
Lower Bound	0.000	0.118	0.176	0.059	0.059	0.000	0.000	0.118	0.000	0.530

Failure Mode: EXTERNAL LEAKAGE - GEL

Failure Cause										Totals
Failure Cause Code	EBR	ECC								
Failure Cause Count	5	2								7
Failure Cause Fraction	0.714	0.286								1.000
Aging										
Yes/No/Unknown	5/0/0	2/0/0								7/0/0
Aging Fractions										
Upper Bound	0.714	0.286								1.000
Lower Bound	0.714	0.286								1.000

TABLE F-5. (continued)

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
MOTOR-OPERATED VALVES

Failure Mode: FAILS TO OPEN/FAILS TO CLOSE - GOC

Failure Cause										Totals
Failure Cause Code	DC	DM	EBR	EDB	ELE	ELH	ELK	EMW	EVM	
Failure Cause Count	1	1	2	2	4	1	2	3	1	17
Failure Cause Fraction	0.059	0.059	0.118	0.118	0.235	0.059	0.118	0.176	0.059	1.000
Aging										
Yes/No/Unknown	0/1/0	0/0/1	2/0/0	1/0/1	1/2/1	0/0/1	0/0/2	0/2/1	1/0/0	5/5/7
Aging Fractions										
Upper Bound	0.000	0.059	0.118	0.118	0.118	0.059	0.118	0.059	0.059	0.708
Lower Bound	0.000	0.000	0.118	0.059	0.059	0.000	0.000	0.000	0.059	0.295

TABLE F-6. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS PNEUMATIC-OPERATED VALVES

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
PNEUMATIC-OPERATED VALVES

Failure Mode: EXTERNAL LEAKAGE - GEL

Failure Cause										Totals
Failure Cause Code	EBR									
Failure Cause Count	5									5
Failure Cause Fraction	1.000									1.000
Aging										
Yes/No/Unknown	5/0/0									5/0/0
Aging Fractions										
Upper Bound	1.000									1.000
Lower Bound	1.000									1.000

Failure Mode: FAILS TO CLOSE - GFC

Failure Cause										Totals
Failure Cause Code	EBR	ECC	EDB	EDI	EVM					
Failure Cause Count	5	1	4	4	1					15
Failure Cause Fraction	0.333	0.067	0.267	0.267	0.067					1.000
Aging										
Yes/No/Unknown	5/0/0	1/0/0	0/1/3	4/0/0	1/0/0					11/1/3
Aging Fractions										
Upper Bound	0.333	0.067	0.200	0.267	0.067					0.934
Lower Bound	0.333	0.067	0.000	0.267	0.067					0.734

TABLE F-6. (continued)

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
PNEUMATIC-OPERATED VALVES

Failure Mode: FAILS TO OPEN - GFO

Failure Cause						Totals
Failure Cause Code	EBF	EBR	EDB	EDI	EDU	
Failure Cause Count	1	3	2	2	1	9
Failure Cause Fraction	0.111	0.333	0.222	0.222	0.111	1.000
Aging						
Yes/No/Unknown	1/0/0	3/0/0	0/0/2	2/0/0	0/0/1	6/0/3
Aging Fractions						
Upper Bound	0.111	0.333	0.222	0.222	0.111	1.000
Lower Bound	0.111	0.333	0.000	0.222	0.000	0.666

Failure Mode: FAILURE TO OPERATE AS REQUIRED - GFR

Failure Cause								Totals
Failure Cause Code	EBB	EBR	EDB	EDI	ELD	EVM	HA	
Failure Cause Count	1	5	2	1	1	2	1	13
Failure Cause Fraction	0.077	0.385	0.154	0.077	0.077	0.154	0.077	1.000
Aging								
Yes/No/Unknown	1/0/0	5/0/0	0/0/2	1/0/0	1/0/0	2/0/0	0/1/0	10/1/2
Aging Fractions								
Upper Bound	0.077	0.385	0.154	0.077	0.077	0.154	0.000	0.924
Lower Bound	0.077	0.385	0.000	0.077	0.077	0.154	0.000	0.770

TABLE F-6. (continued)

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
PNEUMATIC-OPERATED VALVES

Failure Mode: FAILS TO OPEN/FAILS TO CLOSE - GOC

Failure Cause										Totals
Failure Cause Code	EBR	ECC	EDB	EVM						
Failure Cause Count	1	1	1	2						5
Failure Cause Fraction	0.200	0.200	0.200	0.400						1.000
Aging										
Yes/No/Unknown	1/0/0	1/0/0	0/0/1	2/0/0						4/0/1
Aging Fractions										
Upper Bound	0.200	0.200	0.200	0.400						1.000
Lower Bound	0.200	0.200	0.000	0.400						0.800

TABLE F-7. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS MOTOR-DRIVEN PUMPS

