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

Prepared by B.M. Meale, D.G. Satterwhite

EG&G Idaho, Inc.

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ABSTRACT

This report describes the methods, analyses, results, and conclusions of two different aging studies. The first study consists of a survey of light water reactor component failures associated with 15 selected safety and support systems. Analysts used computerized sorting techniques to classify component failures into generic failure categories. The second study consists of careful examination of component failure records to identify and categorize the reported cause of component failures. The systems evaluated in the failure-cause analysis were the auxiliary feedwater, Class 1E electrical power distribution, high-pressure injection, and service water. Tables and figures are presented, indicating the systems and the components within those systems most affected by aging. Also provided are engineering insights drawn from the data. This report is the second of two volumes and presents all of the Volume 1 data from FY-86 combined with the data gathered in FY-87.

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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 study of selected component failure reports. Both the aging survey and the failure-cause study were performed over a two-year period for the U.S. Nuclear Regulatory Commission (NRC) as a part of the Nuclear Plant Aging Research Program. This report is the second volume of a two-volume set addressing the impact of component aging on selected nuclear power plant safety and support systems. Volume 2 combines data from Volume 1[a] and subsequent data into one final data analysis and presentation. 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 the aging-related failure analyses 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 component manufacturers.

The analyses documented in this report examine the NPRDS data using two different procedures. The aging survey analysis used computerized sorting techniques to classify failure reports for 15 complete systems; some of these systems are used in 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. It is a rather gross analysis but does provide relative magnitudes of aging effects in systems and components. The results of the aging survey will help define future in-depth engineering studies of selected systems and components.

The second analytical procedure 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 four safety and support systems. To determine a true root cause of failure in every case is beyond the scope of this study. Such a root cause determination would require a detailed in-depth engineering evaluation of the component and the plant maintenance practices. For this report, guidelines developed by the Root Causes of Component Failures Program[a] were used to evaluate the NPRDS failure reports and identify the failure mechanisms. An aging classification procedure was developed to aid the analyst in distinguishing aging-related from nonaging-related (random) failures. The results of the failure-cause study will be incorporated in system-level aging evaluations using probabilistic risk assessment (PRA) techniques.

Aging Survey Analysis

In the aging survey, NPRDS data were obtained for 15 different light water reactor safety and support systems. The NPRDS information was used to create a computerized data base which was analyzed to identify

a. B. M. Meale and D. G. Satterwhite, *An Aging Failure Survey of Light Water Reactor Safety Systems and Components, Vol. 1*, NUREG/CR-4747, EGG-2473, July 1987.

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

time-dependent failure contributions of system-specific components. The failures were grouped into five generic failure categories based upon the NPRDS classification of the failure. Mechanisms of failure were not determined during this analysis since mechanism determinations cannot be made using computerized sorting techniques. 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, an uncertainty analysis was performed to provide an indication of the confidence to be placed in the data analysis results.

Analyzing the five generic failure categories determined that, for these systems, many nuclear power plant component failures are due to aging (32%). The *other* category is the largest failure category, containing 49% of the failures. This category consists of failures for which the utility personnel could not identify the cause or the cause could not be assigned to another NPRDS category. The size of this category is indicative of the difficulties encountered in identifying 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. It is recognized that the aging category could also contain an unknown number of misclassified failures. However, comparison to the reported failure-cause study (discussed below), where the number of unclassified failures (15%) is significantly smaller and the aging fractions are generally higher, indicates that this misclassification is probably minimal. The additional generic failure categories of *design and installation*, *testing and maintenance*, and *human-related* contained 10%, 7.5%, and 1.5% of the failures, respectively.

Results of the aging survey established that, on one hand, normally operating fluid systems tend to exhibit slightly higher proportions of aging-related failures than normally standby systems; on the other hand, however, system dependencies for component aging were generally not statistically identifiable. There were several exceptions to this finding. Pumps in the component cooling water system, valves in the containment isolation system, supports in the high-pressure injection system, and switches in Class 1E electrical power distribution and reactor protection systems were all identified as having statistically distinguishable aging impacts when compared to similar components in other systems.

An evaluation of the data to determine system effects indicated that only a small fraction of the failures caused *loss of system function*. Additionally, no dominant system effect category was evident.

Analyses of the collected data indicate that valves, valve operators, and pumps have the highest potential for aging impacts on system operation based on their corresponding failure population and aging fractions. In the component-level analysis, which determines the aging impacts on the performance of the component, 50% to 60% of the reported valve failures were aging-related failures. At the component level, the valves in the containment isolation system were the components most affected by aging mechanisms. However, care should be taken in drawing a conclusion concerning actual failure of the containment isolation system valves. Because of very/stringent surveillance requirements, those valves may not have actually failed but instead may have failed an operational specification when tested (which is reportable). In the system-level analysis, which indicates the component's aging importance within the system, the average aging fraction (in percent) for valves is 12.5%. The systems where the impact of valve aging (at the system level) is relatively important are containment isolation (28%) and main feedwater (21%), followed by auxiliary feedwater, component cooling water, and service water to a lesser extent. At the component level, aging fractions for valve operators are also relatively constant between systems (approximately 25%). However, aging in valve operators does not produce a significant failure contribution at the system level (only 4%). Pumps are the second most aging-impacted component. Pumps in the component cooling water system have the highest aging fraction (in percent) at both the component level (75%) and the system level (14%). At the component level, the average failure fraction (in percent) for pumps is 45%; and, at the system level, the average failure fraction (in percent) for pumps is 4%. Furthermore, the data for components, such as motors, heat exchangers, pipes, and circuit breakers, indicate that these components are statistically independent across systems and do not produce a significant failure contribution at the system level (less than 5%).

Another analysis ranked the system-specific component aging fractions at the system level. This analysis indicates that valves in the containment isolation system exhibit the highest aging-related fraction (0.28) of all the system-specific components analyzed. Aging-related failures of valves in main feedwater, auxiliary feedwater, component cooling water, and service water systems also rank with the top five system-specific components. Pumps in the component cooling water system exhibit the highest aging-related fraction, at the system level, for pumps and rank sixth on the list of important system-specific components.

A study was also made of the time dependency of aging-related failures for system-specific components. The time-dependent analysis indicated potential time dependencies in aging-related failures. Most of the data indicate the potential for increasing aging fractions with time. However, some of the data indicate only the potential for a constant trend in the aging fractions with time. The data utilized in this study are impacted by variables such as plant maintenance practices, the age of the plant, and reporting practices. This information, which is needed to assess the impact of these variables on aging, is not available from the NPRDS source data.

Reported Failure-Cause Analysis

The failure-cause analysis of component failures used a cause categorization scheme to classify the reported cause-of-failure information for aging-related and nonaging-related failures for selected light water reactor systems. The analysis identified the component failure modes and associated failure mechanisms. The systems chosen for this analysis were auxiliary feedwater, Class 1E electrical power distribution, high-pressure injection (which included some associated chemical and volume control components), and service water. The cause identification information provides insights into the effects of aging failures versus nonaging failures on system performance.

The analysis evaluated 2012 NPRDS component failure records. Results of the analysis indicate that the auxiliary feedwater system has a lower-bound aging-related fraction (expressed in percent) of 57% and an upper bound of 79% for aging-related failures; the chemical and volume control system exhibited 61% to 84% aging-related failures; the high-pressure injection system exhibited 54% to 82% aging-related failures; and the service water system exhibited 67% to 85% aging-related failures. The subsystems of the Class 1E electrical power distribution system exhibited the following lower- and upper-bound aging fractions (expressed in percent): dc power subsystem 28% to 57%, emergency onsite power subsystem 58% to 77%, and instrumentation and uninterruptible power supply subsystem 51% to 98%. The results also indicate that two components in the auxiliary feedwater system, one component in the Class 1E electrical power distribution system, one component in the high-pressure injection system, and two components in the service water system dominated the failure contributions.

Pneumatic-operated valves and check valves contributed the largest number of failures within the auxiliary feedwater system. These components exhibited relatively high aging-related failure fractions. The aging-related failure fraction (in percent) for pneumatic-operated valves had a lower bound of 63% and an upper bound of 79%. The fraction (in percent) for check valves had a range of 87% to 92%. The dominant failure mode for pneumatic-operated valves was *fails to close*, which accounts for 49% of the pneumatic-operated valve failures. The dominant failure mode for check valves was *internal leakage*, which accounts for 73% of the check valve failures. The dominant aging failure cause for both these components was *wear*. The *wear* mechanism accounted for 39% of the pneumatic-operated valve failures, with the valve operator being the subcomponent most affected. For auxiliary feedwater check valves, the *wear* mechanism accounted for 60% of the check valve failures, with the valve seat being the piece part most affected.

In the high-pressure injection system, motor-operated valves dominated the system failures with *wear* and *binding/out of adjustment* being the dominant mechanisms. *Wear* mechanism accounted for 28.5% of the motor-operated valve failures, and *binding/out of adjustment* accounted for 20%. Limit switches and torque switches were the subcomponents most affected by these two mechanisms. The dominant failure mode for high-pressure injection motor-operated valves was *fails to close*, which accounted for 29% of the failures. *Binding/out of adjustment* was the dominant failure cause for the failure mode *fails to close*, accounting for 30% of the *fails to close* failures. The valve operator sustained the largest number of *binding/out of adjustment* closure failures, with the piece parts affected being the torque and limit switches.

For the chemical and volume control portion of the high-pressure injection system, the component with the highest potential for causing system failure is also the motor-operated valve. There were 46 reported failures associated with the chemical and volume control system. The dominant failure mode for these valves is *fails to close* (48% of total motor-operated valve failures), which is the same as for the high-pressure injection system. These closure failures, however, were dominated by *wear*. The *wear* mechanism accounted for 45% of the closure failures. The dominant piece part affected by the *wear* mechanism was the valve seat.

Motor-operated valves and motor-driven pumps contributed the largest number of failures within the service water system. Aging-related failure fractions (in percent) for motor-operated valves were a lower bound of 39% and an upper bound of 84%. Fractions (in percent) for motor-driven pumps are 77% and 84%, respectively. The dominant failure mode for motor-operated valves was *fails to close*, which accounts for 39% of the motor-operated valve failures. The dominant failure mode for motor-driven pumps was *fails to run*, which accounts for 53% of the motor-driven pump failures. The dominant aging failure cause for these two components was *wear*. The *wear* mechanism accounts for 13% of the motor-operated valve failures, with the valve stem connection to the valve operator being the piece part most affected. For service water motor-driven pumps, the *wear* mechanism accounts for 45% of the failures, with the pump seals and packing being the subcomponents most affected.

Within the Class 1E electrical power distribution system, the diesel generators in the emergency onsite power subsystem dominated the failures with a lower-bound aging-related percentage of 58% and an upper bound of 76%. The dominant aging cause for the emergency onsite power subsystem was *wear*. The failure records indicate that the failures due to wear 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 instrumentation and uninterruptible power supply subsystem also account for a relatively large failure count. These failures are dominated by electrical failures. The major contributors to these electrical failures are blown fuses, defective fuses, and defective solid-state components. However, there were few aging-related failures identified for this component.

Analysis of the system-specific failure causes regardless of component or failure mode indicate that, for the fluid systems, *wear* was the dominant failure cause. *Wear* accounted for 30% of the failures in the auxiliary feedwater system, 38% in the chemical and volume control system, 21% in the high-pressure injection system, and 32% in the service water system. In the Class 1E electrical power distribution subsystems, *faulty module* dominated the failures in the dc power supply subsystem and the instrumentation and uninterruptible power supply subsystem. *Wear* dominated the failures in the emergency onsite power supply subsystem. The factors which, in turn, caused the wear, corrosion, or other behavior are not addressed in the NPRDS failure records and, thus, are also not addressed in this study. However, these factors are being studied in other tasks of the NRC Nuclear Plant Aging Research Program.

FOREWORD

This report is the second 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 failure-cause results presented in Volumes 1 and 2 will address the risk importance of time-dependent, aging-related failures. 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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ACRONYMS

AFW	auxiliary feedwater system
B&W	Babcock & Wilcox Company
CCW	component cooling water system
CTF	containment fan system
CTIS	containment isolation 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
LPIS	low-pressure injection system
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
RBC	reactor building cooling system
RCIC	reactor core isolation cooling system
RHR	residual heat removal system
RPS	reactor protection trip system
RXC	reactor coolant system
SBL	standby liquid control system
SWS	service water system
UPS	instrument and uninterruptible power supply subsystem
WEC	Westinghouse Electric Corporation
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 plants. These problems have raised questions about the age-dependent degradation of safety equipment at operating plants. Many of these aging 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). This program uses component failure data from Licensee Event Reports (LERs) and the Nuclear Plant Reliability Data System (NPRDS); the latter is maintained by the Institute of Nuclear Power Operations (INPO). Specific program objectives include: (a) identifying which LWR 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. One of the NPAR Program tasks at the INEL is to evaluate the extent to which aging has affected the performance of LWR safety and support systems.

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

The two studies documented in this report address these two objectives using two different procedures to analyze NPRDS data. The first study, an aging survey, used computerized sorting techniques to classify NPRDS failures into five generic failure categories, and the second study, a failure-cause analysis, utilized a detailed categorization scheme to classify selected NPRDS failures by the reported mechanism causing the failure. The intent of the studies is to provide a comparative measure of aging effects in systems and components. This measure of aging effects could be incorporated into a probabilistic risk assessment (PRA) analysis to address the component importances due to aging and help set priorities of components for in-depth engineering studies. The results are represented in terms of failure fractions that relate aging-related failures to nonaging-related failures. The fractions used in these two analyses are defined as:

- *Failure-category fractions*: For the failure-category fractions, the number of failures for all components in a system classified in one particular failure category is compared to the total failure count reported for that particular system. The five failure categories are aging, design and installation, testing and maintenance, human-related, and other.

- *Component aging fractions*: The component aging fractions are calculated at the component level and the system level. For

a. Bibliographic information on the first volume is as follows: B. M. Meale and D. G. Satterwhite, *An Aging Failure Survey of Light Water Reactor Safety Systems and Components, Vol. 1*, NUREG/CR-4747, EGG-2473, July 1987.

the component aging fractions, at the component level, the number of aging-related failures for a specific component in a particular system is compared to the total failure count for that specific component in that particular system. This comparison is useful in determining the aging impacts on the performance of the component. For the component aging fractions, at the system level, the number of aging-related failures for a specific component in a particular system is compared to the total failure count for all components in that particular system. This comparison gives a representation of the component's aging importance within the system. (This should not be confused with an importance that would be obtained from a PRA calculation.)

- *Time-dependent aging fractions*: For the time-dependent aging fractions, the number of aging-related failures for a specific component in a particular system within a selected age interval is compared to the total number of failures for that specific component in that particular system for the selected age interval.

- *Failure-cause fractions*: The failure-cause fractions are calculated at the component level and the system level. For the failure-cause fractions, at the component level, the number of aging-related failures corresponding to a specific failure cause for a component-specific failure mode in a system is compared to the total number of failures for that component-specific failure mode in the system of interest. For the failure-cause fractions, at the system level, the number of aging-related failures for a specific failure cause in a system is compared to the total failure count for that particular system.

The aging survey used computerized sorting techniques to sort NPRDS failure reports for 15 LWR safety, support, and power conversion systems, for 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 as identified in the NPRDS data base. It is a rather gross analysis but provides relative magnitudes of aging effects between systems and components.

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 (WEC), 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. The systems surveyed are as follows:

1. Class 1E electrical power distribution (1E)—WEC, B&W, GE
2. Auxiliary feedwater (AFW)—WEC, B&W
3. Component cooling water (CCW)—WEC, B&W, GE
4. Containment fan (CTF)—WEC
5. Containment isolation (CTIS)—WEC, B&W
6. High-pressure injection (HPIS)—WEC, GE, B&W
7. Low-pressure injection (LPIS)—GE
8. Main feedwater (MFW)—B&W, GE
9. Reactor building cooling (RBC)—B&W
10. Reactor core isolation cooling (RCIC)—GE
11. Reactor protection trip (RPS)—WEC, GE, B&W
12. Reactor coolant (RXC)—GE, B&W
13. Residual heat removal (RHR)—WEC, GE, B&W
14. Service water (SWS)—WEC, B&W, GE
15. Standby liquid control (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 categories and assign them to one of five 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 failure-cause analysis consisted of examining selected NPRDS records to determine a failure cause for component failures associated with the auxiliary feedwater, Class 1E electrical power distribution, high-pressure injection (which included some associated chemical and volume control components), and service water systems. The purpose of the failure-cause determination was to identify the aging mechanisms that caused the component failures. The depth of this analysis was limited to the level of resolution available in the NPRDS failure records. To determine a true root cause of failure in every case is beyond the scope of this study. Such a determination would require a detailed in-depth engineering evaluation to be performed on the components and the plant maintenance practices. Guidelines developed by the Root Causes of Component Failures Program[2] were used to evaluate the NPRDS failure reports and identify the failure mechanisms. An aging classification procedure was developed to aid the analyst in distinguishing aging-related from nonaging-related (random) failures.

These systems were selected for the aging failure-cause analysis for the following reasons:

1. PRAs indicate that support systems (those supplying power or cooling to the front-line preventive or mitigative systems) tend to dominate risk in many plants.

2. Corresponding systems exist in all nuclear plants.

3. Significant amounts of data have been gathered on failures in these systems.

The failure-cause information is useful in the evaluation of the influence of aging on plant risk using 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.

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 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 from both 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 studies. Section 3 defines *aging* and describes the methodology. Section 4 presents the results of the aging survey and failure-cause identification analysis. The survey and failure-cause results are summarized in Section 5.

2. DEFINITIONS

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

1. *Age*—The intent of the aging survey was to produce a time-dependent failure data base for various component failures. Therefore, for this analysis, 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 then placed into the following four age divisions: 0 to 4.9 yr, 5 to 9.9 yr, 10 to 14.9 yr, and 15 to 20 yr. However, this age calculation may not reflect the actual age of the component because the in-service date provided by NPRDS is defined as the actual date the system or component went into service. Therefore, in some cases, the in-service date as reported in the component engineering record is not the date the component went into service but the date the system became operational or the criticality or low-power operations date. Ideally, the age of the component should be calculated from the date when the component itself was placed into service (including preoperational testing). This would more accurately reflect the actual impact of aging on component failures since the wear on the component during testing would be reflected in the age calculation. Also, the NPRDS in-service date is updated only when a component is replaced; therefore, the time-dependent data would reflect replacement but not repair. Furthermore, no attempt was made to identify how many times the same component failed.

2. *Cause Categories*—The cause categories refer to the nine failure categories used by NPRDS to classify a failure, e.g., *design/engineering, incorrect procedure, wearout*. Additional information concerning this categorization is contained in Appendix A, Table A-1.

3. *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, loose parts.*

4. *Components*—In the aging survey, the component designations developed by the NPRDS are used. The NPRDS utilizes generic names which sometimes refer to more than one specific component. The failure-category data are presented using these designations. Appendix A (Table A-2) includes definitions of the NPRDS component acronyms. In the failure-cause analysis, more specific component designations are used with specific component boundaries as developed for the Root Causes of Component Failures Program.[2]

5. *Component Aging Fractions*—The component aging fractions are calculated at the component level and the system level. For the component aging fractions, at the component level, the number of aging-related failures for a specific component in a particular system is compared to the total failure count for that specific component in that particular system. This comparison is useful in determining the aging impacts on the performance of the component. For the component aging fractions, at the system level, the number of aging-related failures for a specific component in a particular system is compared to the total failure count for all components in that particular system. This comparison gives a representation of the component's aging importance within the system. (This should not be confused with an importance that would be obtained from a PRA calculation.)

6. *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.

7. *Failure*—Failure is defined as a reduced functional efficiency or effectiveness of a

component or the loss of ability of the component to perform its intended function.

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

   a. *Aging*—These are failures that are the consequence of expected, time-dependent wear or degradation.

   b. *Design and Installation*—These include 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.

   c. *Human-Related*—These include failures attributable to incorrect procedures that were followed correctly and failures caused or aggravated by personnel errors, including failure to follow procedures correctly.

   d. *Other/Unknown*—These include failures attributable to failure or misoperation of another component or system and failures for which the cause cannot be assigned to any of the other failure categories.

   e. *Testing and Maintenance*—These are 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.

9. *Failure-Category Fractions*—For the failure-category fractions, the number of failures for all components in a system classified in one particular failure category (see above) is compared to the total failure count reported for that particular system.

10. *Failure-Cause Fractions*—The failure-cause fractions are calculated at the component level and the system level. For the failure-cause fractions, at the component level, the number of aging-related failures corresponding to a specific failure cause for a component-specific failure mode in a system is compared to the total number of failures for that component-specific failure mode in the system of interest. For the failure-cause fractions, at the system level, the number of aging-related failures for a specific failure cause in a system is compared to the total failure count for that particular system.

11. *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.

12. *Reported Failure Cause*—This is 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.

13. *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 Failures Program.[2]

14. *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) contains a list of the system effect codes and their corresponding descriptions.

15. *Time-Dependent Aging Fractions*—For the time-dependent aging fractions, the number of aging-related failures for a specific component in a particular system within a selected age interval is compared to the total number of failures for that specific component in that particular system in the selected age interval.

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 analyses 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, and cyclic fatigue, 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 materials, stressors, and environment 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 meticulous 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 (LERs) 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 use of the LER system for identifying aging-related failures.

Plant-specific 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-specific 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 LERS. However, individual plants have relatively small failure populations, and access to the plant data records is very limited. Gaining access to plant-specific 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 the Institute of Nuclear Power Operations (INPO). Data are submitted 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 the 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 component 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:

1. 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.

2. Many of the equipment failures reported to NPRDS are not reported in LERs since LERs have no requirement to report certain single equipment failures.

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

4. 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.

5. For reported failures, the data base contains sufficient information to allow a reasonable determination of the relative number of failures attributable to various mechanisms. Only 15% of the 2012 NPRDS records examined for the failure-cause analysis were unclassifiable into one of the cause or effect codes developed for use in the Root Causes of the Component Failures Program.[2]

Some limitations are:

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

2. Incipient failures are not reportable under NPRDS reporting requirements.

3. Complete maintenance histories of failed components are not available and the effects of test and maintenance activities on aging-related failures are masked. Therefore, time-line histories needed for aging evaluations are not available through NPRDS.

4. Accurate component service age calculations are difficult to obtain from NPRDS data. The age calculations obtainable from NPRDS reflect the years between the in-service date and the component failure date. The in-service date provided by NPRDS is defined as the actual date the system or component went into service. Therefore, in some cases, the in-service date as reported in the component engineering record is not the date the component went into service but the date the system became operational or the criticality or low power operations date. Ideally the age of component should be calculated from the date when the component was placed into service (including preoperational testing). This would more accurately reflect the actual impact of aging on component failures since the wear on the component during testing would be reflected in the age calculation. Also, in-service dates reflect replacement but not overhaul or major repairs.

5. Approximately 50% of the NPRDS data is placed in the *unknown* or *other devices* failure categories by the reporting utility. This reflects the practice of replacing a component or piece part without establishing the reason for failure. This problem in classification of failures can be significantly offset if manual examinations of the failure records are performed as in a failure-cause analysis.

6. In many cases, the NPRDS cause description codes do not reflect the mechanism causing the failure but are related to the effect of the failure. This makes aging mechanism identification difficult and makes a true *root cause of failure*

determination impossible unless additional information is included in the failure narrative.

7. Many of the narratives provided in the NPRDS failure record do not provide sufficient information to verify the cause category or cause description codes chosen to classify the failure. For example, in many of the NPRDS records that have coded the cause category as *testing and maintenance*, the narrative or the cause description code will indicate an aging-related mechanism such as *wear*. The narrative may state or imply that the failure was discovered during testing and maintenance but does not state that the *wearout* was due to testing and maintenance.

8. The narratives contain ambiguous words such as bad, defective, and worn out and use these words interchangeably. This adds confusion as to whether a failure is aging-related or whether the piece part was incorrectly manufactured.

In view of the above strengths and weaknesses, the NPRDS data can supply only relative information regarding which light water reactor (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 probabilistic risk assessment (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; this information identifies the nuclear steam system supplier (NSSS), 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, cause codes, and a failure description narrative.

The NPRDS data are reported by specific utilities and categorized by NSSS-specific system designations. Table 1 is a list of these NSSS-specific system designations for the 15 systems analyzed in the aging survey.

The failure reports in the NPRDS are classified into nine categories, referred to as cause categories. These categories refer to general causes, such as *engineering/design, installation error*, and *wearout*. 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 generic failure categories used in this analysis (as defined in Section 2) was developed so that generic issues could be examined. The correlation between the nine NPRDS cause categories and the five generic aging survey failure categories selected with NRC concurrence is illustrated in Figure 1. Appendix A (Table A-1) contains a list of the NPRDS cause category and NPRDS 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, and component 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 the five broad failure categories and the five system effect categories. These fractions represent an aggregation of all components within a system. Failure fractions within a particular 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 at the component level and the system level. For the component-level fractions, the total failure counts per failure category for a particular component are divided by the total failure counts for that component within the appropriate system. This comparison is useful in determining the impact of a particular failure category on the performance of the component. In the system-level component failure-category fractions, the numerator remained the same but the denominator for the fractions was the total failure count for that system.

Table 1. NPRDS system codes used in aging survey

Nuclear Steam System Supplier			NPRDS System Code Description
WEC	GE	B&W	
Class 1E Electrical Power Distribution			
EBF	EBA	EBE	PLANT AC POWER
EBK	EBJ	EBG	INSTRUMENT AC POWER
ECC	ECB	ECD	DC POWER
EEB	EEA	EEC	EMERGENCY POWER
EEBDAA	EEADAA	EECDAA	DIESEL STARTING AIR
EEBDCA	EEADCA	EECDCA	DIESEL COOLING WATER
EEBFOA	EEAFOA	EECFOA	DIESEL FUEL OIL
EEBLOA	EEALOA	EECLOA	DIESEL LUBE OIL
Auxiliary Feedwater			
HHC		HHB	AUXILIARY/EMERGENCY FEEDWATER
Component Cooling Water			
WBD		WBB	COMPONENT COOLING WATER
	WBA		REACTOR BUILDING CLOSED COOLING WATER
Containment Fan			
SBG			CONTAINMENT FAN
Containment Isolation			
SDB		SDA	CONTAINMENT ISOLATION
High-Pressure Injection			
		PCB	LETDOWN PURIFICATION AND MAKEUP
SFK	SFC	SFD	HIGH PRESSURE INJECTION
	SFB		HIGH PRESSURE CORE SPRAY
SFKUHI			HIGH PRESSURE UPPER HEAD SUBSYSTEM
Low-Pressure Injection			
	SFA		LOW PRESSURE CORE SPRAY
Main Feedwater			
	CHA	HHA	FEEDWATER
Reactor Building Cooling			
		SBB	REACTOR BUILDING COOLING
Reactor Core Isolation Cooling			
	CEA		REACTOR CORE ISOLATION COOLING

Table 1. (continued)

Nuclear Steam System Supplier			NPRDS System Code Description
WEC	GE	B&W	
Reactor Protection Trip			
IBG	IBA	IBB	REACTOR PROTECTION
IBK		IBC	ENGINEERED SAFEGUARDS ACTUATION
	IBAIAA		NEUTRON LEVEL SUBSYSTEM
Reactor Coolant			
	CBA	CBD	REACTOR COOLANT
Residual Heat Removal			
CFF	CFA	CFC	RESIDUAL HEAT REMOVAL/LOW PRESSURE INJECTION
Service Water			
WAD	WAA	WAB	SERVICE WATER
Standby Liquid Control			
	PCA		STANDBY LIQUID CONTROL

This comparison gives a representation of the failure category importance within the system. (This should not be confused with an importance that would be obtained from a PRA calculation.)

Using the component failure-category fractions for aging (component-level fractions in which the denominator is the total failure count per component within a specific system), an uncertainty study was performed using Chi-square testing and adjusted residual analyses.[8] The Chi-square test of independency examines all systems together. A standard statistical hypothesis test was performed for each component. The hypothesis chosen for the test was that no differences in aging fractions existed for similar components placed in different systems. This hypothesis of independence underlies the formulation of the Chi-square test statistic. The hypothesis is either rejected or not rejected by comparing the test statistic to a quantile of its distribution. 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 specific component between systems. A family significance level of 0.05 means that if no components have significant differences between systems, one can expect 5% of the *family* components to show significance (the *family* consisted of 31 different components). These 31 different components are based on the NPRDS component designations; therefore, some designations contain several types of components. For example, the NPRDS designation GENERA includes generators, inverters, and alternators, and the designation VALVE includes all types of valves.

The Chi-square testing of systems with an expected failure count of less than five was excluded from the analysis. The remaining component data were compared to the Chi-square contingency table quantiles to determine differences in aging effects for the component between systems. When no statistically significant difference occurred, the component failure counts for the component from all involved systems were combined to calculate an overall aging fraction

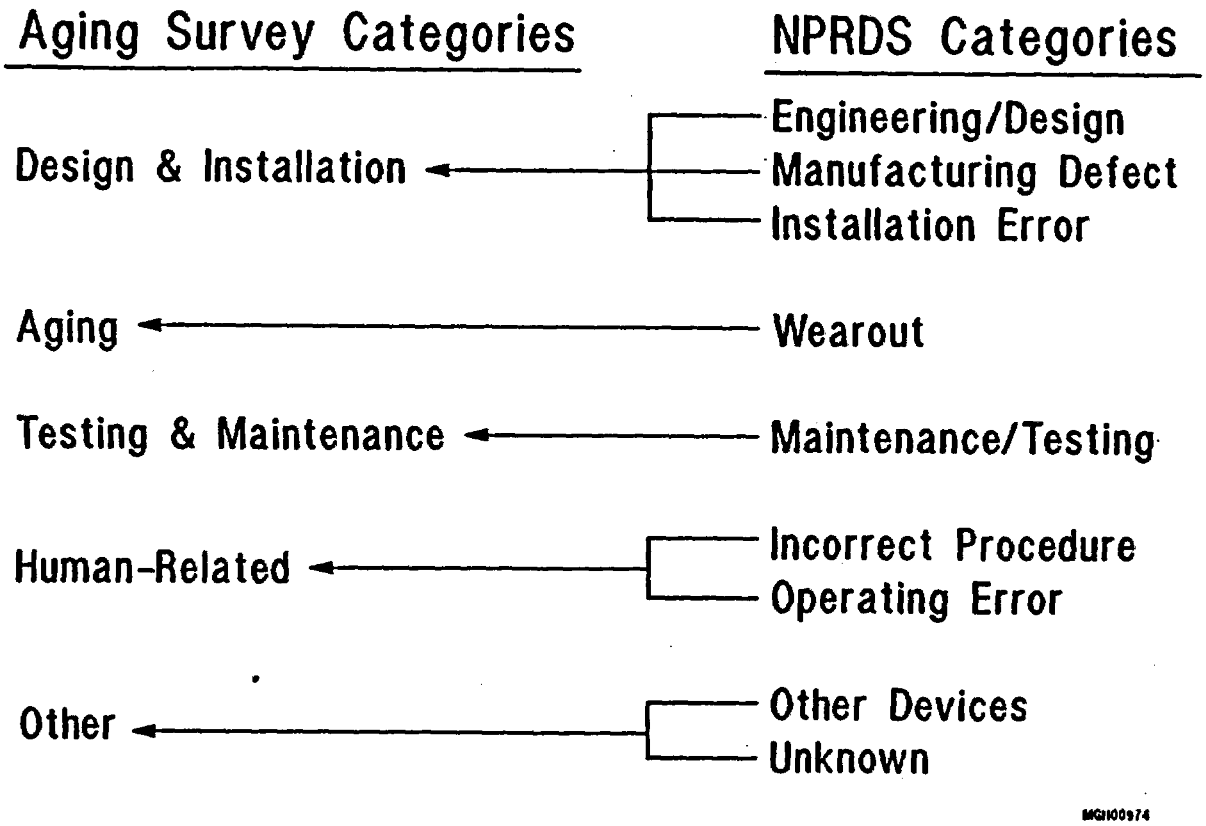

Figure 1. Relationship of the NPRDS cause categories and the aging survey failure categories.

irrespective of system. A 95% confidence interval was calculated for the composite fraction.

When the Chi-square testing indicated statistically significant aging-effect differences for some components in different systems, an adjusted residual analysis was performed. Adjusted residuals refer to the components' statistical residuals being adjusted by their variance. The variance takes into account the system-specific component aging fraction, total failures observed in that particular system, component-specific aging fraction for all systems, and the Chi-square test statistic data contribution. The adjusted residual analysis identifies system-specific components for which aging impacts are statistically distinguishable when compared to other systems. For the remaining systems, it is assumed that no statistically significant differences exist. 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 failures due to aging were calculated according to the method described in Reference 9.

The aging survey analysis also included a time-dependent study of aging failures versus nonaging failures to evaluate their relationship with respect to component age. The aging failures in the four age divisions were tallied for each system-specific component. The time-dependent aging fractions for the four age divisions were calculated for the components within the specific systems by dividing their total aging failures per age division by their total failures per age division.

3.4 Reported Failure-Cause Analysis

The methods used in the reported failure-cause identification study are similar to those used in previous work performed at 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 discernible 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 require a manual examination of failure records including compiling and organizing specific information concerning the component and its failure.

The detail and depth of the information in the NPRDS records vary for different components, systems, and plants. To accommodate these differences, the categorization scheme (or list) consists of three levels, in accordance with the failure-cause categorization scheme as developed by the Root Causes of Component Failures Program.[2] A portion of the root cause categorization scheme to show the general structure is presented in Table 2. This table shows the full-depth level of detail for the first general category. The entire categorization scheme is presented in Appendix B (Table B-2), 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: aging, nonaging, or conditional 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*. Nonaging-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 indicates that a time-dependent process is present. A failure categorized with a conditional aging code is classified nonaging 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 this case, the failure is assigned an *unknown* aging classification.

This failure-cause identification study was oriented towards analyzing component failures in specific systems. The system configurations used in the failure-cause analysis were developed for use in the Root Causes of Component Failures Program.[2] These configurations differ somewhat from the system configurations used within the NPRDS. In the current analysis, these differences led to some failure records that were reported within the NPRDS high-pressure injection system configuration being analyzed as component failures in the chemical and volume control system.

The component boundaries utilized in the failure-cause analysis are listed in Appendix C, along with examples of subcomponents and piece parts of each component. These component boundaries are also different than the ones used within the NPRDS. For example, NPRDS separates failures of valves and valve operators, whereas the failure-cause study considers these as one component. The boundary for diesel generators also differs considerably from the boundary used within the NPRDS.

The failure modes, and definitions thereof, used in the failure-cause identification are presented 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 single train of a multiple-train redundant diesel generator subsystem.

One type of failure-cause fraction, as used in this analysis, was derived for use in a probabilistic risk analysis and is therefore specific to component and failure mode (component-level calculation). Manipulation of the reported failure-cause data base allowed the calculation of cause fractions and aging fractions for the various components for each system. The populations for these fractions

Table 2. 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

are the component failures which occurred due to a specific failure mode. During this process, the number of failures, or counts, was obtained for each component-specific failure mode, individual failure cause, and failure-cause-specific aging classification. The failure-cause fraction for each failure-mode-specific component (excluding components with less than five total failures) was calculated. The number of failure-mode-specific component failures attributed to a particular cause divided by the total number of component failures in that failure mode (excluding the unclassified causes) yields the failure-cause fraction. The aging failure-cause fractions were calculated in the same manner. Failure-cause and aging failure-cause fractions were calculated for each system-specific component (excluding components with less than five total failures).

Failure-cause fractions, at the system level, were calculated for each system-specific failure cause. For these calculations, the failure count per failure cause was divided by the total failure count for the particular system. This type of calculation allows the analyst to identify and rank dominant mechanisms in the specific systems.

The aging-related failure-cause fraction data presented in this study reflect upper and lower bounds derived from the operational data source. These bounds are developed to account for 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 nonaging. 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 failure-cause fractions. The upper bounds are calculated using the failures classified as *unknown* as aging-related failures, while the lower bounds are calculated using them as nonaging-related failures.

4. RESULTS

This section describes the results of the aging survey and the failure-cause analysis. Since the two studies used the wide spectrum on NPRDS data, the results represent an average, and plant-specific effects of maintenance or environment tend to be masked. Data gathered in FY-87 have been combined with the data gathered in FY-86, which were presented in Volume 1. Therefore, portions of the data presented in this section are repetitive. Engineering insights based on the complete data are presented in this volume.

4.1 Aging Survey Analysis

The data resulting from the aging survey analysis of the NPRDS failure data are presented in Appendix E. The information is organized by specific system (auxiliary feedwater, component cooling water, etc.). For each system, the following is provided: (a) definitions of the data fields and other information presented in the tables, (b) summary tables for system-level failure-category fractions and system effect fractions, (c) two tables (for each system) that present component failure-category fractions, and (d) detailed aging survey tables. (These detailed tables tabulate an extensive amount of data and are included as microfiche on the inside back cover.)

For each system, the first component failure-category fraction table in Appendix E lists fractions (at the component level) which are calculated using the total system-specific component failure count (failures for the particular component) as the denominator. The second component failure-category fraction table in Appendix E lists fractions (at the system level) calculated using the total system failure count (failures for all components in the system) as the denominator. The significance of these differing types of data presentation will be discussed below. The data summaries and results are an aggregate of the information contained in the detailed aging survey tables.

Table 3 is an illustration of the format of the detailed aging survey tables. The tables contain the distribution of failures in the five aging survey categories for each five-year age increment for the system-specific component designation. Some component designations are detailed only to the major NPRDS components designation, as shown by the information for SUPORT data in the table. For other components, the component engineering data were utilized to provide a more detailed breakdown of designations, as shown in the table 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 14 of the 15 systems, valve types were differentiated because they are an important component in PRA analysis (reactor protection trip system does not contain valves). However, instrumentation components were only differentiated in the reactor protection trip system because, in that system, the amount of data for instrumentation components is extensive.

4.1.1 Aging Survey Results for Failure Categories and System Effect Categories.

The failure-category fractions in percent (by system) for the five generic failure categories for all 15 systems are shown in Figures 2 through 6, with each figure corresponding to an individual category. Analysis of data for the failure categories indicates that the dominant failure categories are *aging* (32%) (Figure 3) and *other* (49%) (Figure 6). *Human-related* failures (Figure 5) contribute only about 1.5% to the total of failures reported. Failures in the *testing and maintenance* (Figure 4) and *design and installation* (Figure 2) categories are responsible for approximately 7.5% and 10%, respectively.

The *other* category consists of failures for which utility personnel could not identify the cause of failure or the cause could not be assigned to another NPRDS 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. However, it is also possible that the aging category could contain other types of failures. Examination of the reported failure-cause study (discussed in the next section), where the number of unclassified failures (15%) is significantly smaller, indicates generally higher component aging fractions and thus tends to support the conclusion that the *other* category contains a significant number of aging-induced failures.

Examination of aging failure-category data (Figure 3) indicates that, in general, normally

Table 3. Example of detailed aging survey tables

						Age of Component and Failure Category[a]																			
						0-4.9 Years					5-9.9 Years					10-14.9 Years					15-20 Years				
NSSS	System	Component	Failure Total	Sys Eff No.	Sys Eff Co.[b]	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.

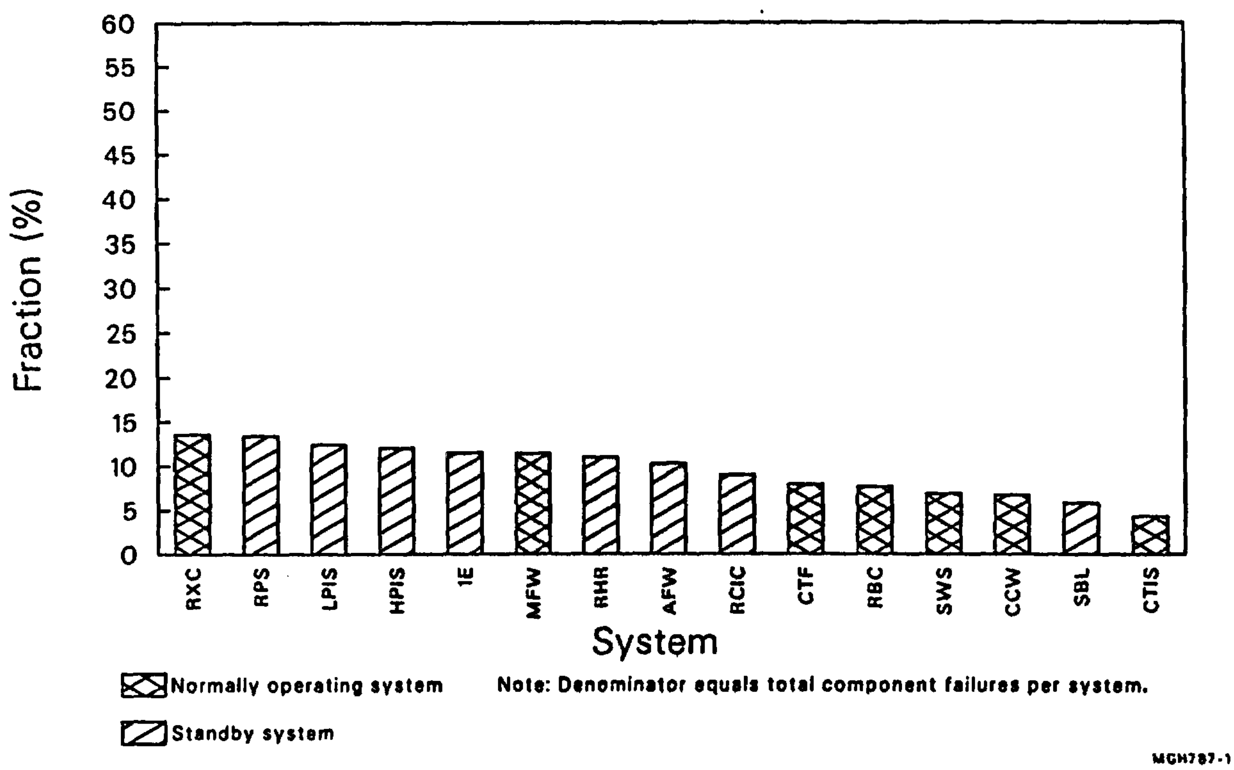

Figure 2. Fractions of the total failures within specified systems due to design error.

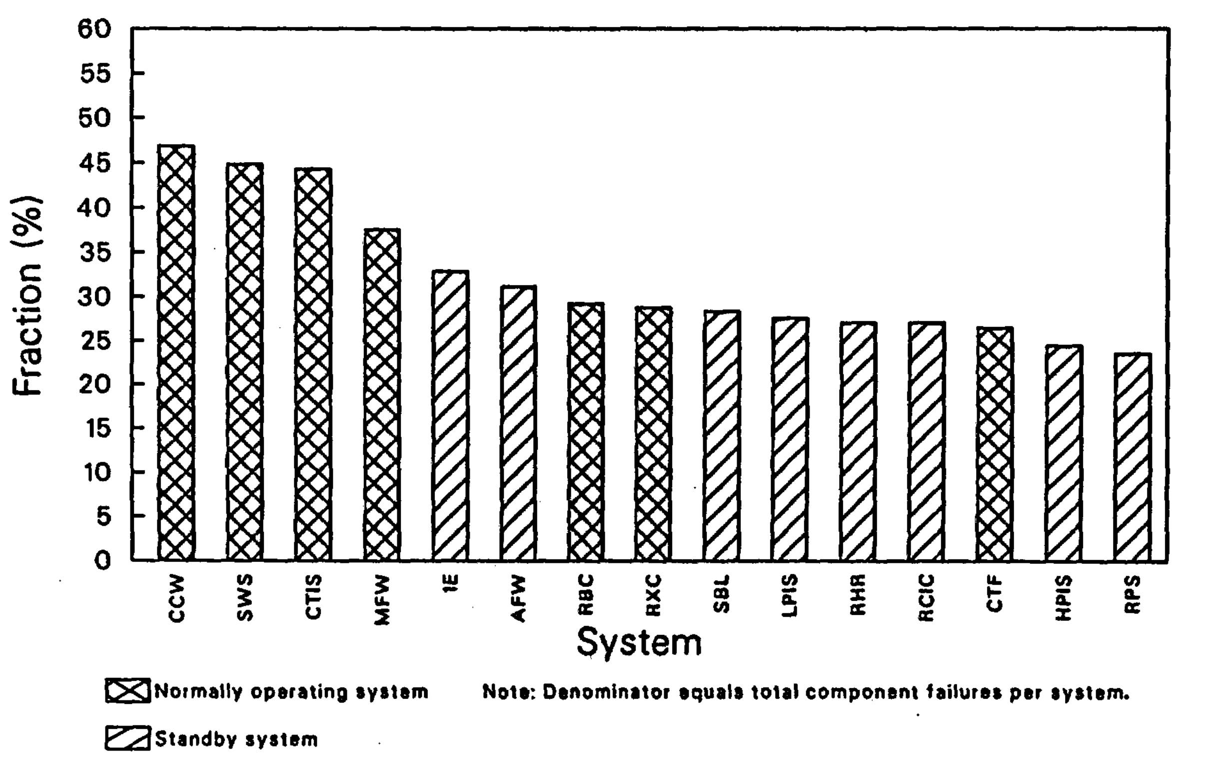

Figure 3. Fractions of the total failures within specified systems due to aging.