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
MOTOR-DRIVEN PUMPS

Failure Mode: EXTERNAL LEAKAGE - GEL

Failure Cause										Totals
Failure Cause Code	EBB	EBF	EBR	EDB	EDI	EVM	HAM	HEM	HEO	
Failure Cause Count	1	1	45	1	9	2	1	1	1	
Failure Cause Fraction	0.016	0.016	0.703	0.016	0.141	0.031	0.016	0.016	0.016	
Aging										
Yes/No/Unknown	1/0/0	1/0/0	45/0/0	0/0/1	8/1/0	2/0/0	0/1/0	0/1/0	1/0/0	
Aging Fractions										
Upper Bound	0.016	0.016	0.703	0.016	0.125	0.031	0.000	0.000	0.016	
Lower Bound	0.016	0.016	0.703	0.000	0.125	0.031	0.000	0.000	0.016	

Failure Mode: EXTERNAL LEAKAGE - GEL(continued)

Failure Cause										Totals
Failure Cause Code	SPM	SPO								
Failure Cause Count	1	1								64
Failure Cause Fraction	0.016	0.016								1.000
Aging										
Yes/No/Unknown	1/0/0	1/0/0								60/3/1
Aging Fractions										
Upper Bound	0.016	0.016								0.955
Lower Bound	0.016	0.016								0.939

TABLE F-7. (continued)

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
MOTOR-DRIVEN PUMPS

Failure Mode: FAILS TO RUN - GFU

Failure Cause										Totals
Failure Cause Code	DC	DCI	DM	EAO	EBE	EBR	ECC	EDB	EDI	
Failure Cause Count	1	1	3	1	2	29	4	10	23	
Failure Cause Fraction	0.011	0.011	0.033	0.011	0.022	0.319	0.044	0.110	0.253	
Aging										
Yes/No/Unknown	1/0/0	1/0/0	0/3/0	1/0/0	2/0/0	29/0/0	4/0/0	1/4/5	16/7/0	
Aging Fractions										
Upper Bound	0.011	0.011	0.000	0.011	0.022	0.319	0.044	0.066	0.176	
Lower Bound	0.011	0.011	0.000	0.011	0.022	0.319	0.044	0.011	0.176	

Failure Mode: FAILS TO RUN - GFU(continued)

Failure Cause										Totals
Failure Cause Code	EDU	EI	ELI	ELO	ELS	EMW	EVM	HAM	HEM	
Failure Cause Count	4	1	2	1	1	1	3	1	1	
Failure Cause Fraction	0.044	0.011	0.022	0.011	0.011	0.011	0.033	0.011	0.011	
Aging										
Yes/No/Unknown	3/1/0	0/1/0	2/0/0	1/0/0	0/0/1	0/1/0	3/0/0	0/1/0	0/1/0	
Aging Fractions										
Upper Bound	0.033	0.000	0.022	0.011	0.011	0.000	0.033	0.000	0.000	
Lower Bound	0.033	0.000	0.022	0.011	0.000	0.000	0.033	0.000	0.000	

TABLE F-7. (continued)

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
MOTOR-DRIVEN PUMPS

Failure Mode: FAILS TO RUN - GFU(continued)

Failure Cause			Totals
Failure Cause Code	HPM	SPM	
Failure Cause Count	1	1	91
Failure Cause Fraction	0.011	0.011	1.000
Aging			
Yes/No/Unknown	0/1/0	1/0/0	65/20/6
Aging Fractions			
Upper Bound	0.000	0.011	0.781
Lower Bound	0.000	0.011	0.715

Failure Mode: FAILS TO START - GFS

Failure Cause								Totals
Failure Cause Code	EBF	EBR	EDB	EDI	ELC	ELF	EMH	
Failure Cause Count	1	1	4	3	1	1	1	12
Failure Cause Fraction	0.083	0.083	0.333	0.250	0.083	0.083	0.083	1.000
Aging								
Yes/No/Unknown	1/0/0	1/0/0	0/0/4	1/2/0	1/0/0	0/1/0	0/1/0	4/4/4
Aging Fractions								
Upper Bound	0.083	0.083	0.333	0.083	0.083	0.000	0.000	0.665
Lower Bound	0.083	0.083	0.000	0.083	0.083	0.000	0.000	0.332

TABLE F-8. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS STRAINERS

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
STRAINERS

Failure Mode: LOSS OF FUNCTION - GLF

Failure Cause					Totals
Failure Cause Code	EBR	ECC	HAM	HPM	
Failure Cause Count	8	3	1	1	13
Failure Cause Fraction	0.615	0.231	0.077	0.077	1.000
Aging					
Yes/No/Unknown	8/0/0	3/0/0	0/1/0	0/0/1	11/1/1
Aging Fractions					
Upper Bound	0.615	0.231	0.000	0.077	0.923
Lower Bound	0.615	0.231	0.000	0.000	0.846

Failure Mode: PLUGGED - GPL

Failure Cause			Totals
Failure Cause Code	EAO	EDI	
Failure Cause Count	2	6	8
Failure Cause Fraction	0.250	0.750	1.000
Aging			
Yes/No/Unknown	2/0/0	4/2/0	6/2/0
Aging Fractions			
Upper Bound	0.250	0.500	0.750
Lower Bound	0.250	0.500	0.750

TABLE F-9. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS CIRCUIT BREAKERS, AC

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
CIRCUIT BREAKERS, AC

Failure Mode: FAILURE TO OPERATE - GFP

Failure Cause										Totals
Failure Cause Code	EBF	EBM	EBR	EDB	EDI	HEM				
Failure Cause Count	2	1	2	2	3	1				11
Failure Cause Fraction	0.182	0.091	0.182	0.182	0.273	0.091				1.000
Aging										
Yes/No/Unknown	2/0/0	0/0/1	2/0/0	1/0/1	3/0/0	0/1/0				8/1/2
Aging Fractions										
Upper Bound	0.182	0.091	0.182	0.182	0.273	0.000				0.910
Lower Bound	0.182	0.000	0.182	0.091	0.273	0.000				0.728

Failure Mode: OPEN (PREMATURE) - GSO

Failure Cause										Totals
Failure Cause Code	EDB	EDI	ELE	ELW	SPC					
Failure Cause Count	1	1	1	2	1					6
Failure Cause Fraction	0.167	0.167	0.167	0.333	0.167					1.000
Aging										
Yes/No/Unknown	0/1/0	0/1/0	0/1/0	1/0/1	0/1/0					1/4/1
Aging Fractions										
Upper Bound	0.000	0.000	0.000	0.333	0.000					0.333
Lower Bound	0.000	0.000	0.000	0.167	0.000					0.167

TABLE F-10. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS FLOW INDICATORS

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
FLOW INDICATORS

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

Failure Cause										Totals
Failure Cause Code	ELF									
Failure Cause Count	1									1
Failure Cause Fraction	1.000									1.000
Aging										
Yes/No/Unknown	0/0/1									0/0/1
Aging Fractions										
Upper Bound	1.000									1.000
Lower Bound	0.000									0.000

Failure Mode: FAILURE TO OPERATE - GFP

Failure Cause										Totals
Failure Cause Code	EDI	ELT								
Failure Cause Count	1	3								4
Failure Cause Fraction	0.250	0.750								1.000
Aging										
Yes/No/Unknown	0/1/0	3/0/0								3/1/0
Aging Fractions										
Upper Bound	0.000	0.750								0.750
Lower Bound	0.000	0.750								0.750

TABLE F-11. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS FLOW SWITCHES

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
FLOW SWITCHES

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

											Totals
Failure Cause											
Failure Cause Code	EDI	ELD	ELI	ELT							
Failure Cause Count	1	13	1	1							16
Failure Cause Fraction	0.062	0.812	0.062	0.062							1.000
Aging											
Yes/No/Unknown	1/0/0	13/0/0	1/0/0	1/0/0							16/0/0
Aging Fractions											
Upper Bound	0.062	0.812	0.062	0.062							1.000
Lower Bound	0.062	0.812	0.062	0.062							1.000

TABLE F-12. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS PRESSURE INDICATORS

SYSTEM
ESSENTIAL SERVICE WATER SYSTEM

COMPONENT
PRESSURE INDICATORS

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

Failure Cause				Totals
Failure Cause Code	EDI	EDT	ELT	
Failure Cause Count	2	2	1	5
Failure Cause Fraction	0.400	0.400	0.200	1.000
Aging				
Yes/No/Unknown	2/0/0	2/0/0	0/0/1	4/0/1
Aging Fractions				
Upper Bound	0.400	0.400	0.200	1.000
Lower Bound	0.400	0.400	0.000	0.800

Failure Mode: FAILURE TO OPERATE - GFP

Failure Cause		Totals
Failure Cause Code	EDT	
Failure Cause Count	1	1
Failure Cause Fraction	1.000	1.000
Aging		
Yes/No/Unknown	0/0/1	0/0/1
Aging Fractions		
Upper Bound	1.000	1.000
Lower Bound	0.000	0.000

TABLE F-13. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR UPS CIRCUIT BREAKERS, AC

SYSTEM
INSTRUMENT & UNINTERRUPTIBLE POWER SUPPLY SYSTEM - CLASS 1E

COMPONENT
CIRCUIT BREAKERS, AC

Failure Mode: FAILURE TO OPERATE - GFP

Failure Cause										**Totals**
Failure Cause Code	EBR	ELE	HE							
Failure Cause Count	1	1	3							5
Failure Cause Fraction	0.200	0.200	0.600							1.000
Aging										
Yes/No/Unknown	1/0/0	0/1/0	0/3/0							1/4/0
Aging Fractions										
Upper Bound	0.200	0.000	0.000							0.200
Lower Bound	0.200	0.000	0.000							0.200

TABLE F-14. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR UPS INVERTERS

SYSTEM
INSTRUMENT & UNINTERRUPTIBLE POWER SUPPLY SYSTEM - CLASS 1E

COMPONENT
INVERTERS

Failure Mode: LOSS OF FUNCTION - GLF

Failure Cause										Totals
Failure Cause Code	DE	DM	EBR	EDB	EL	ELA	ELD	ELE	ELF	
Failure Cause Count	5	2	5	2	2	1	2	9	18	
Failure Cause Fraction	0.079	0.032	0.079	0.032	0.032	0.016	0.032	0.143	0.286	
Aging										
Yes/No/Unknown	0/4/1	0/2/0	5/0/0	0/0/2	1/0/1	0/0/1	2/0/0	0/8/1	5/4/9	
Aging Fractions										
Upper Bound	0.016	0.000	0.079	0.032	0.032	0.016	0.032	0.016	0.222	
Lower Bound	0.000	0.000	0.079	0.000	0.016	0.000	0.032	0.000	0.079	