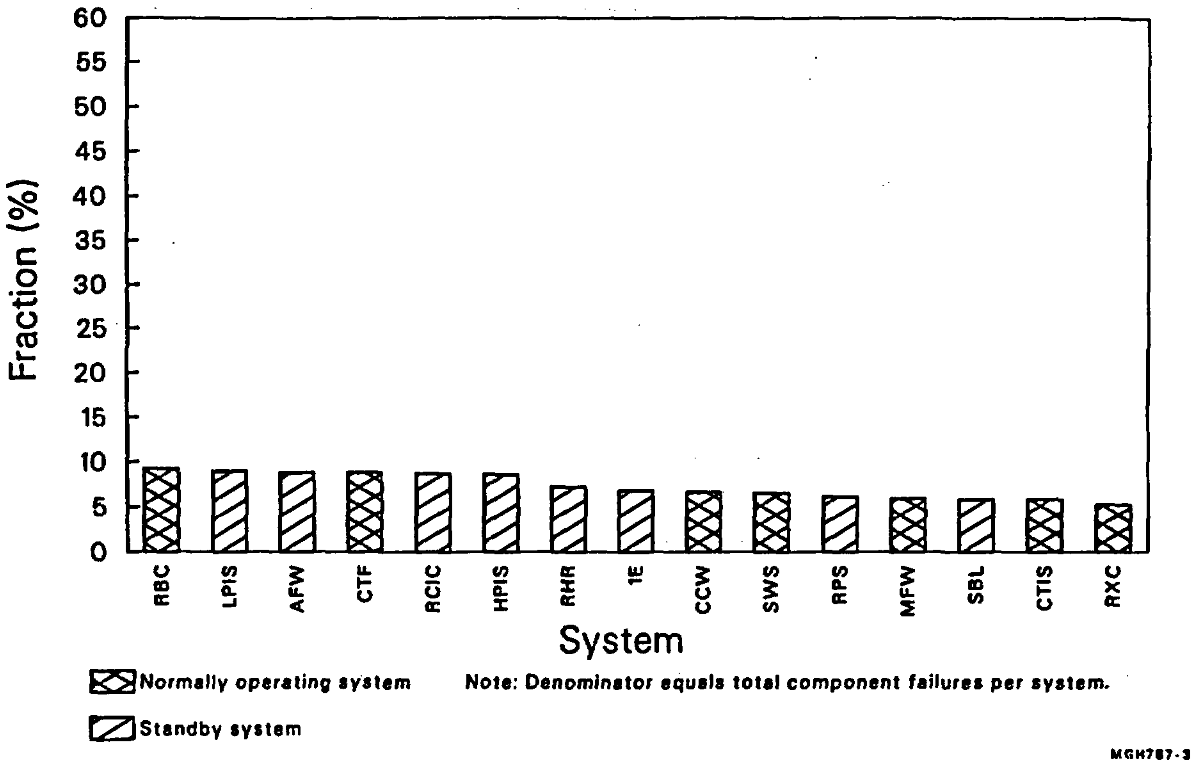

Figure 4. Fractions of the total failures within specified systems due to testing and maintenance.

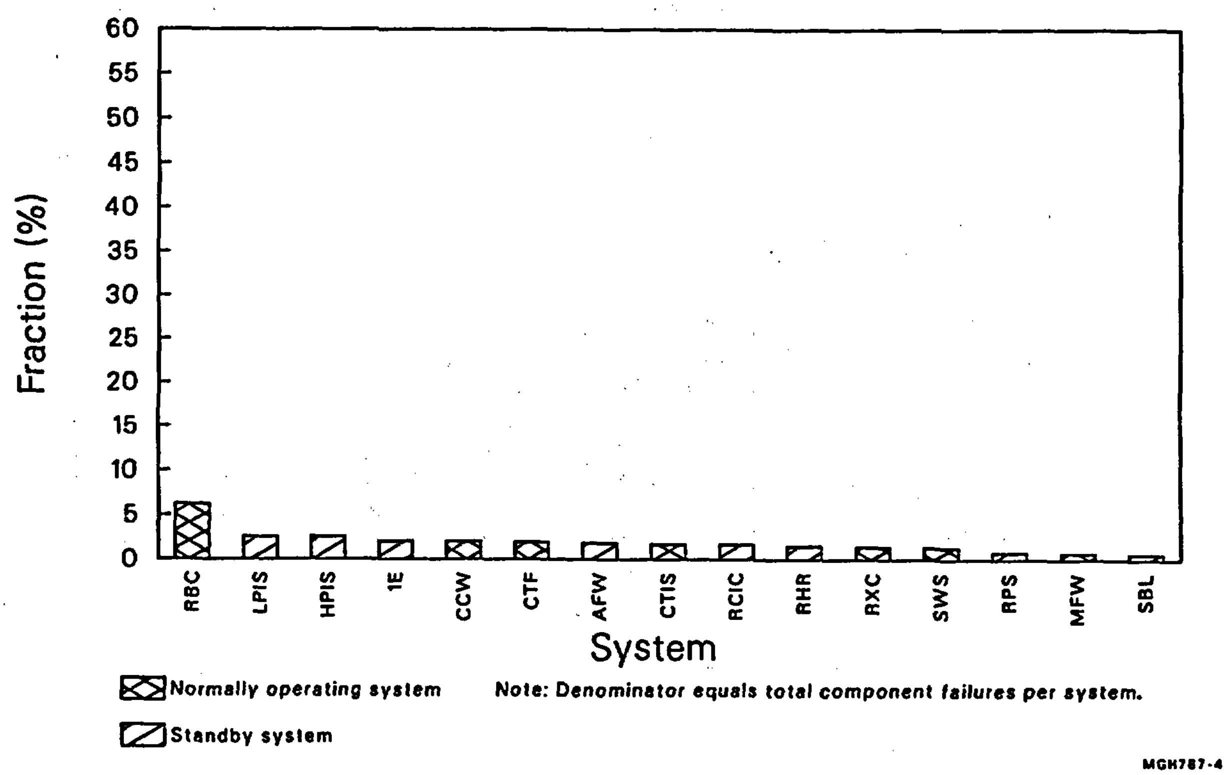

Figure 5. Fractions of the total failures within specified systems due to human-related actions.

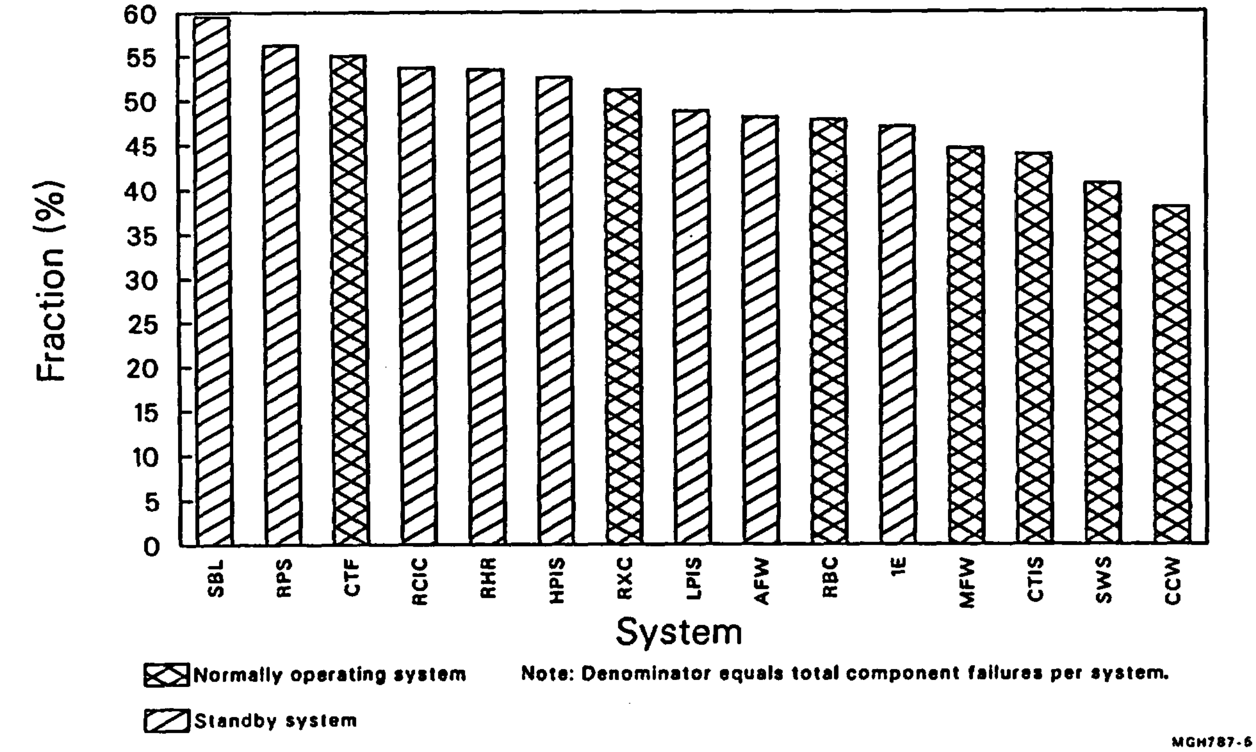

Figure 6. Fractions of the total failures within specified systems which are unknown or categorized as *other.*

operating systems exhibit slightly higher aging fractions than standby systems. The average aging fraction (in percent) for normally operating systems is 36.8%, while the average aging fraction (in percent) for standby systems is 27.7%. The normally operating systems with the highest aging fractions are component cooling water, service water, and containment isolation. The component cooling water system in nuclear power plants is operating at all times. This constant operation results in a higher incidence of aging failures. River, lake, or ocean water are the normal sources for service water. These influent waters contain particulates and debris that accelerate some aging mechanisms such as erosion and corrosion and increase the chance of failures due to foreign material intrusion. Containment isolation components must meet strict criteria defined in the technical specifications or are considered failed.

The relationship of failures to the reported system effects is presented in Figures 7 through 11. Examination of these figures indicates that, although the fractions in the *system function unaffected* (Figure 11) category are slightly higher than the other four system effect categories, there was no clearly dominant system effect category. However, very few failures caused a total loss of system function (see Figure 7) in any of the systems.

4.1.2 Aging Survey Results for Specific Components. Component-specific aging fractions can be expressed in several illustrative ways. One way would be to express the component aging fraction in terms of only the failures experienced by that component within its respective system. This component-level aging fraction representation is useful to determine the aging impacts on the performance of the component. Another way of representing the component aging fraction is to express it in terms of all of the various component failures in a system (this representation is referred to as being performed at the system level). In this representation, the aging failures experienced by a particular component are related to the total number of failures of all of the components in a particular system, thereby giving a representation of the component's aging importance within the system. However, this should not be confused with an importance that would be obtained from a probabilistic risk calculation.

To measure the uncertainty of the aging fraction data, a statistical uncertainty study was performed

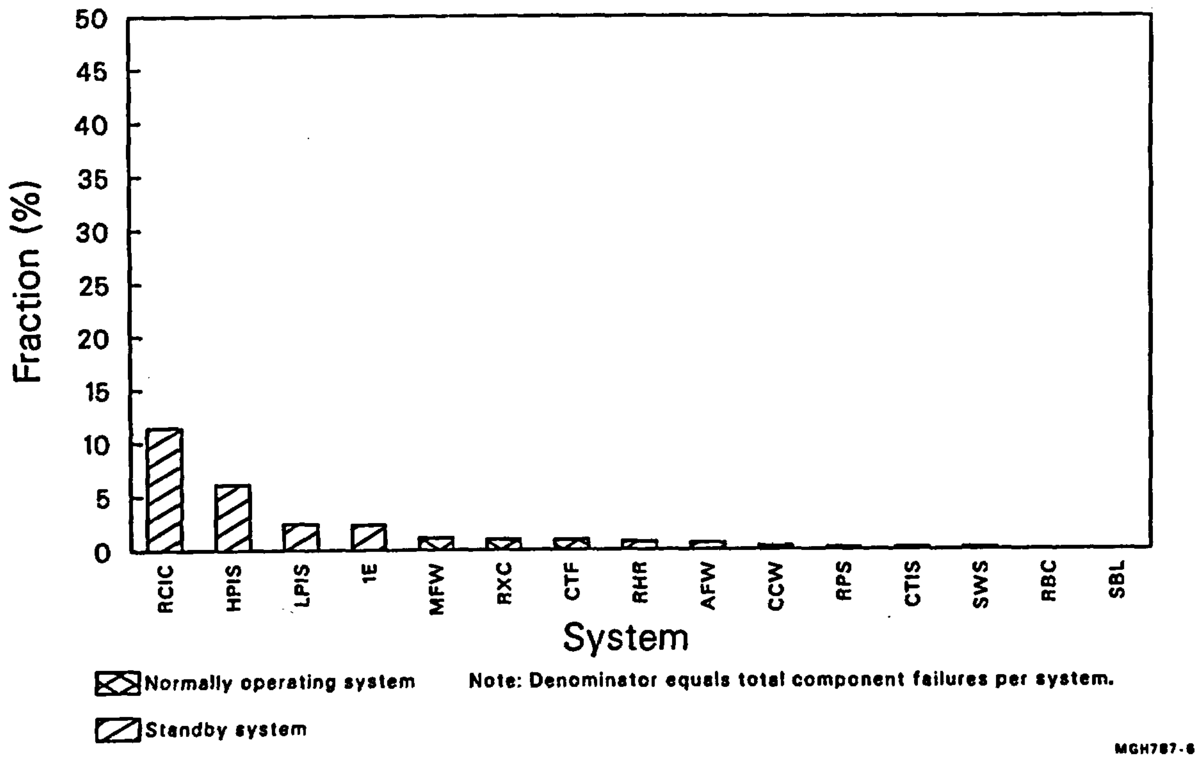

Figure 7. Fractions of the total failures within specified systems which resulted in a complete loss of system function.

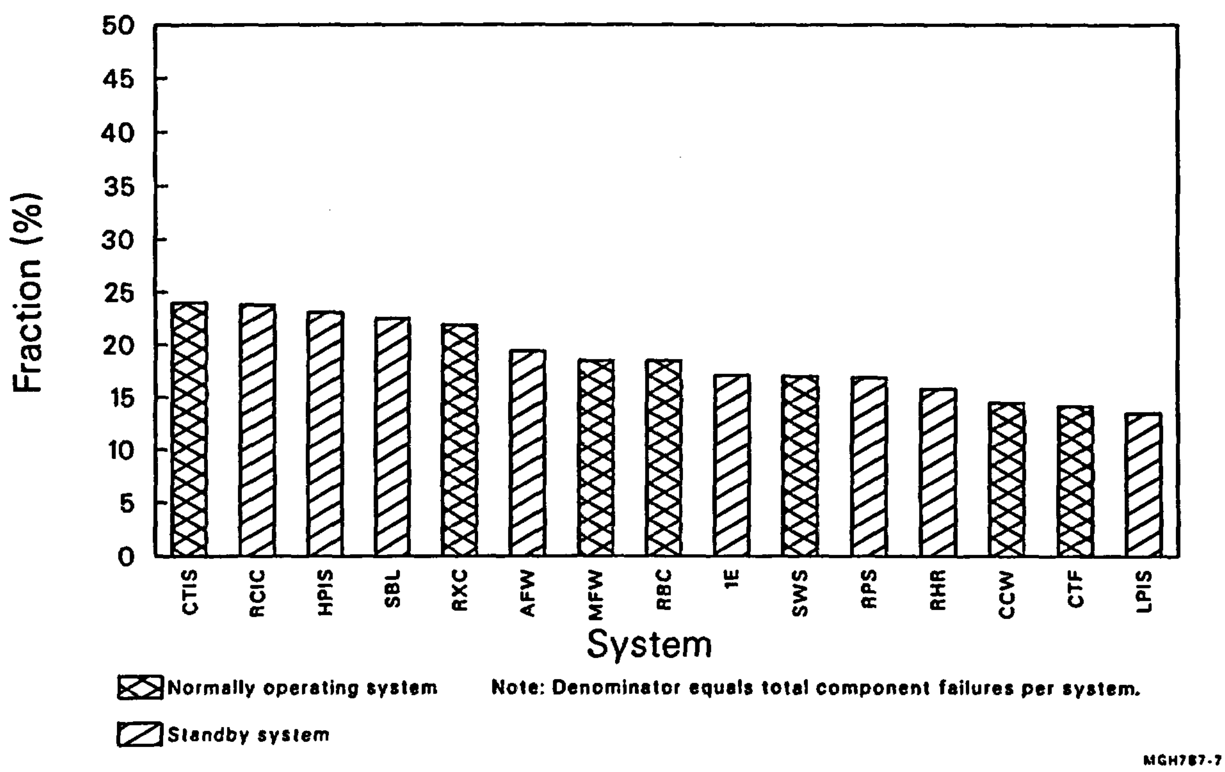

Figure 8. Fractions of the total failures within specified systems which resulted in degraded system operation.

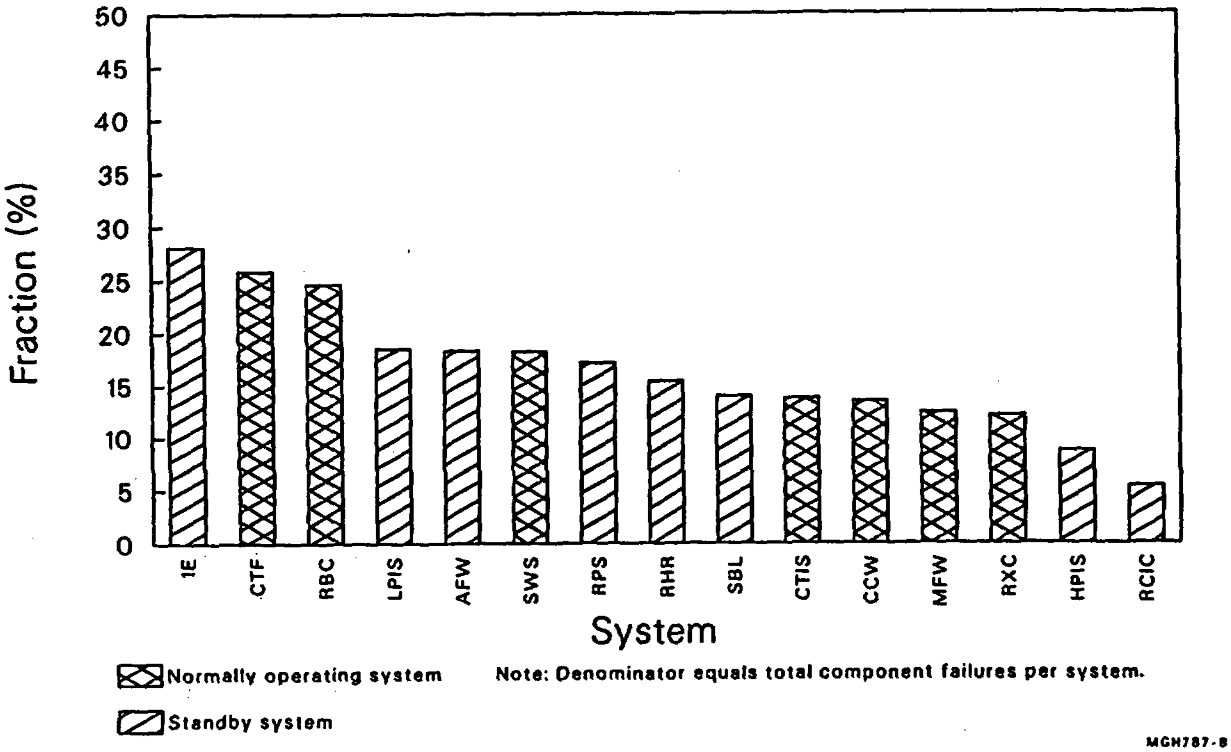

Figure 9. Fractions of the total failures within specified systems which resulted in a loss of redundancy.

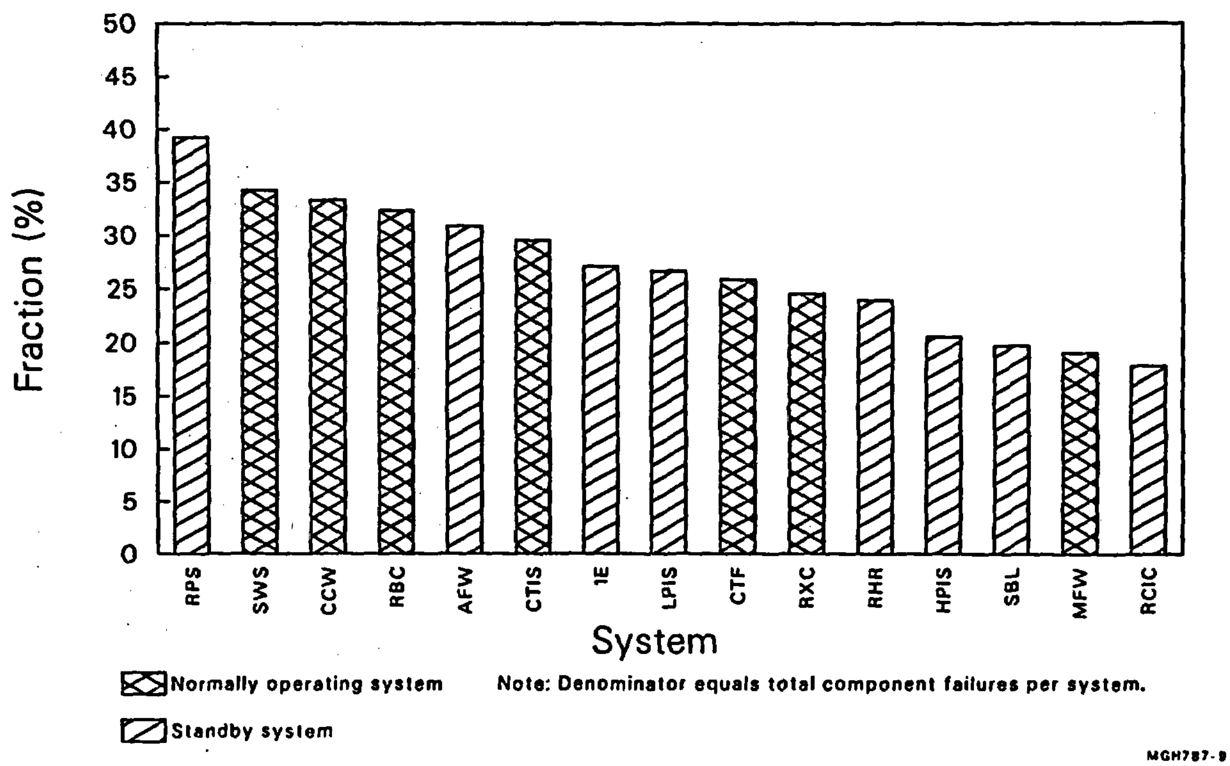

Figure 10. Fractions of the total failures within specified systems which resulted in loss of subsystem/channel.

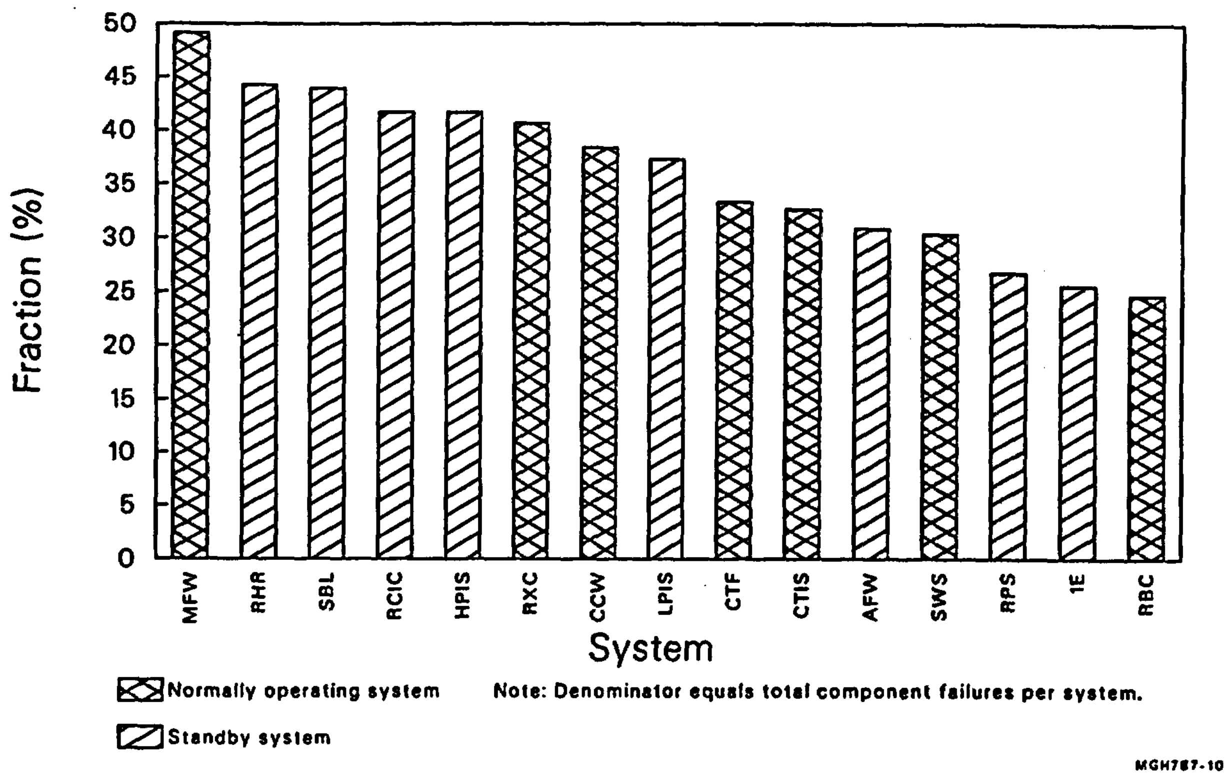

Figure 11. Fractions of the total failures within specified systems in which the system function was unaffected.

on the system-specific component aging fractions to identify statistically which components exhibit a system-dependent aging impact (the denominator is the total number of failures for the particular component within its respective system). The results of this study are presented in Tables 4 and 5. The components were divided into two groups. Components for which the systems exhibited no statistical dependency related to aging effect are listed in Table 4. Components for which system dependency of aging effects could be statistically determined are listed in Table 5. Only four components demonstrated any statistically significant differences between aging fractions across systems. These components were pumps, supports, switches, and valves. These results are somewhat different from those presented in Volume 1. The difference is primarily due to the performance of a more rigorous statistical analysis using adjusted residual techniques.

Aging fraction representations for selected components are presented throughout the following discussion. The first figure of each two-figure set displays the component aging fractions at the component level (i.e., the number of aging-related failures divided by the total number of failures of that particular component in a specified system) along with their associated estimated confidence intervals. The numbers shown with each data point are the number of failures associated with that component in that system. The second figure displays the component aging fractions, at the system level, which reflect the importance of aging for that component within the particular system. The system-level fractions are calculated by taking the number of aging-related failures for a specific component and dividing it by the total number of failures of all components in that system. These figures represent only a subset of the data presented in Appendix E. The component data shown in the figures are for the NPRDS component designations which roll up data for similar component types. For example, data for all types of valves, such as check valves, motor-operated valves, and pneumatic-operated valves, are combined for the data illustrated for valves. Appendix E must be consulted to obtain information about the specific components included in the component designation. The components illustrated were chosen for several reasons: (a) they tend to have high aging fractions in some systems, (b) they are represented in a majority of the systems, and (c) they are used in probabilistic

Table 4. Uncertainty study: no statistical system dependency related to aging

Component	Aging Fraction	95% Confidence Interval
Accumulator[a]	0.17	(0.05, 0.37)
Air dry[b]	0.50	(0.07, 0.93)
Annunciator[a]	0.50	(0.12, 0.88)
Battery and battery charging units[a]	0.32	(0.26, 0.38)
Blower-compressor[c]	0.60	(0.54, 0.66)
Circuit breaker[c]	0.26	(0.23, 0.30)
Electrical conductor[a]	0.09	(0.03, 0.20)
Engine[a]	0.25	(0.22, 0.29)
Filter[c]	0.56	(0.46, 0.65)
Generator/alternator/inverter[c]	0.24	(0.20, 0.29)
Heat exchangers[c]	0.52	(0.45, 0.58)
Heater[a]	0.14	(0.07, 0.25)
Instrumentation: computation module[c]	0.28	(0.25, 0.30)
Instrumentation: controller[c]	0.23	(0.19, 0.28)
Instrumentation: indicator/recorder[c]	0.25	(0.21, 0.28)
Instrumentation: electric power supply[a]	0.27	(0.22, 0.32)
Instrumentation: isolation device[a]	0.45	(0.29, 0.62)
Mechanical function unit[c]	0.31	(0.27, 0.41)
Motor[c]	0.36	(0.30, 0.43)
Penetration[a]	0.80	(0.28, 0.99)
Pipe[a]	0.26	(0.19, 0.35)
Relay[c]	0.25	(0.21, 0.29)
Transformer[a]	0.16	(0.05, 0.34)
Turbine[a]	0.16	(0.11, 0.23)
Valve operator[c]	0.25	(0.24, 0.27)
Vessel[b]	0.42	(0.15, 0.72)

a. The deletion of systems with expected cell count less than 5.0 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 5.0 were deleted. The remaining system/component data were used to calculate the aging fraction and confidence interval.

Table 5. Uncertainty study: statistical system dependency related to aging

Component	Aging Fraction	95% Confidence Interval	Systems
Instrumentation-switch[a]	0.19	(0.16, 0.23)	1E, RPS
	0.10	(0.09, 0.13)	HPIS, LPIS, RCIC, RHR, RXC, SWS
Pump[a]	0.75	(0.70, 0.81)	CCW
	0.45	(0.42, 0.49)	1E, AFW, HPIS, LPIS, MFW, RHR, RXC, SBL, SWS
Supports[a]	0.37	(0.27, 0.48)	HPIS
	0.20	(0.16, 0.24)	LPIS, MFW, RCIC, RHR, RXC
Valve[a]	0.58	(0.53, 0.63)	CTIS
	0.49	(0.47, 0.51)	1E, AFW, CCW, CTF, HPIS, LPIS, MFW, RCIC, RHR, RXC, SBL, SWS

a. Systems with expected cell count of less than 5.0 were deleted. The remaining system/component data were used to calculate the aging fraction and confidence interval.

risk assessments (PRAs). For use in PRAs, data for some NPRDS component designations are usually combined for components such as motor-operated valves (valves and valve operators) and motor-driven pumps (pumps and motors).

4.1.2.1 Aging Survey Results for Valves. Aging fraction data for valves are presented in Figures 12 and 13. Data in Figure 12 indicate that component aging fractions, at the component level, for valves are relatively significant and consistent between systems at 50% to 60%. The exceptions are standby liquid control and containment fan systems, where valve aging failures were less evident. Examination of Figure 12 reveals that the associated confidence intervals for the valve fractions are reasonably small (20%) due to the large valve failure populations. The confidence intervals imply that aging in valves is independent of the system in which the valves reside. However, the uncertainty study ascertained that aging in valves residing in the containment isolation system is system-dependent. The uncertainty study also ascertained that valves in the containment isolation system have a higher aging fraction (0.58) than valves in the other systems (0.49 composite) containing valves. Even though the analyses of the aging fractions of valves, at the component level, indicate that there is little system-to-system variability, data in Figure 13 indicate that, at the system level, systems can be identified where aging of valves has a greater impact on system performance. The data presented in Figure 13 indicate that the systems where the impact of valve aging is relatively important are containment isolation (28%) and main feedwater (21%) systems, followed by auxiliary feedwater (17%), component cooling water (16%), and service water (16%) systems to a lesser extent. Also data in Figure 13 show that, at the system level, the average aging fraction (in percent) for valves is 12.5%. This is the highest average aging fraction, at the system level, for any of the NPRDS component designations. Therefore, valves are considered to have the most significant contribution to the aging-related failures in the systems in which they reside as compared to other components.

Even though the analysis indicates that valves in the containment isolation system are impacted by aging-related failures, care should be taken in drawing a conclusion concerning actual failure of these valves. The technical specifications concerning the performance of these valves and their associated valve operators are rigorous. Technical specifications govern the maximum acceptable leak rate and maximum acceptable response time. When any of the performance requirements in the technical

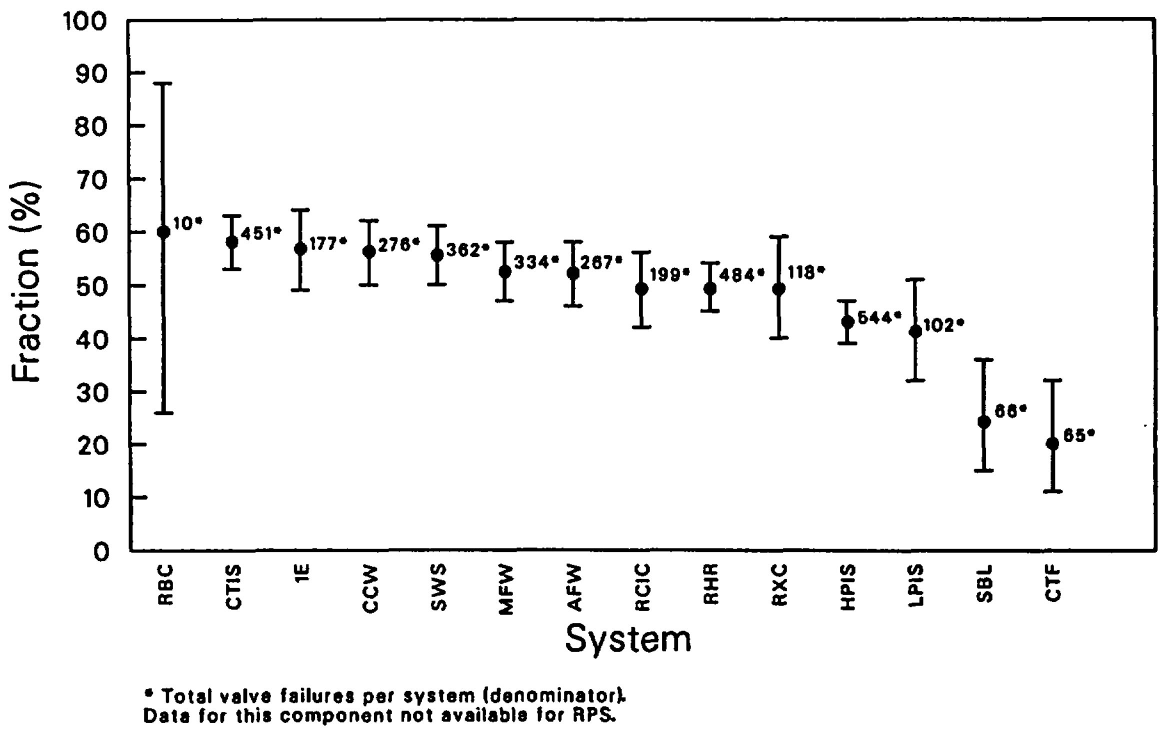

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Figure 12. Fractions of valve failures within specified systems due to aging.

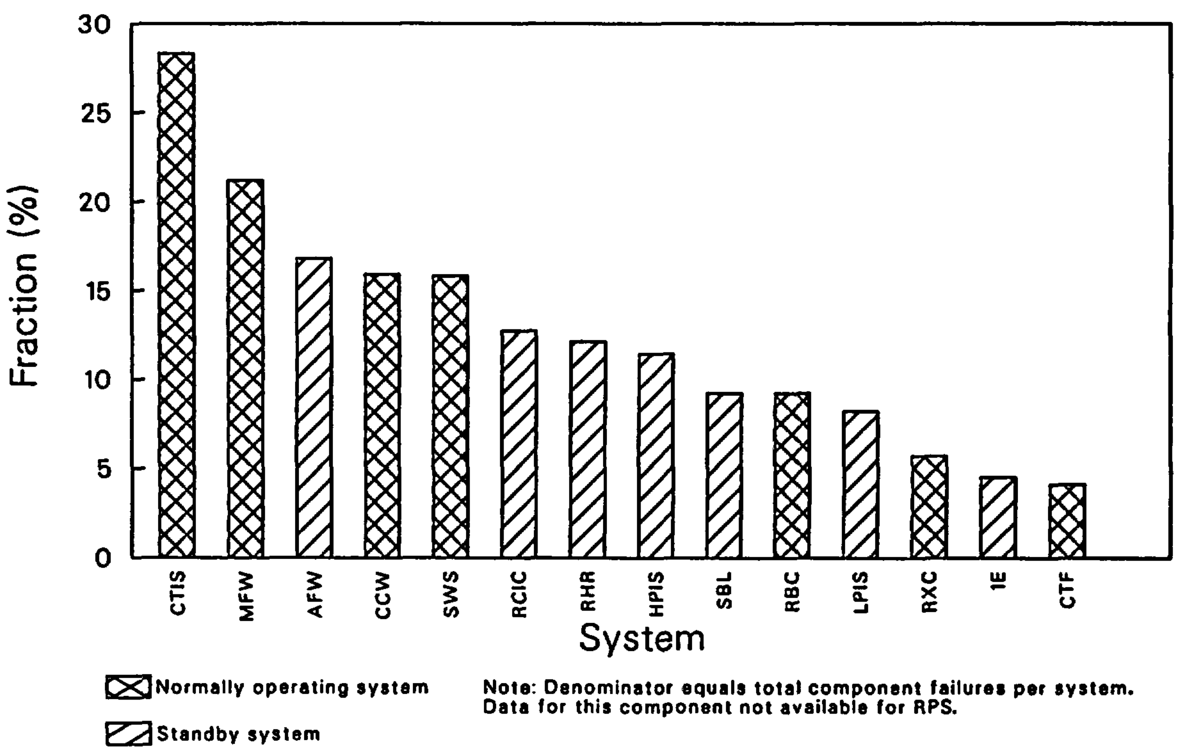

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Figure 13. Fractions of total component failures for specified systems due to aging in valves.

specifications are not met, the valve is considered failed. These rigorous performance requirements and the importance of valves in the containment isolation system may account for the failure population associated with these valves. Also, it should be noted that the NPRDS system boundary for the containment isolation system differs from the definition normally used by utilities (they consider it primarily an instrument and actuation system). The NPRDS containment isolation system configuration consists of valves and valve operators, as well as the instrumentation, annunciators, and circuit breakers associated with these valves. Valves accounted for 49% (see Appendix E) of the reported failures for the containment isolation system. The majority of the reported valve failures (see Appendix E) were for pneumatic-operated valves (62.5%) and motor-operated valves (12.5%).

4.1.2.2 Aging Survey Results for Valve Operators. Aging fraction data for valve operators are presented in Figures 14 and 15. Data in Figure 14 indicate that aging, at the component level, in valve operators is also relatively constant between systems at approximately 25%. The confidence intervals associated with valve operators are slightly larger than those associated with valves due to the failure population being slightly smaller. The three systems with very large confidence intervals and very small failure populations are the reactor building cooling, Class 1E electrical power distribution, and standby liquid control systems. The remaining 11 systems exhibited confidence intervals similar to each other and overlap adequately to be considered basically the same. Thus, data in Figure 14 indicate that aging associated with valve operators is independent of the system in which the valve operators reside. The results of the uncertainty analysis support this observation since valve operators showed no statistical system dependency related to aging. The uncertainty study's composite aging fraction for valve operators is 0.25 with an associated confidence interval of 0.24 to 0.27. Data illustrated in Figure 15 indicate that aging in valve operators does not produce a significant failure contribution at the system level. Based on all failures in a system, the average aging fraction (in percent) for valve operators across all 14 systems in which they reside is only 4%. Further examination of Figure 15 shows that valve operators in the containment isolation system have the highest aging fraction at the system level. Valve operators accounted for 38% (see Appendix E) of the total reported failures for the containment isolation system, and 12% of the total reported failures were due to aging in valve operators. The majority of reported valve operator failures in the containment isolation system (see Appendix E) were for valve operators associated with pneumatic-operated valves (74.5%) and motor-operated valves (21%). These valve operators in the containment isolation system must be able to close the valves within a maximum acceptable response time. Not meeting these response times constitutes a failure and is reportable under NPRDS guidelines.

4.1.2.3 Aging Survey Results for Pumps. The aging fraction data for pumps are presented in Figures 16 and 17. These figures identify pumps in the component cooling water system as having the highest aging fraction at both the component level (75%, see Figure 16) and the system level (14%, see Figure 17). This is a reasonable observation since the component cooling water system is operating in a nuclear power plant at all times. The constant pump operation results in increased aging effects. This is a unique factor since most systems within a nuclear power plant are not operating during all phases of reactor operations. Some systems are not required during refueling outages, and some are placed in a standby mode during power operations. The uncertainty study further indicates that the component cooling water pumps have statistically distinguishable aging impacts when compared to other systems. The uncertainty study results state that component cooling water pumps have a higher aging fraction (0.75) than pumps in the other 11 systems containing pumps (0.45 composite). These aging fractions indicate that pump aging-related failures have a significant impact on their respective system's operation. Data in Figure 16 also show that the confidence intervals associated with the pump aging fractions, at the component level, vary considerably and are larger than the ones associated with valves and valve operators. The total failure count for pumps is also smaller than the total for valves and valve operators. Additionally, data in Figure 17 show that, at the system level, aging of pumps within the service water (11%) and standby liquid control (7%) systems is slightly more important than aging in pumps within the other nine systems containing pumps. These nine systems all exhibit less than 5% aging-related fraction at the system level. Pumps in both the service water and standby liquid control systems are adversely affected by the fluid they pump. Service water is usually river or ocean water which contains particulates and debris that can plug, erode, and corrode

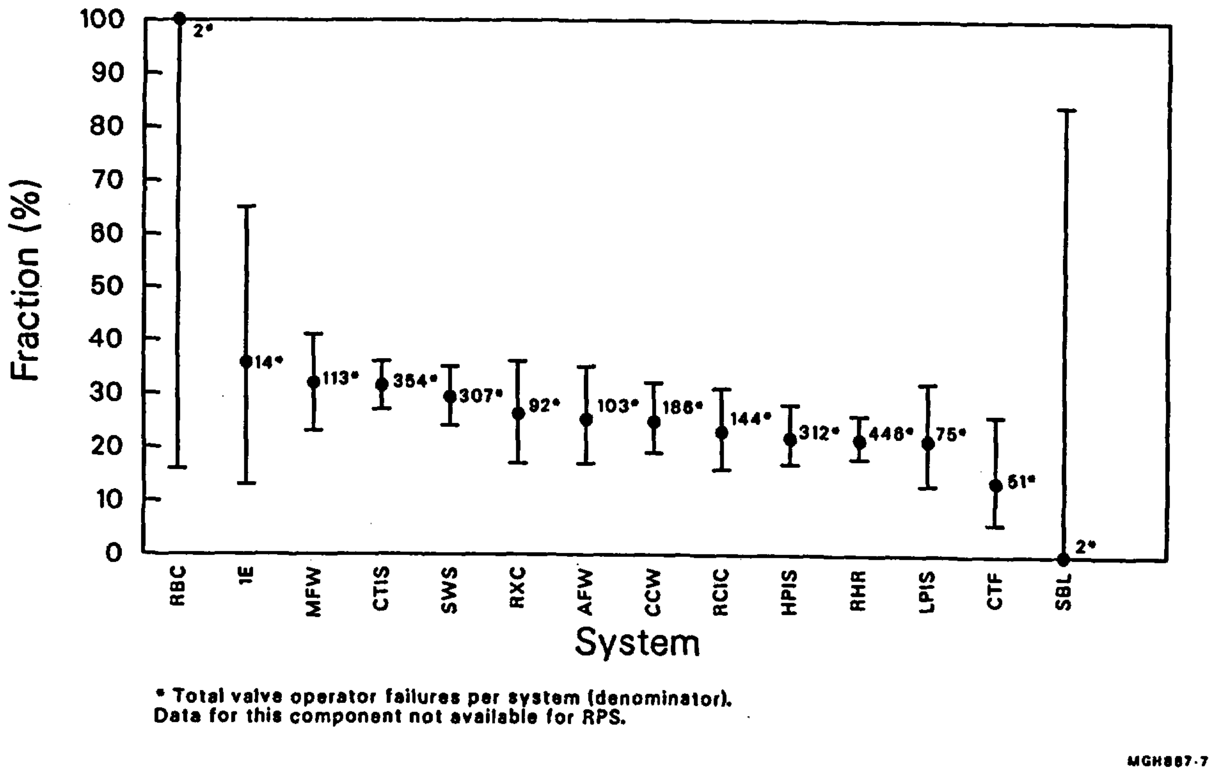


Figure 14. Fractions of valve operator failures within specified systems due to aging.