Failure Mode: LOSS OF FUNCTION - GLF(continued)

Failure Cause										Totals
Failure Cause Code	ELI	ELO	ELS	ELT	ELV	HE	HEM			
Failure Cause Count	2	2	8	1	1	1	2			63
Failure Cause Fraction	0.032	0.032	0.127	0.016	0.016	0.016	0.032			1.000
Aging										
Yes/No/Unknown	2/0/0	2/0/0	1/3/4	0/0/1	0/1/0	0/1/0	0/2/0			18/25/20
Aging Fractions										
Upper Bound	0.032	0.032	0.079	0.016	0.000	0.000	0.000			0.604
Lower Bound	0.032	0.032	0.016	0.000	0.000	0.000	0.000			0.286

TABLE F-15. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR DC POWER BATTERIES

SYSTEM
DC POWER SUPPLY SYSTEM - CLASS 1E

COMPONENT
BATTERIES

Failure Mode: LOSS OF FUNCTION - GLF

Failure Cause										Totals
Failure Cause Code	DM	EBB	EL	ELF	ELG	ELL	ELS			
Failure Cause Count	3	1	1	1	1	1	2			10
Failure Cause Fraction	0.300	0.100	0.100	0.100	0.100	0.100	0.200			1.000
Aging										
Yes/No/Unknown	3/0/0	0/0/1	0/0/1	0/0/1	1/0/0	1/0/0	0/0/2			5/0/5
Aging Fractions										
Upper Bound	0.300	0.100	0.100	0.100	0.100	0.100	0.200			1.000
Lower Bound	0.300	0.000	0.000	0.000	0.100	0.100	0.000			0.500

TABLE F-16. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR DC POWER BATTERY CHARGING UNIT

SYSTEM
DC POWER SUPPLY SYSTEM - CLASS 1E

COMPONENT
BATTERY CHARGING UNITS

Failure Mode: LOSS OF FUNCTION - GLF

Failure Cause										Totals
Failure Cause Code	EBR	EDB	EDI	EL	ELA	ELD	ELF	ELO	ELR	
Failure Cause Count	1	2	1	3	1	1	23	1	1	
Failure Cause Fraction	0.029	0.057	0.029	0.086	0.029	0.029	0.657	0.029	0.029	
Aging										
Yes/No/Unknown	1/0/0	0/0/2	1/0/0	1/0/2	0/0/1	1/0/0	14/0/9	0/0/1	0/1/0	
Aging Fractions										
Upper Bound	0.029	0.057	0.029	0.086	0.029	0.029	0.657	0.029	0.000	
Lower Bound	0.029	0.000	0.029	0.029	0.000	0.029	0.400	0.000	0.000	

Failure Mode: LOSS OF FUNCTION - GLF(continued)

Failure Cause										Totals
Failure Cause Code	ELS									
Failure Cause Count	1									35
Failure Cause Fraction	0.029									1.000
Aging										
Yes/No/Unknown	0/0/1									18/1/16
Aging Fractions										
Upper Bound	0.029									0.974
Lower Bound	0.000									0.516

TABLE F-17. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR EMERGENCY POWER CIRCUIT BREAKERS

SYSTEM
EMERGENCY ON-SITE POWER SUPPLY SYSTEM

COMPONENT
CIRCUIT BREAKERS, AC

Failure Mode: FAILURE TO OPERATE - GFP

Failure Cause			Totals
Failure Cause Code	EBR	EDB	
Failure Cause Count	2	3	5
Failure Cause Fraction	0.400	0.600	1.000
Aging			
Yes/No/Unknown	2/0/0	0/0/3	2/0/3
Aging Fractions			
Upper Bound	0.400	0.600	1.000
Lower Bound	0.400	0.000	0.400

TABLE F-18. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR EMERGENCY POWER DIESEL GENERATOR

SYSTEM
EMERGENCY ON-SITE POWER SUPPLY SYSTEM

COMPONENT
DIESEL GENERATORS

Failure Mode: FAILS TO START - GFS

Failure Cause										Totals
Failure Cause Code	DEI	EBR	EDB	EDI	EEN	EL	ELF	ELR	ELT	
Failure Cause Count	2	2	3	3	1	2	1	1	1	
Failure Cause Fraction	0.111	0.111	0.167	0.167	0.056	0.111	0.056	0.056	0.056	
Aging										
Yes/No/Unknown	2/0/0	2/0/0	0/1/2	2/1/0	0/1/0	0/2/0	1/0/0	0/1/0	0/1/0	
Aging Fractions										
Upper Bound	0.111	0.111	0.111	0.111	0.000	0.000	0.056	0.000	0.000	
Lower Bound	0.111	0.111	0.000	0.111	0.000	0.000	0.056	0.000	0.000	