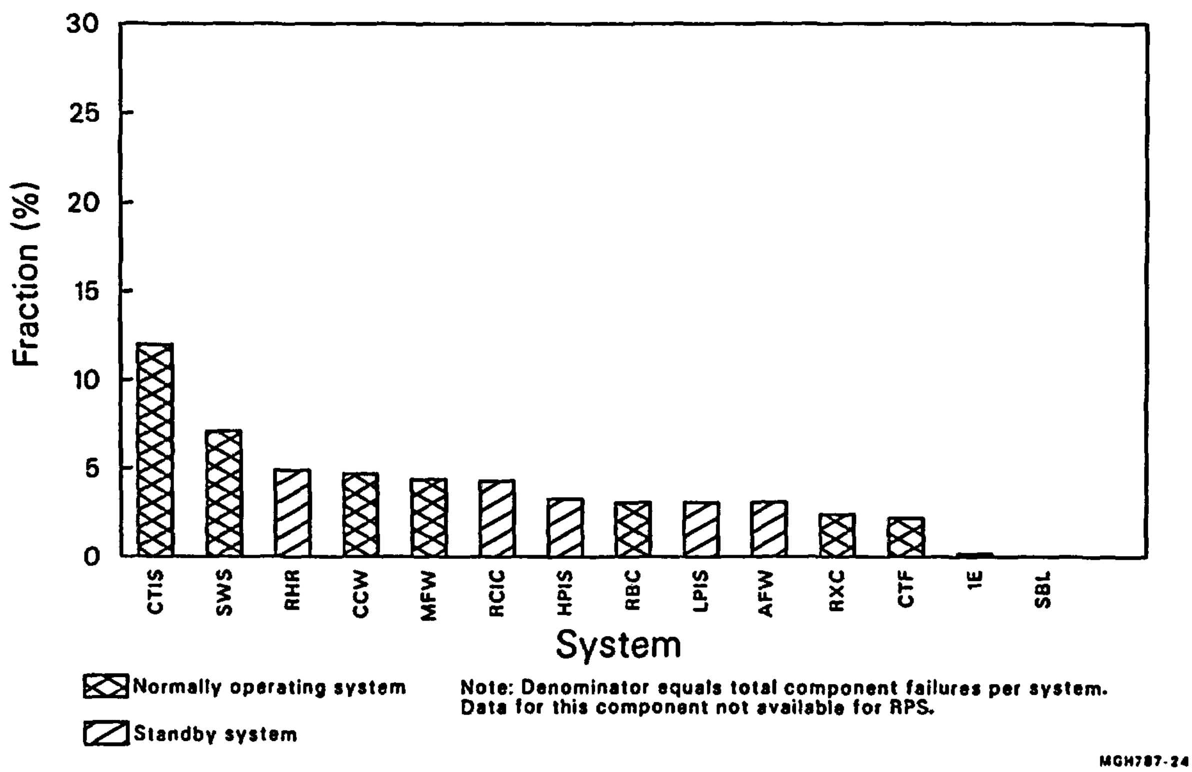


Figure 15. Fractions of total component failures for specified systems due to aging in valve operators.

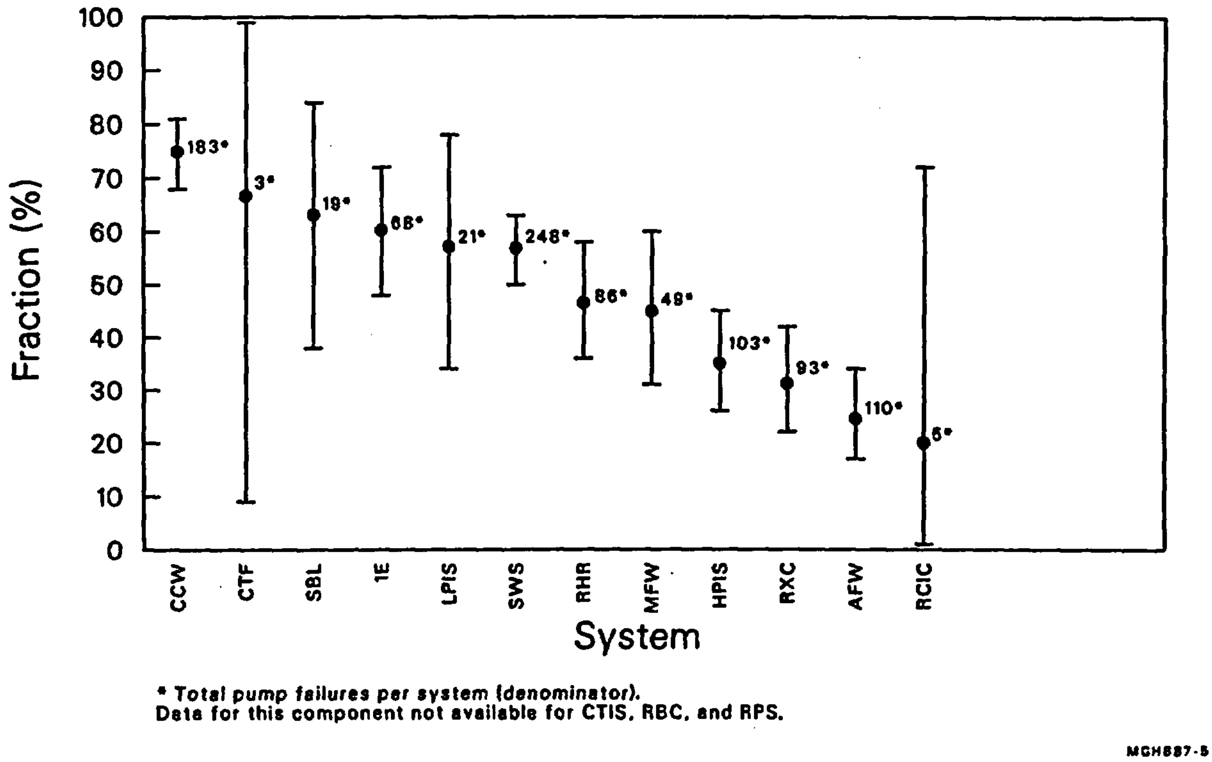


Figure 16. Fractions of pump failures within specified systems due to aging.

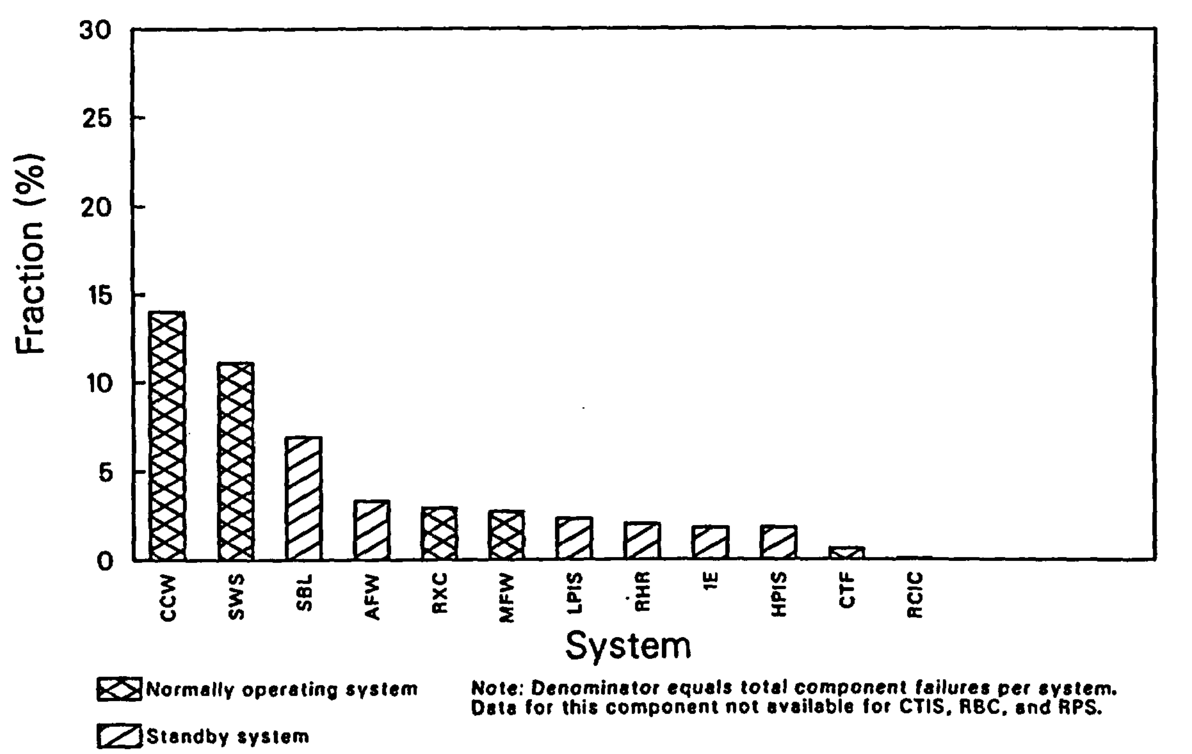


Figure 17. Fractions of total component failures for specified systems due to aging in pumps.

pump internals. Standby liquid control is a boric acid injection system. The boric acid environment can be very damaging to pump seals.

4.1.2.4 Aging Survey Results for Motors. The aging fraction data for motors are presented in Figures 18 and 19. NPRDS reporting guidelines for motors state that all motors used as a prime mover or driver of a reportable component, such as a pump, blower, or generator, are separately reportable. Motors that are a part of such components as valve operators, circuit breakers, and battery chargers are considered a piece part of the respective component and reported as that component.[10] Data in Figure 18 show that, at the component level, motors in the Class 1E electrical power distribution system exhibit the highest aging fraction. The data in Figure 18 also show that the confidence intervals associated with the aging fractions calculated for motors are relatively large due to the small failure populations. Data in Figure 19 show that, at the system level, aging-related failures of motors are relatively insignificant contributors to total failures, with the average aging-related failure fraction (in percent) being approximately 1.5%. Of the various systems, motors in the reactor building cooling system exhibit the highest aging fraction. The motors in the reactor building cooling system drive the blowers in that system. These blowers are operating continuously to cool the reactor building. Motor failures in the reactor building cooling system account for 17% of the total reported system failures, with 6% being related to aging.

4.1.2.5 Aging Survey Results for Heat Exchangers. The aging fraction data for heat exchangers are presented in Figures 20 and 21. Data in Figure 20 show that, at the component level, heat exchangers have a relatively high aging fraction (ranging from 30% to 68%). Of these systems, the main feedwater heat exchangers have the highest aging fraction. These heat exchangers are used as feedwater heaters and are located downstream of the turbine exhaust. It is suspected that the steam environment contributes to the degradation process. However, the uncertainty study results and examination of the confidence intervals in Figure 20 indicate aging of heat exchangers does not show a system dependence. Data in Figure 21 indicate that, at the system level, heat exchangers are not significant contributors to system failure, with the average aging fraction being 2%. The component cooling water system has the highest aging fraction. Aging-related failures of component cooling water heat exchangers accounted for 5% of the total reported failures in that system. These heat exchangers use service water to remove heat from the component cooling water. In many cases, the impurities in the service water erode the tubes. As stated above, the component cooling water system is in constant use; therefore, these heat exchangers have service water flowing through their tubes continuously, which contributes to the aging of the heat exchangers.

4.1.2.6 Aging Survey Results for Pipes. The aging fraction data for pipes are presented in Figures 22 and 23. The failure populations for pipes were very small. The reactor cooling system had the largest population of pipe failures with 35 failures, followed by low-pressure injection system (20) and high-pressure injection system (19). The confidence intervals associated with pipes are very large due to the small failure population for each system. Thus, aging in pipes is statistically independent of the system in which they reside. The composite component aging fraction resulting from the statistical analysis for pipes is 0.26 with an associated confidence interval of 0.19 to 0.35. Data in Figure 23 show that the pipe failures in the reactor cooling system are only 1% of the total component failures in that system and that pipe failures in the other systems exhibit an even smaller fraction of the total component failures in their respective systems. Thus, aging-related pipe failures are not significant contributors to the failure populations within those systems.

4.1.2.7 Aging Survey Results for Circuit Breakers. The aging fraction data for circuit breakers are presented in Figures 24 and 25. Circuit breakers appear in all 15 systems studied. Their population ranges from two in the standby liquid control system to 243 in the Class 1E electrical power distribution system; therefore, their confidence intervals (Figure 24) vary considerably. Data in Figure 24 show that the main feedwater system has the highest aging-related fraction for circuit breakers, but the failure population is only nine. The Class 1E electrical power distribution system, which has the largest population, has a relatively low aging-related fraction (0.24) associated with it. Data in Figure 25 show that, at the system level, aging in circuit breakers does not significantly impact system operation. The average aging-related fraction (in percent) at the system level is 2%.

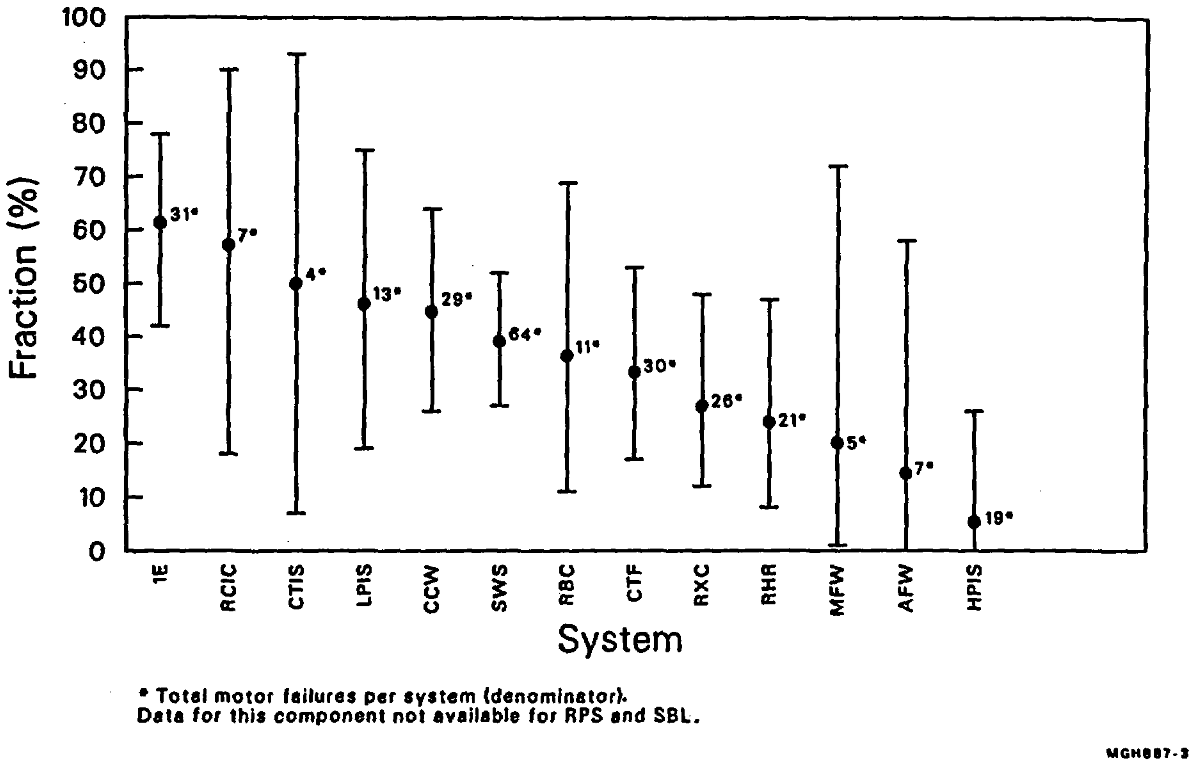


Figure 18. Fractions of motor failures within specified systems due to aging.

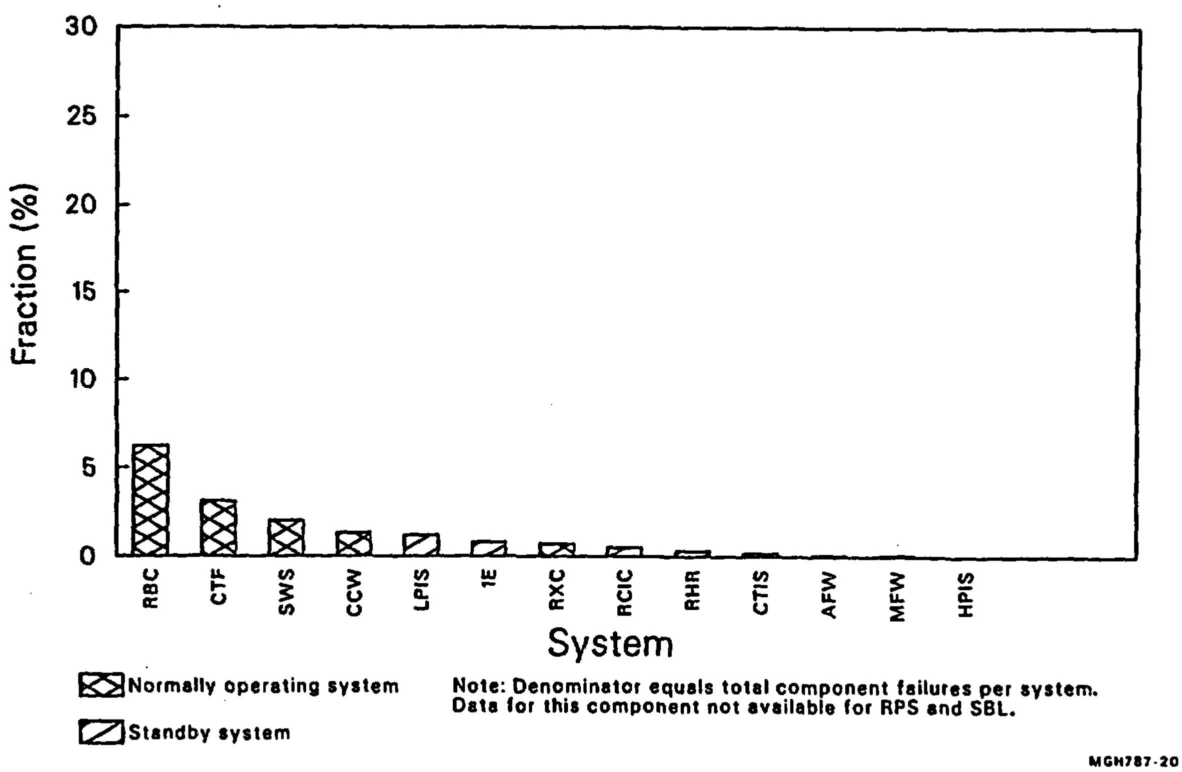


Figure 19. Fractions of total component failures for specified systems due to aging in motors.

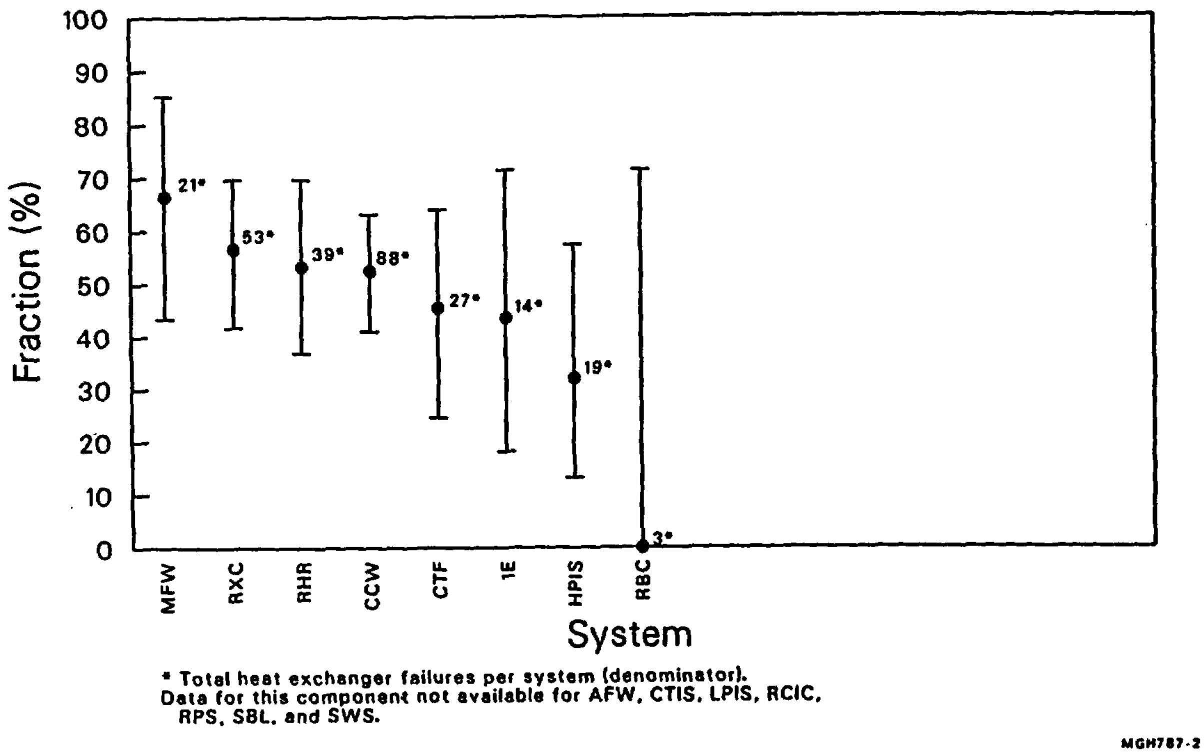


Figure 20. Fractions of heat exchanger failures within specified systems due to aging.

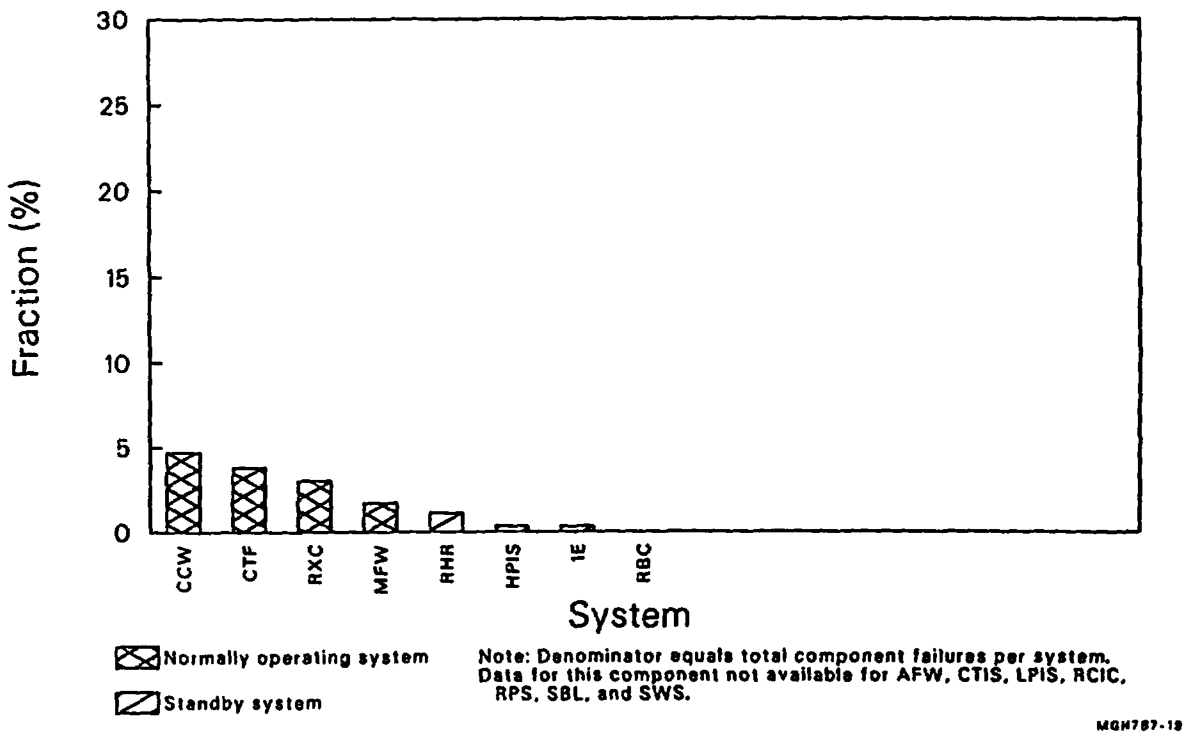


Figure 21. Fractions of total component failures for specified systems due to aging in heat exchangers.

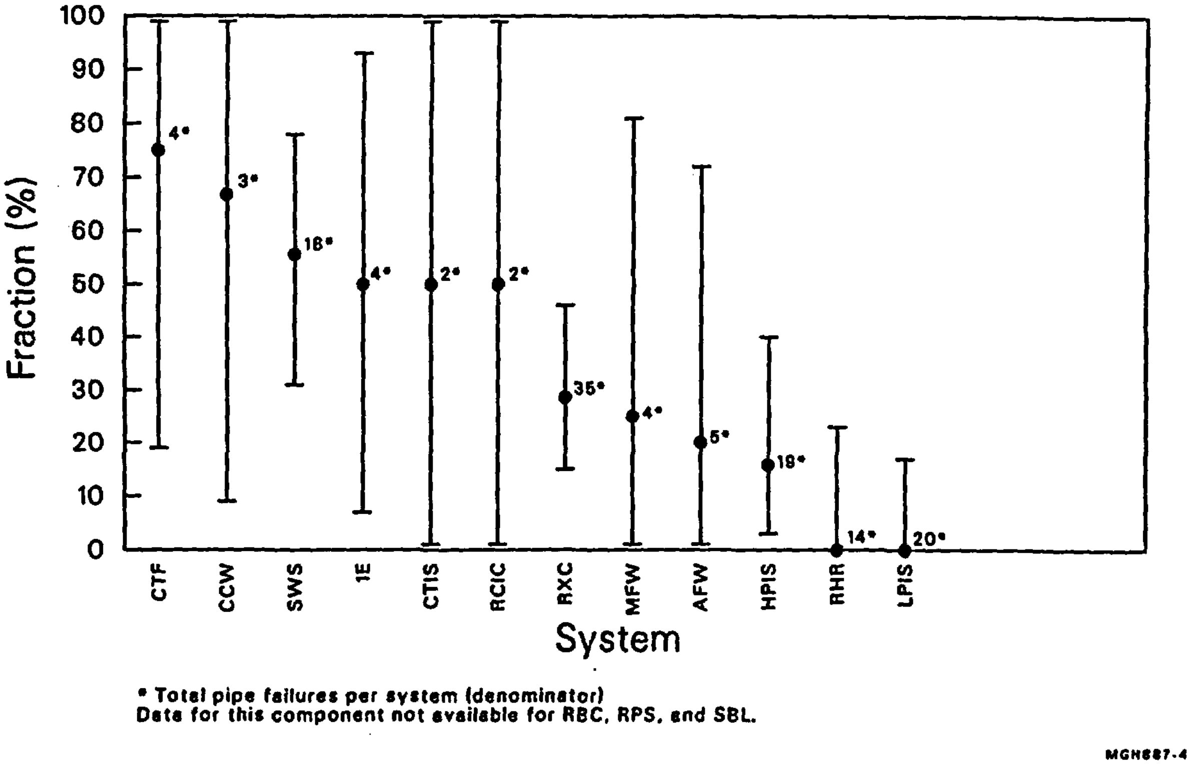


Figure 22. Fractions of pipe failures within specified systems due to aging.

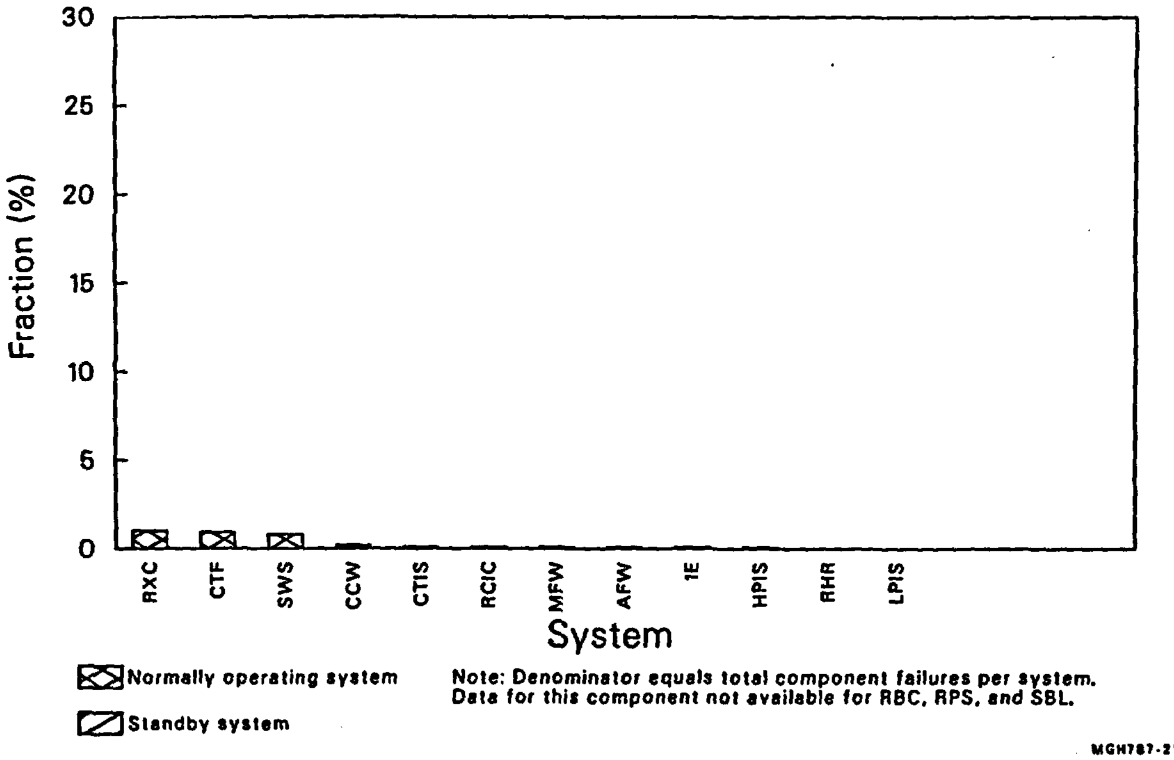


Figure 23. Fractions of total component failures for specified systems due to aging in pipes.

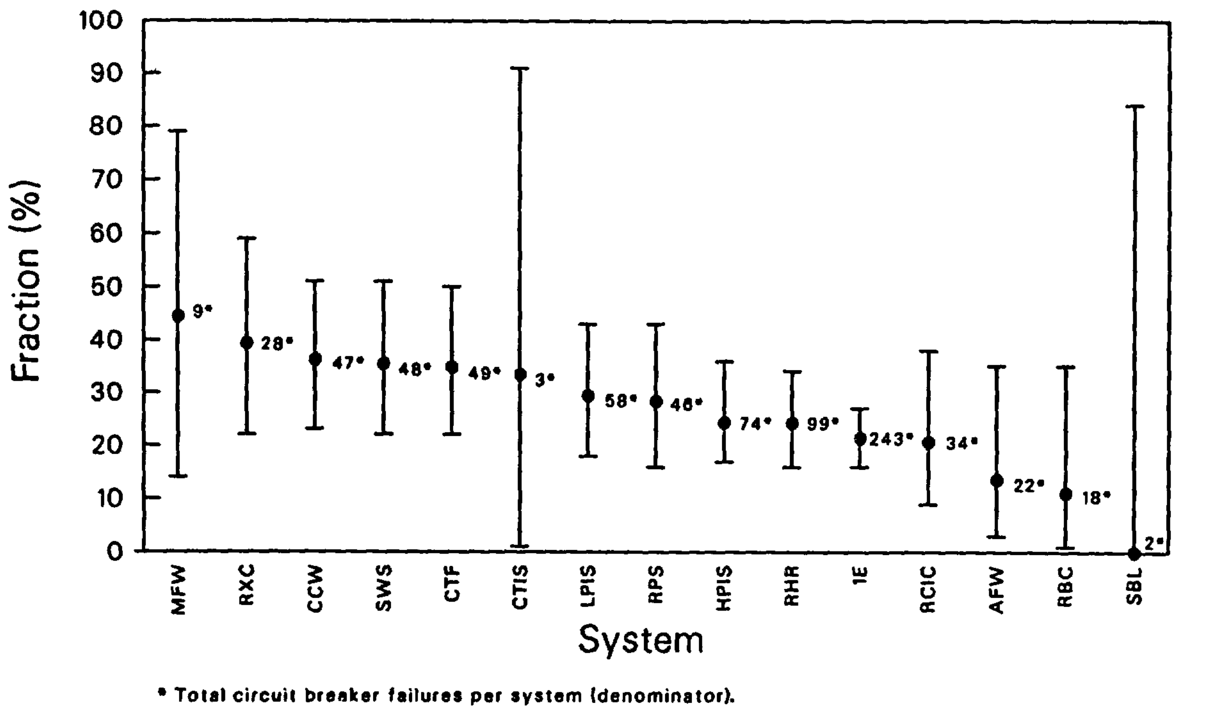


Figure 24. Fractions of circuit breaker failures within specified systems due to aging.

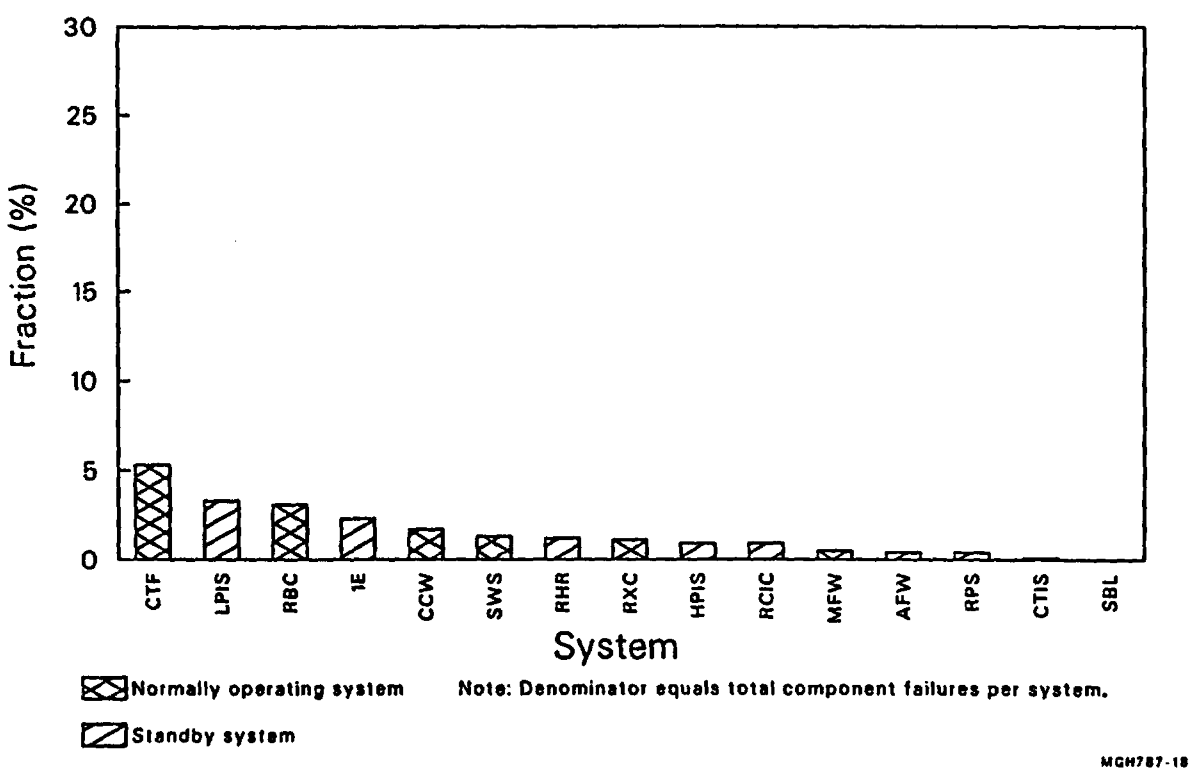


Figure 25. Fractions of total component failures for specified systems due to aging in circuit breakers.

4.1.3 Aging Survey Results at the System Level. Based on the analyses, the components which exhibit statistical system dependency and significant aging fractions are valves and pumps. A ranking of the system-specific component aging fractions, at the system level, is presented in Table 6. Table 6 is a list of only the system-specific components whose aging-related fraction (in percent) at the system level is greater than 5%. These fractions are calculated by dividing the number of aging-related failures for a specific component by the total number of failures for all components in its respective system. Valves in the containment isolation system exhibit the highest aging-related fraction (0.28) of all the system-specific components analyzed. Valve aging-related failures in main feedwater, auxiliary feedwater, component cooling water, and service water also rank in the top five system-specific components. Pumps in the component cooling water system exhibit the highest aging-related fraction for pumps, at the system level, and rank sixth on the list of important system-specific components.

4.1.4 Aging Survey Results of Time-Dependent Study. A study was made of the time dependency of aging-related failures for system-specific components. The time-dependent aging fractions for system-specific components having at least 50 failure counts are listed in Table 7. Since valves and pumps had the highest failure populations, data for these two components were chosen to illustrate the time-dependent fractions. Confidence intervals were calculated for the valve and pump data to illustrate any potential trending of the data. Data in Figure 26 illustrate the time-dependent fractions for valves in six different systems along with their associated confidence intervals. Similar pump data are shown in Figure 27. The systems chosen for the illustration were the six systems with the largest component populations for that component. The fractions were calculated using the component failure population within each of the time intervals (number in parentheses in the figures) as the normalizing basis.

The data exhibit discernible time dependencies in aging-related failures as indicated in Figure 26 by the data for valves in the high-pressure injection, residual heat removal, and main feedwater systems. Examination of the time-dependent fractions along with their postulated confidence intervals indicates that most of the illustrated data have the potential for increasing aging-related failure fractions with time. However, in some cases, such as the data for pumps in the Class 1E electrical power distribution system (Figure 27) and the data for valves in the component cooling water system (Figure 26), the time-dependent aging fractions and confidence intervals indicate the potential for constant aging fractions with time.

It was expected that the pattern would show an increase in aging failures with an increase in the age of the component up to the useful lifetime of the component. However, some of the components studied may have useful lifetimes only in the range of 5 to 10 yr. This is especially true of the component piece parts or internals that age more rapidly than the component structural parts. Furthermore, very few components have experienced an exposure time into the 15-to-20-yr range. This causes the existing time-dependent aging fractions to be very uncertain due to sparse data. This is illustrated in Figures 26 and 27 by the large confidence intervals calculated for the fractions in the 15-to-20-yr division. Additionally, the data utilized in this study are affected by variables such as plant maintenance practices, the age of the plant, and NPRDS reporting practices. 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 maintenance practices and component maintenance histories would have to be studied. As discussed earlier, this type of analysis was beyond the scope of the current study.

The data exhibit potential time-dependent trends when the postulated confidence intervals are considered, with most components having an increasing (to some degree) failure rate with time. However, some components may statistically or actually have constant failure rates, which would indicate that aging effects are not important to these components over their lifetimes. Statistical analysis could be used to calculate the failure rate increases but was beyond the scope of this study.

4.2 Reported Failure-Cause Analysis

In the reported failure-cause analysis, 2012 component failure records were carefully evaluated. Table 8 is a summary of all the component failures for the systems studied in this analysis. The data are ordered by lower-bound aging fraction.