Failure Mode: FAILS TO START - GFS(continued)

Failure Cause										Totals
Failure Cause Code	EMW									
Failure Cause Count	2									18
Failure Cause Fraction	0.111									1.000
Aging										
Yes/No/Unknown	0/2/0									7/9/2
Aging Fractions										
Upper Bound	0.000									0.500
Lower Bound	0.000									0.389

TABLE F-18. (continued)

SYSTEM
EMERGENCY ON-SITE POWER SUPPLY SYSTEM

COMPONENT
DIESEL GENERATORS

Failure Mode: FAILS TO RUN - GFU

Failure Cause										Totals
Failure Cause Code	DEI	EBB	EBF	EBM	EBR	EDB	EDI	EDU	EL	
Failure Cause Count	1	2	1	1	14	4	3	2	1	
Failure Cause Fraction	0.022	0.043	0.022	0.022	0.304	0.087	0.065	0.043	0.022	
Aging										
Yes/No/Unknown	0/1/0	2/0/0	1/0/0	0/0/1	14/0/0	1/2/1	2/1/0	2/0/0	0/0/1	
Aging Fractions										
Upper Bound	0.000	0.043	0.022	0.022	0.304	0.043	0.043	0.043	0.022	
Lower Bound	0.000	0.043	0.022	0.000	0.304	0.022	0.043	0.043	0.000	

Failure Mode: FAILS TO RUN - GFU(continued)

Failure Cause										Totals
Failure Cause Code	ELD	ELE	ELF	ELO	ELS	EVM	HEM	SPC		
Failure Cause Count	5	2	3	1	3	1	1	1		46
Failure Cause Fraction	0.109	0.043	0.065	0.022	0.065	0.022	0.022	0.022		1.000
Aging										
Yes/No/Unknown	5/0/0	0/2/0	2/0/1	0/0/1	2/0/1	1/0/0	0/1/0	0/1/0		32/8/6
Aging Fractions										
Upper Bound	0.109	0.000	0.065	0.022	0.065	0.022	0.000	0.000		0.825
Lower Bound	0.109	0.000	0.043	0.000	0.043	0.022	0.000	0.000		0.694

TABLE F-18. (continued)

SYSTEM
EMERGENCY ON-SITE POWER SUPPLY SYSTEM

COMPONENT
DIESEL GENERATORS

Failure Mode: NO FAILURE - GNF

Failure Cause										Totals
Failure Cause Code	DE	DM	EBB	EBF	EBR	ECC	EDB	EDI	EDO	
Failure Cause Count	1	2	2	5	6	1	4	2	1	
Failure Cause Fraction	0.020	0.041	0.041	0.102	0.122	0.020	0.082	0.041	0.020	
Aging										
Yes/No/Unknown	0/1/0	0/1/1	2/0/0	5/0/0	6/0/0	1/0/0	1/0/3	2/0/0	0/1/0	
Aging Fractions										
Upper Bound	0.000	0.020	0.041	0.102	0.122	0.020	0.082	0.041	0.000	
Lower Bound	0.000	0.000	0.041	0.102	0.122	0.020	0.020	0.041	0.000	

Failure Mode: NO FAILURE - GNF(continued)

Failure Cause										Totals
Failure Cause Code	EDS	EDU	EL	ELD	ELF	ELO	ELT	ELW	EMW	
Failure Cause Count	1	1	2	1	1	1	3	1	9	
Failure Cause Fraction	0.020	0.020	0.041	0.020	0.020	0.020	0.061	0.020	0.184	
Aging										
Yes/No/Unknown	1/0/0	1/0/0	0/0/2	1/0/0	0/0/1	1/0/0	1/0/2	0/0/1	2/6/1	
Aging Fractions										
Upper Bound	0.020	0.020	0.041	0.020	0.020	0.020	0.061	0.020	0.061	
Lower Bound	0.020	0.020	0.000	0.020	0.000	0.020	0.020	0.000	0.041	

TABLE F-18. (continued)

SYSTEM
EMERGENCY ON-SITE POWER SUPPLY SYSTEM

COMPONENT
DIESEL GENERATORS

Failure Mode: NO FAILURE - GNF(continued)

Failure Cause										**Totals**
Failure Cause Code	EPL	EVM	HEM							
Failure Cause Count	1	3	1							49
Failure Cause Fraction	0.020	0.061	0.020							1.000
Aging										
Yes/No/Unknown	0/1/0	3/0/0	0/0/1							27/10/12
Aging Fractions										
Upper Bound	0.000	0.061	0.020							0.792
Lower Bound	0.000	0.061	0.000							0.548

TABLE F-19. FAILURE CAUSE TALLIES FOR SYSTEM EFFECT[a]

System	System Effect	Component	Count[b]	Failure Cause
Essential Service Water System	Degraded System Operations	Circuit Breaker, AC	1	EBR
			1	EDB
			1	EDI
			1	HEM
		Temperature Control Indicator	1	EDB
		Flow Indicator	2	ELT
		Motor	1	ELC
		Pipe	1	EBE
			1	ECC
		Motor-Driven Pump	10	EBR
			6	EDB
			5	EDI
			1	EI
			1	EVM
			1	HAM
			1	HPM
			1	SPM
			1	SPO
		Relay	1	DE
		Overcurrent Relay (DC)	1	ELO
		Strainer	1	EDI
			1	HAM
		Flow Switch	3	ELD
			1	ELI
			1	ELT
		Differential Pressure Switch	1	EDI
		Pressure Switch	1	EDI
			1	ELD
		Check Valve	2	EBE
			4	EBR
		Hand Control Valve	1	EBR
			1	ECC
			1	HEM
			2	HEO
		Motor-Operated Valve	1	DCI
			1	DEI
			2	DM
			2	EBR
			1	ECC
			7	EDB
			1	EDI
			2	ELE
			1	ELH
			2	ELK
			1	ELO

TABLE F-19. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Essential Service Water (continued)	Degraded System Operation (continued)	Motor-Operated Valve (continued)	1	ELR
			1	ELS
			1	EMW
		Pneumatic-Operated Valve	6	EBR
			4	EDB
			2	EDI
			1	ELD
			3	EVM
		Relief Valve	1	EBE
	System Function/Operations Unaffected	Circuit Breaker, AC	1	EBR
			2	EDI
			1	ELE
		Flow Indicator	1	ELF
			1	ELT
		Pressure Indicator	1	EDI
			1	EDT
			1	ELT
		Temperature Indicator	2	ELT
		Zone Modifier	1	EDB
		Motor-Driven Pump	1	DC
			1	EBB
			1	EBE
			1	EBF
			24	EBR
			1	ECC
			5	EDB
			3	EDI
			2	EDU
			1	ELC
			1	EMW
			2	EVM
			2	HEM
			1	SPM
		Relay	1	EBR
		Snubber	1	DCI
			1	ECC
		Strainer	3	EBR
			2	ECC
			3	EDI
		Flow Switch	10	ELD
		Differential Pressure Switch	2	ELD
		Level Switch	1	EMW
		Position-Limit Switch	1	EBR
		Level Transmitter	1	EDI

TABLE F-19. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Essential Service Water (continued)	System Function/Operation Unaffected (continued)	Check Valve	2	EBE
			3	EBR
			3	ECC
			1	EDB
			2	EDI
			1	HPM
		Hand Control Valve	1	EBE
			2	EBR
			2	ECC
			2	HEO
		Motor-Operated Valve	1	DC
			2	EBE
			1	EBF
			12	EBR
			1	ECC
			18	EDB
			2	EDI
			1	EDU
			1	EL
			2	ELE
			1	ELK
			1	ELO
			1	ELT
			1	HEM
			1	HEO
			1	HPM
		Pneumatic-Operated Valve	1	EBB
			1	EBF
			9	EBR
			1	ECC
			1	EDB
			1	EDI
			1	EDU
			1	EVM
			1	HA
		Vent Valve	1	EBE
			1	EDB
	Loss of Redundancy	Circuit Breaker, AC	1	EBM
			2	EDB
		Differential Pressure Control Recorder	1	EDI
		Flow Indicator	1	EDI
		Flow Modifier	1	ELD
		Motor	1	ELS
		Electric Power Supply	1	ELE

TABLE F-19. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Essential Service Water (continued)	Loss of Redundancy (continued)	Motor-Driven Pump	3	DM
			1	EAO
			1	EBF
			16	EBR
			1	ECC
			4	EDB
			12	EDI
			2	EDU
			1	ELF
			1	ELI
			1	ELS
			1	EMH
			1	EVM
		Relay	1	ELC
		Strainer	4	EBR
		Pressure Switch	1	ECC
			1	EL
		Check Valve	1	DCI
			1	DE
			2	EBR
			1	ECC
		Hand Control Valve	1	ECC
			1	EDB
			1	EDI
		Motor-Operated Valve	2	EBR
			5	EDB
			1	EL
			1	ELO
			1	EMW
		Pneumatic-Operated Valve	1	ECC
			1	EDB
			1	EDI
	Loss of Subsystem/Channel	Circuit Breaker, AC	2	EBF
			1	EDI
			2	ELW
			1	SPC
		Differential Pressure Control Recorder	1	EBR
		Pressure Indicator	1	EDI
			2	EDT
		Motor	1	EDI
		Pipe	1	ECC
			1	EMI
		Motor-Driven Pump	1	DCI

TABLE F-19. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Essential Service Water (continued)	Loss of Subsystem/Channel (continued)	Motor-Driven Pump (continued)	1	EBE
			25	EBR
			2	ECC
			15	EDI
			1	ELI
			1	ELO
			1	EVM
			1	HAM
			1	HEO
		Snubber	1	D
			1	EDI
		Strainer	2	EAO
			1	EBR
			1	ECC
			2	EDI
			1	HPM
		Support	1	DEI
			1	EBR
		Flow Switch	1	EDI
		Differential Pressure Switch	1	EBR
		Temperature Switch	1	ELT
		Thermowell	1	ECC
		Check Valve	5	EBR
			3	ECC
		Hand Control Valve	1	ECC
			1	EDB
		Motor-Operated Valve	3	EBE
			3	EBR
			3	ECC
			8	EDB
			2	EDI
			1	EDU
			1	EL
			2	ELO
			1	ELS
			1	EMW
			3	EVM
			1	HEM
			1	HEO
		Pneumatic-Operated Valve	4	EBR
			3	EDB
			3	EDI
			1	EVM
		Relief Valve	1	EBR
			1	EDI
		Safety/Relief Valve	1	EDB