Table 6. Ranking of system-specific components by system-level aging fractions

System	Component	Aging Fraction
Containment isolation	Valve	0.283
Main feedwater	Valve	0.212
Auxiliary feedwater	Valve	0.168
Component cooling water	Valve	0.159
Service water	Valve	0.158
Component cooling water	Pump	0.140
Reactor core isolation cooling	Valve	0.127
Residual heat removal	Valve	0.121
Containment isolation	Valve operator	0.120
High-pressure injection	Valve	0.114
Service water	Pump	0.111
Standby liquid control	Valve	0.092
Reactor building cooling	Valve	0.092
Low-pressure injection	Valve	0.082
Reactor protection trip	Instrumentation: computation module	0.073
Service water	Valve operator	0.071
Standby liquid control	Pump	0.069
Reactor building cooling	Motor	0.062
Low-pressure injection	Support	0.062
Class 1E electrical power distribution	Blower	0.059
Reactor cooling	Valve	0.057
Class 1E electrical power distribution	Engine	0.056
Containment fan	Circuit breaker	0.053

Table 7. System-specific component time-dependent aging fractions[a]

System	Component	Total Failures	Fraction (0 to 4.9 y)	Fraction (5 to 9.9 y)	Fraction (10 to 14.9 y)	Fraction (15 to 20 y)
1E	Battery	243	0.317	0.379	0.271	0.111
1E	Blower	217	0.552	0.635	0.735	0.167
1E	Circuit breaker	249	0.222	0.177	0.231	0.231
HPIS	Circuit breaker	74	0.107	0.324	0.333	0.333
LPIS	Circuit breaker	58	0.083	0.462	0.333	0.167
RHR	Circuit breaker	100	0.235	0.179	0.318	0.500
1E	Engine	512	0.155	0.197	0.504	0.000
SWS	Filter	101	0.676	0.518	0.375	0.000
1E	Generator/alternator/inverter	403	0.211	0.223	0.250	0.667
CCW	Heat exchanger	88	0.625	0.312	0.727	0.304
RXC	Heat exchanger	53	0.333	0.316	0.840	0.000
1E	Instrumentation: switch	93	0.241	0.250	0.214	0.000
HPIS	Instrumentation: switch	358	0.026	0.085	0.250	0.000
LPIS	Instrumentation: switch	63	0.100	0.125	0.357	0.000
RCIC	Instrumentation: switch	177	0.067	0.058	0.333	0.000
RHR	Instrumentation: switch	207	0.078	0.183	0.150	0.000
RPS	Instrumentation: switch	514	0.172	0.182	0.237	0.200
RXC	Instrumentation: switch	83	0.043	0.194	0.115	0.667
RPS	Instrumentation: controller	209	0.229	0.182	0.246	1.000
HPIS	Instrumentation: recorder	55	0.143	0.357	0.667	0.000
RHR	Instrumentation: recorder	79	0.167	0.147	0.286	0.000
RPS	Instrumentation: recorder	219	0.150	0.208	0.404	0.387
RXC	Instrumentation: recorder	103	0.200	0.289	0.293	0.000
RPS	Instrumentation: computation module	932	0.251	0.278	0.329	0.526

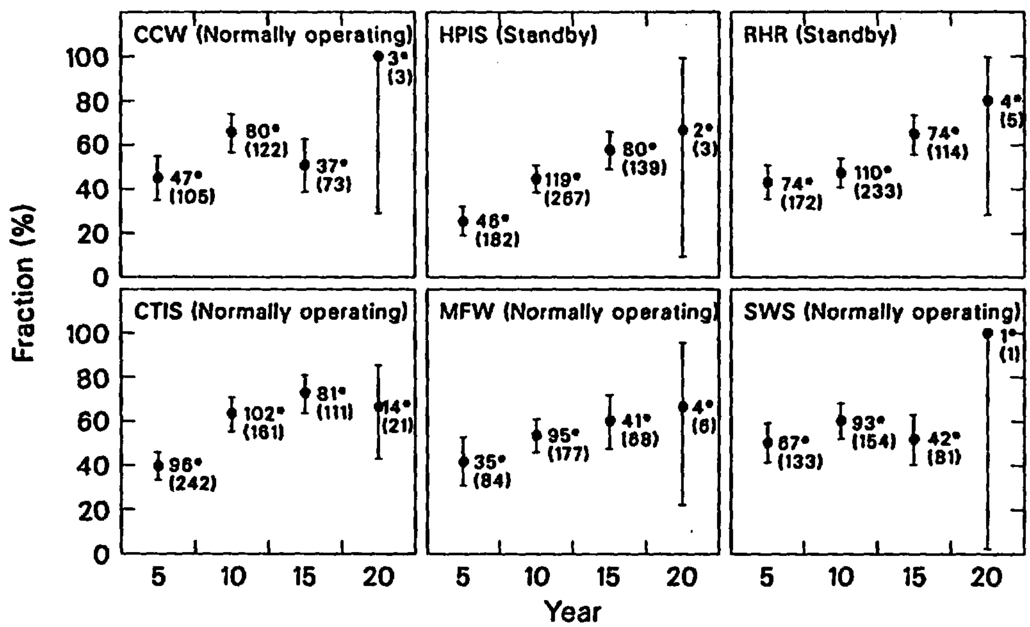
Table 7. (continued)

System	Component	Total Failures	Fraction (0 to 4.9 y)	Fraction (5 to 9.9 y)	Fraction (10 to 14.9 y)	Fraction (15 to 20 y)
RPS	Instrumentation: electric power supply	270	0.204	0.266	0.270	0.667
AFW	Instrumentation: transmitter	78	0.020	0.261	0.200	0.000
CCW	Instrumentation: transmitter	61	0.150	0.231	0.000	1.000
HPIS	Instrumentation: transmitter	262	0.104	0.107	0.182	0.000
MFW	Instrumentation: transmitter	82	0.147	0.222	0.083	0.000
RHR	Instrumentation: transmitter	184	0.130	0.060	0.161	0.500
RPS	Instrumentation: transmitter	942	0.206	0.113	0.328	0.222
RXC	Instrumentation: transmitter	123	0.024	0.159	0.037	0.000
1E	Mechanical function unit	55	0.118	0.421	0.222	0.000
SWS	Motor	66	0.300	0.286	0.611	0.000
1E	Pump	69	0.619	0.630	0.524	0.000
AFW	Pump	111	0.132	0.120	0.531	0.000
CCW	Pump	185	0.585	0.717	0.910	0.714
HPIS	Pump	103	0.242	0.290	0.487	0.000
RHR	Pump	87	0.500	0.385	0.545	1.000
RXC	Pump	94	0.295	0.378	0.167	1.000
SWS	Pump	252	0.488	0.602	0.581	1.000
1E	Relay	89	0.182	0.188	0.391	1.000
RPS	Relay	381	0.168	0.252	0.363	0.000
HPIS	Support	84	0.217	0.550	0.190	0.000
LPIS	Support	54	0.333	0.280	0.143	1.000
MFW	Support	55	0.054	0.294	0.000	0.000
RHR	Support	204	0.074	0.169	0.079	0.000
RXC	Support	88	0.254	0.409	0.286	0.000
AFW	Turbine	60	0.115	0.115	0.167	0.500

Table 7. (continued)

System	Component	Total Failures	Fraction (0 to 4.9 y)	Fraction (5 to 9.9 y)	Fraction (10 to 14.9 y)	Fraction (15 to 20 y)
1E	Valve	193	0.511	0.603	0.595	0.500
AFW	Valve	276	0.550	0.473	0.543	0.000
CCW	Valve	303	0.448	0.656	0.507	1.000
CTF	Valve	66	0.107	0.250	0.143	0.667
CTIS	Valve	535	0.397	0.634	0.730	0.667
HPIS	Valve	591	0.253	0.446	0.576	0.667
LPIS	Valve	103	0.276	0.364	0.538	1.000
MFW	Valve	335	0.417	0.537	0.603	0.667
RCIC	Valve	200	0.368	0.495	0.615	0.000
RHR	Valve	524	0.430	0.472	0.649	0.800
RXC	Valve	128	0.382	0.478	0.704	0.000
SBL	Valve	69	0.118	0.200	0.700	0.000
SWS	Valve	369	0.504	0.604	0.519	1.000
AFW	Valve operator	105	0.237	0.310	0.176	0.000
CCW	Valve operator	186	0.175	0.321	0.190	0.667
CTF	Valve operator	52	0.094	0.200	0.200	0.000
CTIS	Valve operator	354	0.317	0.323	0.302	0.200
HPIS	Valve operator	316	0.158	0.227	0.287	0.000
LPIS	Valve operator	75	0.040	0.440	0.167	0.000
MFW	Valve operator	115	0.217	0.368	0.407	0.250
RCIC	Valve operator	144	0.261	0.182	0.281	0.000
RHR	Valve operator	447	0.164	0.239	0.273	0.200
RXC	Valve operator	92	0.189	0.231	0.385	0.333
SWS	Valve operator	311	0.333	0.288	0.222	0.000

a. Fractions calculated by dividing total aging-related failures within a time component division by the total component failures within that time division.



* Total number of aging-related valve failures.
( ) Total number of valve failures within age division.

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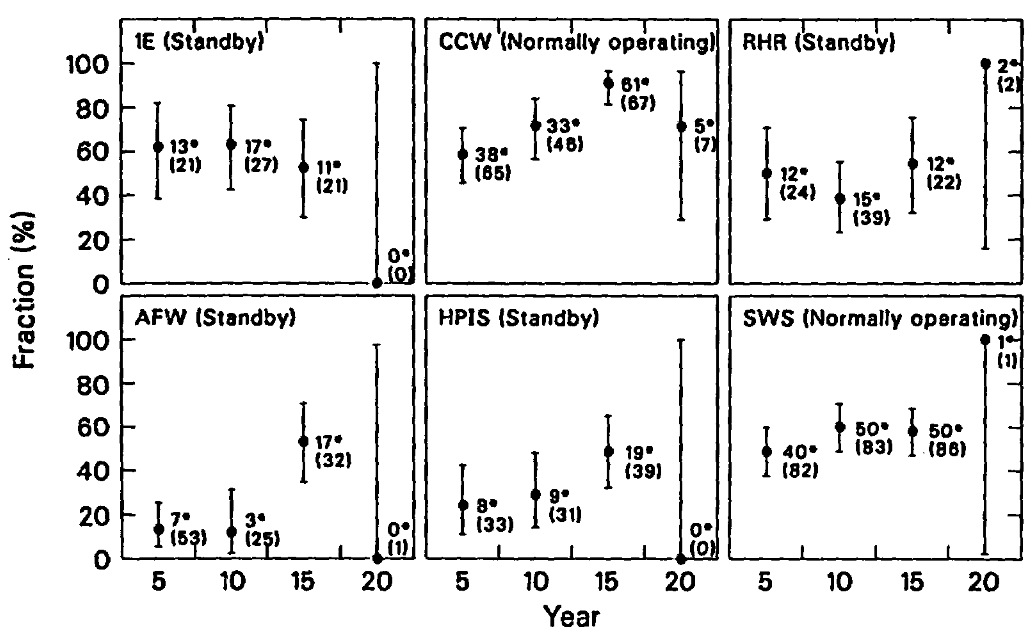
Figure 26. Time-dependent aging fractions for valves.



* Total number of aging-related pump failures.
( ) Total number of pump failures within age division.

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Figure 27. Time-dependent aging fractions for pumps.

Table 8. Component failures and aging fractions as determined by the reported causes of failure study[a]

System/Components[b]	Total[c] Failures	Lower-Bound Aging Total	Upper-Bound Aging Total	Lower-[d] Bound Aging Fraction	Upper-[d] Bound Aging Fraction
Auxiliary Feedwater					
Relief valve	7	7	7	1.000	1.000
Check valve	90	78	83	0.867	0.922
Hand control valve	16	12	15	0.750	0.938
Snubber	7	5	5	0.714	0.714
Pneumatic-operated valve	100	63	79	0.630	0.790
Circuit breaker	8	5	7	0.625	0.875
Flow transmitter	27	14	22	0.519	0.815
Motor-operated valve	43	22	36	0.512	0.837
Flow control recorder	10	5	9	0.500	0.900
Motor-driven pump	63	30	42	0.476	0.667
Turbine-driven pump	58	27	38	0.466	0.655
Level controller	18	8	17	0.444	0.944
Pressure switch	21	9	18	0.429	0.857
Pressure controller	7	3	5	0.429	0.714
Flow controller	19	8	13	0.421	0.684
Relay	12	5	9	0.417	0.750
Level control indicator	20	7	14	0.350	0.700
Pressure transmitter	17	5	12	0.294	0.706
Support	5	0	4	0.000	0.800
Total	548	313	435		
System aging fractions				0.571	0.794
Chemical and Volume Control					
Motor-driven pump	29	23	25	0.793	0.862
Motor-operated valve	46	34	43	0.739	0.935
Level controller	7	4	4	0.571	0.571
Heat tracing heater	9	5	7	0.556	0.778
Circuit breaker	5	1	4	0.200	0.800
Level transmitter	19	3	14	0.158	0.737
Total	115	70	97		
System aging fractions				0.609	0.843
Class 1E Electrical Power Distribution					
DC Power Supply Subsystem					
Inverter	63	18	38	0.286	0.603
Circuit breaker	5	1	1	0.200	0.200
Total	68	19	39		
Subsystem aging fractions				0.279	0.574

Table 8. (continued)

System/Components[b]	Total[c] Failures	Lower-Bound Aging Total	Upper-Bound Aging Total	Lower-[d] Bound Aging Fraction	Upper-[d] Bound Aging Fraction
Class 1E Electrical Power Distribution (continued)					
Emergency Onsite Power Supply Subsystem					
Diesel generator	113	66	86	0.584	0.761
Circuit breaker	5	2	5	0.400	1.000
Total	118	68	91		
Subsystem aging fractions				0.576	0.771
Uninterruptible Power Supply Subsystem					
Battery charging unit	35	18	34	0.514	0.971
Battery	10	5	10	0.500	1.000
Total	45	23	44		
Subsystem aging fractions				0.511	0.978
High-Pressure Injection					
Relief valve	18	17	17	0.944	0.944
Snubber	10	9	10	0.900	1.000
Check valve	18	15	15	0.833	0.833
Pneumatic-operated valve	10	8	10	0.800	1.000
Hand control valve	12	7	9	0.583	0.750
Circuit breaker	11	6	9	0.545	0.818
Pressure transmitter	6	3	6	0.500	1.000
Heat tracing heater	21	10	14	0.476	0.667
Motor-driven pump	17	8	12	0.471	0.706
Motor-operated valve	70	32	53	0.457	0.757
Flow transmitter	17	7	17	0.412	1.000
Load sequence controller	10	4	6	0.400	0.600
Level transmitter	21	4	20	0.190	0.952
Total	241	130	198		
System aging fractions				0.539	0.822
Service Water					
Flow switch	16	16	16	1.000	1.000
Check valve	31	27	28	0.871	0.903
Strainer	21	17	18	0.810	0.857
Motor-driven pump	167	129	140	0.772	0.838
Pneumatic-operated valve	47	36	45	0.766	0.957

Table 8. (continued)

System/Components[b]	Total[c] Failures	Lower-Bound Aging Total	Upper-Bound Aging Total	Lower-[d] Bound Aging Fraction	Upper-[d] Bound Aging Fraction
Service Water (continued)					
Pressure indicator	6	4	6	0.667	1.000
Hand control valve	17	11	12	0.647	0.706
Flow indicator	5	3	4	0.600	0.800
Circuit breaker	17	9	12	0.529	0.706
Motor-operated valve	111	43	93	0.387	0.838
Total	438	295	374		
System aging fractions				0.674	0.854

a. Data have been listed by lower-bound aging fractions.

b. Data used exclude components with <5 total failure counts.

c. Data used exclude failure records in which failure cause was unclassifiable.

d. Fraction denominator is system/component combination failure total.

The complete data analysis set is presented in Appendix F. The data presented in Table 8 consist of the total failures, lower-bound total aging failures, upper-bound total aging failures, lower-bound aging fraction, and upper-bound aging fraction for system-specific component combinations. The upper-bound data include, as aging-related failures, the records with an aging classification of *unknown*; whereas, the lower-bound data exclude those records. The data presented represent the aggregation of the specific component and failure mode data presented in Appendix F. The study determined (Table 8) that the auxiliary feedwater system has a lower-bound fraction (expressed in percent) of 57% and an upper bound of 79% for aging-related failures; the chemical and volume control system exhibited 61% to 84% aging-related failures; the high-pressure injection system exhibited 54% to 82%; and the service water system exhibited 67% to 85%, respectively. The subsystems of the Class 1E electrical power distribution system exhibited the following lower- and upper-bound aging fractions (expressed in percent), respectively: direct current power subsystem, 28% to 57%; emergency onsite power subsystem, 58% to 77%; and instrumentation and uninterruptible power supply subsystem, 51% to 98%.

The following sections discuss the detailed results of the reported failure-cause analysis for the auxiliary feedwater, high-pressure injection, service water, and Class 1E electrical power distribution systems. Only the significant failure modes and failure causes are covered. A failure mode is considered significant if 20% or greater of the failures for a system-specific component are due to that particular failure mode. Significant failure causes are defined as failure causes that have greater than five failure counts and that account for greater than 10% of the failures within a particular analytical boundary. Additional data may be presented in the referenced figures and tables. These additional data are provided for comparative analysis only. The referenced figures illustrate both the upper- and lower-bound aging fractions for the particular analytical boundary. A crosshatch indicates when the lower bound and the upper bound overlap.

Table 9 is a summary of the failure data from this study for selected systems and components. Only the *dominant failure causes (counts greater than five)* with their respective failure mode are itemized. The values in the *total counts* column refer to the total number of failures for the system-specific component and the specific failure mode listed. The upper- and lower-bound aging fractions are also indicated.

Table 9. Reported failure-cause identification summary

System/Components	Failure Mode	Total Counts	Dominant Failure Cause	Failure-Cause Fraction	Lower-Bound Aging Fraction	Upper-Bound Aging Fraction
Auxiliary Feedwater						
Check valves	External leakage	13	Wear	0.615	0.615	0.615
	Fails to operate as required	8	Design error	0.750	0.750	0.750
	Internal leakage	66	Wear	0.697	0.697	0.697
			Human maintenance error	0.106	0.000	0.015
Hand control valves	External leakage	6	Wear	1.000	1.000	1.000
Motor-driven pumps	External leakage	14	Wear	1.000	1.000	1.000
	Fails to run	33	Wear	0.212	0.212	0.212
			Water intrusion	0.212	0.000	0.000
Pneumatic-operated valves	External leakage	8	Wear	0.875	0.875	0.875
	Fails to close	49	Wear	0.367	0.367	0.367
			Binding/out of adjustment	0.204	0.082	0.184
			Foreign material intrusion	0.224	0.020	0.041
	Fails to open	20	Wear	0.300	0.300	0.300
	Fails to operate as required	10	Wear	0.600	0.600	0.600
Turbine-driven pumps	Fails to run	39	Wear	0.282	0.282	0.282
			Binding/out of adjustment	0.179	0.026	0.179
Chemical and Volume Control						
Motor-driven pumps	External leakage	7	Wear	1.000	1.000	1.000
	Fails to run	21	Wear	0.667	0.667	0.667

Table 9. (continued)

System/Components	Failure Mode	Total Counts	Dominant Failure Cause	Failure-Cause Fraction	Lower-Bound Aging Fraction	Upper-Bound Aging Fraction
Chemical and Volume Control (continued)						
Motor-operated valves	External leakage	9	Wear	0.889	0.889	0.889
	Fails to close	22	Wear	0.455	0.455	0.455
Class 1E Electrical Power Distribution						
DC Power Supply Subsystem						
Battery chargers	Loss of function	35	Faulty module	0.657	0.400	0.657
Emergency Onsite Power Supply Subsystem						
Diesel generator	Fails to run	43	Wear	0.326	0.326	0.326
	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
Instrument and Uninterruptible Power Supply Subsystem						
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
High-Pressure Injection						
Check valves	Internal leakage	15	Wear	0.600	0.600	0.600
Motor-operated valves	External leakage	7	Wear	0.857	0.857	0.857
	Fails to close	20	Binding/out of adjustment	0.300	0.100	0.250

Table 9. (continued)

System/Components	Failure Mode	Total Counts	Dominant Failure Cause	Failure-Cause Fraction	Lower-Bound Aging Fraction	Upper-Bound Aging Fraction
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	89	Wear	0.326	0.326	0.326
			Binding/out of adjustment	0.112	0.011	0.067
			Foreign material intrusion	0.258	0.180	0.180
	External leakage	64	Wear	0.703	0.703	0.703
			Foreign material intrusion	0.141	0.125	0.125
Strainers	Loss of function	13	Wear	0.615	0.615	0.615
	Plugged	8	Foreign material intrusion	0.750	0.500	0.500

4.2.1 Reported Failure-Cause Results for Auxiliary Feedwater System. Selected data for the auxiliary feedwater system are illustrated in Figures 28 through 30. The total number of component failures in Figure 28 and Table 8 indicates that pneumatic-operated valves and check valves are the two auxiliary feedwater components having the highest potential impact on the system due to aging. There were 100 failures examined for pneumatic-operated valves and 90 failures for check valves. The aging-related failure fraction (in percent) for pneumatic-operated valves has a lower bound of 63% and an upper bound of 79%. The fraction for check valves ranges from 87% to 92%. The dominant failure causes for pneumatic-operated valves were *wear* and *binding/out of adjustment* which comprise 39% and 16%, respectively, of the total pneumatic-operated valve failures (see Table F-14). The dominant failure cause for check valves was *wear*, which accounts for 60% of the total check valve failures (see Table F-4).

Data, by selected failure modes, for pneumatic-operated valves in the auxiliary feedwater system are shown in Figure 29. The dominant failure mode for pneumatic-operated valves was *fails to close* which accounted for 49% of the pneumatic-operated valve failures. As indicated by the data in Figure 29 and Table 9, the dominant aging-related failure causes for pneumatic-operated valve failures for the failure mode *fails to close* were *wear* (37%) and *binding/out of adjustment* (20%). The study determined the subcomponents most affected by the *wear* mechanism were the valve operator and the valve internals. Similarly, the piece parts affected by the *binding/out of adjustment* mechanism were the limit and torque switches in the valve operator. Failures due to *foreign material intrusion* accounted for 22% of the pneumatic-operated valve *fails to close* failures. However, the majority of these failures were nonaging-related. The failure mode, *fails to open*, accounted for 20% of the pneumatic-operated valve failures. The data shown in Figure 29 and Table 9 indicate that the dominant aging-related failure cause for pneumatic-operated valve failures for the failure mode *fails to open* was *wear* (30%). The study determined the subcomponents most affected by the *wear* mechanism were piece parts of the valve operator such as air regulators, limit switches, and couplings.

Data, by selected failure modes, for check valves in the auxiliary feedwater system are shown in Figure 30. The dominant failure mode for auxiliary feedwater check valves was *internal leakage*, which accounted for 73% of the check valve failures. The *wear* mechanism accounted for 70% of the check valve failures for the failure mode *internal leakage* (see Figure 30 and Table 9). The piece part most affected by the *wear* mechanism in check valves for the failure mode *internal leakage* was the valve seat.

The data in Figure 28 and Table 8 also indicate that motor-driven pumps and turbine-driven pumps in the auxiliary feedwater system have relatively significant impact on the system performance due to total number of failures for these components (63 and 58, respectively). Aging accounted for 48% of the motor-driven pump failures and 47% of the turbine-driven pump failures. The dominant failure mode for both types of pumps was *fails to run*, which accounted for 52% of the motor-driven pump failures and 67% of the turbine-driven pump failures. The dominant aging-related failure cause for the *fails to run* failure mode for both types of pumps was *wear*. *Wear* accounted for 21% of the *fails to run* failures for motor-driven pumps and 28% of the *fails to run* failures for turbine-driven pumps. For motor-driven pump failures, the motor bearings were the dominant piece part that failed due to the *wear* mechanism. The study determined the turbine was the subcomponent most affected by the *wear* mechanism in the turbine-driven pump failures. The dominant turbine piece parts that were affected included seals, O-rings, packing, and governor valves.

4.2.2 Reported Failure-Cause Results for High-Pressure Injection System. Selected data for the high-pressure injection system are illustrated in Figures 31 and 32. The total number of component failures, as shown in Figure 31 and Table 8, indicates that the component in the high-pressure injection system with the highest potential impact on system performance was the motor-operated valve. There were 70 failures reported for motor-operated valves. The dominant failure cause for motor-operated valves was *wear*. *Wear* accounted for 28.5% of the total motor-operated valve failures in the high-pressure injection system followed by *binding/out of adjustment* (20%), *human maintenance error* (13%), and *foreign material intrusion* (11.5%) (see Table F-42). The subcomponent most affected by the *wear* mechanism was the valve operator. *Binding/out of adjustment* affected the valve operator's torque and limit switches, and *foreign material intrusion* failed the valve operator's contacts.

Data, by selected failure modes, for motor-operated valves in the high-pressure injection system are illustrated in Figure 32. The dominant

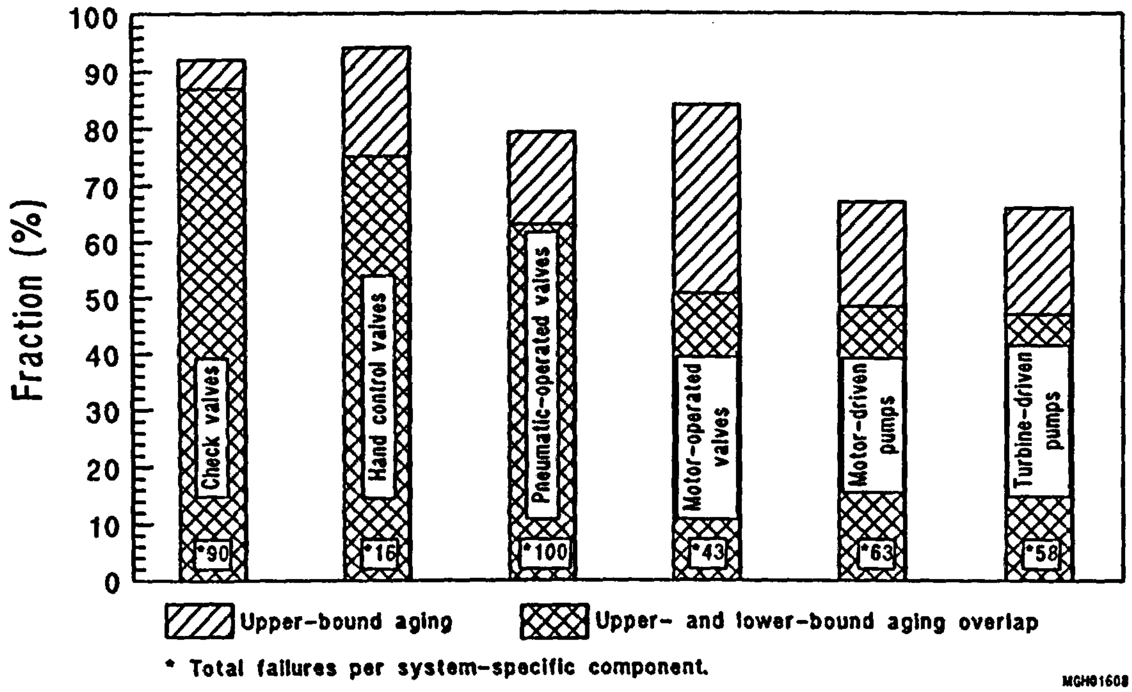

Figure 28. Component aging fractions for the auxiliary feedwater system.

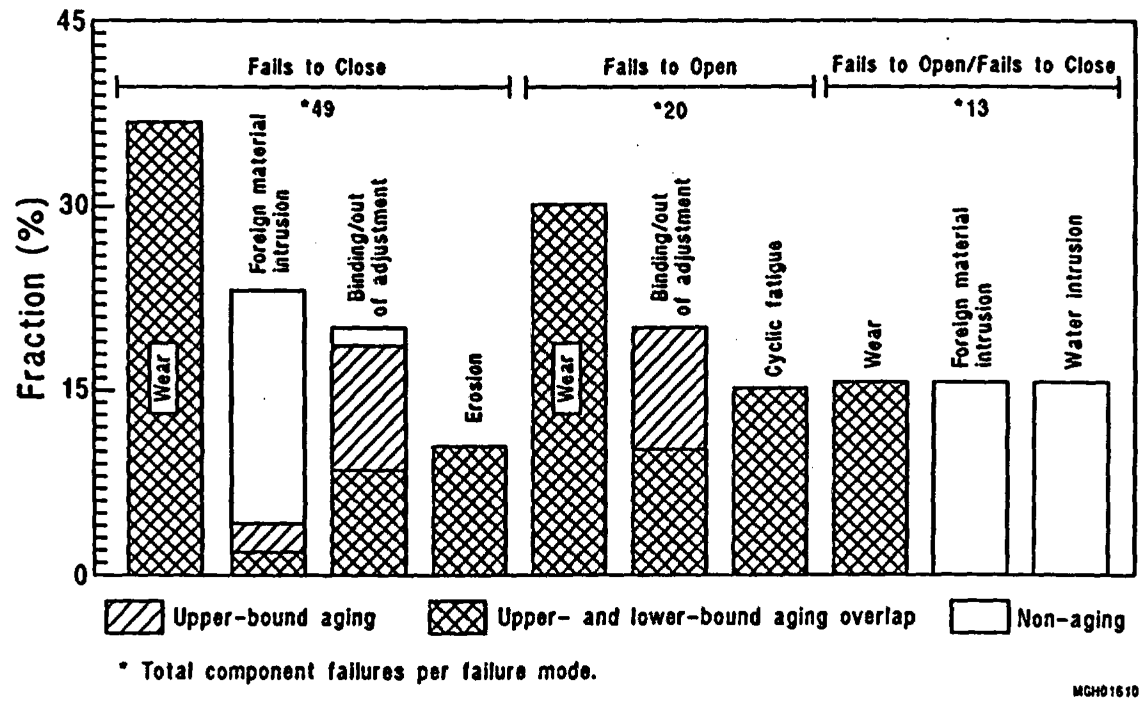

Figure 29. Failure-cause and aging fractions for auxiliary feedwater pneumatic-operated valves for selected failure modes.

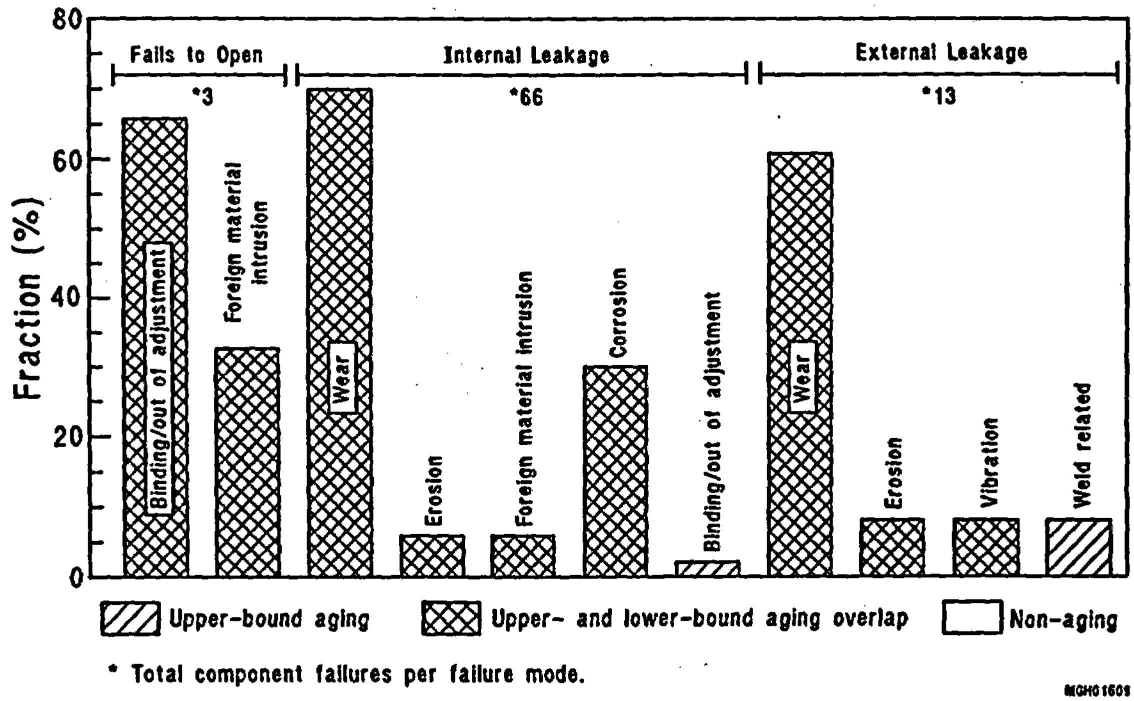

Figure 30. Failure-cause and aging fractions for auxiliary feedwater check valves for selected failure modes.

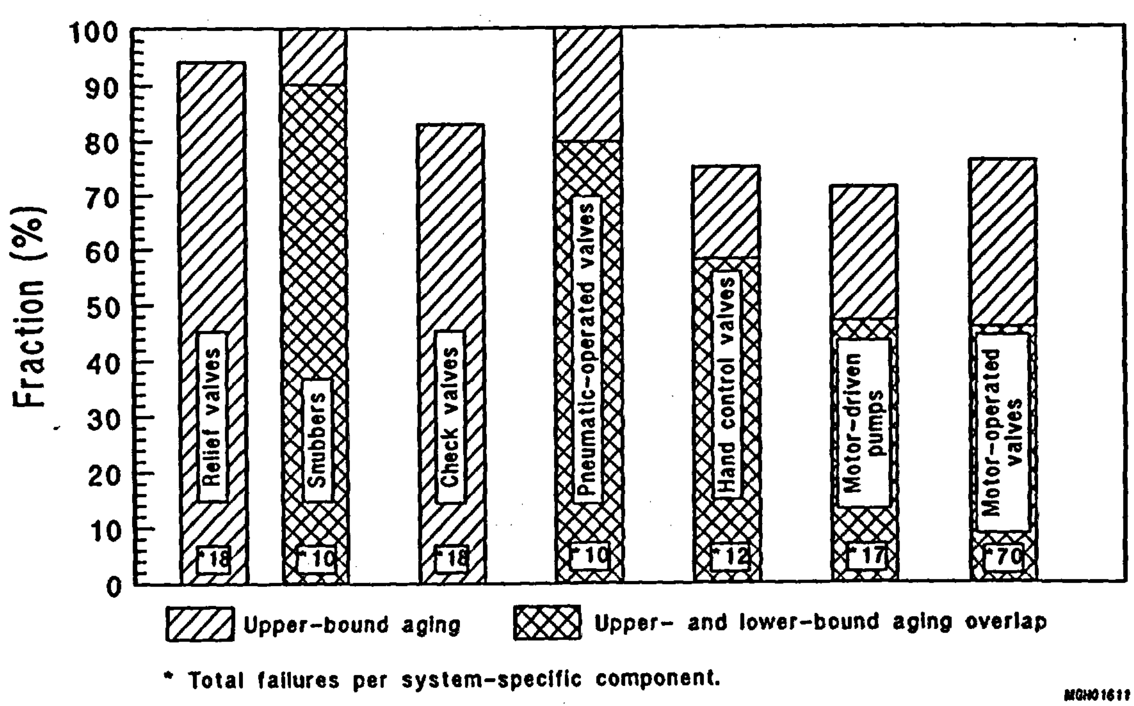

Figure 31. Component aging fractions for the high-pressure injection system.

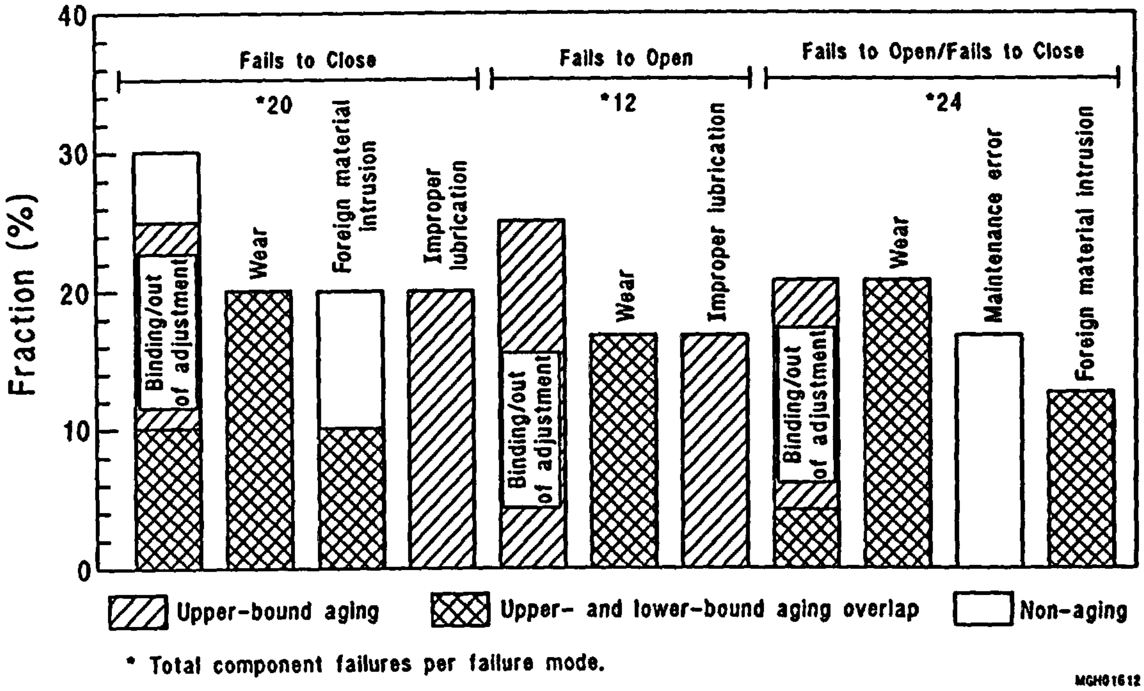

Figure 32. Failure-cause and aging fractions for high-pressure injection system motor-operated valves for selected failure modes.

failure modes for high-pressure injection motor-operated valves were *fails to open/fails to close* (34%) and *fails to close* (29%). None of the failure causes for the failure mode *fails to open/fails to close* were determined to be significant because their failure counts were not greater than five. However, for the failure mode *fails to close, binding/out of adjustment* was the dominant failure cause, having accounted for 30% of these failures (see Figure 32 and Table 9). The valve operator dominated the *binding/out of adjustment* closure failures with the piece parts affected being the torque and limit switches.

For the chemical and volume control portion of the high-pressure injection system, the component with the highest potential for affecting system performance was also the motor-operated valve (see Table 8). There were 46 reported failures associated with the chemical and volume control system. The dominant failure mode for these valves was *fails to close* (48% of total motor-operated valve failures), which was the same as for the high-pressure injection system. These closure failures, however, were dominated by *wear*. The *wear* mechanism accounted for 45% of the closure failures (see Table 9). The dominant piece part affected by the *wear* mechanism was the valve seat.

4.2.3 Reported Failure-Cause Results for Service Water System. Selected data for the service water system are illustrated in Figures 33 through 35. The total number of component failures in Figure 33 and Table 8 indicates that the service water component having the highest potential impact on the system due to aging was the motor-driven pump. There were 167 failures reported for motor-driven pumps. The dominant failure causes for motor-driven pumps were *wear* (45%) and *foreign material intrusion* (21%) (see Table F-52). The subcomponents most affected by the *wear* mechanism were the pump seals and packing. The *foreign material intrusion* failures were primarily due to sand and other particulates sometimes found in influent service water.

Data, by selected failure mode, for motor-driven pumps in the service water system are illustrated in Figure 34. The dominant failure modes for these pumps were *fails to run* (53%) and *external leakage* (38%). *Wear* and *foreign material intrusion* were the dominant reported failure causes of these two failure modes. Data in Figure 34 and Table 9 indicate that *wear* accounted for 32.6% of the *fails to run* failures and 70.3% of the *external leakage* failures; and *foreign material intrusion* accounted for 14% of the *fails to run* failures and 25.8% of the *external leakage* failures. Inspection of the failure records

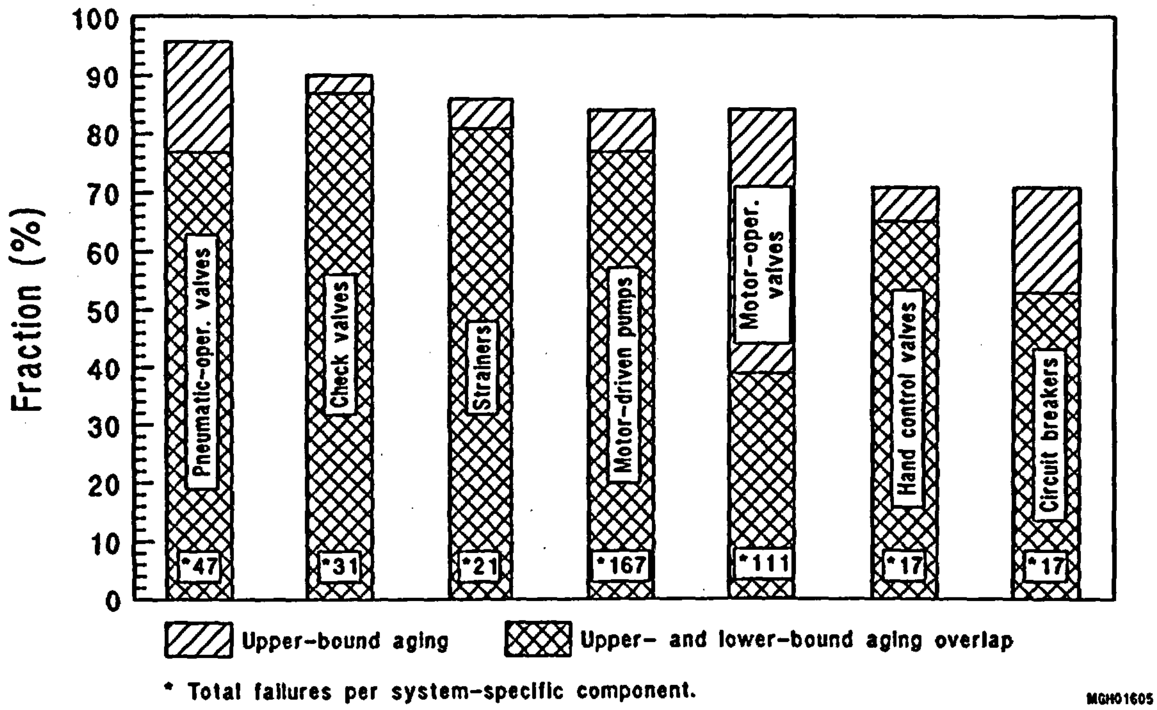

Figure 33. Component aging fractions for the service water system.

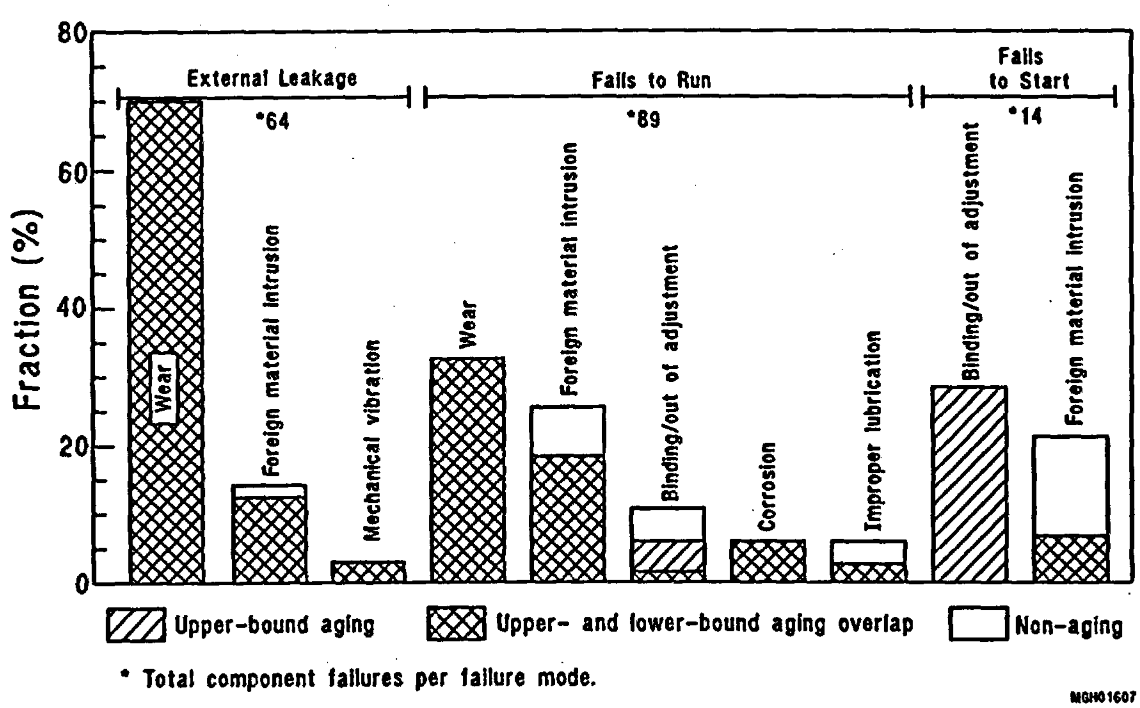

Figure 34. Failure-cause and aging fractions for service water motor-driven pumps for selected failure modes.

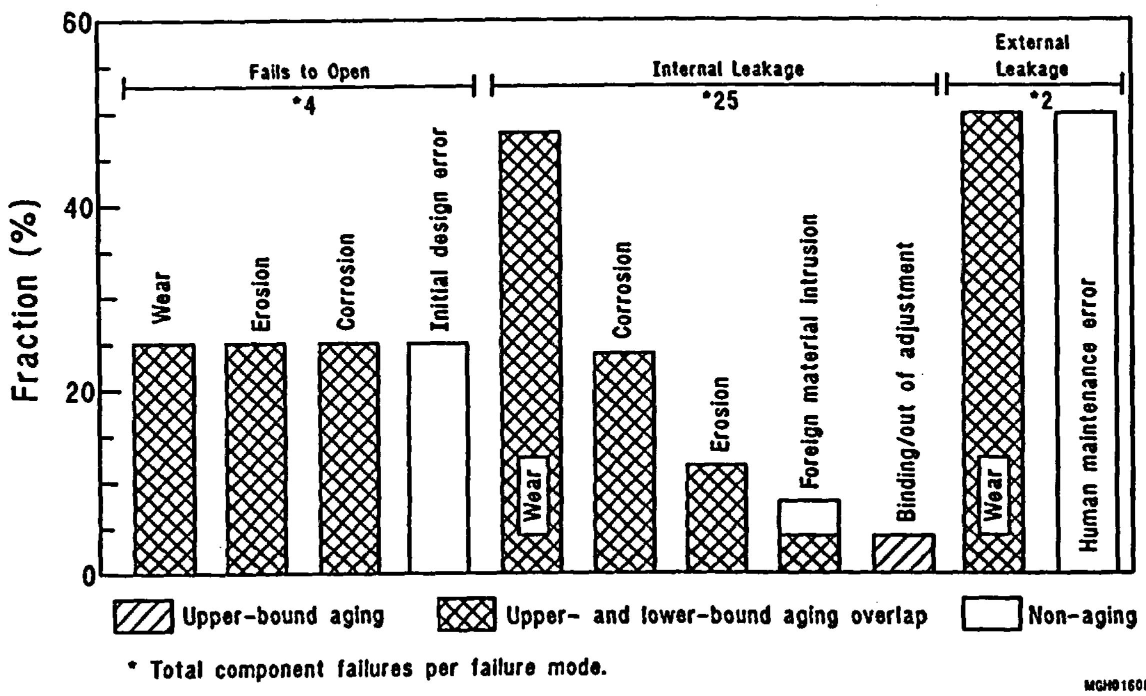

Figure 35. Failure-cause and aging fractions for service water check valves for selected failure modes.

pertinent to service water system motor-driven pumps shows that the failures for the failure mode *external leakage* were caused by *wear* of the pump seals and pump packing or *foreign material intrusion* into the pump seals. The *wear* mechanism affecting the motor-driven pump failures for the failure mode *fails to run* was associated with the pump internals such as bearings, impeller, and shaft. Many of these failures stated internal wear or general pump wearout as the cause of failure. The *wear* mechanism was also associated with the motor of the motor-driven pump and usually affected the motor bearings. As stated above, sand and other particulates found in the influent water were the dominant cause of the *foreign material intrusion* failures.

The service water system components with the second highest potential for aging impacts on system operation were motor-operated valves. There were 111 failures reported for motor-operated valves (see Figure 33 and Table 8). The resulting potential aging fraction range (in percent) was 39% to 84%. The largest number of failures occurred for the failure mode *fails to close*. Inspection of the failure records indicates that *wear* is the dominant aging failure cause. *Wear*, which accounted for 13% of the motor-operated valve failures (see Table F-53), often caused the failure of the valve stem connection to the valve operator. Data in Table 9 further indicate that, for motor-operated valves, the *out of adjustment* failure cause 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 were significantly affected by aging. The aging fractions calculated for service water system check valves range from 0.87 to 0.90 (see Figure 33 and Table 8). Data for service water check valves by selected failure modes are illustrated in Figure 35. The dominant failure mode was *internal leakage* (81%), with the dominant aging failure causes having been *wear* (48%) and *corrosion* (24%). Examination of the failure records indicates that the piece parts most affected by *wear* were the valve seat and valve disc, as would be expected. Failures of the valve body and the valve internals were attributable to *corrosion*.

Service water system strainers exhibited the second highest lower-bound aging-related failure fraction (see Figure 33 and Table 8). Inspection of the failure records indicates that packing wear and plugging due to particulate in the influent water were the dominant contributors to failure of service water strainers.

4.2.4 Reported Failure-Cause Results for Class 1E Electrical Power Distribution System. Selected data for the Class 1E electrical power distribution system are illustrated in Figures 36 and 37. The total number of component failures in Figure 36 and Table 8 indicates that the diesel generators were the largest single contributor of failures for the Class 1E subsystems. This was, in part, because of the component boundaries developed for the diesel generator for the failure-cause study (see Appendix C). Aging-related failures comprised 58% to 76% of the total diesel generator failures within the emergency onsite power supply subsystem. The largest single aging failure cause for diesel generators was *wear* (19.5%) (see Table F-31).

Data, by selected failure modes, for diesel generators in the Class 1E emergency power subsystem are illustrated in Figure 37. The dominant failure mode for diesel generators was *fails to run* (38%). The dominant failure cause for diesel generator *fails to run* failures was *wear* (32.6%). The failure records indicated that the wear failures were distributed over four diesel generator subsystems: diesel cooling water, diesel fuel oil, diesel lube oil, and diesel starting air. The components most affected were valves and pumps.

Inverters in the instrumentation and uninterruptible power supply subsystem of the Class 1E system also accounted for a relatively large failure count (63). These failures were dominated by electrical failures. Examination of the NPRDS failure records indicates that the major contributors to these electrical failures were blown fuses, defective fuses, and defective solid-state components. There were few aging-related failures found for this component.

4.2.5 Reported Failure-Cause Results at the System Level. System-specific component fractions and aging fractions at the system level are listed in Table 10; the dominant system-specific components (component fraction greater than 0.05) with their associated upper- and lower-bound aging fractions are illustrated in Figure 38. Inspection of Figure 38 and Table 10 indicates that, at the system level, the components of importance in the auxiliary feedwater system were pneumatic-operated valves, check valves, motor-driven pumps, and turbine-driven pumps. Of these components, check valves had the highest aging percentage range of 14% to 15% (percentages calculated at the system level). For the chemical and volume control (not shown in Figure 38) and high-pressure injection systems, the component of importance, at the system level, was the motor-operated valve. The aging percentage range for motor-operated valves in the chemical and volume control system was 30% to 37% and in the high-pressure injection system, 13% to 22%. The components in the service water system with the highest system importance were motor-driven pumps, motor-operated valves, and pneumatic-operated valves. The motor-driven pumps had an aging percentage range of 30% to 32% at the system level, motor-operated valves had a range of 10% to 21%, and pneumatic-operated valves had a range of 8% to 10%. Furthermore, the data in Figure 38 and Table 10 indicate that, for the Class 1E electrical power distribution subsystems, battery charging units (40% to 76%) dominated the dc power supply subsystem, diesel generators (56% to 73%) dominated the emergency power supply subsystem, and inverters (26% to 56%) dominated the instrument and uninterruptible power supply subsystem.

The failure-cause fractions by system regardless of the component or failure mode are listed in Table 11, and the dominant system-specific failure causes (failure-cause fraction greater than 0.05) with their associated upper- and lower-bound aging fractions are illustrated in Figures 39 and 40. Data in Figure 39 and Table 11 indicate that, at the system level, the *wear* failure cause dominated all the fluid systems. *Wear* accounted for 30% of the failures in the auxiliary feedwater system, 38% in the chemical and volume control system (not shown in Figure 39), 21% in the high-pressure injection system, and 32% in the service water system. Furthermore, the data in Figure 40 and Table 11 indicate that, in the Class 1E electrical power distribution subsystem, *faulty module* dominated the failures in the dc power subsystem and the instrumentation and uninterruptible power supply subsystem and *wear* dominated the failures in the emergency onsite power supply subsystem.

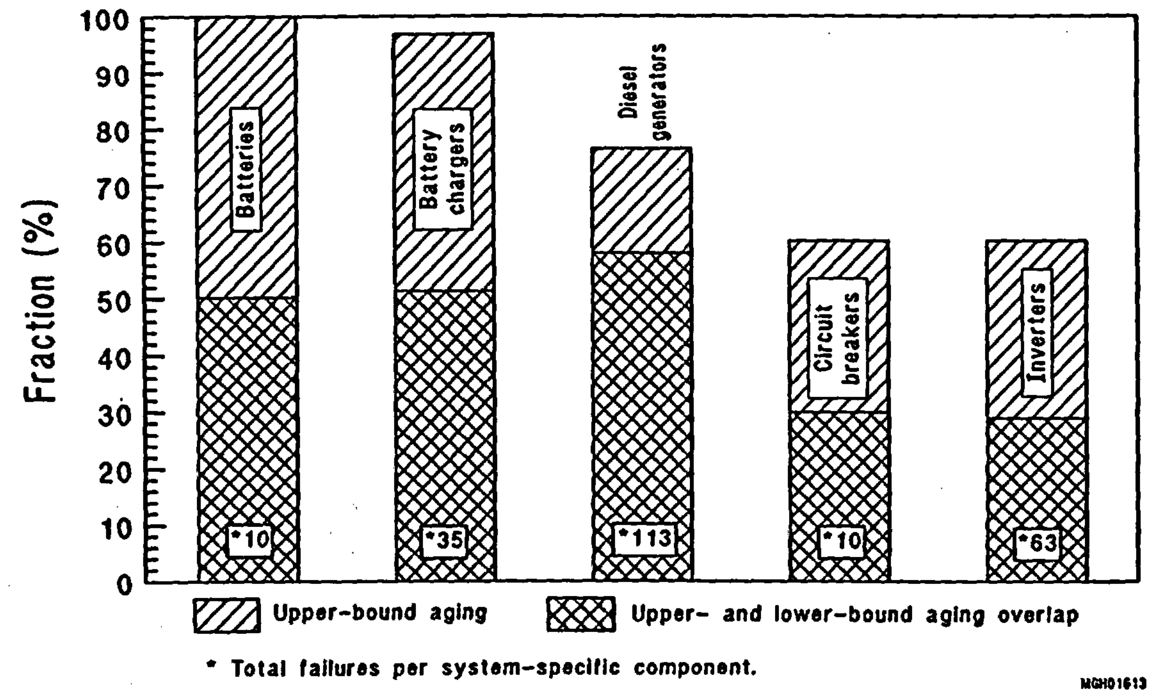

Figure 36. Component aging fractions for the Class 1E electrical power distribution system.

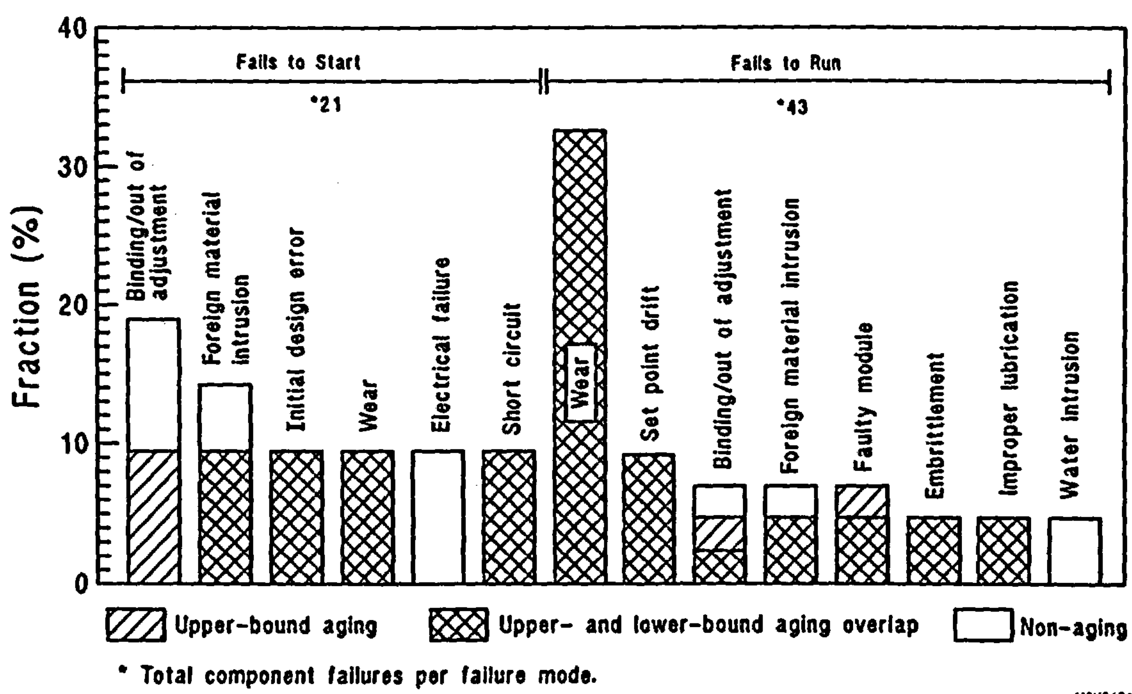

Figure 37. Failure-cause and aging fractions for Class 1E diesel generators for selected failure modes.

Table 10. System fractions for system-specific components[a]

System/Components[b]	Total[c] Failures	Lower-Bound Aging Total	Upper-Bound Aging Total	Component[d] Fraction	Lower-[d] Bound Aging Fraction	Upper-[d] Bound Aging Fraction
Auxiliary Feedwater						
Pneumatic-oper. valve	100	63	79	0.182	0.115	0.144
Check valve	90	78	83	0.164	0.142	0.151
Motor-driven pump	63	30	42	0.115	0.055	0.077
Turbine-driven pump	58	27	38	0.106	0.049	0.069
Motor-operated valve	43	22	36	0.078	0.040	0.066
Flow transmitter	27	14	22	0.049	0.026	0.040
Pressure switch	21	9	18	0.038	0.016	0.033
Level control indicator	20	7	14	0.036	0.013	0.026
Flow controller	19	8	13	0.035	0.015	0.024
Level controller	18	8	17	0.033	0.015	0.031
Pressure transmitter	17	5	12	0.031	0.009	0.022
Hand control valve	16	12	15	0.029	0.022	0.027
Relay	12	5	9	0.022	0.009	0.016
Flow control recorder	10	5	9	0.018	0.009	0.016
Circuit breaker	8	5	7	0.015	0.009	0.013
Relief valve	7	7	7	0.013	0.013	0.013
Snubber	7	5	5	0.013	0.009	0.009
Pressure controller	7	3	5	0.013	0.005	0.009
Support	5	0	4	0.009	0.000	0.007
Total	548	313	435			
Chemical and Volume Control						
Motor-operated valve	46	34	43	0.400	0.296	0.374
Motor-driven pump	29	23	25	0.252	0.200	0.217
Level transmitter	19	3	14	0.165	0.026	0.122
Heat tracing heater	9	5	7	0.078	0.043	0.061
Level controller	7	4	4	0.061	0.035	0.035
Circuit breaker	5	1	4	0.043	0.009	0.035
Total	115	70	97			
Class 1E Electrical Power Distribution						
DC Power Supply Subsystem						
Battery charging unit	35	18	34	0.778	0.400	0.756
Battery	10	5	10	0.222	0.111	0.222
Total	45	23	44			
Emergency Onsite Power Supply Subsystem						
Diesel generator	113	66	86	0.958	0.559	0.729
Circuit breaker	5	2	5	0.042	0.017	0.042
Total	118	68	91			

Table 10. (continued)

System/Components[b]	Total[c] Failures	Lower-Bound Aging Total	Upper-Bound Aging Total	Component[d] Fraction	Lower-[d] Bound Aging Fraction	Upper-[d] Bound Aging Fraction
Class 1E Electrical Power Distribution (continued)						
Instrument and Uninterruptible Power Supply Subsystem						
Inverter	63	18	38	0.926	0.265	0.559
Circuit breaker	5	1	1	0.074	0.015	0.015
Total	68	19	39			
High-Pressure Injection						
Motor-operated valve	70	32	53	0.290	0.133	0.220
Level transmitter	21	4	20	0.087	0.017	0.083
Heat tracing heater	21	10	14	0.087	0.041	0.058
Relief valve	18	17	17	0.075	0.071	0.071
Check valve	18	15	15	0.075	0.062	0.062
Motor-driven pump	17	8	12	0.071	0.033	0.050
Flow transmitter	17	7	17	0.071	0.029	0.071
Hand control valve	12	7	9	0.050	0.029	0.037
Circuit breaker	11	6	9	0.046	0.025	0.037
Load seq. controller	10	4	6	0.041	0.017	0.025
Pneumatic-oper. valve	10	8	10	0.041	0.033	0.041
Snubber	10	9	10	0.041	0.037	0.041
Pressure transmitter	6	3	6	0.025	0.012	0.025
Total	241	130	198			
Service Water						
Motor-driven pump	167	129	140	0.381	0.295	0.320
Motor-operated valve	111	43	93	0.253	0.098	0.212
Pneumatic-oper. valve	47	36	45	0.107	0.082	0.103
Check valve	31	27	28	0.071	0.062	0.064
Strainer	21	17	18	0.048	0.039	0.041
Circuit breaker	17	9	12	0.039	0.021	0.027
Hand control valve	17	11	12	0.039	0.025	0.027
Flow switch	16	16	16	0.037	0.037	0.037
Pressure indicator	6	4	6	0.014	0.009	0.014
Flow indicator	5	3	4	0.011	0.007	0.009
Total	438	295	374			

a. Data have been listed by lower-bound aging fractions.

b. Data used exclude failure records in which failure cause was unclassifiable.

c. Data used exclude components with <5 total failure counts.

d. Fraction denominator is total system failures.

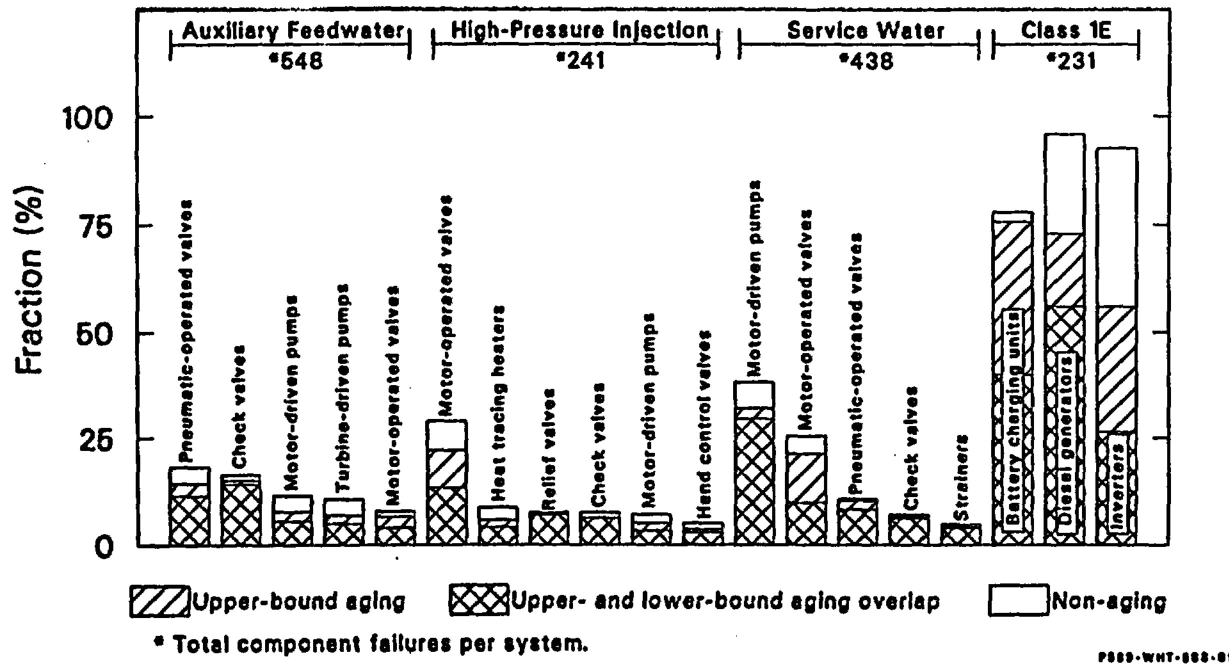

Figure 38. System fractions for dominant system-specific components.

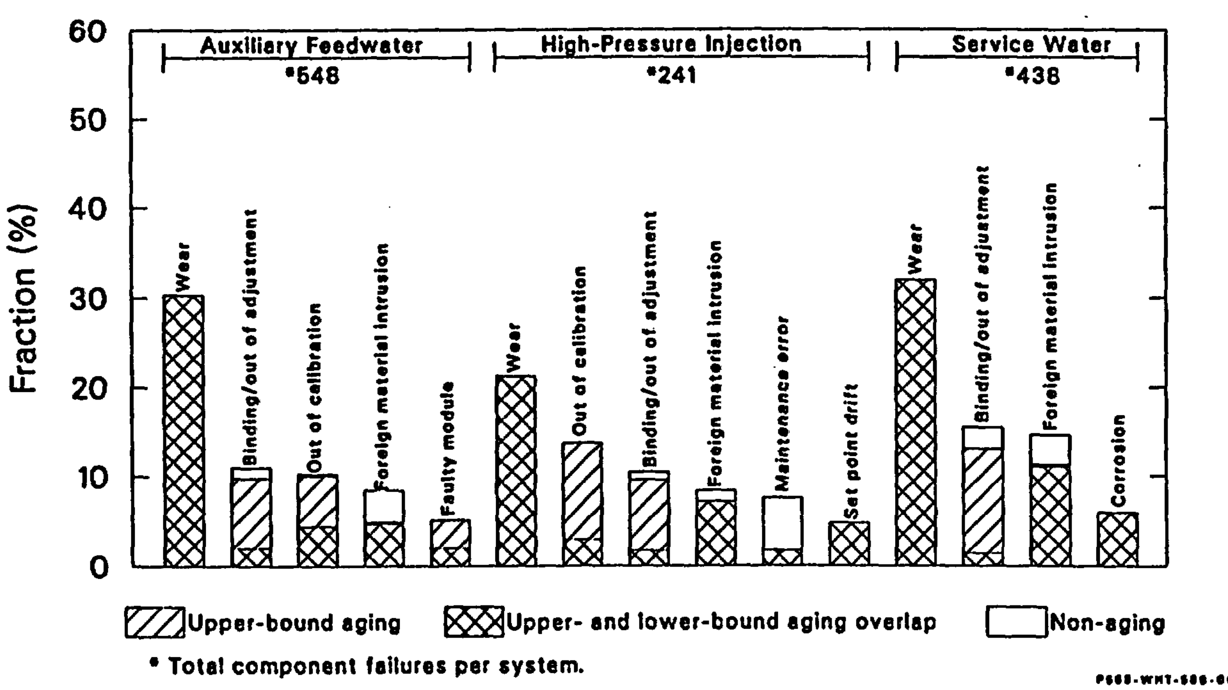

Figure 39. System fractions for dominant system-specific failure causes in auxiliary feedwater, high-pressure injection, and service water systems.

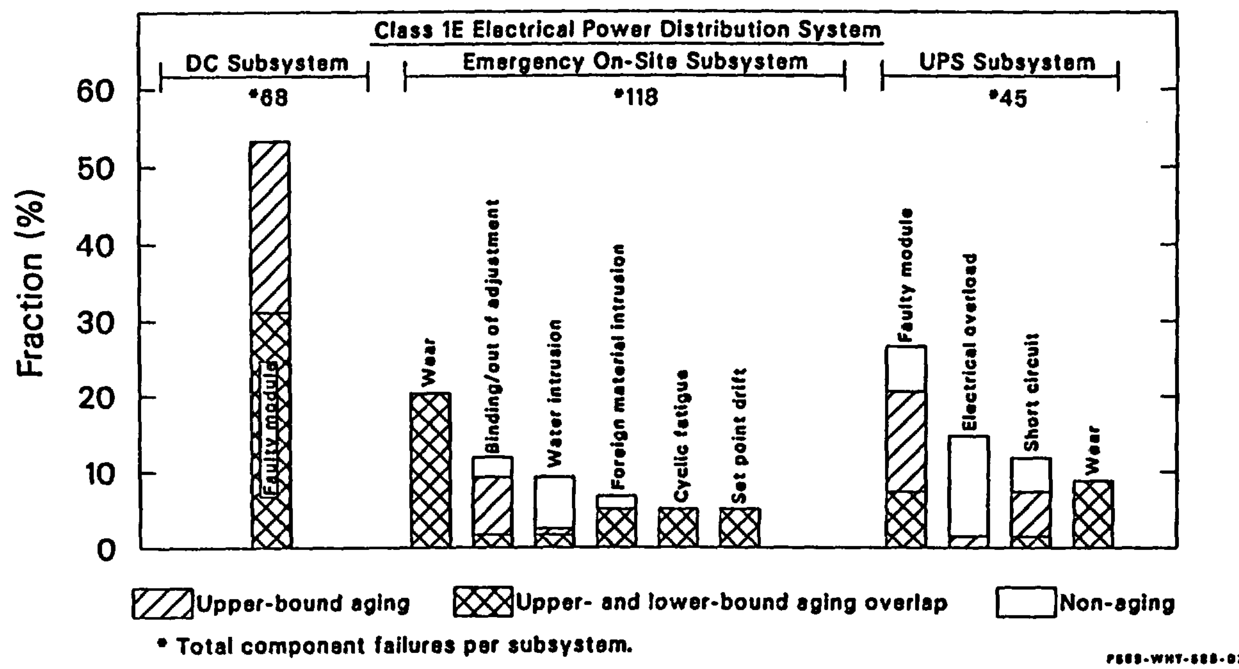

Figure 40. System fractions for dominant system-specific failure causes in Class 1E electrical power distribution subsystems.

Table 11. System-specific failure-cause fractions[a]

System/Failure Cause[b]	Failure-[c] Cause Total	Failure-[d] Cause Fraction	Lower-Bound Aging Fraction	Upper-Bound Aging Fraction
Auxiliary Feedwater[e]				
Wear (EBR)	166	0.303	0.303	0.303
Binding/out of adjustment (EDB)	60	0.109	0.020	0.097
Out of calibration (EDT)	56	0.102	0.044	0.100
Foreign material intrusion (EDI)	46	0.084	0.047	0.049
Faulty module (ELF)	28	0.051	0.020	0.051
Failure to follow procedure: maintenance activity (HPM)	25	0.046	0.002	0.004
Design error (DE)	19	0.035	0.015	0.018
Erosion (EBE)	15	0.027	0.027	0.027
Water intrusion (EMW)	14	0.026	0.002	0.002
Cyclic fatigue (EBF)	12	0.022	0.022	0.022
Set point drift (EDS)	11	0.020	0.020	0.020
Manufacturing error (DM)	8	0.015	0.000	0.007
Corrosion (ECC)	7	0.013	0.013	0.013
Improper lubrication (EDU)	6	0.011	0.007	0.011
Mechanical vibration (EVM)	6	0.011	0.011	0.011
Chemical and Volume Control[f]				
Wear (EBR)	44	0.383	0.383	0.383
Out of calibration (EDT)	14	0.122	0.043	0.122
Foreign materials intrusion (EDI)	14	0.122	0.043	0.043
Binding/out of adjustment (EDB)	14	0.122	0.009	0.104
Class 1E Electrical Power Distribution				
DC Power Subsystem[g]				
Faulty module (ELF)	24	0.533	0.311	0.533

Table 11. (continued)

System/Failure Cause[b]	Failure-[c] Cause Total	Failure-[d] Cause Fraction	Lower-Bound Aging Fraction	Upper-Bound Aging Fraction
Class 1E Electrical Power Distribution (continued)				
Emergency Onsite Power Subsystem[h]				
Wear (EBR)	24	0.203	0.203	0.203
Binding/out of adjustment (EDB)	14	0.119	0.017	0.093
Water intrusion (EMW)	11	0.093	0.017	0.025
Foreign materials intrusion (EDI)	8	0.068	0.051	0.051
Cyclic fatigue (EBF)	6	0.051	0.051	0.051
Set point drift (ELD)	6	0.051	0.051	0.051
Instrumentation and Uninterruptible Power Supply Subsystem[i]				
Faulty module (ELF)	18	0.265	0.074	0.206
Electrical overload (ELE)	10	0.147	0.000	0.015
Short circuit (ELS)	8	0.118	0.015	0.074
Wear (EBR)	6	0.088	0.088	0.088
High-Pressure Injection[j]				
Wear (EBR)	51	0.212	0.212	0.212
Out of calibration (EDT)	33	0.137	0.029	0.137
Binding/out of adjustment (EDB)	25	0.104	0.017	0.095
Foreign materials intrusion (EDI)	20	0.083	0.071	0.071
Failure to follow procedure: maintenance activity (HPM)	18	0.075	0.017	0.017
Set point drift (EDS)	12	0.050	0.050	0.050
Design error (DE)	8	0.033	0.004	0.008
Cyclic fatigue (EBF)	7	0.029	0.029	0.029
Improper lubrication (EDU)	7	0.029	0.004	0.029
Service Water[k]				
Wear (EBR)	140	0.320	0.320	0.320

Table 11. (continued)

System/Failure Cause[b]	Failure-[c] Cause Total	Failure-[d] Cause Fraction	Lower-Bound Aging Fraction	Upper-Bound Aging Fraction
Service Water[k] (continued)				
Binding/out of adjustment (EDB)	68	0.155	0.014	0.130
Foreign materials intrusion (EDI)	64	0.146	0.110	0.112
Corrosion (ECC)	26	0.059	0.059	0.059
Set point drift (ELD)	14	0.032	0.032	0.032
Mechanical vibration (EVM)	13	0.030	0.030	0.030
Erosion (EBE)	12	0.027	0.027	0.027
Improper lubrication (EDU)	7	0.016	0.007	0.011
Human error: operation activity (HEO)	7	0.016	0.002	0.002
Open circuit (ELO)	6	0.014	0.002	0.014
Out of calibration (ELT)	6	0.014	0.011	0.014
Cyclic fatigue (EBF)	6	0.014	0.014	0.014
Human error: maintenance error (HEM)	6	0.014	0.000	0.000

a. Data have been listed for system/failure-cause count > 5.

b. Data used exclude components with <5 total failure counts.

c. Data used exclude failure records in which failure cause was unclassifiable.

d. Data have been listed by system/failure-cause fractions.

e. Denominator for AFW fractions is total AFW failures (548).

f. Denominator for CVCS fractions is total CVCS failures (115).

g. Denominator for dc power fractions is total dc power failures (45).

h. Denominator for emergency power fractions is total emergency power failures (118).

i. Denominator for UPS fractions is total UPS failures (68).

j. Denominator for HPIS fractions is total HPIS failures (241).

k. Denominator for SWS fractions is total SWS failures (438).

5. SUMMARY

This section summarizes the aging survey analysis and reported failure-cause analysis.

5.1 Aging Survey Analysis

The purpose of the analysis is to identify light water reactor safety and support systems and their associated components that demonstrate a susceptibility to aging-related failures affecting system performance. This has been accomplished through the use of a data base constructed from operational events recorded in the NPRDS. Analyses performed on the data provided several insights concerning the effect of aging failures on the selected systems.

The NPRDS-reported failures were collected into five generic failure categories. It was determined that, for the systems analyzed, many nuclear power plant component failures are due to aging (32%). The *other* category is the largest failure category, containing 49% of the failures. 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 additional generic failure categories of *design and installation*, *testing and maintenance*, and *human-related* contained 10%, 7.5%, and 1.5% of the failures, respectively.

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.

The analysis established that, on the one hand, normally operating fluid systems tend to exhibit slightly higher proportions of aging-related failures than normally standby systems; however, on the other hand, system dependencies for component aging were generally not statistically identifiable. The exceptions to this finding were pumps in the component cooling water system, valves in the containment isolation system, supports in the high-pressure injection system, and switches in Class 1E electrical power supply and reactor protection systems. These were all identified as having statistically distinguishable aging impacts when compared to similar components in other systems.

Analyses of the collected data indicate that valves, valve operators, and pumps tended to have the highest potential for aging impacts on system operation based on their corresponding failure population and aging fractions. In the component-level analysis, which determines the aging impacts on the performance of the component, 50% to 60% of the reported valve failures were aging-related failures. At the component level, the valves contained in the containment isolation system were the most affected by aging mechanisms. However, care should be taken in drawing a conclusion concerning actual failure of the containment isolation system valves due to the stringent surveillance requirements on these valves. They may not have actually failed but may instead have failed an operational specification when tested (which is reportable as a failure). In the system-level analysis, which gives a representation of the component's aging importance within the system, the average aging fraction (in percent) for valves is 12.5%. The systems where the impact of valve aging (at the system level) is relatively important are containment isolation (28%) and main feedwater (21%), followed by auxiliary feedwater, component cooling water, and service water to a lesser extent. Aging, at the component level, in valve operators is also relatively constant between systems at approximately 25%. However, aging in valve operators does not produce a significant failure contribution at the system level (only 4%). Pumps are the second most aging-impacted component. Pumps in the component cooling water system have the highest aging fraction (in percent) at both the component level (75%) and the system level (14%). At the component level, the average failure fraction (in percent) for pumps is 45%; and, at the system level, the average failure fraction (in percent) for pumps is 4%. Furthermore, the data for components such as motors, heat exchangers, pipes, and circuit breakers indicate that these components are statistically independent across systems and do not produce a significant failure contribution at the system level (less than 5%). The distribution of failures between component types can be found in the discussion in Section 4.1 and Appendix E.

The analysis has additionally identified the systems and their associated components that are impacting system performance due to aging-related failures. Table 6 in Section 4.1 depicts the relationship of aging-related component failures to the total number of component failures in a specific system. Once again, it is evident that valves and, to some extent, pumps are dominating the aging impacts on system performance. This analysis indicates that valves in the containment isolation system exhibit the highest aging-related fraction (0.28) of all the system-specific components analyzed. Aging-related failures of valves in main feedwater, auxiliary feedwater, component cooling water, and service water systems also rank with the top five system-specific components. Pumps in the component cooling water system exhibit the highest aging-related fraction for pumps, at the system level, and rank sixth on the list of important system-specific components. These results presented in Table 6 are indicative of component aging importance within its respective system. However, this should not be confused with a risk importance obtained from a probabilistic risk analysis.

The time-dependent aging analysis indicated the potential for some definite time dependencies in aging-related failures. Most of the data indicated the potential for increasing aging fractions with time. However, some of the data indicated the potential for a constant trend in the aging fractions with time. The data utilized in this study are impacted by variables such as plant maintenance practices, the age of the plant, and reporting practices. This information, needed to assess how these variables impact aging, is not available from the NPRDS source data.

In conclusion, the aging survey analysis has identified system and component aging effects that can be used for guidance in selecting safety and support system components for detailed engineering studies. The information presented in this report can be combined with plant-specific risk information to evaluate which components are most susceptible to aging and then correlate that with their risk importances.

5.2 Reported Failure-Cause Analysis

The purpose of the analysis is to identify specific aging failure causes for selected safety and support systems. This has been accomplished through the use of a data base constructed from operational events recorded in the NPRDS. The data base has been constructed using a failure-cause categorization and aging classification scheme. Analyses performed on the data provide detailed information concerning the component failure modes and aging mechanisms affecting the selected systems and components. These data are intended to be used in probabilistic risk analysis calculations to identify the risk impacts of aging failures on these components.

The failure-cause identification analysis has provided insights into the effects of aging-related failures in auxiliary feedwater, Class 1E electrical power distribution, high-pressure injection, and service water systems. In general, the fluid systems exhibit higher aging fractions than the electrical power distribution systems. The components with the most potential aging-related impacts on system performance are valves and pumps in the fluid systems and diesel generators in the electrical power distribution system. The dominant aging mechanism for the fluid systems is *wear*; whereas, the dominant aging mechanism for the electrical power distribution systems is *faulty module*, which is a failure of a solid-state subcomponent.

Results of the analysis indicate that the auxiliary feedwater system has a lower-bound fraction (expressed in percent) of 57% and an upper bound of 79% for aging-related failures, the chemical and volume control system exhibited 61% to 84% aging-related failures, the high-pressure injection system exhibited 54% to 82% aging-related failures, and the service water system exhibited 67% to 85% aging-related failures. The subsystems of the Class 1E electrical power distribution system exhibited the following lower- and upper-bound aging fractions (expressed in percent): dc power subsystem, 28% to 57%; emergency onsite power subsystem, 58% to 77%; and instrumentation and uninterruptible power supply subsystem, 51% to 98%.

The results also indicate that two components in the auxiliary feedwater system, one component in the high-pressure injection system, two components in the service water system, and one component in the Class 1E electrical power distribution system dominated the failure contributions.

The dominant components in the auxiliary feedwater system were pneumatic-operated valves (63% to 79%) and check valves (78% to 83%). *Wear* was the significant aging mechanism affecting the valves. The dominant failure mode for pneumatic-operated valves was *fails to close*. The failure mode *internal leakage* accounted for the majority of the check valve failures.

Motor-operated valve failures dominated the high-pressure injection system (46% to 76%). The dominant failure mode was *fails to close*, which accounted for 29% of the valve failures. The dominant failure causes were *wear* (28.5%), *binding/out* *of adjustment* (20%), *human maintenance error* (13%), and *foreign material intrusion* (11.5%).

For the chemical and volume control portion of the high-pressure injection system, the component that dominated the system failures is also the motor-operated valve. The dominant failure mode for these valves is *fails to close* (48% of total motor-operated valve failures), which is the same as for the high-pressure injection system. These closure failures, however, were dominated by *wear*. The *wear* mechanism accounted for 45% of the closure failures.

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 both *wear* and *foreign material intrusion*. These aging mechanisms are present 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 0.58 to 0.76 within the emergency onsite power supply subsystem. The aging mechanism most prominent for the diesel generator was *wear*, which was 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.

The results of the failure-cause study can be incorporated in system-level aging evaluations that use PRA techniques. The use of PRA techniques provides a quantitative statement about risk and safety. Therefore, the influence of an aging mechanism on plant risk can be determined.

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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 and 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 and Service Wear (A)		
NPRDS Cause Category:	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

Table A-1. (continued)

Testing and Maintenance (T)		
NPRDS Cause Category:	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
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: Bistables/Switches
ICNTRL	-	Instrumentation: Controllers
INDREC	-	Instrumentation: Indicators/Recorders
INTCPM	-	Instrumentation: Integrator/Computation Modules
IPWSUP	-	Instrumentation: Electric Power Supplies
ISODEV	-	Instrumentation: Isolation Devices
IXMITR	-	Instrumentation: Transmitters/Elements
MECFUN	-	Mechanical Function Units
MOTOR	-	Motors
PENETR	-	Penetrations
PIPE	-	Pipes, Fittings
PUMP	-	Pumps
RELAY	-	Relays
SUPORT	-	Shock Suppressors and Supports
TRANSF	-	Transformers
TURBIN	-	Turbines
VALVE	-	Valves and Dampers
VALVOP	-	Valve Operators
VESSEL	-	Pressure Vessels

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

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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 Date. 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 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 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

Plant ID:	PC record number: ________
	Person / Date
Docket number:	
	Coding: ________
Report type: NPRDS	Quality assurance: ________
Report number:	Failure sequences: ________
	Sequences this page: ________
Plant type:	CCF: ________
Plant group:	Event date:[a] ________
Manufacturer:[b]	In-service date:[c] ________
Model number:[d]	Age:[e] ________
Util. component ID:	
	Out-of-service (replacement) date:[f] ____
Safety class:	

	Code	Description
Root 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 Interval	Check Testing		
	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 records.

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

d. Taken directly from the NPRDS records.

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 nonaging 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

E Environmental stress

- EA Animate causes
  - EAB Metal-sheathed bacteria - aging-related
  - EAE Animal encroachment - conditional aging-related
  - EAO Aquatic organisms - conditional aging-related

Table B-2. (continued)

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	
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	

Table B-2. (continued)

	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
	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

Table B-2. (continued)

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

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
SHO Operations activity
SHQ Quality assurance activity
SHT Testing/surveillance activity

Table B-2. (continued)

	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*

This cause 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 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 and binding/out of adjustment. 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 buildup 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: a 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 ferric 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 degradation 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 within the specified range, but is neither a short circuit nor 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 a random event, such as impact. In the latter situation, the failure is non-aging.

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 is 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 in 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.

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 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 over-torques 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 accelerate 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 accelerate 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 refer 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 preventive 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 REPORTED FAILURE-CAUSE ANALYSIS

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COMPONENT BOUNDARIES FOR THE REPORTED FAILURE-CAUSE ANALYSIS

This appendix describes the component boundaries used in the reported failure cause analysis. Examples of subcomponents and piece parts are also given for each of the components.

Accumulators

Accumulators are units composed of pressured vessels, valves, and piping. Accumulators are used to store pressurized borated water for emergency injection into the reactor core. The boundary is considered to be the pressurized vessel and associated isolation valves and piping.

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

Circuit Breakers (continued)

Piece Parts (continued):

- 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.

Filter/Strainer (continued)

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.

Piece Parts:

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

Heat Tracing Heaters

Heat tracing heaters are electrical cables surrounded by insulating materials. Heat tracing heaters are wrapped around piping and components to regulate heating of the borated water within the piping or components so that the boric acid will not solidify. The boundary is considered to be the cable, insulation, and regulating devices.

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
- Resistor
- 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 a 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:

- Indicators

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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)

Controllers
Transmitters
Switches
Timers
Thermowell[a]
Cables

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

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.

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 or welded connection.

Piece Parts:

Pipes
Tubing

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.

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.

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.

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 itself. The piece parts for these devices are shown in the matrix presented in Table C-1 (see following page).

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)

Valves, Air-Operated

The air-operated valve boundary includes the valve and the pneumatic operator. The valve is defined as the valve body, all internals, and seals. The pneumatic operator is defined as all components inside the operator housing that are necessary to make the valve function correctly. 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)

Table C-1. Supports and snubbers piece parts

	Device			
	CS	VSS	MS	HS
Housing/body/cylinder	x	x	x	x
Wiper	—	—	—	x
Turnbuckle	x	—	—	x
Reservoir	—	—	—	x
Rod/Hanger	—	x	—	—
Bleed Plug	—	—	—	x
Welded Attachment	x	x	—	—
Clamp	—	—	—	x
Steel 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

Valves, Check

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

Valves, Manual

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

Valves, Manual (continued)

Valve Piece Parts (continued):

- Bonnet
- Closure member
- Flange
- Valve body
- Bolts, nuts
- Valve seat
- Seals
- Mechanical stop

Valves, Motor-Operated

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

Valves, Over-Pressure Protection

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

Valves, Over-Pressure Protection (continued)

Piece Parts (continued):

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

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

APPENDIX D

FAILURE MODE CODES AND DEFINITIONS

Table D-1. Failure mode codes

Component	Code	Description
Accumulator	GLF	Loss of function
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
Heat Tracing Heater	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

Table D-1. (continued)

Component	Code	Description
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
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
	GFR	Fails to operate as required
	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

Accumulator

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

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.

Table D-2. (continued)

Heat Tracing Heater

1. Loss of function—This is the failure of the heat tracing heater to provide adequate heating function to maintain boron in solution within the piping and components.

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.

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 operation of the relay.

Table D-2. (continued)

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.

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 15 subsections. These subsections contain information pertinent to the 15 systems analyzed and appear in the following order:

1. Class 1E electrical power distribution (1E)
2. Auxiliary feedwater (AFW)
3. Component cooling water (CCW)
4. Containment fan (CTF)
5. Containment isolation (CTIS)
6. High-pressure injection (HPIS)
7. Low-pressure injection (LPIS)
8. Main feedwater (MFW)
9. Reactor building cooling (RBC)
10. Reactor core isolation cooling (RCIC)
11. Reactor protection trip (RPS)
12. Reactor coolant (RXC)
13. Residual heat removal (RHR)
14. Service water (SWS)
15. Standby liquid control (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 NPRDS component divisions and the corresponding component-level fractions for the five generic failure categories. These component fractions for the failure categories were calculated by dividing the total failure counts per failure category for a particular component by the total failure counts for that component within the appropriate system.
4. A summary table listing component fractions at the system level for the five generic failure categories. These fractions were calculated by dividing the total failure counts corresponding to a failure category for a particular component by the total failure counts for all components within the appropriate system.
5. 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 EEBFOA-DIESEL FUEL OIL EEBLOA-DIESEL LUBE OIL	
COMPONENTS:	ACCUMU AIRDRY ANNUNC BATTRY BLOWER CKTBRK ELECON ENGINE FILTER GENERA HEATER HTEXCH IBISSW ICNTRL	INDREC INTCPM IPWSUP IXMITR MECFUN MOTOR PIPE PUMP RELAY TRANSF TURBIN VALVE VALVOP

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

Failure Category Totals		
Design Failures	=	261
Aging Failures	=	741
Test and Maintenance Failures	=	153
Human Related Failures	=	46
Other Failures	=	1059
Total		2260
Failure Category Fractions		
Design Fraction	=	0.115
Aging Fraction	=	0.328
Test and Maintenance Fraction	=	0.068
Human Related Fraction	=	0.020
Other Fraction	=	0.469
System Effect Totals		
Loss of System Function	=	51
Degraded System Operation	=	387
Loss of Redundancy	=	634
Loss of Subsystem/Channel	=	611
System Function Unaffected	=	577
Total		2260
System Effect Fractions		
Loss of System Function Fraction	=	0.023
Degraded System Operation Fraction	=	0.171
Loss of Redundancy Fraction	=	0.281
Loss of Subsystem/Channel Fraction	=	0.270
System Function Unaffected Fraction	=	0.255

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

Components[b]	Total	Design	Aging	Testing	Human	Other
Blower	215	0.005	0.623	0.056	0.005	0.312
Motor	31	0.097	0.613	0.065	—	0.226
Pump	68	0.074	0.603	0.088	—	0.235
Valve	177	0.146	0.567	0.101	0.006	0.180
Instrumentation: Electric Power Supply	2	—	0.500	—	—	0.500
Pipe	4	—	0.500	—	—	0.500
Airdry	4	—	0.500	—	—	0.500
Filter	13	0.308	0.462	0.154	—	0.077
Heat Exchanger	14	—	0.429	—	—	0.571
Heater	11	0.182	0.364	0.091	—	0.364
Valve Operator	14	0.143	0.357	0.071	—	0.429
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
Instrumentation: Recorder	8	—	0.250	0.125	—	0.625
Relay	88	0.125	0.250	0.045	0.034	0.545
Instrumentation: Switch	93	0.065	0.237	0.065	0.011	0.624
Generator/Inverter/Alternator	390	0.115	0.236	0.033	0.015	0.600
Circuit Breaker	243	0.144	0.214	0.058	0.045	0.539
Turbine	5	0.200	0.200	—	—	0.600
Transformer	30	0.233	0.133	0.033	—	0.600
Instrumentation: Transmitter	24	0.042	0.125	0.125	—	0.708
Electrical Conductor	24	0.542	0.083	0.125	—	0.250
Instrumentation: Computation Module	1	—	—	1.000	—	—

Table E-3. (continued)

Components[b]	Total	Design	Aging	Testing	Human	Other
Accumulator	2	—	—	—	—	1.000
Annunciator	1	—	—	—	—	1.000
Instrumentation: Controller	4	0.500	—	—	—	0.500
Total	2259					

a. Denominator equals total component failures per system.

b. Components ordered by aging fractions.