TABLE F-19. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Medium-Voltage Power System--Class 1E	Degraded System Operations	Cable	1	ELI
		Circuit Breaker, AC	1	ELE
		Transformer	1	ELI
	System Function/Operations Unaffected	Circuit Breaker, AC	1	HPM
		Transformer	1	EBR
	Loss of Redundancy	Circuit Breaker, AC	1	HPM
	Loss of Subsystem/Channel	Circuit Breaker, AC	1	ELC
		Transformer	1	EMW
			1	HEM
Low-Voltage Power System--Class 1E	Degraded System Operations	Circuit Breaker, AC	1	ELO
	System Function/Operations Unaffected	Circuit Breaker, AC	2	ELT
		Relay	1	SPC
	Loss of Redundancy	Bus	1	HEM
	Loss of Subsystem/Channel	Relay	1	DEI
			1	ELS
Instrument & Uninterruptible Power System--Class 1E	Degraded System Operations	Circuit Breaker, AC	3	HE
		Inverter	1	DE
			1	EBR
			1	ELD
			3	ELE
			2	ELF
			1	ELO
			4	ELS
			1	HE
			1	HEM
	System Function/Operations Unaffected	Inverter	3	EBR
			1	EDB
			1	ELD
			3	ELE
			7	ELF
			1	ELI
			1	ELO
			1	ELS
			1	ELT

TABLE F-19. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Instrument & Uninterruptible Power System--Class 1E (continued)	Loss of Redundancy	Circuit Breaker, AC	1	ELE
		Inverter	2	DE
			2	DM
			1	EBR
			1	ELA
			3	ELE
			4	ELF
			1	ELI
			1	ELS
	Loss of System Function	Inverter	1	DE
			1	ELF
	Loss of Subsystem/Channel	Circuit Breaker, AC	1	EBR
		Inverter	1	DE
			1	EDB
			2	EL
			4	ELF
			2	ELS
			1	ELV
			1	HEM
DC Power System--Class 1E	Degraded System Operations	Battery	1	ELL
		Battery Charger	1	EDI
			2	EL
			1	ELD
			6	ELF
			1	ELS
		Circuit Breaker, AC	1	ELL
	System Function/Operations Unaffected	Battery	3	DM
			1	EL
			1	ELF
			1	ELG
			1	ELS
		Battery Charger	1	EDB
			1	ELA
			2	ELF
			1	ELR
	Loss of Redundancy	Battery Charger	1	EBR
			9	ELF
			1	ELO

TABLE F-19. (continued)

System	System Effect	Component	Count[b]	Failure Cause
DC Power System--Class 1E (continued)	Loss of Subsystem/Channel	Battery	1	EBB
			1	ELS
		Battery Charger	1	EDB
			1	EL
			6	ELF
Emergency On-Site Power Supply System	Degraded System Operations	Circuit Breaker, AC	1	EBR
			3	EDB
		Diesel Generator	2	EBB
			1	EBF
			6	EBR
			4	EDB
			2	EDI
			1	EDO
			1	EDU
			1	ELD
			2	ELF
			1	ELR
			1	ELS
			3	ELT
			1	ELW
			5	EMW
			1	EPL
	System Function/Operations Unaffected	Diesel Generator	1	DE
			1	EBB
			1	EBM
			7	EBR
			4	EDB
			2	EDI
			1	EDU
			2	EL
			2	ELD
			3	ELF
			3	EVM
			1	SPC
		Temperature Indicator	1	EDB
	Loss of Redundancy	Circuit Breaker, AC	1	EBR
		Diesel Generator	2	DEI
			2	DM
			6	EBR
			1	EDB
			1	EDI
			1	EDU
			1	EEN

TABLE F-19. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Emergency On-Site Power Supply System (continued)	Loss of Redundancy (continued)	Diesel Generator (continued)	2	EL
			1	ELD
			1	ELE
			4	EMW
			1	EVM
	Loss of Subsystem/Channel	Diesel Generator	1	DEI
			1	EBB
			5	EBF
			3	EBR
			1	ECC
			2	EDB
			3	EDI
			1	EDS
			1	EL
			2	ELD
			1	ELE
			2	ELO
			2	ELS
			1	ELT
			2	EMW
			2	HEM
		Timer	1	EBR

a. Table summary does not contain data for any failure categorized unclassified (Table F-20).

b. Total counts: 732.