Table E-4. Class 1E electrical power component failure category system fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Blower	215	—	0.059	0.005	—	0.030
Engine	496	0.029	0.056	0.022	0.006	0.107
Valve	177	0.012	0.045	0.008	—	0.014
Generator/Alternator/Inverter	390	0.020	0.041	0.006	0.003	0.104
Battery	242	0.012	0.035	0.005	0.003	0.053
Circuit Breaker	243	0.015	0.023	0.006	0.005	0.058
Pump	68	0.002	0.018	0.003	—	0.007
Instrumentation: Switch	93	0.003	0.010	0.003	—	0.026
Relay	88	0.005	0.010	0.002	0.001	0.021
Motor	31	0.001	0.008	0.001	—	0.003
Mechanical Function Unit	55	0.003	0.006	0.002	0.001	0.012
Heat Exchanger	14	—	0.003	—	—	0.004
Filter	13	0.002	0.003	0.001	—	—
Valve Operator	14	0.001	0.002	—	—	0.003
Heater	11	0.001	0.002	—	—	0.002
Transformer	30	0.003	0.002	—	—	0.008
Airdry	4	—	0.001	—	—	0.001
Instrumentation: Transmitter	24	—	0.001	0.001	—	0.008
Instrumentation: Recorder	8	—	0.001	—	—	0.002
Pipe	4	—	0.001	—	—	0.001
Electrical Conductor	24	0.006	0.001	0.001	—	0.003
Instrumentation: Computation Module	1	—	—	—	—	—
Annunciator	1	—	—	—	—	—
Accumulator	2	—	—	—	—	0.001
Turbine	5	—	—	—	—	0.001

Table E-4. (continued)

Components[b]	Total	Design	Aging	Testing	Human	Other
Instrumentation: Electric Power Supply	2	—	—	—	—	—
Instrumentation: Controller	4	0.001	—	—	—	0.001
Total	2259					

a. Denominator equals total system failures.

b. Components ordered by aging fractions.

Table E-5. 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 CKTBRK ENGINE IBISSW ICNTRL INDREC INTCPM IPWSUP ISODEV IXMITR MECFUN MOTOR PIPE PUMP RELAY SUPORT TURBIN VALVE VALVOP

Table E-6. 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-7. Auxiliary feedwater component failure category fractions[a]

Components[b]	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: Electronic 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
Total	829					

a. Denominator equals total component failures per system.

b. Components ordered by aging fractions.

Table E-8. Auxiliary feedwater component failure category system fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Valve	267	0.031	0.168	0.027	0.002	0.094
Pump	110	0.012	0.033	0.012	0.004	0.072
Valve Operator	103	0.010	0.031	0.013	0.002	0.068
Instrumentation: Controller	47	0.002	0.019	0.001	—	0.034
Instrumentation: Computation Module	26	—	0.012	0.004	—	0.016
Instrumentation: Transmitter	77	0.013	0.010	0.002	0.004	0.064
Turbine	60	0.011	0.010	0.007	0.004	0.041
Instrumentation: Switch	24	0.001	0.007	—	—	0.021
Relay	12	0.004	0.005	0.002	—	0.004
Mechanical Function Unit	16	0.001	0.004	0.005	0.002	0.007
Circuit Breaker	22	0.004	0.004	0.006	—	0.013
Instrumentation: Recorder	19	—	0.002	0.002	—	0.018
Annunciator	1	—	0.001	—	—	—
Instrumentation: Isolation Device	2	—	0.001	—	—	0.001
Instrumentation: Electric Power Supply	3	0.001	0.001	—	—	0.001
Support	22	0.010	0.001	0.004	—	0.012
Motor	7	—	0.001	—	—	0.007
Pipe	5	0.002	0.001	—	—	0.002
Engine	6	—	—	0.002	—	0.005
Total	829					

a. Denominator equals total system failures.

b. Components ordered by aging fractions.

Table E-9. Component cooling water system

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

Table E-10. Component cooling water system totals and fractions

Failure Category Totals		
Design Failures	=	65
Aging Failures	=	457
Test and Maintenance Failures	=	64
Human Related Failures	=	20
Other Failures	=	370
Total		976
Failure Category Fractions		
Design Fraction	=	0.067
Aging Fraction	=	0.468
Test and Maintenance Fraction	=	0.066
Human Related Fraction	=	0.020
Other Fraction	=	0.379
System Effect Totals		
Loss of System Function	=	3
Degraded System Operation	=	142
Loss of Redundancy	=	131
Loss of Subsystem/Channel	=	325
System Function Unaffected	=	375
Total		976
System Effect Fractions		
Loss of System Function Fraction	=	0.003
Degraded System Operation Fraction	=	0.145
Loss of Redundancy Fraction	=	0.134
Loss of Subsystem/Channel Fraction	=	0.333
System Function Unaffected Fraction	=	0.384

Table E-11. Component cooling water component failure category fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Pump	183	0.060	0.749	0.044	—	0.148
Pipe	3	—	0.667	—	—	0.333
Instrumentation: Controller	7	—	0.571	0.143	—	0.286
Valve	276	0.025	0.562	0.069	0.029	0.315
Heat Exchanger	88	0.102	0.523	0.045	0.034	0.295
Relay	6	0.167	0.500	—	0.167	0.167
Support	17	0.059	0.471	—	—	0.471
Motor	29	0.069	0.448	0.069	0.034	0.379
Circuit Breaker	47	0.085	0.362	0.064	0.021	0.468
Instrumentation: Computation Module	14	—	0.286	—	—	0.714
Valve Operator	186	0.091	0.247	0.086	0.011	0.565
Instrumentation: Switch	27	0.037	0.222	0.037	—	0.704
Instrumentation: Recorder	28	0.107	0.214	0.214	—	0.464
Instrumentation: Transmitter	61	0.115	0.164	0.066	0.066	0.590
Penetration	1	—	—	—	—	1.000
Accumulator	1	—	—	—	—	1.000
Electrical Conductor	2	1.000	—	—	—	—
Total	976					

a. Denominator equals total component failures per system.

b. Components ordered by aging fractions.

Table E-12. Component cooling water component failure category system fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Valve	276	0.007	0.159	0.019	0.008	0.089
Pump	183	0.011	0.140	0.008	—	0.028
Valve Operator	186	0.017	0.047	0.016	0.002	0.108
Heat Exchanger	88	0.009	0.047	0.004	0.003	0.027
Circuit Breaker	47	0.004	0.017	0.003	0.001	0.023
Motor	29	0.002	0.013	0.002	0.001	0.011
Instrumentation: Transmitter	61	0.007	0.010	0.004	0.004	0.037
Support	17	0.001	0.008	—	—	0.008
Instrumentation: Switch	27	0.001	0.006	0.001	—	0.019
Instrumentation: Recorder	28	0.003	0.006	0.006	—	0.013
Instrumentation: Computation Module	14	—	0.004	—	—	0.010
Instrumentation: Controller	7	—	0.004	0.001	—	0.002
Relay	6	0.001	0.003	—	0.001	0.001
Pipe	3	—	0.002	—	—	0.001
Penetration	1	—	—	—	—	0.001
Accumulator	1	—	—	—	—	0.001
Electrical Conductor	2	0.002	—	—	—	—
Total	976					

a. Denominator equals total system failures.

b. Components ordered by aging fractions.

Table E-13. Containment fan system

NSSS:	E-WESTINGHOUSE
SYSTEM:	SBG-CONTAINMENT FAN COOLING
COMPONENTS:	BLOWER CKTBRK ELECON FILTER HTEXCH IBISSW ICNTRL INDREC INTCPM IXMITR MOTOR PIPE PUMP RELAY VALVE VALVOP

Table E-14. Containment fan system totals and fractions

Failure Category Totals		
Design Failures	=	25
Aging Failures	=	84
Test and Maintenance Failures	=	28
Human Related Failures	=	6
Other Failures	=	175
Total		318
Failure Category Fractions		
Design Fraction	=	0.079
Aging Fraction	=	0.264
Test and Maintenance Fraction	=	0.088
Human Related Fraction	=	0.019
Other Fraction	=	0.550
System Effect Totals		
Loss of System Function	=	3
Degraded System Operation	=	45
Loss of Redundancy	=	82
Loss of Subsystem/Channel	=	82
System Function Unaffected	=	106
Total		318
System Effect Fractions		
Loss of System Function Fraction	=	0.009
Degraded System Operation Fraction	=	0.142
Loss of Redundancy Fraction	=	0.258
Loss of Subsystem/Channel Fraction	=	0.258
System Function Unaffected Fraction	=	0.333

Table E-15. Containment fan component failure category fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Relay	3	—	1.000	—	—	—
Instrumentation: Computation Module	2	—	1.000	—	—	—
Pipe	4	—	0.750	—	—	0.250
Pump	3	—	0.667	—	—	0.333
Blower	28	0.071	0.464	—	0.036	0.429
Heat Exchanger	27	0.037	0.444	0.037	—	0.481
Instrumentation: Controller	5	—	0.400	—	—	0.600
Circuit Breaker	49	0.041	0.347	0.061	0.041	0.510
Motor	30	0.033	0.333	0.067	0.033	0.533
Valve	65	0.092	0.200	0.200	0.031	0.477
Valve Operator	51	0.176	0.137	0.118	—	0.569
Instrumentation: Switch	1	—	—	—	—	1.000
Filter	1	—	—	—	—	1.000
Electrical Conductor	1	—	—	—	—	1.000
Instrumentation: Transmitter	43	0.047	—	0.070	—	0.884
Instrumentation: Recorder	5	0.400	—	—	—	0.600
Total	318					

a. Denominator equals total component failures per system.

b. Components ordered by aging fractions.

Table E-16. Containment fan component failure category system fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Circuit Breaker	49	0.006	0.053	0.009	0.006	0.079
Blower	28	0.006	0.041	—	0.003	0.038
Valve	65	0.019	0.041	0.041	0.006	0.097
Heat Exchanger	27	0.003	0.038	0.003	—	0.041
Motor	30	0.003	0.031	0.006	0.003	0.050
Valve Operator	51	0.028	0.022	0.019	—	0.091
Relay	3	—	0.009	—	—	—
Pipe	4	—	0.009	—	—	0.003
Instrumentation: Controller	5	—	0.006	—	—	0.009
Instrumentation: Computation Module	2	—	0.006	—	—	—
Pump	3	—	0.006	—	—	0.003
Instrumentation: Transmitter	43	0.006	—	0.009	—	0.119
Electrical Conductor	1	—	—	—	—	0.003
Instrumentation: Switch	1	—	—	—	—	0.003
Filter	1	—	—	—	—	0.003
Instrumentation: Recorder	5	0.006	—	—	—	0.009
Total	318					

a. Denominator equals total system failures.

b. Components ordered by aging fractions.

Table E-17. Containment isolation system

NSSS:	A-BABCOCK & WILCOX E-WESTINGHOUSE
SYSTEM:	A-BABCOCK & WILCOX SDA-CONTAINMENT ISOLATION E-WESTINGHOUSE SDB-CONTAINMENT ISOLATION
COMPONENTS:	BLOWER CKTBRK ELECON IBISSW ICNTRL INDREC INTCPM IPWSUP IXMITR MOTOR PENETR PIPE RELAY SUPORT VALVE VALVOP

Table E-18. Containment isolation system totals and fractions

Failure Category Totals		
Design Failures	=	40
Aging Failures	=	410
Test and Maintenance Failures	=	54
Human Related Failures	=	16
Other Failures	=	406
Total		926
Failure Category Fractions		
Design Fraction	=	0.043
Aging Fraction	=	0.443
Test and Maintenance Fraction	=	0.058
Human Related Fraction	=	0.017
Other Fraction	=	0.438
System Effect Totals		
Loss of System Function	=	2
Degraded System Operation	=	222
Loss of Redundancy	=	127
Loss of Subsystem/Channel	=	273
System Function Unaffected	=	302
Total		926
System Effect Fractions		
Loss of System Function Fraction	=	0.002
Degraded System Operation Fraction	=	0.240
Loss of Redundancy Fraction	=	0.137
Loss of Subsystem/Channel Fraction	=	0.295
System Function Unaffected Fraction	=	0.326

Table E-19. Containment isolation component failure category fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Penetration	4	—	1.000	—	—	—
Valve	451	0.040	0.581	0.053	0.004	0.322
Blower	16	—	0.562	0.062	—	0.375
Pipe	2	—	0.500	—	—	0.500
Instrumentation: Controllers	2	—	0.500	—	—	0.500
Motor	4	—	0.500	—	—	0.500
Instrumentation: Transmitters	32	0.031	0.375	—	—	0.594
Circuit Breaker	3	—	0.333	—	—	0.667
Valve Operator	354	0.045	0.314	0.079	0.014	0.548
Instrumentation: Computation Modules	5	—	0.200	0.200	—	0.600
Instrumentation: Electric Power Supply	15	0.133	0.200	—	—	0.667
Instrumentation: Recorders	11	0.091	0.182	—	—	0.727
Relay	8	0.250	0.125	—	—	0.625
Support	10	—	—	—	0.900	0.100
Instrumentation: Switch	8	—	—	—	—	1.000
Electrical Conductors	1	—	—	—	—	1.000
Total	926					

a. Denominator equals total component failures per system.

b. Components ordered by aging fractions.

Table E-20. Containment isolation component failure category system fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Valve	451	0.019	0.283	0.026	0.002	0.157
Valve Operator	354	0.017	0.120	0.030	0.005	0.210
Instrumentation: Transmitter	32	0.001	0.013	—	—	0.021
Blower	16	—	0.010	0.001	—	0.006
Penetration	4	—	0.004	—	—	—
Instrumentation: Electric Power Supply	15	0.002	0.003	—	—	0.011
Instrumentation: Recorder	11	0.001	0.002	—	—	0.009
Motor	4	—	0.002	—	—	0.002
Circuit Breaker	3	—	0.001	—	—	0.002
Instrumentation: Controller	2	—	0.001	—	—	0.001
Instrumentation: Computation Module	5	—	0.001	0.001	—	0.003
Pipe	2	—	0.001	—	—	0.001
Relay	8	0.002	0.001	—	—	0.005
Support	10	—	—	—	0.010	0.001
Electrical Conductor	1	—	—	—	—	0.001
Instrumentation: Switch	8	—	—	—	—	0.009
Total	926					

a. Denominator equals total system failures.

b. Components ordered by aging fractions.

Table E-21. High-pressure injection system

NSSS:	A-BABCOCK & WILCOX C-GENERAL ELECTRIC E-WESTINGHOUSE
SYSTEM:	A-BABCOCK & WILCOX PCB-LETDOWN PURIFICATION AND MAKEUP SFD-HIGH PRESSURE INJECTION C-GENERAL ELECTRIC SFB-HIGH PRESSURE CORE SPRAY SFC-HIGH PRESSURE COOLANT INJECTION E-WESTINGHOUSE SFK-HIGH PRESSURE SAFETY INJECTION SFKUHI-HIGH PRESSURE SAFETY INJECTION - UPPER HEAD SUBSYSTEM
COMPONENTS:	ACCUMU CKTBRK ELECON FILTER GENERA HEATER HTEXCH IBISSW ICNTRL INDREC INTCPM IPWSUP IXMITR MECFUN MOTOR PIPE PUMP RELAY SUPORT TURBIN VALVE VALVOP

Table E-22. High-pressure injection system totals and fractions

Failure Category Totals		
Design Failures	=	244
Aging Failures	=	493
Test and Maintenance Failures	=	173
Human Related Failures	=	51
Other Failures	=	1068
Total		2029
Failure Category Fractions		
Design Fraction	=	0.120
Aging Fraction	=	0.243
Test and Maintenance Fraction	=	0.085
Human Related Fraction	=	0.025
Other Fraction	=	0.526
System Effect Totals		
Loss of System Function	=	120
Degraded System Operation	=	469
Loss of Redundancy	=	178
Loss of Subsystem/Channel	=	417
System Function Unaffected	=	845
Total		2029
System Effect Fractions		
Loss of System Function Fraction	=	0.059
Degraded System Operation Fraction	=	0.231
Loss of Redundancy Fraction	=	0.088
Loss of Subsystem/Channel Fraction	=	0.206
System Function Unaffected Fraction	=	0.416

Table E-23. High-pressure injection component failure category fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Valve	544	0.103	0.430	0.077	0.020	0.369
Support	84	0.167	0.369	0.024	0.048	0.393
Pump	103	0.107	0.350	0.097	0.039	0.408
Instrumentation: Electric Power Supply	3	—	0.333	—	—	0.667
Heat Exchanger	19	0.474	0.316	—	0.105	0.105
Instrumentation: Recorder	55	—	0.309	0.109	—	0.582
Filter	7	0.143	0.286	0.429	—	0.143
Mechanical Function Unit	23	0.087	0.261	0.261	—	0.391
Circuit Breaker	74	0.162	0.243	0.095	0.041	0.460
Valve Operator	312	0.099	0.218	0.125	0.022	0.535
Relay	12	0.333	0.167	—	0.083	0.417
Instrumentation: Controller	44	0.091	0.159	0.068	—	0.682
Pipe	19	0.105	0.158	0.053	0.053	0.632
Turbine	35	0.143	0.143	0.171	0.029	0.514
Heater	36	0.111	0.111	0.111	0.167	0.500
Instrumentation: Transmitter	261	0.188	0.111	0.069	0.008	0.625
Instrumentation: Switch	357	0.104	0.064	0.067	0.017	0.748
Motor	19	0.105	0.053	0.053	0.105	0.684
Electrical Conductor	4	—	—	—	—	1.000
Generator/Inverter/Alternator	1	—	—	—	—	1.000
Accumulator	4	—	—	—	0.250	0.750
Instrumentation: Computation Module	13	0.077	—	0.077	—	0.846
Total	2029					

a. Denominator equals total component failures per system.

b. Components ordered by aging fractions.

Table E-24. High-pressure injection component failure category system fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Valve	544	0.028	0.115	0.021	0.005	0.099
Valve Operator	312	0.015	0.034	0.019	0.003	0.082
Pump	103	0.005	0.018	0.005	0.002	0.021
Support	84	0.007	0.015	0.001	0.002	0.016
Instrumentation: Transmitter	261	0.024	0.014	0.009	0.001	0.080
Instrumentation: Switch	357	0.018	0.011	0.012	0.003	0.132
Circuit Breaker	74	0.006	0.009	0.003	0.001	0.017
Instrumentation: Recorder	55	—	0.008	0.003	—	0.016
Mechanical Function Unit	23	0.001	0.003	0.003	—	0.004
Instrumentation: Controller	44	0.002	0.003	0.001	—	0.015
Heat Exchanger	19	0.004	0.003	—	0.001	0.001
Heater	36	0.002	0.002	0.002	0.003	0.009
Turbine	35	0.002	0.002	0.003	—	0.009
Pipe	19	0.001	0.001	—	—	0.006
Filter	7	—	0.001	0.001	—	—
Relay	12	0.002	0.001	—	—	0.002
Instrumentation: Electric Power Supply	3	—	—	—	—	0.001
Generator/Alternator/Inverter	1	—	—	—	—	—
Electrical Conductor	4	—	—	—	—	0.002
Motor	19	0.001	—	—	0.001	0.006
Accumulator	4	—	—	—	—	0.001
Instrumentation: Computation Module	13	—	—	—	—	0.005
Total	2029					

a. Denominator equals total system failures.

b. Components ordered by aging fractions.

Table E-25. Low-pressure injection system

NSSS:	C-GENERAL ELECTRIC
SYSTEM:	SFA-LOW PRESSURE CORE SPRAY
COMPONENTS:	BATTRY CKTBRK ELECON IBISSW ICNTRL INDREC IPWSUP IXMITR MOTOR PIPE PUMP RELAY SUPORT VALVE VALVOP

Table E-26. Low-pressure injection system totals and fractions

Failure Category Totals		
Design Failures	=	57
Aging Failures	=	125
Test and Maintenance Failures	=	41
Human Related Failures	=	12
Other Failures	=	223
Total		458
Failure Category Fractions		
Design Fraction	=	0.124
Aging Fraction	=	0.273
Test and Maintenance Fraction	=	0.090
Human Related Fraction	=	0.026
Other Fraction	=	0.487
System Effect Totals		
Loss of System Function	=	11
Degraded System Operation	=	62
Loss of Redundancy	=	92
Loss of Subsystem/Channel	=	122
System Function Unaffected	=	171
Total		458
System Effect Fractions		
Loss of System Function Fraction	=	0.024
Degraded System Operation Fraction	=	0.135
Loss of Redundancy Fraction	=	0.201
Loss of Subsystem/Channel Fraction	=	0.266
System Function Unaffected Fraction	=	0.373

Table E-27. Low-pressure injection component failure category fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Electrical Conductor	1	—	1.000	—	—	—
Pump	21	—	0.571	—	—	0.429
Instrumentation: Electric Power Supply	2	—	0.500	—	—	0.500
Motor	13	0.077	0.462	0.154	—	0.308
Valve	102	0.020	0.412	0.098	0.039	0.431
Instrumentation: Transmitter	8	—	0.375	—	—	0.625
Support	54	0.259	0.296	0.056	0.019	0.370
Circuit Breaker	58	0.103	0.293	0.138	0.052	0.414
Valve Operator	75	0.120	0.213	0.120	0.027	0.520
Instrumentation: Switch	63	0.048	0.159	0.079	0.032	0.683
Instrumentation: Recorder	11	0.091	0.091	0.273	—	0.545
Battery	4	—	—	—	—	1.000
Instrumentation: Controller	8	—	—	—	—	1.000
Pipe	20	0.850	—	—	—	0.150
Relay	18	0.222	—	0.056	—	0.722
Total	458					

a. Denominator equals total component failures per system.

b. Components ordered by aging fractions.

Table E-28. Low-pressure injection component failure category system fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Valve	102	0.004	0.092	0.022	0.009	0.096
Circuit Breaker	58	0.013	0.037	0.017	0.007	0.052
Valve Operator	75	0.020	0.035	0.020	0.004	0.085
Support	54	0.031	0.035	0.007	0.002	0.044
Pump	21	—	0.026	—	—	0.020
Instrumentation: Switch	63	0.007	0.022	0.011	0.004	0.094
Motor	13	0.002	0.013	0.004	—	0.009
Instrumentation: Transmitter	8	—	0.007	—	—	0.011
Instrumentation: Electric Power Supply	2	—	0.002	—	—	0.002
Instrumentation: Recorder	11	0.002	0.002	0.007	—	0.013
Electrical Conductor	1	—	0.002	—	—	—
Battery	4	—	—	—	—	0.009
Pipe	20	0.037	—	—	—	0.007
Relay	18	0.009	—	0.002	—	0.028
Instrumentation: Controller	8	—	—	—	—	0.017
Total	458					

a. Denominator equals total system failures.

b. Components ordered by aging fractions.

Table E-29. 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-30. 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-31. Main feedwater component failure category fractions[a]

Components[b]	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: Electric 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	—	—
Total	827					

a. Denominator equals total component failures per system.

b. Components ordered by aging fractions.

Table E-32. Main feedwater component failure category system fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Valve	334	0.044	0.212	0.017	0.002	0.129
Valve Operator	113	0.010	0.044	0.015	0.002	0.067
Pump	49	0.008	0.027	0.006	0.001	0.017
Heat Exchanger	21	0.001	0.017	0.001	—	0.006
Instrumentation: Transmitter	82	0.002	0.017	0.005	—	0.075
Instrumentation: Computation Module	41	—	0.012	0.001	—	0.036
Support	55	0.033	0.008	0.004	0.001	0.021
Turbine	26	0.004	0.007	0.002	—	0.018
Instrumentation: Recorder	43	0.001	0.006	0.002	—	0.042
Instrumentation: Switch	11	0.002	0.006	—	—	0.005
Circuit Breaker	9	0.001	0.005	—	—	0.005
Mechanical Function Unit	15	0.001	0.005	0.001	—	0.011
Relay	3	—	0.004	—	—	—
Instrumentation: Controller	10	—	0.002	0.001	—	0.008
Pipe	4	0.002	0.001	—	—	0.001
Instrumentation: Electric Power Supply	2	—	0.001	—	—	0.001
Motor	5	0.004	0.001	—	—	0.001
Instrumentation: Isolation Device	1	—	—	—	—	0.001
Filter	3	—	—	0.004	—	—
Total	827					

a. Denominator equals total system failures.

b. Components ordered by aging fractions.

Table E-33. Reactor building cooling system

NSSS:	A-BABCOCK & WILCOX
SYSTEM:	SBB-REACTOR BUILDING COOLING
COMPONENTS:	BLOWER CKTBRK HTEXCH INDREC IXMITR MOTOR VALVE VALVOP

Table E-34. Reactor building cooling system totals and fractions

Failure Category Totals		
Design Failures	=	5
Aging Failures	=	19
Test and Maintenance Failures	=	6
Human Related Failures	=	4
Other Failures	=	31
Total		65
Failure Category Fractions		
Design Fraction	=	0.077
Aging Fraction	=	0.292
Test and Maintenance Fraction	=	0.092
Human Related Fraction	=	0.062
Other Fraction	=	0.477
System Effect Totals		
Loss of System Function	=	0
Degraded System Operation	=	12
Loss of Redundancy	=	16
Loss of Subsystem/Channel	=	21
System Function Unaffected	=	16
Total		65
System Effect Fractions		
Loss of System Function Fraction	=	0.000
Degraded System Operation Fraction	=	0.185
Loss of Redundancy Fraction	=	0.246
Loss of Subsystem/Channel Fraction	=	0.323
System Function Unaffected Fraction	=	0.246

Table E-35. Reactor building cooling component failure category fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Valve Operator	2	—	1.000	—	—	—
Valve	10	0.200	0.600	0.100	—	0.100
Motor	11	—	0.364	0.091	—	0.545
Blower	7	0.143	0.286	—	0.286	0.286
Instrumentation: Recorder	12	—	0.250	0.083	0.083	0.583
Circuit Breaker	18	0.111	0.111	0.056	0.056	0.667
Heat Exchanger	3	—	—	—	—	1.000
Instrumentation: Transmitter	2	—	—	1.000	—	—
Total	65					

a. Denominator equals total component failures per system.

b. Components ordered by aging fractions.

Table E-36. Reactor building cooling component failure category system fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Valve	10	0.031	0.092	0.015	—	0.015
Motor	11	—	0.062	0.015	—	0.092
Instrumentation: Recorder	12	—	0.046	0.015	0.015	0.108
Blower	7	0.015	0.031	—	0.031	0.031
Circuit Breaker	18	0.031	0.031	0.015	0.015	0.185
Valve Operator	2	—	0.031	—	—	—
Heat Exchanger	3	—	—	—	—	0.046
Instrumentation: Transmitter	2	—	—	0.031	—	—
Total	65					

a. Denominator equals total system failures.

b. Components ordered by aging fractions.

Table E-37. Reactor core isolation cooling system

NSSS:	C-GENERAL ELECTRIC
SYSTEM:	CEA-REACTOR CORE ISOLATION COOLING
COMPONENTS:	CKTBRK ELECON GENERA IBISSW ICNTRL INDREC INTCPM IXMITR MECFUN MOTOR PIPE PUMP RELAY SUPORT TURBIN VALVE VALVOP

Table E-38. Reactor core isolation cooling system totals and fractions

Failure Category Totals		
Design Failures	=	70
Aging Failures	=	209
Test and Maintenance Failures	=	67
Human Related Failures	=	13
Other Failures	=	415
Total		774
Failure Category Fractions		
Design Fraction	=	0.090
Aging Fraction	=	0.270
Test and Maintenance Fraction	=	0.087
Human Related Fraction	=	0.017
Other Fraction	=	0.536
System Effect Totals		
Loss of System Function	=	88
Degraded System Operation	=	184
Loss of Redundancy	=	41
Loss of Subsystem/Channel	=	138
System Function Unaffected	=	323
Total		774
System Effect Fractions		
Loss of System Function Fraction	=	0.114
Degraded System Operation Fraction	=	0.238
Loss of Redundancy Fraction	=	0.053
Loss of Subsystem/Channel Fraction	=	0.178
System Function Unaffected Fraction	=	0.417

Table E-39. Reactor core isolation cooling component failure category fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Motor	7	0.143	0.571	0.143	—	0.143
Pipe	2	—	0.500	—	—	0.500
Instrumentation: Computation Module	10	0.100	0.500	0.100	—	0.300
Valve	199	0.080	0.492	0.075	0.020	0.332
Instrumentation Recorder	26	0.115	0.346	—	0.077	0.462
Support	36	0.056	0.278	0.028	—	0.639
Valve Operator	144	0.090	0.229	0.111	0.007	0.562
Instrumentation: Transmitter	44	0.045	0.227	0.023	0.023	0.682
Circuit Breaker	34	0.147	0.206	0.059	—	0.588
Pump	5	0.200	0.200	0.200	—	0.400
Instrumentation: Controller	27	0.111	0.185	0.074	—	0.630
Mechanical Function Unit	17	0.118	0.176	0.059	—	0.647
Turbine	31	0.129	0.161	0.129	0.032	0.548
Relay	10	0.200	0.100	0.300	0.100	0.300
Instrumentation: Switch	176	0.085	0.097	0.108	0.017	0.693
Generator/Inverter/ Alternator	5	—	—	—	—	1.000
Electrical Conductor	1	—	—	—	—	1.000
Total	774					

a. Denominator equals total component failures per system.

b. Components ordered by aging fractions.

Table E-40. Reactor core isolation cooling component failure category system fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Valve	199	0.021	0.127	0.019	0.005	0.085
Valve Operator	144	0.017	0.043	0.021	0.001	0.105
Instrumentation: Switch	176	0.019	0.022	0.025	0.004	0.158
Support	36	0.003	0.013	0.001	—	0.030
Instrumentation: Transmitter	44	0.003	0.013	0.001	0.001	0.039
Instrumentation: Recorder	26	0.004	0.012	—	0.003	0.016
Circuit Breaker	34	0.006	0.009	0.003	—	0.026
Instrumentation: Computation Module	10	0.001	0.006	0.001	—	0.004
Instrumentation: Controller	27	0.004	0.006	0.003	—	0.022
Turbine	31	0.005	0.006	0.005	0.001	0.022
Motor	7	0.001	0.005	0.001	—	0.001
Mechanical Function Unit	17	0.003	0.004	0.001	—	0.014
Relay	10	0.003	0.001	0.004	0.001	0.004
Pump	5	0.001	0.001	0.001	—	0.003
Pipe	2	—	0.001	—	—	0.001
Generator/Inverter/Alternator	5	—	—	—	—	0.006
Electrical Conductor	1	—	—	—	—	0.001
Total	774					

a. Denominator equals total system failures.

b. Components ordered by aging fractions.

Table E-41. Reactor protection trip system

NSSS:	A-BABCOCK & WILCOX C-GENERAL ELECTRIC E-WESTINGHOUSE
SYSTEM:	A-BABCOCK & WILCOX IBB-REACTOR PROTECTION IBC-(ENGINEERED) SAFETY FEATURE SUBSYSTEM
	C-GENERAL ELECTRIC IBA-REACTOR PROTECTION IBAIAA-REACTOR PROTECTION - NEUTRON LEVEL SUBSYSTEM
	E-WESTINGHOUSE IBG-REACTOR PROTECTION AND LOGIC IBK-ENGINEERED SAFEGUARDS ACTUATION
COMPONENTS:	ANNUNC CKTBRK ELECON GENERA IBISSW ICNTRL INDREC INTCPM IPWSUP ISODEV IXMITR RELAY

Table E-42. Reactor protection trip system totals and fractions

Failure Category Totals		
Design Failures	=	472
Aging Failures	=	829
Test and Maintenance Failures	=	214
Human Related Failures	=	27
Other Failures	=	1985
Total		3533
Failure Category Fractions		
Design Fraction	=	0.134
Aging Fraction	=	0.235
Test and Maintenance Fraction	=	0.061
Human Related Fraction	=	0.008
Other Fraction	=	0.562
System Effect Totals		
Loss of System Function	=	6
Degraded System Operation	=	598
Loss of Redundancy	=	603
Loss of Subsystem/Channel	=	1384
System Function Unaffected	=	943
Total		3533
System Effect Fractions		
Loss of System Function Fraction	=	0.002
Degraded System Operation Fraction	=	0.169
Loss of Redundancy Fraction	=	0.171
Loss of Subsystem/Channel Fraction	=	0.392
System Function Unaffected Fraction	=	0.267

Table E-43. Reactor protection trip component failure category fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Instrumentation: Isolation Device	31	0.032	0.387	—	—	0.581
Annunciator	3	0.333	0.333	—	—	0.333
Generator/Alternator/ Inverter	16	0.250	0.312	0.125	—	0.312
Circuit Breaker	46	0.087	0.283	0.087	—	0.543
Instrumentation: Computation Module	918	0.062	0.281	0.035	0.009	0.613
Instrumentation: Recorder	214	0.121	0.271	0.061	0.005	0.542
Relay	377	0.265	0.255	0.029	0.016	0.435
Instrumentation: Electric Power Supply	268	0.071	0.254	0.060	—	0.616
Instrumentation: Controller	207	0.092	0.237	0.053	—	0.618
Instrumentation: Switch	513	0.273	0.187	0.062	0.010	0.468
Instrumentation: Transmitter	928	0.108	0.184	0.098	0.008	0.596
Electrical Conductor	12	0.083	0.167	0.167	—	0.583
Total	3533					

a. Denominator equals total component failures per system.

b. Components ordered by aging fractions.

Table E-44. Reactor protection trip component failure category system fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Instrumentation: Computation Module	918	0.016	0.073	0.009	0.002	0.159
Instrumentation: Transmitter	928	0.028	0.048	0.026	0.002	0.157
Relay	377	0.028	0.027	0.003	0.002	0.046
Instrumentation: Switch	513	0.040	0.027	0.009	0.001	0.068
Instrumentation: Electric Power Supply	268	0.005	0.019	0.005	—	0.047
Instrumentation: Recorder	214	0.007	0.016	0.004	—	0.033
Instrumentation: Controller	207	0.005	0.014	0.003	—	0.036
Circuit Breaker	46	0.001	0.004	0.001	—	0.007
Instrumentation: Isolation Device	31	—	0.003	—	—	0.005
Generator/Alternator/Inverter	16	0.001	0.001	0.001	—	0.001
Electrical Conductor	12	—	0.001	0.001	—	0.002
Annunciator	3	—	—	—	—	—
Total	3533					

a. Denominator equals total system failures.

b. Components ordered by aging fractions.

Table E-45. Reactor coolant system

NSSS:	A-BABCOCK & WILCOX C-GENERAL ELECTRIC
SYSTEM:	A-BABCOCK & WILCOX CBD-REACTOR COOLANT C-GENERAL ELECTRIC CBA-REACTOR RECIRCULATION
COMPONENTS:	CKTBRK ELECON GENERA HTEXCH IBISSW ICNTRL INDREC INTCPM IPWSUP IXMITR MECFUN MOTOR PIPE PUMP RELAY SUPORT TRANSF VALVE VALVOP VESSEL

Table E-46. Reactor coolant system totals and fractions

Failure Category Totals		
Design Failures	=	138
Aging Failures	=	290
Test and Maintenance Failures	=	53
Human Related Failures	=	14
Other Failures	=	517
Total		1012
Failure Category Fractions		
Design Fraction	=	0.136
Aging Fraction	=	0.287
Test and Maintenance Fraction	=	0.052
Human Related Fraction	=	0.014
Other Fraction	=	0.511
System Effect Totals		
Loss of System Function	=	9
Degraded System Operation	=	222
Loss of Redundancy	=	121
Loss of Subsystem/Channel	=	248
System Function Unaffected	=	412
Total		1012
System Effect Fractions		
Loss of System Function Fraction	=	0.009
Degraded System Operation Fraction	=	0.219
Loss of Redundancy Fraction	=	0.120
Loss of Subsystem/Channel Fraction	=	0.245
System Function Unaffected Fraction	=	0.407

Table E-47. Reactor coolant component failure category fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Transformer	1	—	1.000	—	—	—
Instrumentation: Electric Power Supply	3	—	0.667	—	—	0.333
Heat Exchanger	53	0.094	0.566	0.075	—	0.264
Mechanical Function Unit	20	0.050	0.500	—	—	0.450
Valve	118	0.102	0.492	0.034	0.017	0.356
Vessel	12	0.167	0.417	—	—	0.417
Circuit Breaker	28	0.036	0.393	0.036	—	0.536
Generator/Alternator/Inverter	47	0.043	0.319	0.106	0.021	0.511
Pump	93	0.258	0.312	0.054	0.022	0.355
Support	87	0.425	0.299	0.011	0.046	0.218
Pipe	35	0.400	0.286	—	—	0.314
Motor	26	0.192	0.269	0.192	—	0.346
Instrumentation: Recorder	103	0.019	0.262	0.087	0.010	0.621
Valve Operator	92	0.098	0.261	0.087	0.011	0.543
Relay	16	0.125	0.250	0.125	—	0.500
Instrumentation: Controller	26	0.077	0.154	0.115	—	0.654
Instrumentation: Switch	81	0.160	0.148	—	0.012	0.679
Instrumentation: Computation Module	45	0.044	0.133	—	—	0.822
Instrumentation: Transmitter	123	0.041	0.073	0.049	0.016	0.821
Electrical Conductor	3	—	—	—	—	1.000
Total	1012					

a. Denominator equals total component failures per system.

b. Components ordered by aging fractions.

Table E-48. Reactor cooling component failure category system fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Valve	118	0.012	0.057	0.004	0.002	0.042
Heat Exchanger	53	0.005	0.030	0.004	—	0.014
Pump	93	0.024	0.029	0.005	0.002	0.033
Instrumentation: Recorder	103	0.002	0.027	0.009	0.001	0.063
Support	87	0.037	0.026	0.001	0.004	0.019
Valve Operator	92	0.009	0.024	0.008	0.001	0.049
Generator/Alternator/Inverter	47	0.002	0.015	0.005	0.001	0.024
Instrumentation: Switch	81	0.013	0.012	—	0.001	0.054
Circuit Breaker	28	0.001	0.011	0.001	—	0.015
Pipe	35	0.014	0.010	—	—	0.011
Mechanical Function Unit	20	0.001	0.010	—	—	0.009
Instrumentation: Transmitter	123	0.005	0.009	0.006	0.002	0.100
Motor	26	0.005	0.007	0.005	—	0.009
Instrumentation: Computation Module	45	0.002	0.006	—	—	0.037
Vessel	12	0.002	0.005	—	—	0.005
Relay	16	0.002	0.004	0.002	—	0.008
Instrumentation: Controller	26	0.002	0.004	0.003	—	0.017
Instrumentation: Electric Power Supply	3	—	0.002	—	—	0.001
Transformer	1	—	0.001	—	—	—
Electrical Conductor	3	—	—	—	—	0.003
Total	1012					

a. Denominator equals total system failures.

b. Components ordered by aging fractions.

Table E-49. Residual heat removal system

NSSS:	A-BABCOCK & WILCOX C-GENERAL ELECTRIC E-WESTINGHOUSE
SYSTEM:	A-BABCOCK & WILCOX CFC-DECAY HEAT REMOVAL/LOW PRESSURE INJECTION C-GENERAL ELECTRIC CFA-RESIDUAL HEAT REMOVAL/LOW PRESSURE INJECTION E-WESTINGHOUSE CFF-RESIDUAL HEAT REMOVAL/LOW PRESSURE INJECTION
COMPONENTS:	ACCUMU ANNUNC CKTBRK ELECON HEATER HTEXCH IBISSW ICNTRL INDREC INTCPM IPWSUP ISODEV IXMITR MOTOR PIPE PUMP RELAY SUPORT VALVE VALVOP

Table E-50. Residual heat removal system totals and fractions

Failure Category Totals		
Design Failures	=	216
Aging Failures	=	531
Test and Maintenance Failures	=	142
Human Related Failures	=	29
Other Failures	=	1050
Total		1968
Failure Category Fractions		
Design Fraction	=	0.110
Aging Fraction	=	0.270
Test and Maintenance Fraction	=	0.072
Human Related Fraction	=	0.015
Other Fraction	=	0.534
System Effect Totals		
Loss of System Function	=	14
Degraded System Operation	=	311
Loss of Redundancy	=	303
Loss of Subsystem/Channel	=	470
System Function Unaffected	=	870
Total		1968
System Effect Fractions		
Loss of System Function Fraction	=	0.007
Degraded System Operation Fraction	=	0.158
Loss of Redundancy Fraction	=	0.154
Loss of Subsystem/Channel Fraction	=	0.239
System Function Unaffected Fraction	=	0.442

Table E-51. Residual heat removal component failure category fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Annunciator	1	—	1.000	—	—	—
Instrumentation: Isolation Device	4	—	1.000	—	—	—
Heat Exchanger	39	0.103	0.538	0.026	—	0.333
Valve	484	0.079	0.492	0.058	0.012	0.360
Pump	86	0.093	0.465	0.070	0.035	0.337
Instrumentation: Electric Power Supply	11	—	0.273	—	—	0.727
Instrumentation: Computation Module	27	0.037	0.259	0.037	—	0.667
Instrumentation: Controller	24	0.083	0.250	0.083	—	0.583
Circuit Breaker	99	0.152	0.242	0.091	—	0.515
Motor	21	0.190	0.238	0.048	—	0.524
Valve Operator	446	0.096	0.215	0.096	0.025	0.567
Relay	27	0.074	0.185	0.111	—	0.630
Instrumentation: Recorder	78	0.051	0.167	0.064	—	0.718
Instrumentation: Transmitter	182	0.099	0.121	0.099	0.011	0.670
Instrumentation: Switch	203	0.099	0.118	0.059	0.015	0.709
Support	202	0.223	0.109	0.059	0.020	0.589
Heater	12	0.083	—	—	—	0.917
Accumulator	5	0.200	—	—	—	0.800
Electrical Conductor	3	—	—	0.333	—	0.667
Pipe	14	0.714	—	—	—	0.286
Total	1968					

a. Denominator equals total component failures per system.

b. Components ordered by aging fractions.

Table E-52. Residual heat removal component failure category system fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Valve	484	0.019	0.121	0.014	0.003	0.088
Valve Operator	446	0.022	0.049	0.022	0.006	0.129
Pump	86	0.004	0.020	0.003	0.002	0.015
Circuit Breaker	99	0.008	0.012	0.005	—	0.026
Instrumentation: Switch	203	0.010	0.012	0.006	0.002	0.073
Support	202	0.023	0.011	0.006	0.002	0.060
Heat Exchanger	39	0.002	0.011	0.001	—	0.007
Instrumentation: Transmitter	182	0.009	0.011	0.009	0.001	0.062
Instrumentation: Recorder	78	0.002	0.007	0.003	—	0.028
Instrumentation: Computation Module	27	0.001	0.004	0.001	—	0.009
Motor	21	0.002	0.003	0.001	—	0.006
Instrumentation: Controller	24	0.001	0.003	0.001	—	0.007
Relay	27	0.001	0.003	0.002	—	0.009
Instrumentation: Isolation Device	4	—	0.002	—	—	—
Instrumentation: Electric Power Supply	11	—	0.002	—	—	0.004
Annunciator	1	—	0.001	—	—	—
Accumulator	5	0.001	—	—	—	0.002
Heater	12	0.001	—	—	—	0.006
Electrical Conductor	3	—	—	0.001	—	0.001
Pipe	14	0.005	—	—	—	0.002
Total	1968					

a. Denominator equals total system failures.

b. Components ordered by aging fractions.

Table E-53. 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-54. 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-55. Service water system failure category fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Instrumentation: Electric 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
Total	1272					

a. Denominator equals total component failures per system.

b. Components ordered by aging fractions.

Table E-56. Service water component failure category system fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Valve	362	0.019	0.158	0.011	0.007	0.090
Pump	248	0.009	0.111	0.015	—	0.061
Valve Operator	307	0.017	0.071	0.028	0.003	0.122
Filter	98	0.008	0.044	0.003	—	0.022
Motor	64	0.004	0.020	0.001	0.001	0.025
Circuit Breaker	48	0.002	0.013	0.003	0.002	0.017
Pipe	18	—	0.008	0.001	—	0.006
Instrumentation: Switch	38	0.002	0.008	0.001	—	0.019
Instrumentation: Controller	17	0.001	0.007	0.002	—	0.004
Instrumentation: Recorder	22	0.001	0.004	—	—	0.013
Instrumentation: Transmitter	27	0.001	0.002	0.001	—	0.017
Instrumentation: Electric Power Supply	2	—	0.002	—	—	—
Support	10	0.002	0.001	—	—	0.005
Relay	5	0.002	—	—	—	0.002
Instrumentation: Computation Module	2	—	—	—	—	0.002
Electrical Conductor	4	0.001	—	—	—	0.002
Total	1272					

a. Denominator equals total system failures.

b. Components ordered by aging fractions.

Table E-57. 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-58. 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-59. Standby liquid control component failure category fractions[a]

Components[b]	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: Electric 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
Total	173					

a. Denominator equals total component failures per system.

b. Components ordered by aging fractions.

Table E-60. Standby liquid control component failure category system fractions[a]

Components[b]	Total	Design	Aging	Testing	Human	Other
Valve	66	0.029	0.092	0.035	—	0.225
Pump	19	0.006	0.069	—	—	0.035
Instrumentation: Transmitter	17	0.012	0.029	—	—	0.058
Instrumentation: Recorder	14	—	0.023	—	—	0.058
Accumulator	12	0.006	0.023	0.012	—	0.029
Heater	10	—	0.012	0.006	—	0.040
Instrumentation: Switch	14	—	0.012	—	—	0.069
Instrumentation: Controller	5	—	0.006	0.006	—	0.017
Instrumentation: Electric Power Supply	4	—	0.006	—	—	0.017
Relay	2	—	0.006	—	—	0.006
Support	6	—	0.006	—	—	0.029
Circuit Breaker	2	—	—	—	0.006	0.006
Valve Operator	2	0.006	—	—	—	0.006
Total	173					

a. Denominator equals total system failures.

b. Components ordered by aging fractions.

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-3 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. Table F-3 summarizes the failure records that were categorized as *unclassifiable*. Tables F-4 through F-56 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 having five or more failure counts, excluding the unclassified causes. The failure causes are presented in alphabetical order in the tables. Table F-57 summarizes the failure records by system effect, excluding the unclassifiable failure records.

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

System	Components[b]	Failure Mode	Failure Mode Code	Counts[c]
Auxiliary Feedwater System	Check Valve	External Leakage	GEL	13
		Fails to Open	GFO	3
		Failure to Operate as Required	GFR	8
		Internal Leakage	GIL	66
	Circuit Breaker, AC	Fails to Close	GFC	1
		Fails to Operate	GFP	7
	Flow Controller	Erroneous/Erratic Signals	GEE	8
		Fails to Operate	GFP	11
	Flow Control Recorder	Erroneous/Erratic Signals	GEE	9
		Fails to Operate	GFP	1
	Flow Transmitter	Erroneous/Erratic Signals	GEE	25
		Fails to Operate	GFP	2
	Hand Control Valve	External Leakage	GEL	6
		Fails to Close	GFC	5
		Fails to Open	GFO	1
		Failure to Operate as Required	GFR	3
		Internal Leakage	GIL	1
	Level Control	Erroneous/Erratic Signals	GEE	7
		Fails to Operate	GFP	11
	Level Control Indicator	Erroneous/Erratic Signals	GEE	7
		Fails to Operate	GFP	13
	Motor-Driven Pump	External Leakage	GEL	14
		Fails to Run	GFU	33
		Fails to Start	GFS	16
	Motor-Operated Valve	External Leakage	GEL	1
		Fails to Close	GFC	14
		Fails to Open	GFO	11
		Fails to Open/Fails to Close	GOC	9
		Failure to Operate as Required	GFR	8
	Pneumatic-Operated Valve	External Leakage	GEL	8
		Fails to Close	GFC	49
		Fails to Open	GFO	20
		Fails to Open/Fails to Close	GOC	13
		Failure to Operate as Required	GFR	10
	Pressure Control	Erroneous/Erratic Signals	GEE	5
		Fails to Operate	GFP	2

TABLE F-1. (continued)

System	Components[b]	Failure Mode	Failure Mode Code	Counts[c]
Auxiliary Feedwater System (continued)	Pressure Switch	Erroneous/Erratic Signals	GEE	12
		Fails to Operate	GFP	9
	Pressure Transmitter	Erroneous/Erratic Signals	GEE	14
		Fails to Operate	GFP	3
	Relay	Fails to Open	GFO	2
		Fails to Operate	GFP	7
		Short Circuit	GSH	3
	Relief Valve	Fails to Close	GFC	1
		Opens (Premature)	GSO	6
	Snubber	Loss of Function	GLF	7
	Support	Loss of Function	GLF	5
	Turbine-Driven Pump	External Leakage	GEL	6
		Fails to Run	GFU	39
		Fails to Start	GFS	13
Chemical and Volume Control System	Circuit Breaker, AC	Fails to Operate	GFP	5
	Heat Tracing Heater	Loss of Function	GLF	9
	Level Control	Erroneous/Erratic Signals	GEE	7
	Level Transmitter	Erroneous/Erratic Signals	GEE	17
		Fails to Operate	GFP	2
	Motor-Driven Pump	External Leakage	GEL	7
		Fails to Run	GFU	21
		Fails to Start	GFS	1
	Motor-Operated Valve	External Leakage	GEL	9
		Fails to Close	GFC	22
		Fails to Open	GFO	3
		Fails to Open/Fails to Close	GOC	8
		Failure to Operate as Required	GFR	2
		Internal Leakage	GIL	2
Class 1E Electrical Power Distribution System				
DC Power Subsystem	Battery	Loss of Function	GLF	10
	Battery Charger	Loss of Function	GLF	35
Emergency On-site Power Supply Subsystem	Circuit Breaker, AC	Fails to Operate	GFP	5
	Diesel Generator	Fails to Run	GFU	43
		Fails to Start	GFS	21
		No Failure	GNF	49

TABLE F-1. (continued)

System	Components[b]	Failure Mode	Failure Mode Code	Counts[c]
Class 1E Electrical Power Distribution System (continued)				
Instrumentation & Uninterruptible Power Supply Subsystem	Circuit Breaker, AC	Fails to Operate	GFP	5
	Inverter	Loss of Function	GLF	63
High Pressure Injection System	Check Valve	External Leakage	GEL	3
		Internal Leakage	GIL	15
	Circuit Breaker, AC	Fails to Operate	GFP	11
	Flow Transmitter	Erroneous/Erratic Signals	GEE	14
		Fails to Operate	GFP	3
	Hand Control Valve	External Leakage	GEL	4
		Fails to Close	GFC	2
		Fails to Open	GFO	1
		Fails to Open/Fails to Close	GOC	1
		Failure to Operate as Required	GFR	4
	Heat Tracing Heater	Loss of Function	GLF	21
	Level Transmitter	Erroneous/Erratic Signals	GEE	21
	Load Sequence Controller	Erroneous/Erratic Signals	GEE	2
		Fails to Operate	GFP	8
	Motor-Driven Pump	External Leakage	GEL	2
		Fails to Run	GFU	11
		Fails to Start	GFS	4
	Motor-Operated Valve	External Leakage	GEL	7
		Fails to Close	GFC	20
		Fails to Open	GFO	12
		Fails to Open/Fails to Close	GOC	24
		Failure to Operate as Required	GFR	7
	Pneumatic-Operated Valve	External Leakage	GEL	1
		Fails to Close	GFC	5
		Fails to Open	GFO	1
		Fails to Open/Fails to Close	GOC	2
		Internal Leakage	GIL	1
	Pressure Transmitter	Erroneous/Erratic Signals	GEE	6
	Relief Valve	Fails to Close	GFC	5
		Fails to Open	GFO	9
		Opens (Premature)	GSO	4
	Snubber	Loss of Function	GLF	10

TABLE F-1. (continued)

System	Components[b]	Failure Mode	Failure Mode Code	Counts[c]
Service Water System	Check Valve	External Leakage	GEL	2
		Fails to Open	GFO	4
		Internal Leakage	GIL	25
	Circuit Breaker, AC	Fails to Operate	GFP	11
		Opens (Premature)	GSO	6
	Flow Indicator	Erroneous/Erratic Signals	GEE	1
		Fails to Operate	GFP	4
	Flow Switch	Erroneous/Erratic Signals	GEE	16
	Hand Control Valve	External Leakage	GEL	2
		Fails to Close	GFC	7
		Fails to Open	GFO	1
		Fails to Open/Fails to Close	GOC	1
		Failure to Operate as Required	GFR	6
	Motor-Driven Pump	External Leakage	GEL	64
		Fails to Run	GFU	89
		Fails to Start	GFS	14
	Motor-Operated Valve	External Leakage	GEL	7
		Fails to Close	GFC	43
		Fails to Open	GFO	27
		Fails to Open/Fails to Close	GOC	17
		Failure to Operate as Required	GFR	17
	Pnuematic-Operated Valve	External Leakage	GEL	5
		Fails to Close	GFC	15
		Fails to Open	GFO	9
		Fails to Open/Fails to Close	GOC	5
		Failure to Operate as Required	GFR	13
	Pressure Indicator	Erroneous/Erratic Signals	GEE	5
		Fails to Operate	GFP	1
	Strainer	Loss of Function	GLF	13
		Plugged	GPL	8

a. See Table F-3 for summary of data categorized as unclassifiable.

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

c. Total counts: 1573.

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

System	Components	Failure Mode	Failure Mode Code	Counts[b]
Auxiliary Feedwater System	Annunciator	Erroneous/Erratic Signals	GEE	1
	Controller (parameter not specified)	Fails to Operate	GFP	1
	Current Indicating Controller	Erroneous/Erratic Signals	GEE	1
	Differential Pressure Controller	Erroneous/Erratic Signals	GEE	3
		Fails to Operate	GFP	1
	Differential Pressure Transmitter	Erroneous/Erratic Signals	GEE	3
		Fails to Operate	GFP	1
	Electically Operated (Solenoid) Valve	Fails to Close	GFC	1
		Fails to Open	GFO	1
		Fails to Open/Fails to Close	GOC	1
		Plugged	GPL	1
	Flow Indicating Controller	Erroneous/Erratic Signals	GEE	2
	Flow Indicating Switch	Erroneous/Erratic Signals	GEE	1
	Flow Switch	Fails to Operate	GFP	2
	Hand Switch	Fails to Operate	GFP	4
	Hydraulic Valve	Failure to Operate as Required	GFR	2
		Fails to Open/Fails to Close	GOC	1
	Level Control Recorder	Fails to Operate	GFP	1
	Level Recorder	Erroneous/Erratic Signals	GEE	1
	Level Switch	Fails to Operate	GFP	1
	Level Transmitter	Erroneous/Erratic Signals	GEE	4

TABLE F-2. (continued)

System	Components	Failure Mode	Failure Mode Code	Counts[b]
Auxiliary Feedwater System (continued)	Pipe	Plugged	GPL	2
		Rupture	GRU	2
	Pressure Control Recorder	Erroneous/Erratic Signals	GEE	2
	Speed Controller	Fails to Operate	GFP	1
	Switch (parameter not specified)	Fails to Operate	GFP	2
Chemical and Volume Control System	Check Valve	Internal Leakage	GIL	1
	Flow Transmitter	Erroneous/Erratic Signals	GEE	1
	Hand Control Valve	External Leakage	GEL	2
	Level Control Recorder	Erroneous/Erratic Signals	GEE	1
	Level Switch	Erroneous/Erratic Signals	GEE	1
	Mechanical Valve	Fails to Close	GFC	3
	Pneumatic-Operated Valve	External Leakage	GEL	1
		Fails to Close	GFC	1
	Pressure Switch	Fails to Operate	GFP	1
	Relief Valve	Opens (Premature)	GSO	1
	Temperature Switch	Erroneous/Erratic Signals	GEE	4
Class 1E Electrical Power Distribution System				
DC Power Subsystem	Circuit Breaker, AC	Fails to Operate	GFP	1
Emergency On-Site Power Supply Subsystem	Temperature Indicator	Erroneous/Erratic Signals	GEE	1
	Timer	Erroneous/Erratic Signals	GEE	1
Low-Voltage Power Supply Subsystem	Bus	Loss of Function	GLF	1
	Circuit Breaker, AC	Fails to Operate	GFP	3
	Relay	Fails to Operate	GFP	2
		Short Circuit	GSH	1

TABLE F-2. (continued)

System	Components	Failure Mode	Failure Mode Code	Counts[b]
Class 1E Electrical Power Distribution System (continued)				
Medium-Voltage Power Supply Subsystem	Cable	Loss of Function	GLF	1
	Circuit Breaker, AC	Fails to Operate	GFP	3
		Opens (Premature)	GSO	1
	Transformer	Loss of Function	GLF	4
High Pressure Injection System	Current Switch	Erroneous/Erratic Signals	GEE	1
	Flow Modifier	Erroneous/Erratic Signals	GEE	1
	Hydraulic Valve	External Leakage	GEL	1
		Fails to Close	GFC	1
		Fails to Open	GFO	2
	Mechanical Valve	Fails to Close	GFC	1
	Orifice	Rupture	GRU	1
	Pipe	Rupture	GRU	4
	Pressure Control Recorder	Erroneous/Erratic Signals	GEE	2
	Pressure Controller	Erroneous/Erratic Signals	GEE	1
	Pressure Modifier	Erroneous/Erratic Signals	GEE	1
	Pressure Switch	Fails to Operate	GFP	1
Service Water System	DC Overcurrent Relay	Fails to Operate	GFP	1
	Differential Pressure Indicating Switch	Erroneous/Erratic Signals	GEE	4
	Differential Pressure Control Recorder	Erroneous/Erratic Signals	GEE	1
		Fails to Operate	GFP	1
	Electric Power Supply	Loss of Function	GLF	1
	Flow Modifier	Erroneous/Erratic Signals	GEE	1

TABLE F-2. (continued)

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

a. Table summary does not contain data for any failure categorized unclassifiable (Table F-3).

b. Total counts: 140.

TABLE F-3. SUMMARY OF RECORDS IN WHICH THE FAILURE CAUSE WAS UNCLASSIFIABLE

System	Component	Failure Mode	System Effect	Aging	Counts
Auxiliary Feedwater System	Check Valve	External Leakage	System Function Unaffected	YES	1
		Internal Leakage	Degraded System Operations	UNK	1
			Loss of Redundancy	UNK	2
			Loss of Subsystem/Channel	UNK	1
				YES	1
			System Function Unaffected	UNK	1
				YES	1
	Circuit Breaker, AC	Fails to Operate	Loss of Subsystem/Channel	UNK	1
	Controller (parameter not specified)	Erroneous/Erratic Signals	System Function Unaffected	UNK	2
	Flow Controller	Erroneous/Erratic Signals	System Function Unaffected	YES	1
		Fails to Operate	System Function Unaffected	YES	1
	Flow Transmitter	Erroneous/Erratic Signals	Loss of Subsystem/Channel	UNK	1
			System Function Unaffected	UNK	2
	Hand Control Valve	Fails to Close	Loss of Redundancy	YES	1
			System Function Unaffected	YES	1
	Hand Switch	Fails to Operate	Degraded System Operations	UNK	1
	Level Controller	Erroneous/Erratic Signals	Loss of Redundancy	YES	1
	Motor-Driven Pump	Fails to Run	Degraded System Operations	NO	1
				UNK	2
			Loss of Redundancy	UNK	2
			System Function Unaffected	UNK	2
		Fails to Start	Degraded System Operations	NO	1
				UNK	1
			Loss of Redundancy	UNK	1
			System Function Unaffected	UNK	2
	Motor-Operated Valve	Fails to Close	Loss of Subsystem/Channel	NO	1
				UNK	1
			System Function Unaffected	UNK	3
		Fails to Open	Loss of Redundancy	UNK	1
		Fails to Open/Fails to Close	Loss of Subsystem/Channel	UNK	1
	Pneumatic-Operated Valve	External Leakage	Loss of Subsystem/Channel	UNK	1
		Fails to Close	Loss of Redundancy	UNK	1
			Loss of Subsystem/Channel	UNK	1
			System Function Unaffected	UNK	1
		Fails to Open	Degraded System Operations	UNK	3
			Loss of Redundancy	UNK	2
			Loss of Subsystem/Channel	UNK	1
				YES	1
			System Function Unaffected	NO	1

TABLE F-3. (continued)

System	Component	Failure Mode	System Effect	Aging	Counts
Auxiliary Feedwater System (continued)	Pneumatic-Operated Valve (continued)	Fails to Open/Fails to Close	Degraded System Operations	UNK	1
			Loss of Subsystem/Channel	UNK	2
		Failure to Operate as Required	Loss of Redundancy	YES	1
			Loss of Subsystem/Channel	UNK	1
			System Function Unaffected	UNK	1
	Pressure Control Recorder	Fails to Operate	System Function Unaffected	UNK	4
	Pressure Switch	Erroneous/Erratic Signals	Loss of Redundancy	UNK	1
		Fails to Operate	Degraded System Operations	UNK	2
			Loss of Redundancy	NO	2
	Pressure Transmitter	Erroneous/Erratic Signals	System Function Unaffected	YES	1
		Fails to Operate	Loss of Redundancy	UNK	1
			System Function Unaffected	UNK	1
	Relief Valve	Fails to Close	Loss of Redundancy	YES	1
		Opens (Premature)	System Function Unaffected	UNK	2
	Snubber	Loss of Function	Loss of Subsystem/Channel	UNK	4
			System Function Unaffected	UNK	4
	Turbine-Driven Pump	Fails to Run	Loss of Redundancy	UNK	1
			Loss of Subsystem/Channel	YES	1
			System Function Unaffected	YES	1
		Fails to Start	Degraded System Operations	UNK	1
			Loss of Subsystem/Channel	UNK	1
			System Function Unaffected	UNK	2
Class 1E Electrical Power Distribution System					
DC Power Subsystem	Battery	Loss of Function	Loss of Subsystem/Channel	UNK	1
	Battery Charger	Loss of Function	System Function Unaffected	YES	1
Emergency On-Site Power Subsystem	Diesel Generator	Fails to Run	Degraded System Operations	NO	1
				UNK	2
				YES	3
			Loss of Redundancy	UNK	2
				YES	2
			Loss of Subsystem/Channel	NO	1
			System Function Unaffected	UNK	1
				YES	4

TABLE F-3. (continued)

System	Component	Failure Mode	System Effect	Aging	Counts
Class 1E Electrical Power Distribution System (continued)					
Emergency On-Site Power Subsystem (continued)	Diesel Generator (continued)	Fails to Start	Degraded System Operations	NO	1
				UNK	1
				YES	1
			Loss of Redundancy	NO	1
				UNK	2
			Loss of Subsystem/Channel	UNK	2
		No Failure	Degraded System Operations	NO	1
				UNK	1
				YES	1
			Loss of Redundancy	UNK	2
			Loss of Subsystem/Channel	UNK	1
				YES	1
			System Function Unaffected	UNK	2
	Temperature Indicator	Erroneous/Erratic Signals	System Function Unaffected	YES	1
Instrumentation & Uninterruptible Power Supply Subsystem	Inverter	Loss of Function	Degraded System Operations	YES	1
			System Function Unaffected	UNK	1
Low-Voltage Power Subsystem	Bus	Loss of Function	System Function Unaffected	UNK	1
	Circuit Breaker, AC	Fails to Operate	Degraded System Operations	NO	1
				UNK	1
			Loss of Subsystem/Channel	UNK	2
			System Function Unaffected	NO	1
Medium-Voltage Power Subsystem	Transformer	Loss of Function	Degraded System Operations	UNK	1
			Loss of Subsystem/Channel	YES	1
Chemical and Volume Control System	Check Valve	External Leakage	Loss of Subsystem/Channel	UNK	1
	Circuit Breaker, AC	Fails to Operate	Loss of Redundancy	UNK	1
			Loss of Subsystem/Channel	UNK	1
	Motor-Driven Pump	Fails to Run	Loss of Redundancy	YES	1
			Loss of Subsystem/Channel	YES	1
			System Function Unaffected	UNK	1
				YES	5
		Fails to Start	Degraded System Operations	YES	1
	Motor-Operated Valve	Fails to Open	Loss of Redundancy	UNK	1
			Loss of Subsystem/Channel	NO	1
		Fails to Open/Fails to Close	Degraded System Operations	UNK	1
			Loss of Subsystem/Channel	UNK	1
			System Function Unaffected	UNK	2

TABLE F-3. (continued)

System	Component	Failure Mode	System Effect	Aging	Counts
Chemical and Volume Control System (continued)	Relief Valve	External Leakage	Degraded System Operations	UNK	1
		Fails to Close	Degraded System Operations	UNK	2
	Temperature Control Recorder	Erroneous/Erratic Signals	System Function Unaffected	UNK	1
	Temperature Transmitter	Fails to Operate	Degraded System Operations	UNK	1
High Pressure Injection System	Accumulator	Loss of Function	System Function Unaffected	YES	1
	Check Valve	External Leakage	Degraded System Operations	UNK	1
			Loss of Subsystem/Channel	UNK	1
			System Function Unaffected	UNK	2
	Circuit Breaker, AC	Fails to Operate	Degraded System Operations	UNK	2
			Loss of Redundancy	UNK	4
				YES	1
			Loss of Subsystem/Channel	UNK	1
				YES	1
			System Function Unaffected	UNK	2
	Flow Transmitter	Fails to Operate	Loss of Subsystem/Channel	YES	1
			System Function Unaffected	UNK	6
	Hand Control Valve	Fails to Close	Loss of Subsystem/Channel	UNK	1
		Fails to Open/Fails to Close	System Function Unaffected	UNK	2
	Heat Tracing Heater	Loss of Function	Loss of Redundancy	UNK	1
			Loss of Subsystem/Channel	UNK	1
	Load Sequence Controller	Fails to Operate	Loss of Redundancy	UNK	1
	Motor-Driven Pump	External Leakage	System Function Unaffected	UNK	1
		Fails to Run	Loss of Redundancy	UNK	1
			Loss of Subsystem/Channel	YES	1
			System Function Unaffected	YES	1
		Fails to Start	Loss of Redundancy	UNK	2
	Motor-Operated Valve	Fails to Close	Loss of Redundancy	UNK	3
				YES	1
			Loss of Subsystem/Channel	UNK	1
			System Function Unaffected	UNK	1
		Fails to Open	Degraded System Operations	NO	1
				UNK	2
				YES	1
			Loss of Redundancy	UNK	1
			System Function Unaffected	UNK	2
				YES	1

TABLE F-3. (continued)

System	Component	Failure Mode	System Effect	Aging	Counts
High Pressure Injection System (continued)	Motor-Operated Valve (continued)	Fails to Open/Fails to Close	Degraded System Operations	NO	1
			Loss of Subsystem/Channel	UNK	1
				YES	1
			System Function Unaffected	UNK	5
		Failure to Operate as Required	Loss of Subsystem/Channel	NO	1
			System Function Unaffected	UNK	1
	Snubber	Loss of Function	System Function Unaffected	UNK	1
				YES	9
Service Water System	Check Valve	Internal Leakage	Degraded System Operations	UNK	1
			System Function Unaffected	UNK	2
	Circuit Breaker, AC	Fails to Operate	Degraded System Operations	NO	1
				UNK	1
	Flow Switch	Erroneous/Erratic Signals	Loss of Redundancy	UNK	1
	Hand Control Valve	Fails to Open	Loss of Subsystem/Channel	UNK	1
		Failure to Operate as Requires	System Function Unaffected	UNK	1
	Hanger	Loss of Function	Loss of Subsystem/Channel	UNK	3
	Motor-Driven Pump	External Leakage	Degraded System Operations	YES	1
			Loss of Redundancy	YES	1
			Loss of Subsystem/Channel	YES	1
			System Function Unaffected	YES	2
		Fails to Run	Degraded System Operations	YES	1
			Loss of Redundancy	YES	1
			Loss of Subsystem/Channel	NO	1
				YES	3
			Loss of System Function	UNK	1
			System Function Unaffected	NO	1
				UNK	1
				YES	1
		Fails to Start	Loss of Redundancy	UNK	1
	Motor-Operated Valve	External Leakage	System Function Unaffected	UNK	1
		Fails to Close	Degraded System Operations	NO	1
			Loss of Redundancy	UNK	2
				YES	1
			System Function Unaffected	YES	1
		Fails to Open	Degraded System Operations	UNK	1
			Loss of Redundancy	UNK	1
			Loss of Subsystem/Channel	UNK	3
			System Function Unaffected	UNK	2

TABLE F-3. (continued)

System	Component	Failure Mode	System Effect	Aging	Counts
Service Water System (continued)	Motor-Operated Valve (continued)	Fails to Open/Fails to Close	Degraded System Operations	UNK	1
			Loss of Redundancy	UNK	1
			Loss of Subsystem/Channel	NO	1
			System Function Unaffected	UNK	1
		Failure to Operate as Required	Degraded System Operations	YES	1
			Loss of Subsystem/Channel	UNK	2
			System Function Unaffected	YES	1
	Pneumatic-Operated Valve	External Leakage	System Function Unaffected	YES	1
		Fails to Close	Degraded System Operations	YES	2
			Loss of Subsystem/Channel	NO	2
			System Function Unaffected	UNK	2
				YES	1
		Fails to Open	Loss of Subsystem/Channel	UNK	2
		Fails to Open/Fails to Close	Loss of Redundancy	UNK	3
				YES	1
			Loss of Subsystem/Channel	UNK	2
		Failure to Operate as Required	Degraded System Operations	YES	1
			System Function Unaffected	YES	1
	Pressure Switch	Fails to Operate	Degraded System Operations	UNK	1
	Strainer	Loss of Function	Degraded System Operations	UNK	2
			Loss of Redundancy	UNK	1
			Loss of Subsystem/Channel	NO	1
				UNK	3

TABLE F-4. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR AFW CHECK VALVES

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
CHECK VALVES

Failure Mode: EXTERNAL LEAKAGE - GEL

Failure Cause										Totals
Failure Cause Code	DM	EBE	EBR	EBW	EVM	HPM				
Failure Cause Count	1	1	8	1	1	1				13
Failure Cause Fraction	0.077	0.077	0.615	0.077	0.077	0.077				1.000
Aging										
Yes/No/Unknown	0/0/1	1/0/0	8/0/0	0/0/1	1/0/0	1/0/0				11/0/2
Aging Fractions										
Upper Bound	0.077	0.077	0.615	0.077	0.077	0.077				1.000
Lower Bound	0.000	0.077	0.615	0.000	0.077	0.077				0.846

Failure Mode: FAILS TO OPEN - GFO

Failure Cause										Totals
Failure Cause Code	EDB	EDI								
Failure Cause Count	2	1								3
Failure Cause Fraction	0.667	0.333								1.000
Aging										
Yes/No/Unknown	2/0/0	1/0/0								3/0/0
Aging Fractions										
Upper Bound	0.667	0.333								1.000
Lower Bound	0.667	0.333								1.000

TABLE F-4. (continued)

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
CHECK VALVES

Failure Mode: FAILURE TO OPERATE AS REQUIRED - GFR

Failure Cause										Totals
Failure Cause Code	DE	EVM	HPM							
Failure Cause Count	6	1	1							8
Failure Cause Fraction	0.750	0.125	0.125							1.000
Aging										
Yes/No/Unknown	6/0/0	1/0/0	0/1/0							7/1/0
Aging Fractions										
Upper Bound	0.750	0.125	0.000							0.875
Lower Bound	0.750	0.125	0.000							0.875

Failure Mode: INTERNAL LEAKAGE - GIL

Failure Cause										Totals
Failure Cause Code	DE	EBE	EBR	ECC	EDB	EDI	HPM			
Failure Cause Count	2	4	46	2	1	4	7			66
Failure Cause Fraction	0.030	0.061	0.697	0.030	0.015	0.061	0.106			1.000
Aging										
Yes/No/Unknown	1/0/1	4/0/0	46/0/0	2/0/0	0/0/1	4/0/0	0/6/1			57/6/3
Aging Fractions										
Upper Bound	0.030	0.061	0.697	0.030	0.015	0.061	0.015			0.909
Lower Bound	0.015	0.061	0.697	0.030	0.000	0.061	0.000			0.864

TABLE F-5. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR AFW CIRCUIT BREAKERS, AC

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
CIRCUIT BREAKERS, AC

Failure Mode: FAILS TO CLOSE - GFC

Failure Cause		Totals
Failure Cause Code	EDI	
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

Failure Mode: FAILURE TO OPERATE - GFP

Failure Cause						Totals
Failure Cause Code	EBR	EDU	EL	EVM	HPM	
Failure Cause Count	3	1	1	1	1	7
Failure Cause Fraction	0.429	0.143	0.143	0.143	0.143	1.000
Aging						
Yes/No/Unknown	3/0/0	0/0/1	0/0/1	1/0/0	0/1/0	4/1/2
Aging Fractions						
Upper Bound	0.429	0.143	0.143	0.143	0.000	0.858
Lower Bound	0.429	0.000	0.000	0.143	0.000	0.572

TABLE F-6. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR AFW FLOW CONTROLLERS

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
FLOW CONTROLLERS

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

Failure Cause										Totals
Failure Cause Code	EDB	EDI	EDT	ELF	HPM					
Failure Cause Count	1	1	3	2	1					8
Failure Cause Fraction	0.125	0.125	0.375	0.250	0.125					1.000
Aging										
Yes/No/Unknown	0/0/1	1/0/0	1/0/2	1/0/1	0/1/0					3/1/4
Aging Fractions										
Upper Bound	0.125	0.125	0.375	0.250	0.000					0.875
Lower Bound	0.000	0.125	0.125	0.125	0.000					0.375

Failure Mode: FAILURE TO OPERATE - GFP

Failure Cause										Totals
Failure Cause Code	EDI	EDS	EL	ELF	ELK	HPM				
Failure Cause Count	3	1	2	3	1	1				11
Failure Cause Fraction	0.273	0.091	0.182	0.273	0.091	0.091				1.000
Aging										
Yes/No/Unknown	0/3/0	1/0/0	1/1/0	2/0/1	1/0/0	0/1/0				5/5/1
Aging Fractions										
Upper Bound	0.000	0.091	0.091	0.273	0.091	0.000				0.546
Lower Bound	0.000	0.091	0.091	0.182	0.091	0.000				0.455

TABLE F-7. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR AFW FLOW CONTROL RECORDERS

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
FLOW CONTROL RECORDERS

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

Failure Cause										Totals
Failure Cause Code	EBR	EDI	EDT							
Failure Cause Count	2	1	6							9
Failure Cause Fraction	0.222	0.111	0.667							1.000
Aging										
Yes/No/Unknown	2/0/0	0/1/0	3/0/3							5/1/3
Aging Fractions										
Upper Bound	0.222	0.000	0.667							0.889
Lower Bound	0.222	0.000	0.333							0.555

Failure Mode: FAILURE TO OPERATE - GFP

Failure Cause										Totals
Failure Cause Code	ELO									
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-8. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR AFW FLOW TRANSMITTERS

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
FLOW TRANSMITTERS

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

Failure Cause							Totals
Failure Cause Code	DM	EDB	EDI	EDS	EDT	ELF	
Failure Cause Count	4	1	2	2	12	4	25
Failure Cause Fraction	0.160	0.040	0.080	0.080	0.480	0.160	1.000
Aging							
Yes/No/Unknown	0/4/0	0/0/1	1/1/0	2/0/0	9/0/3	1/0/3	13/5/7
Aging Fractions							
Upper Bound	0.000	0.040	0.040	0.080	0.480	0.160	0.800
Lower Bound	0.000	0.000	0.040	0.080	0.360	0.040	0.520

Failure Mode: FAILURE TO OPERATE - GFP

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

TABLE F-9. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR AFW HAND CONTROL VALVES

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
HAND CONTROL VALVES

Failure Mode: EXTERNAL LEAKAGE - GEL

Failure Cause										Totals
Failure Cause Code	EBR									
Failure Cause Count	6									6
Failure Cause Fraction	1.000									1.000
Aging										
Yes/No/Unknown	6/0/0									6/0/0
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	HPM							
Failure Cause Count	3	1	1							5
Failure Cause Fraction	0.600	0.200	0.200							1.000
Aging										
Yes/No/Unknown	3/0/0	1/0/0	0/1/0							4/1/0
Aging Fractions										
Upper Bound	0.600	0.200	0.000							0.800
Lower Bound	0.600	0.200	0.000							0.800

TABLE F-9. (continued)

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
HAND CONTROL VALVES

Failure Mode: FAILS TO OPEN - GFO

Failure Cause										Totals
Failure Cause Code	EDB									
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 AS REQUIRED - GFR

Failure Cause										Totals
Failure Cause Code	DM	EBE								
Failure Cause Count	2	1								3
Failure Cause Fraction	0.667	0.333								1.000
Aging										
Yes/No/Unknown	0/0/2	1/0/0								1/0/2
Aging Fractions										
Upper Bound	0.667	0.333								1.000
Lower Bound	0.000	0.333								0.333

TABLE F-9. (continued)

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
HAND CONTROL VALVES

Failure Mode: INTERNAL LEAKAGE - GIL

Failure Cause										Totals
Failure Cause Code	EBR									
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-10. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR AFW LEVEL CONTROL INDICATORS

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
LEVEL CONTROL INDICATORS

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

Failure Cause										Totals
Failure Cause Code	EDB	EDT	ELF							
Failure Cause Count	1	3	3							7
Failure Cause Fraction	0.143	0.429	0.429							1.000
Aging										
Yes/No/Unknown	0/0/1	1/0/2	2/0/1							3/0/4
Aging Fractions										
Upper Bound	0.143	0.429	0.429							1.000
Lower Bound	0.000	0.143	0.286							0.429

Failure Mode: FAILURE TO OPERATE - GFP

Failure Cause										Totals
Failure Cause Code	DE	EBF	EBR	EDB	ELE	ELF	ELL	HPM		
Failure Cause Count	1	1	1	3	1	4	1	1		13
Failure Cause Fraction	0.077	0.077	0.077	0.231	0.077	0.308	0.077	0.077		1.000
Aging										
Yes/No/Unknown	0/1/0	1/0/0	1/0/0	0/3/0	0/1/0	1/0/3	1/0/0	0/1/0		4/6/3
Aging Fractions										
Upper Bound	0.000	0.077	0.077	0.000	0.000	0.308	0.077	0.000		0.539
Lower Bound	0.000	0.077	0.077	0.000	0.000	0.077	0.077	0.000		0.308

TABLE F-11. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR AFW LEVEL CONTROLLERS

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
LEVEL CONTROLLERS

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

Failure Cause			Totals
Failure Cause Code	EDT	ELF	
Failure Cause Count	3	4	7
Failure Cause Fraction	0.429	0.571	1.000
Aging			
Yes/No/Unknown	1/0/2	3/0/1	4/0/3
Aging Fractions			
Upper Bound	0.429	0.571	1.000
Lower Bound	0.143	0.429	0.572

Failure Mode: FAILURE TO OPERATE - GFP

Failure Cause							Totals
Failure Cause Code	DE	EBF	EDB	ELF	ELO	ELS	
Failure Cause Count	1	3	1	4	1	1	11
Failure Cause Fraction	0.091	0.273	0.091	0.364	0.091	0.091	1.000
Aging							
Yes/No/Unknown	0/1/0	3/0/0	0/0/1	1/0/3	0/0/1	0/0/1	4/1/6
Aging Fractions							
Upper Bound	0.000	0.273	0.091	0.364	0.091	0.091	0.910
Lower Bound	0.000	0.273	0.000	0.091	0.000	0.000	0.364

TABLE F-12. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR AFW MOTOR-DRIVEN PUMPS

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
MOTOR-DRIVEN PUMPS

Failure Mode: EXTERNAL LEAKAGE - GEL

Failure Cause										Totals
Failure Cause Code	EBR									
Failure Cause Count	14									14
Failure Cause Fraction	1.000									1.000
Aging										
Yes/No/Unknown	14/0/0									14/0/0
Aging Fractions										
Upper Bound	1.000									1.000
Lower Bound	1.000									1.000

Failure Mode: FAILS TO START - GFS

Failure Cause										Totals
Failure Cause Code	DE	EBR	EDB	EDI	EDO	EDT	EMW	HPM		
Failure Cause Count	4	1	4	1	1	3	1	1		16
Failure Cause Fraction	0.250	0.062	0.250	0.062	0.062	0.188	0.062	0.062		1.000
Aging										
Yes/No/Unknown	1/3/0	1/0/0	0/1/3	1/0/0	0/1/0	0/0/3	0/1/0	1/0/0		3/7/6
Aging Fractions										
Upper Bound	0.062	0.062	0.188	0.062	0.000	0.188	0.000	0.000		0.562
Lower Bound	0.062	0.062	0.000	0.062	0.000	0.000	0.000	0.000		0.186

TABLE F-12. (continued)

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
MOTOR-DRIVEN PUMPS

Failure Mode: FAILS TO RUN - GFU

Failure Cause										Totals
Failure Cause Code	DE	EBC	EBF	EBR	EDB	EDI	EDS	EDT	EDU	
Failure Cause Count	1	1	2	7	1	1	2	1	1	
Failure Cause Fraction	0.030	0.030	0.061	0.212	0.030	0.030	0.061	0.030	0.030	
Aging										
Yes/No/Unknown	0/1/0	0/1/0	2/0/0	7/0/0	0/1/0	1/0/0	2/0/0	0/0/1	1/0/0	
Aging Fractions										
Upper Bound	0.000	0.000	0.061	0.212	0.000	0.030	0.061	0.030	0.030	
Lower Bound	0.000	0.000	0.061	0.212	0.000	0.030	0.061	0.000	0.030	

Failure Mode: FAILS TO RUN - GFU(continued)

Failure Cause										Totals
Failure Cause Code	EI	EL	ELA	ELS	EMW	EPL	HPC	HPM		
Failure Cause Count	1	1	3	1	7	1	1	1		33
Failure Cause Fraction	0.030	0.030	0.091	0.030	0.212	0.030	0.030	0.030		1.000
Aging										
Yes/No/Unknown	0/1/0	0/0/1	0/0/3	0/0/1	0/7/0	0/1/0	0/1/0	0/1/0		13/14/6
Aging Fractions										
Upper Bound	0.000	0.030	0.091	0.030	0.000	0.000	0.000	0.000		0.575
Lower Bound	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.394

TABLE F-13. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR AFW MOTOR-OPERATED VALVES

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
MOTOR-OPERATED VALVES

Failure Mode: EXTERNAL LEAKAGE - GEL

Failure Cause										Totals
Failure Cause Code	EBR									
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

Failure Mode: FAILS TO CLOSE - GFC

Failure Cause										Totals
Failure Cause Code	DE	EBE	EBR	ECC	EDB	EDI	EDU	HPM		
Failure Cause Count	2	1	5	1	2	1	1	1		14
Failure Cause Fraction	0.143	0.071	0.357	0.071	0.143	0.071	0.071	0.071		1.000
Aging										
Yes/No/Unknown	0/2/0	1/0/0	5/0/0	1/0/0	1/0/1	1/0/0	1/0/0	0/1/0		10/3/1
Aging Fractions										
Upper Bound	0.000	0.071	0.357	0.071	0.143	0.071	0.071	0.000		0.784
Lower Bound	0.000	0.071	0.357	0.071	0.071	0.071	0.071	0.000		0.712

TABLE F-13. (continued)

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
MOTOR-OPERATED VALVES

Failure Mode: FAILS TO OPEN - GFO

Failure Cause				Totals
Failure Cause Code	EDB	EDI	HAM	
Failure Cause Count	5	5	1	11
Failure Cause Fraction	0.455	0.455	0.091	1.000
Aging				
Yes/No/Unknown	0/0/5	5/0/0	0/1/0	5/1/5
Aging Fractions				
Upper Bound	0.455	0.455	0.000	0.910
Lower Bound	0.000	0.455	0.000	0.455

Failure Mode: FAILURE TO OPERATE AS REQUIRED - GFR

Failure Cause							Totals
Failure Cause Code	EBE	EBR	EDB	ELS	ELW	HPO	
Failure Cause Count	1	1	3	1	1	1	8
Failure Cause Fraction	0.125	0.125	0.375	0.125	0.125	0.125	1.000
Aging							
Yes/No/Unknown	1/0/0	1/0/0	0/0/3	0/0/1	0/0/1	0/1/0	2/1/5
Aging Fractions							
Upper Bound	0.125	0.125	0.375	0.125	0.125	0.000	0.875
Lower Bound	0.125	0.125	0.000	0.000	0.000	0.000	0.250

TABLE F-13. (continued)

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
MOTOR-OPERATED VALVES

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

Failure Cause										Totals
Failure Cause Code	EBR	EDB	EDI	ELE	ELW	HPM				
Failure Cause Count	2	3	1	1	1	1				9
Failure Cause Fraction	0.222	0.333	0.111	0.111	0.111	0.111				1.000
Aging										
Yes/No/Unknown	2/0/0	1/0/2	1/0/0	0/1/0	0/0/1	0/1/0				4/2/3
Aging Fractions										
Upper Bound	0.222	0.333	0.111	0.000	0.111	0.000				0.777
Lower Bound	0.222	0.111	0.111	0.000	0.000	0.000				0.444

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

Failure Cause										Totals
Failure Cause Code	EDB	EDI	EDT							
Failure Cause Count	1	1	3							5
Failure Cause Fraction	0.200	0.200	0.600							1.000
Aging										
Yes/No/Unknown	0/0/1	1/0/0	2/0/1							3/0/2
Aging Fractions										
Upper Bound	0.200	0.200	0.600							1.000
Lower Bound	0.000	0.200	0.400							0.600

TABLE F-13. (continued)

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
MOTOR-OPERATED VALVES

Failure Mode: FAILURE TO OPERATE - GFP

Failure Cause										Totals
Failure Cause Code	EMW									
Failure Cause Count	2									2
Failure Cause Fraction	1.000									1.000
Aging										
Yes/No/Unknown	0/2/0									0/2/0
Aging Fractions										
Upper Bound	0.000									0.000
Lower Bound	0.000									0.000

TABLE F-14. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR AFW PNEUMATIC-OPERATED VALVES