TABLE F-20. SUMMARY OF RECORDS IN WHICH THE FAILURE CAUSE WAS UNCLASSIFIABLE

System	Component	Failure Mode	System Effect	Aging	Counts
Essential Service Water System	Circuit Breaker, AC	Fails to Operate	Degraded System Operations	NO	1
				UNK	1
	Pressure Switch	Fails to Operate	Degraded System Operations	UNK	1
	Flow Switch	Erroneous/Erratic Signals	Loss of Redundancy	UNK	1
	Check Valve	Internal Leakage	Degraded System Operations	UNK	1
			System Function Unaffected	UNK	2
	Hanger	Loss of Function	Loss of Subsystem/Channel	UNK	3
	Hand Control Valve	Fails to Open	Loss of Subsystem/Channel	UNK	1
		Failure to Operate as Requires	System Function Unaffected	UNK	1
	Motor-Driven Pump	External Leakage	Degraded System Operations	YES	1
			System Function Unaffected	YES	2
			Loss of Redundancy	YES	1
			Loss of Subsystem/Channel	YES	1
		Fails to Start	Loss of Redundancy	UNK	1
		Fails to Run	Degraded System Operations	YES	1
			System Function Unaffected	NO	1
				UNK	1
				YES	1
			Loss of Redundancy	YES	1
			Loss of System Function	UNK	1
			Loss of Subsystem/Channel	NO	1
				YES	3
	Motor-Operated Valve	External Leakage	System Function Unaffected	UNK	1
		Fails to Close	Degraded System Operations	NO	1
			System Function Unaffected	YES	1
			Loss of Redundancy	UNK	2
				YES	1
		Fails to Open	Degraded System Operations	UNK	1
			System Function Unaffected	UNK	2
			Loss of Redundancy	UNK	1
			Loss of Subsystem/Channel	UNK	3
		Failure to Operate as Required	Degraded System Operations	YES	1
			System Function Unaffected	YES	1
			Loss of Subsystem/Channel	UNK	2
		Fails to Open/Fails to Close	Degraded System Operations	UNK	1
			System Function Unaffected	UNK	1
			Loss of Redundancy	UNK	1
			Loss of Subsystem/Channel	NO	1

TABLE F-20. (continued)

System	Component	Failure Mode	System Effect	Aging	Counts
Essential Service Water System (continued)	Pneumatic-Operated Valve	External Leakage	System Function Unaffected	YES	1
		Fails to Close	Degraded System Operations	YES	2
			System Function Unaffected	UNK	2
				YES	1
			Loss of Subsystem/Channel	NO	2
		Fails to Open		UNK	2
		Failure to Operate as Required	Degraded System Operations	YES	1
			System Function Unaffected	YES	1
		Fails to Open/Fails to Close	Loss of Redundancy	UNK	3
				YES	1
			Loss of Subsystem/Channel	UNK	2
	Strainer	Loss of Function	Degraded System Operations	UNK	2
			Loss of Redundancy	UNK	1
			Loss of Subsystem/Channel	NO	1
				UNK	3
Medium-Voltage Power System--Class 1E	Transformer	Loss of Function	Degraded System Operations	UNK	1
			Loss of Subsystem/Channel	YES	1
Low-Voltage Power System--Class 1E	Circuit Breaker, AC	Fails to Operate	Degraded System Operations	NO	1
				UNK	1
			System Function Unaffected	NO	1
			Loss of Subsystem/Channel	UNK	2
	Bus	Loss of Function	System Function Unaffected	UNK	1
Instrument & Uninterruptible	Inverter	Loss of Function	Degraded System Operations	YES	1
			System Function Unaffected	UNK	1
DC Power System--Class 1E	Battery	Loss of Function	Loss of Subsystem/Channel	UNK	1
	Battery Charger	Loss of Function	System Function Unaffected	YES	1
Emergency On-Site Power System--Class 1E	Diesel Generator	Fails to Start	Degraded System Operations	NO	1
				YES	1
			Loss of Redundancy	NO	1
				UNK	2
			Loss of Subsystem/Channel	UNK	2
		Fails to Run	Degraded System Operations	NO	1
				UNK	3
				YES	3
			System Function Unaffected	UNK	1
				YES	4
			Loss of Redundancy	UNK	2
				YES	2
			Loss of Subsystem/Channel	NO	1

TABLE F-20. (continued)

System	Component	Failure Mode	System Effect	Aging	Counts
Emergency On-Site Power System--Class 1E (continued)	Diesel Generator (continued)	No Failure	Degraded System Operations	NO	1
				UNK	1
				YES	1
			System Function Unaffected	UNK	2
			Loss of Redundancy	UNK	2
			Loss of Subsystem/Channel	UNK	1
				YES	1
	Temperature Indicator	Erroneous/Erratic Signals	System Function Unaffected	YES	1

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13. ABSTRACT (200 words or less)

This report describes the methods, analyses, results, and conclusions of two different aging studies. The first analysis consists of a survey of light water reactor component failures associated with selected safety and support systems. Tables are presented, indicating the systems and the components within those systems most affected by aging. Also provided are engineering insights drawn from the data. The second analysis consists of identifying and categorizing the reported failure causes of component failures. The systems used in the failure-cause analysis were service water systems and Class 1E electrical power distribution systems for Babcock & Wilcox Company pressurized water reactors and service water systems for boiling water reactors.

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