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
PNEUMATIC-OPERATED VALVES

Failure Mode: EXTERNAL LEAKAGE - GEL

Failure Cause										Totals
Failure Cause Code	EBR	HPM								
Failure Cause Count	7	1								8
Failure Cause Fraction	0.875	0.125								1.000
Aging										
Yes/No/Unknown	7/0/0	0/1/0								7/1/0
Aging Fractions										
Upper Bound	0.875	0.000								0.875
Lower Bound	0.875	0.000								0.875

Failure Mode: FAILS TO CLOSE - GFC

Failure Cause										Totals
Failure Cause Code	EBE	EBF	EBR	EDB	EDI	ELF	ELS	HEO		
Failure Cause Count	5	1	18	10	11	1	1	2		49
Failure Cause Fraction	0.102	0.020	0.367	0.204	0.224	0.020	0.020	0.041		1.000
Aging										
Yes/No/Unknown	5/0/0	1/0/0	18/0/0	5/1/4	1/9/1	0/0/1	0/0/1	2/0/0		32/10/7
Aging Fractions										
Upper Bound	0.102	0.020	0.367	0.184	0.041	0.020	0.020	0.041		0.794
Lower Bound	0.102	0.020	0.367	0.082	0.020	0.000	0.000	0.041		0.652

TABLE F-14. (continued)

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
PNEUMATIC-OPERATED VALVES

Failure Mode: FAILS TO OPEN - GFO

Failure Cause										Totals
Failure Cause Code	DM	EBF	EBR	EDB	EDI	EDU	EMW	HAM	HPM	
Failure Cause Count	1	3	6	4	1	1	1	2	1	20
Failure Cause Fraction	0.050	0.150	0.300	0.200	0.050	0.050	0.050	0.100	0.050	1.000
Aging										
Yes/No/Unknown	0/0/1	3/0/0	6/0/0	2/0/2	1/0/0	0/0/1	1/0/0	0/2/0	0/1/0	13/3/4
Aging Fractions										
Upper Bound	0.050	0.150	0.300	0.200	0.050	0.050	0.050	0.000	0.000	0.850
Lower Bound	0.000	0.150	0.300	0.100	0.050	0.000	0.050	0.000	0.000	0.650

Failure Mode: FAILURE TO OPERATE AS REQUIRED - GFR

Failure Cause										Totals
Failure Cause Code	EBR	EDB	EDU							
Failure Cause Count	6	2	2							10
Failure Cause Fraction	0.600	0.200	0.200							1.000
Aging										
Yes/No/Unknown	6/0/0	0/0/2	2/0/0							8/0/2
Aging Fractions										
Upper Bound	0.600	0.200	0.200							1.000
Lower Bound	0.600	0.000	0.200							0.800

TABLE F-14. (continued)

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
PNEUMATIC-OPERATED VALVES

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

Failure Cause										**Totals**
Failure Cause Code	DE	EBF	EBR	EDB	EDI	EDT	ELE	EMW	HPM	
Failure Cause Count	1	1	2	1	2	2	1	2	1	13
Failure Cause Fraction	0.077	0.077	0.154	0.077	0.154	0.154	0.077	0.154	0.077	1.000
Aging										
Yes/No/Unknown	0/0/1	1/0/0	2/0/0	0/0/1	0/2/0	0/1/1	0/1/0	0/2/0	0/1/0	3/7/3
Aging Fractions										
Upper Bound	0.077	0.077	0.154	0.077	0.000	0.077	0.000	0.000	0.000	0.462
Lower Bound	0.000	0.077	0.154	0.000	0.000	0.000	0.000	0.000	0.000	0.231

TABLE F-15. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR AFW PRESSURE SWITCHES

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
PRESSURE SWITCHES

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

Failure Cause										**Totals**
Failure Cause Code	EDI	EDT								
Failure Cause Count	1	11								12
Failure Cause Fraction	0.083	0.917								1.000
Aging										
Yes/No/Unknown	1/0/0	4/0/7								5/0/7
Aging Fractions										
Upper Bound	0.083	0.917								1.000
Lower Bound	0.083	0.333								0.416

Failure Mode: FAILURE TO OPERATE - GFP

Failure Cause										**Totals**
Failure Cause Code	EBR	ECC	EDB	EDI	EL	ELA	HPC	HPO		
Failure Cause Count	1	2	1	1	1	1	1	1		9
Failure Cause Fraction	0.111	0.222	0.111	0.111	0.111	0.111	0.111	0.111		1.000
Aging										
Yes/No/Unknown	1/0/0	2/0/0	0/0/1	0/1/0	0/0/1	1/0/0	0/1/0	0/1/0		4/3/2
Aging Fractions										
Upper Bound	0.111	0.222	0.111	0.000	0.111	0.111	0.000	0.000		0.666
Lower Bound	0.111	0.222	0.000	0.000	0.000	0.111	0.000	0.000		0.444

TABLE F-16. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR AFW PRESSURE TRANSMITTERS

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
PRESSURE TRANSMITTERS

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

Failure Cause										Totals
Failure Cause Code	EDT	ELF	HPC	HPO	SPM					
Failure Cause Count	9	1	2	1	1					14
Failure Cause Fraction	0.643	0.071	0.143	0.071	0.071					1.000
Aging										
Yes/No/Unknown	3/0/6	0/0/1	0/2/0	0/1/0	0/1/0					3/4/7
Aging Fractions										
Upper Bound	0.643	0.071	0.000	0.000	0.000					0.714
Lower Bound	0.214	0.000	0.000	0.000	0.000					0.214

Failure Mode: FAILURE TO OPERATE - GFP

Failure Cause										Totals
Failure Cause Code	EBM	EBR	ELO							
Failure Cause Count	1	1	1							3
Failure Cause Fraction	0.333	0.333	0.333							1.000
Aging										
Yes/No/Unknown	0/1/0	1/0/0	1/0/0							2/1/0
Aging Fractions										
Upper Bound	0.000	0.333	0.333							0.666
Lower Bound	0.000	0.333	0.333							0.666

TABLE F-17. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR AFW RELAYS

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
RELAYS

Failure Mode: FAILS TO OPEN - GFO

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

Failure Mode: FAILURE TO OPERATE - GFP

Failure Cause										Totals
Failure Cause Code	DE	EDS	ELI	ELW	HPC	HPM				
Failure Cause Count	1	1	2	1	1	1				7
Failure Cause Fraction	0.143	0.143	0.286	0.143	0.143	0.143				1.000
Aging										
Yes/No/Unknown	0/1/0	1/0/0	2/0/0	0/0/1	0/1/0	0/1/0				3/3/1
Aging Fractions										
Upper Bound	0.000	0.143	0.286	0.143	0.000	0.000				0.572
Lower Bound	0.000	0.143	0.286	0.000	0.000	0.000				0.429

TABLE F-17. (continued)

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
RELAYS

Failure Mode: FAILURE TO OPERATE - GFP

Failure Cause											**Totals**
Failure Cause Code	EBR	ELW									
Failure Cause Count	1	2									3
Failure Cause Fraction	0.333	0.667									1.000
Aging											
Yes/No/Unknown	1/0/0	0/0/2									1/0/2
Aging Fractions											
Upper Bound	0.333	0.667									1.000
Lower Bound	0.333	0.000									0.333

TABLE F-18. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR AFW RELIEF VALVES

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
RELIEF VALVES

Failure Mode: FAILS TO CLOSE - GFC

		Totals
Failure Cause		
Failure Cause Code	EBR	
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

Failure Mode: OPEN (PREMATURE) - GSO

			Totals
Failure Cause			
Failure Cause Code	EDI	EDS	
Failure Cause Count	1	5	6
Failure Cause Fraction	0.167	0.833	1.000
Aging			
Yes/No/Unknown	1/0/0	5/0/0	6/0/0
Aging Fractions			
Upper Bound	0.167	0.833	1.000
Lower Bound	0.167	0.833	1.000

TABLE F-19. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR AFW SNUBBERS

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
SNUBBERS

Failure Mode: LOSS OF FUNCTION - GLF

Failure Cause				Totals
Failure Cause Code	EBR	EI	H	
Failure Cause Count	5	1	1	7
Failure Cause Fraction	0.714	0.143	0.143	1.000
Aging				
Yes/No/Unknown	5/0/0	0/1/0	0/1/0	5/2/0
Aging Fractions				
Upper Bound	0.714	0.000	0.000	0.714
Lower Bound	0.714	0.000	0.000	0.714

TABLE F-20. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR AFW SUPPORTS

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
SUPPORTS

Failure Mode: LOSS OF FUNCTION - GLF

Failure Cause											Totals
Failure Cause Code	EBW	EI									
Failure Cause Count	4	1									5
Failure Cause Fraction	0.800	0.200									1.000
Aging											
Yes/No/Unknown	0/0/4	0/1/0									0/1/4
Aging Fractions											
Upper Bound	0.800	0.000									0.800
Lower Bound	0.000	0.000									0.000

TABLE F-21. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR AFW TURBINE-DRIVEN PUMP

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
TURBINE-DRIVEN PUMP

Failure Mode: EXTERNAL LEAKAGE - GEL

Failure Cause			Totals
Failure Cause Code	EBR	EPH	
Failure Cause Count	2	4	6
Failure Cause Fraction	0.333	0.667	1.000
Aging			
Yes/No/Unknown	2/0/0	0/4/0	2/4/0
Aging Fractions			
Upper Bound	0.333	0.000	0.333
Lower Bound	0.333	0.000	0.333

Failure Mode: FAILS TO START - GFS

Failure Cause							Totals
Failure Cause Code	EBF	EBR	EDB	EDI	HAM	HPO	
Failure Cause Count	1	2	4	3	1	2	13
Failure Cause Fraction	0.077	0.154	0.308	0.231	0.077	0.154	1.000
Aging							
Yes/No/Unknown	1/0/0	2/0/0	0/1/3	2/1/0	0/1/0	0/2/0	5/5/3
Aging Fractions							
Upper Bound	0.077	0.154	0.231	0.154	0.000	0.000	0.616
Lower Bound	0.077	0.154	0.000	0.154	0.000	0.000	0.385

TABLE F-21. (continued)

SYSTEM
AUXILIARY FEEDWATER SYSTEM

COMPONENT
TURBINE-DRIVEN PUMP

Failure Mode: FAILS TO RUN - GFU

Failure Cause										Totals
Failure Cause Code	EBE	EBM	EBR	ECC	EDB	EDI	ELF	EMW	EPH	
Failure Cause Count	2	1	11	1	7	3	2	1	1	
Failure Cause Fraction	0.051	0.026	0.282	0.026	0.179	0.077	0.051	0.026	0.026	
Aging										
Yes/No/Unknown	2/0/0	0/1/0	11/0/0	1/0/0	1/0/6	2/1/0	0/0/2	0/1/0	0/1/0	
Aging Fractions										
Upper Bound	0.051	0.000	0.282	0.026	0.179	0.051	0.051	0.000	0.000	
Lower Bound	0.051	0.000	0.282	0.026	0.026	0.051	0.000	0.000	0.000	

Failure Mode: FAILS TO RUN - GFU(continued)

Failure Cause										Totals
Failure Cause Code	EVM	HAM	HE	HPM	SPM					
Failure Cause Count	3	1	1	3	2					39
Failure Cause Fraction	0.077	0.026	0.026	0.077	0.051					1.000
Aging										
Yes/No/Unknown	3/0/0	0/1/0	0/1/0	0/3/0	0/2/0					20/11/8
Aging Fractions										
Upper Bound	0.077	0.000	0.000	0.000	0.000					0.717
Lower Bound	0.077	0.000	0.000	0.000	0.000					0.513

TABLE F-22. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR CVCS CIRCUIT BREAKERS, AC

SYSTEM
CHEMICAL AND VOLUME CONTROL SYSTEM

COMPONENT
CIRCUIT BREAKERS, AC

Failure Mode: FAILURE TO OPERATE - GFP

											Totals
Failure Cause											
Failure Cause Code	EBF	EDB	EL	ELW							
Failure Cause Count	1	2	1	1							5
Failure Cause Fraction	0.200	0.400	0.200	0.200							1.000
Aging											
Yes/No/Unknown	1/0/0	0/0/2	0/1/0	0/0/1							1/1/3
Aging Fractions											
Upper Bound	0.200	0.400	0.000	0.200							0.800
Lower Bound	0.200	0.000	0.000	0.000							0.200

TABLE F-23. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR CVCS HEAT TRACING HEATERS

SYSTEM
CHEMICAL AND VOLUME CONTROL SYSTEM

COMPONENT
HEAT TRACING HEATERS

Failure Mode: LOSS OF FUNCTION - GLF

Failure Cause										Totals
Failure Cause Code	ECC	ELD	ELH	ELO	HAM					
Failure Cause Count	1	1	3	2	2					9
Failure Cause Fraction	0.111	0.111	0.333	0.222	0.222					1.000
Aging										
Yes/No/Unknown	1/0/0	1/0/0	3/0/0	0/0/2	0/2/0					5/2/2
Aging Fractions										
Upper Bound	0.111	0.111	0.333	0.222	0.000					0.777
Lower Bound	0.111	0.111	0.333	0.000	0.000					0.555

TABLE F-24. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR CVCS LEVEL CONTROLLERS

SYSTEM
CHEMICAL AND VOLUME CONTROL SYSTEM

COMPONENT
LEVEL CONTROLLERS

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

Failure Cause											Totals
Failure Cause Code	EBF	EDI	EDT								
Failure Cause Count	1	3	3								7
Failure Cause Fraction	0.143	0.429	0.429								1.000
Aging											
Yes/No/Unknown	1/0/0	0/3/0	3/0/0								4/3/0
Aging Fractions											
Upper Bound	0.143	0.000	0.429								0.572
Lower Bound	0.143	0.000	0.429								0.572

TABLE F-25. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR CVCS LEVEL TRANSMITTERS

SYSTEM
CHEMICAL AND VOLUME CONTROL SYSTEM

COMPONENT
LEVEL TRANSMITTERS

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

										Totals
Failure Cause										
Failure Cause Code	EDI	EDT	ELF	HPO						
Failure Cause Count	4	11	1	1						17
Failure Cause Fraction	0.235	0.647	0.059	0.059						1.000
Aging										
Yes/No/Unknown	0/4/0	2/0/9	1/0/0	0/1/0						3/5/9
Aging Fractions										
Upper Bound	0.000	0.647	0.059	0.000						0.706
Lower Bound	0.000	0.118	0.059	0.000						0.177

Failure Mode: FAILURE TO OPERATE - GFP

										Totals
Failure Cause										
Failure Cause Code	ELF									
Failure Cause Count	2									2
Failure Cause Fraction	1.000									1.000
Aging										
Yes/No/Unknown	0/0/2									0/0/2
Aging Fractions										
Upper Bound	1.000									1.000
Lower Bound	0.000									0.000

TABLE F-26. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR CVCS MOTOR-DRIVEN PUMPS

SYSTEM
CHEMICAL AND VOLUME CONTROL SYSTEM

COMPONENT
MOTOR-DRIVEN PUMPS

Failure Mode: EXTERNAL LEAKAGE - GEL

Failure Cause										Totals
Failure Cause Code	EBR									
Failure Cause Count	7									7
Failure Cause Fraction	1.000									1.000
Aging										
Yes/No/Unknown	7/0/0									7/0/0
Aging Fractions										
Upper Bound	1.000									1.000
Lower Bound	1.000									1.000

Failure Mode: FAILS TO RUN - GFU

Failure Cause										Totals
Failure Cause Code	DE	EBR	EDI	EVM	HPM					
Failure Cause Count	1	14	3	1	2					21
Failure Cause Fraction	0.048	0.667	0.143	0.048	0.095					1.000
Aging										
Yes/No/Unknown	0/1/0	14/0/0	1/2/0	1/0/0	0/1/1					16/4/1
Aging Fractions										
Upper Bound	0.000	0.667	0.048	0.048	0.048					0.811
Lower Bound	0.000	0.667	0.048	0.048	0.000					0.763

TABLE F-26. (continued)

SYSTEM
CHEMICAL AND VOLUME CONTROL SYSTEM

COMPONENT
MOTOR-DRIVEN PUMPS

Failure Mode: FAILS TO START - GFS

Failure Cause										Totals
Failure Cause Code	EDU									
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	0.000									0.000
Lower Bound	0.000									0.000

TABLE F-27. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR CVCS MOTOR-OPERATED VALVES

SYSTEM
CHEMICAL AND VOLUME CONTROL SYSTEM

COMPONENT
MOTOR-OPERATED VALVES

Failure Mode: EXTERNAL LEAKAGE - GEL

Failure Cause										Totals
Failure Cause Code	EBR	ECC								
Failure Cause Count	8	1								9
Failure Cause Fraction	0.889	0.111								1.000
Aging										
Yes/No/Unknown	8/0/0	1/0/0								9/0/0
Aging Fractions										
Upper Bound	0.889	0.111								1.000
Lower Bound	0.889	0.111								1.000

Failure Mode: FAILS TO CLOSE - GFC

Failure Cause										Totals
Failure Cause Code	EBE	EBR	EDB	EDI	HPM					
Failure Cause Count	3	10	5	3	1					22
Failure Cause Fraction	0.136	0.455	0.227	0.136	0.045					1.000
Aging										
Yes/No/Unknown	3/0/0	10/0/0	0/0/5	3/0/0	0/1/0					16/1/5
Aging Fractions										
Upper Bound	0.136	0.455	0.227	0.136	0.000					0.954
Lower Bound	0.136	0.455	0.000	0.136	0.000					0.727

TABLE F-27. (continued)

SYSTEM
CHEMICAL AND VOLUME CONTROL SYSTEM

COMPONENT
MOTOR-OPERATED VALVES

Failure Mode: FAILS TO OPEN - GFO

Failure Cause										Totals
Failure Cause Code	EDB									
Failure Cause Count	3									3
Failure Cause Fraction	1.000									1.000
Aging										
Yes/No/Unknown	0/1/2									0/1/2
Aging Fractions										
Upper Bound	0.667									0.667
Lower Bound	0.000									0.000

Failure Mode: FAILURE TO OPERATE AS REQUIRED - GFR

Failure Cause										Totals
Failure Cause Code	ECC	EDU								
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

TABLE F-27. (continued)

SYSTEM
CHEMICAL AND VOLUME CONTROL SYSTEM

COMPONENT
MOTOR-OPERATED VALVES

Failure Mode: INTERNAL LEAKAGE - GIL

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

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

										Totals
Failure Cause										
Failure Cause Code	EBR	EDB	EDI							
Failure Cause Count	3	4	1							8
Failure Cause Fraction	0.375	0.500	0.125							1.000
Aging										
Yes/No/Unknown	3/0/0	1/1/2	1/0/0							5/1/2
Aging Fractions										
Upper Bound	0.375	0.375	0.125							0.875
Lower Bound	0.375	0.125	0.125							0.625

TABLE F-28. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR CLASS 1E DC POWER BATTERIES

SYSTEM
DC POWER SUPPLY SYSTEM - CLASS 1E

COMPONENT
BATTERIES

Failure Mode: LOSS OF FUNCTION - GLF

										Totals
Failure Cause										
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-29. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR CLASS 1E 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-30. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR CLASS 1E 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-31. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR CLASS 1E 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	ELD	ELE	ELF	
Failure Cause Count	2	2	4	3	1	2	1	1	1	
Failure Cause Fraction	0.095	0.095	0.190	0.143	0.048	0.095	0.048	0.048	0.048	
Aging										
Yes/No/Unknown	2/0/0	2/0/0	0/2/2	2/1/0	0/1/0	0/2/0	1/0/0	0/1/0	1/0/0	
Aging Fractions										
Upper Bound	0.095	0.095	0.095	0.095	0.000	0.000	0.048	0.000	0.048	
Lower Bound	0.095	0.095	0.000	0.095	0.000	0.000	0.048	0.000	0.048	

Failure Mode: FAILS TO START - GFS(continued)

Failure Cause										Totals
Failure Cause Code	ELR	ELS	ELT							
Failure Cause Count	1	2	1							21
Failure Cause Fraction	0.048	0.095	0.048							1.000
Aging										
Yes/No/Unknown	0/1/0	2/0/0	0/1/0							10/9/2
Aging Fractions										
Upper Bound	0.000	0.095	0.000							0.571
Lower Bound	0.000	0.095	0.000							0.476

TABLE F-31. (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	3	3	2	1	
Failure Cause Fraction	0.023	0.047	0.023	0.023	0.326	0.070	0.070	0.047	0.023	
Aging										
Yes/No/Unknown	0/1/0	2/0/0	1/0/0	0/0/1	14/0/0	1/1/1	2/1/0	2/0/0	0/0/1	
Aging Fractions										
Upper Bound	0.000	0.047	0.023	0.023	0.326	0.047	0.047	0.047	0.023	
Lower Bound	0.000	0.047	0.023	0.000	0.326	0.023	0.047	0.047	0.000	

Failure Mode: FAILS TO RUN - GFU(continued)

Failure Cause										Totals
Failure Cause Code	ELD	ELE	ELF	ELO	ELS	EMW	EVM	HEM	SPC	
Failure Cause Count	4	1	3	1	1	2	1	1	1	43
Failure Cause Fraction	0.093	0.023	0.070	0.023	0.023	0.047	0.023	0.023	0.023	1.000
Aging										
Yes/No/Unknown	4/0/0	0/1/0	2/0/1	0/0/1	0/0/1	0/2/0	1/0/0	0/1/0	0/1/0	29/8/6
Aging Fractions										
Upper Bound	0.093	0.000	0.070	0.023	0.023	0.000	0.023	0.000	0.000	0.815
Lower Bound	0.093	0.000	0.047	0.000	0.000	0.000	0.023	0.000	0.000	0.676

TABLE F-31. (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-31. (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-32. 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

										Totals
Failure Cause										
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-33. 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-34. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR HPIS CHECK VALVES

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
CHECK VALVES

Failure Mode: EXTERNAL LEAKAGE - GEL

Failure Cause										Totals
Failure Cause Code	EBR	HPM								
Failure Cause Count	2	1								3
Failure Cause Fraction	0.667	0.333								1.000
Aging										
Yes/No/Unknown	2/0/0	0/1/0								2/1/0
Aging Fractions										
Upper Bound	0.667	0.000								0.667
Lower Bound	0.667	0.000								0.667

Failure Mode: INTERNAL LEAKAGE - GIL

Failure Cause										Totals
Failure Cause Code	DE	EBR	EDB	EDI						
Failure Cause Count	3	9	1	2						15
Failure Cause Fraction	0.200	0.600	0.067	0.133						1.000
Aging										
Yes/No/Unknown	1/2/0	9/0/0	1/0/0	2/0/0						13/2/0
Aging Fractions										
Upper Bound	0.067	0.600	0.067	0.133						0.867
Lower Bound	0.067	0.600	0.067	0.133						0.867

TABLE F-35. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR HPIS CIRCUIT BREAKERS, AC

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
CIRCUIT BREAKERS, AC

Failure Mode: FAILURE TO OPERATE - GFP

Failure Cause										Totals
Failure Cause Code	EBF	EBR	EDB	EI	ELF	ELK	HPM			
Failure Cause Count	3	2	1	1	1	2	1			11
Failure Cause Fraction	0.273	0.182	0.091	0.091	0.091	0.182	0.091			1.000
Aging										
Yes/No/Unknown	3/0/0	2/0/0	0/0/1	0/1/0	1/0/0	0/0/2	0/1/0			6/2/3
Aging Fractions										
Upper Bound	0.273	0.182	0.091	0.000	0.091	0.182	0.000			0.819
Lower Bound	0.273	0.182	0.000	0.000	0.091	0.000	0.000			0.546

TABLE F-36. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR HPIS FLOW TRANSMITTERS

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
FLOW TRANSMITTERS

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

Failure Cause											Totals
Failure Cause Code	EBM	EDB	EDT								
Failure Cause Count	2	1	11								14
Failure Cause Fraction	0.143	0.071	0.786								1.000
Aging											
Yes/No/Unknown	1/0/1	0/0/1	3/0/8								4/0/10
Aging Fractions											
Upper Bound	0.143	0.071	0.786								1.000
Lower Bound	0.071	0.000	0.214								0.285

Failure Mode: FAILURE TO OPERATE - GFP

Failure Cause											Totals
Failure Cause Code	EBF	EBR									
Failure Cause Count	1	2									3
Failure Cause Fraction	0.333	0.667									1.000
Aging											
Yes/No/Unknown	1/0/0	2/0/0									3/0/0
Aging Fractions											
Upper Bound	0.333	0.667									1.000
Lower Bound	0.333	0.667									1.000

TABLE F-37. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR HPIS HAND CONTROL VALVES

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
HAND CONTROL VALVES

Failure Mode: EXTERNAL LEAKAGE - GEL

Failure Cause											Totals
Failure Cause Code	EBR	ECC	HPM								
Failure Cause Count	2	1	1								4
Failure Cause Fraction	0.500	0.250	0.250								1.000
Aging											
Yes/No/Unknown	2/0/0	1/0/0	0/1/0								3/1/0
Aging Fractions											
Upper Bound	0.500	0.250	0.000								0.750
Lower Bound	0.500	0.250	0.000								0.750

Failure Mode: FAILS TO CLOSE - GFC

Failure Cause											Totals
Failure Cause Code	EDI	EDU									
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

TABLE F-37 (continued)

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
HAND CONTROL VALVES

Failure Mode: FAILS TO OPEN - GFO

Failure Cause										Totals
Failure Cause Code	EDI									
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

Failure Mode: FAILURE TO OPERATE AS REQUIRED - GFR

Failure Cause										Totals
Failure Cause Code	DE	DM	EBR							
Failure Cause Count	1	2	1							4
Failure Cause Fraction	0.250	0.500	0.250							1.000
Aging										
Yes/No/Unknown	0/0/1	0/2/0	1/0/0							1/2/1
Aging Fractions										
Upper Bound	0.250	0.000	0.250							0.500
Lower Bound	0.000	0.000	0.250							0.250

TABLE F-37. (continued)

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
HAND CONTROL VALVES

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

Failure Cause										Totals
Failure Cause Code	EDB									
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-38. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR HPIS HEAT TRACING HEATERS

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
HEAT TRACING HEATERS

Failure Mode: LOSS OF FUNCTION - GLF

Failure Cause										Totals
Failure Cause Code	ECC	EDB	ELE	ELH	ELO	ELS	ELW	HAM	HPM	
Failure Cause Count	1	1	1	5	3	1	2	5	1	
Failure Cause Fraction	0.048	0.048	0.048	0.238	0.143	0.048	0.095	0.238	0.048	
Aging										
Yes/No/Unknown	1/0/0	0/0/1	0/0/1	5/0/0	1/0/2	1/0/0	2/0/0	0/5/0	0/1/0	
Aging Fractions										
Upper Bound	0.048	0.048	0.048	0.238	0.143	0.048	0.095	0.000	0.000	
Lower Bound	0.048	0.000	0.000	0.238	0.048	0.048	0.095	0.000	0.000	

Failure Mode: LOSS OF FUNCTION - GLF(continued)

Failure Cause										Totals
Failure Cause Code	SC									
Failure Cause Count	1									21
Failure Cause Fraction	0.048									1.000
Aging										
Yes/No/Unknown	0/1/0									10/7/4
Aging Fractions										
Upper Bound	0.000									0.668
Lower Bound	0.000									0.477

TABLE F-39. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR HPIS LOAD SEQUENCE CONTROLLERS

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
LOAD SEQUENCE CONTROLLERS

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

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

Failure Mode: FAILURE TO OPERATE - GFP

Failure Cause										Totals
Failure Cause Code	DE	EDI	EL	ELF	HEM	HPM				
Failure Cause Count	1	2	1	2	1	1				8
Failure Cause Fraction	0.125	0.250	0.125	0.250	0.125	0.125				1.000
Aging										
Yes/No/Unknown	0/1/0	2/0/0	0/0/1	1/0/1	0/1/0	0/1/0				3/3/2
Aging Fractions										
Upper Bound	0.000	0.250	0.125	0.250	0.000	0.000				0.625
Lower Bound	0.000	0.250	0.000	0.125	0.000	0.000				0.375

TABLE F-40. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR HPIS LEVEL TRANSMITTERS

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
LEVEL TRANSMITTERS

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

Failure Cause										Totals
Failure Cause Code	EDT	ELF	HE							
Failure Cause Count	19	1	1							21
Failure Cause Fraction	0.905	0.048	0.048							1.000
Aging										
Yes/No/Unknown	4/0/15	0/0/1	0/1/0							4/1/16
Aging Fractions										
Upper Bound	0.905	0.048	0.000							0.953
Lower Bound	0.190	0.000	0.000							0.190

TABLE F-41. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR HPIS MOTOR-DRIVEN PUMPS

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
MOTOR-DRIVEN PUMPS

Failure Mode: EXTERNAL LEAKAGE - GEL

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

Failure Mode: FAILS TO START - GFS

Failure Cause										Totals
Failure Cause Code	EDB	EDI	HP	SPO						
Failure Cause Count	1	1	1	1						4
Failure Cause Fraction	0.025	0.025	0.025	0.025						1.000
Aging										
Yes/No/Unknown	0/1/0	0/1/0	0/1/0	0/1/0						0/4/0
Aging Fractions										
Upper Bound	0.000	0.000	0.000	0.000						0.000
Lower Bound	0.000	0.000	0.000	0.000						0.000

TABLE F-41. (continued)

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
MOTOR-DRIVEN PUMPS

Failure Mode: FAILS TO RUN - GFU

Failure Cause										Totals
Failure Cause Code	EBR	EDB	EDI	EDO	HMM	HPM	HPO			
Failure Cause Count	3	2	1	2	1	1	1			11
Failure Cause Fraction	0.273	0.182	0.091	0.182	0.091	0.091	0.091			1.000
Aging										
Yes/No/Unknown	3/0/0	0/0/2	1/0/0	0/0/2	0/1/0	1/0/0	1/0/0			6/1/4
Aging Fractions										
Upper Bound	0.273	0.182	0.091	0.182	0.000	0.091	0.091			0.910
Lower Bound	0.273	0.000	0.091	0.000	0.000	0.091	0.091			0.546

TABLE F-42. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR HPIS MOTOR-OPERATED VALVES

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
MOTOR-OPERATED VALVES

Failure Mode: EXTERNAL LEAKAGE - GEL

Failure Cause										Totals
Failure Cause Code	EBR	HPM								
Failure Cause Count	6	1								7
Failure Cause Fraction	0.857	0.143								1.000
Aging										
Yes/No/Unknown	6/0/0	0/1/0								6/1/0
Aging Fractions										
Upper Bound	0.857	0.000								0.857
Lower Bound	0.857	0.000								0.857

Failure Mode: FAILS TO CLOSE - GFC

Failure Cause										Totals
Failure Cause Code	EBR	EDB	EDI	EDU	ELK	ELS				
Failure Cause Count	4	6	4	4	1	1				20
Failure Cause Fraction	0.200	0.300	0.200	0.200	0.050	0.050				1.000
Aging										
Yes/No/Unknown	4/0/0	2/1/3	2/2/0	0/0/4	0/0/1	0/0/1				8/3/9
Aging Fractions										
Upper Bound	0.200	0.250	0.100	0.200	0.050	0.050				0.850
Lower Bound	0.200	0.100	0.100	0.000	0.000	0.000				0.400

TABLE F-42. (continued)

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
MOTOR-OPERATED VALVES

Failure Mode: FAILS TO OPEN - GFO

Failure Cause										Totals
Failure Cause Code	EBF	EBR	EDB	EDI	EDU	HPM				
Failure Cause Count	1	2	3	1	2	3				12
Failure Cause Fraction	0.083	0.167	0.250	0.083	0.167	0.250				1.000
Aging										
Yes/No/Unknown	1/0/0	2/0/0	0/0/3	1/0/0	0/0/2	0/3/0				4/3/5
Aging Fractions										
Upper Bound	0.083	0.167	0.250	0.083	0.167	0.000				0.750
Lower Bound	0.083	0.167	0.000	0.083	0.000	0.000				0.333

Failure Mode: FAILURE TO OPERATE AS REQUIRED - GFR

Failure Cause										Totals
Failure Cause Code	DE	EBR	EDO	EVM	HPM					
Failure Cause Count	1	3	1	1	1					7
Failure Cause Fraction	0.143	0.429	0.143	0.143	0.143					1.000
Aging										
Yes/No/Unknown	0/1/0	3/0/0	0/0/1	1/0/0	0/1/0					4/2/1
Aging Fractions										
Upper Bound	0.000	0.429	0.143	0.143	0.000					0.715
Lower Bound	0.000	0.429	0.000	0.143	0.000					0.572

TABLE F-42 (continued)

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
MOTOR-OPERATED VALVES

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

Failure Cause										Totals
Failure Cause Code	DE	EBR	ECC	EDB	EDI	ELS	HCO	HPM	SC	
Failure Cause Count	2	5	1	5	3	2	1	4	1	24
Failure Cause Fraction	0.083	0.208	0.042	0.208	0.125	0.083	0.042	0.167	0.042	1.000
Aging										
Yes/No/Unknown	0/2/0	5/0/0	1/0/0	1/0/4	3/0/0	0/0/2	0/1/0	0/4/0	0/1/0	10/8/6
Aging Fractions										
Upper Bound	0.000	0.208	0.042	0.208	0.125	0.083	0.000	0.000	0.000	0.666
Lower Bound	0.000	0.208	0.042	0.042	0.125	0.000	0.000	0.000	0.000	0.417

TABLE F-43. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR HPIS PNEUMATIC-OPERATED VALVES

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
PNEUMATIC-OPERATED VALVES

Failure Mode: EXTERNAL LEAKAGE - GEL

Failure Cause										Totals
Failure Cause Code	EBR									
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

Failure Mode: FAILS TO CLOSE - GFC

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

TABLE F-43. (continued)

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
PNEUMATIC-OPERATED VALVES

Failure Mode: FAILS TO OPEN - GFO

Failure Cause										Totals
Failure Cause Code	ELW									
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

Failure Mode: INTERNAL LEAKAGE - GIL

Failure Cause										Totals
Failure Cause Code	EBE									
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-43. (continued)

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
PNEUMATIC-OPERATED VALVES

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

Failure Cause										**Totals**
Failure Cause Code	EBF									
Failure Cause Count	2									2
Failure Cause Fraction	1.000									1.000
Aging										
Yes/No/Unknown	2/0/0									2/0/0
Aging Fractions										
Upper Bound	1.000									1.000
Lower Bound	1.000									1.000

TABLE F-44. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR HPIS PRESSURE TRANSMITTERS

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
PRESSURE TRANSMITTERS

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

Failure Cause										Totals
Failure Cause Code	EDS	EDT								
Failure Cause Count	3	3								6
Failure Cause Fraction	0.500	0.500								1.000
Aging										
Yes/No/Unknown	3/0/0	0/0/3								3/0/3
Aging Fractions										
Upper Bound	0.500	0.500								1.000
Lower Bound	0.500	0.000								0.500

TABLE F-45. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR HPIS RELIEF VALVES

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
RELIEF VALVES

Failure Mode: FAILS TO CLOSE - GFC

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

Failure Mode: FAILS TO OPEN - GFO

Failure Cause			Totals
Failure Cause Code	EDI	EDS	
Failure Cause Count	2	7	9
Failure Cause Fraction	0.222	0.778	1.000
Aging			
Yes/No/Unknown	2/0/0	7/0/0	9/0/0
Aging Fractions			
Upper Bound	0.222	0.778	1.000
Lower Bound	0.222	0.778	1.000

TABLE F-45. (continued)

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
RELIEF VALVES

Failure Mode: OPEN (PREMATURE) - GSO

Failure Cause											Totals
Failure Cause Code	EDS	HPM	SPM								
Failure Cause Count	2	1	1								4
Failure Cause Fraction	0.500	0.250	0.250								1.000
Aging											
Yes/No/Unknown	2/0/0	1/0/0	0/1/0								3/1/0
Aging Fractions											
Upper Bound	0.500	0.250	0.000								0.750
Lower Bound	0.500	0.250	0.000								0.750

TABLE F-46. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR HPIS SNUBBERS

SYSTEM
HIGH PRESSURE SAFETY INJECTION SYSTEM

COMPONENT
SNUBBERS

Failure Mode: LOSS OF FUNCTION - GLF

										Totals
Failure Cause										
Failure Cause Code	EBR	EDB	ETH	HPM						
Failure Cause Count	2	1	5	2						10
Failure Cause Fraction	0.200	0.100	0.500	0.200						1.000
Aging										
Yes/No/Unknown	2/0/0	0/0/1	5/0/0	2/0/0						9/0/1
Aging Fractions										
Upper Bound	0.200	0.100	0.500	0.200						1.000
Lower Bound	0.200	0.000	0.500	0.200						0.900

TABLE F-47. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS CHECK VALVES

SYSTEM
SERVICE WATER SYSTEM

COMPONENT
CHECK VALVES

Failure Mode: EXTERNAL LEAKAGE - GEL

										Totals
Failure Cause										
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

										Totals
Failure Cause										
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-47. (continued)

SYSTEM
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-48. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS CIRCUIT BREAKERS, AC

SYSTEM
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-49. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS FLOW INDICATORS

SYSTEM
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-50. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS FLOW SWITCHES

SYSTEM
SERVICE WATER SYSTEM

COMPONENT
FLOW SWITCHES

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

Failure Cause					Totals
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-51. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS HAND CONTROL VALVES

SYSTEM
SERVICE WATER SYSTEM

COMPONENT
HAND CONTROL VALVES

Failure Mode: EXTERNAL LEAKAGE - GEL

										Totals
Failure Cause										
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

										Totals
Failure Cause										
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-51. (continued)

SYSTEM
SERVICE WATER SYSTEM

COMPONENT
HAND CONTROL VALVES

Failure Mode: FAILS TO OPEN - GFO

										Totals
Failure Cause										
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

										Totals
Failure Cause										
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-51. (continued)

SYSTEM
SERVICE WATER SYSTEM

COMPONENT
HAND CONTROL VALVES

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

Failure Cause		**Totals**
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-52. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS MOTOR-DRIVEN PUMPS

SYSTEM
SERVICE WATER SYSTEM

COMPONENT
MOTOR-DRIVEN PUMPS

Failure Mode: EXTERNAL LEAKAGE - GEL

	EBB	EBF	EBR	EDB	EDI	EVM	HAM	HEM	HEO	Totals
Failure Cause										
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)

	SPM	SPO								Totals
Failure Cause										
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-52. (continued)

SYSTEM
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	2	1	2	29	4	10	23	
Failure Cause Fraction	0.011	0.011	0.022	0.011	0.022	0.326	0.045	0.112	0.258	
Aging										
Yes/No/Unknown	1/0/0	1/0/0	0/2/0	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	0.326	0.045	0.067	0.180	
Lower Bound	0.011	0.011	0.000	0.011	0.022	0.326	0.045	0.011	0.180	

Failure Mode: FAILS TO RUN - GFU(continued)

Failure Cause										Totals
Failure Cause Code	EDU	ELI	ELO	ELS	EMW	EVM	HAM	HEM	HPM	
Failure Cause Count	4	2	1	1	1	3	1	1	1	
Failure Cause Fraction	0.045	0.022	0.011	0.011	0.011	0.034	0.011	0.011	0.011	
Aging										
Yes/No/Unknown	3/1/0	2/0/0	1/0/0	0/0/1	0/1/0	3/0/0	0/1/0	0/1/0	0/1/0	
Aging Fractions										
Upper Bound	0.034	0.022	0.011	0.011	0.000	0.034	0.000	0.000	0.000	
Lower Bound	0.034	0.022	0.011	0.000	0.000	0.034	0.000	0.000	0.000	

TABLE F-52. (continued)

SYSTEM
SERVICE WATER SYSTEM

COMPONENT
MOTOR-DRIVEN PUMPS

Failure Mode: FAILS TO RUN - GFU(continued)

Failure Cause										Totals
Failure Cause Code	SPM									
Failure Cause Count	1									89
Failure Cause Fraction	0.011									1.000
Aging										
Yes/No/Unknown	1/0/0									65/18/6
Aging Fractions										
Upper Bound	0.011									0.796
Lower Bound	0.011									0.729

Failure Mode: FAILS TO START - GFS

Failure Cause										Totals
Failure Cause Code	DM	EBF	EBR	EDB	EDI	EI	ELC	ELF	EMH	
Failure Cause Count	1	1	1	4	3	1	1	1	1	14
Failure Cause Fraction	0.071	0.071	0.071	0.286	0.214	0.071	0.071	0.071	0.071	1.000
Aging										
Yes/No/Unknown	0/1/0	1/0/0	1/0/0	0/0/4	1/2/0	0/1/0	1/0/0	0/1/0	0/1/0	4/6/4
Aging Fractions										
Upper Bound	0.000	0.071	0.071	0.286	0.071	0.000	0.071	0.000	0.000	0.570
Lower Bound	0.000	0.071	0.071	0.000	0.071	0.000	0.071	0.000	0.000	0.284

TABLE F-53. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS MOTOR-OPERATED VALVES

SYSTEM
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-53. (continued)

SYSTEM
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-53. (continued)

SYSTEM
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-53. (continued)

SYSTEM
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-54. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS PNEUMATIC-OPERATED VALVES

SYSTEM
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-54. (continued)

SYSTEM
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-54. (continued)

SYSTEM
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-55. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS PRESSURE INDICATORS

SYSTEM
SERVICE WATER SYSTEM

COMPONENT
PRESSURE INDICATORS

Failure Mode: ERRONEOUS/ERRATIC SIGNALS - GEE

										Totals
Failure Cause										
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

										Totals
Failure Cause										
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-56. FAILURE CAUSE TALLIES, FAILURE CAUSE FRACTIONS, AND AGING FRACTIONS FOR SWS STRAINERS

SYSTEM
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-57. FAILURE CAUSE TALLIES FOR SYSTEM EFFECT[a]

System	System Effect	Component	Count[b]	Failure Cause
Auxiliary Feedwater System	Degraded System Operations	Check Valve	2	EBE
			3	EBR
			1	EBW
			1	EDB
		Circuit Breaker, AC	1	EVM
		Flow Controller	1	ELF
		Flow Control Recorder	1	ELO
		Hand Switch	1	ELK
		Hydraulic Valve	1	ELW
		Level Control Indicator	1	ELE
			1	ELF
			1	ELL
		Level Controller	1	EDB
		Level Switch	1	ELF
		Motor-Driven Pump	1	EBC
			1	EBF
			1	EBR
			2	EDB
			2	EDI
			2	EDS
			1	EDT
			1	ELA
			1	ELS
			1	EMW
			1	EPL
			1	HPC
		Motor-Operated Valve	2	DE
			1	EBE
			1	EBR
			4	EDB
			1	EDI
		Pneumatic-Operated Valve	1	DE
			1	EBE
			9	EBR
			4	EDB
			5	EDI
			1	ELE
			1	ELF
			1	HEO
		Pressure Switch	1	EBR
			2	ECC
			1	EDB
			1	EDT
			1	EL
			1	ELA
			1	HPO
		Relay	1	EBR
			1	EDB

TABLE F-57. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Auxiliary Feedwater System (continued)	Degraded System Operations (continued)	Relief Valve	3	EDS
		Switch (Parameter not specified)	2	ELK
		Turbine-Driven Pump	2	EBR
			5	EDB
			2	EDI
			2	ELF
			1	EMW
			5	EPH
			1	EVM
			1	HAM
			2	HPM
	Loss of Redundancy	Check Valve	2	DE
			6	EBR
			2	EDI
		Circuit Breaker, AC	1	EBR
			1	EDU
			1	EL
		Differential Pressure Controller	1	ELO
		Flow Controller	3	EDI
		Flow Switch	2	EDI
		Flow Transmitter	1	EBR
			1	EDB
			1	EDI
			1	EDS
			1	ELF
		Hand Switch	1	DM
			1	HPM
		Level Control Indicator	1	DE
			1	EBF
			1	EDB
			2	EDT
			3	ELF
			1	HPM
		Level Controller	1	DE
			2	EBF
			1	ELF
			1	ELO
		Motor-Driven Pump	5	EBR
			1	EDB
			1	EDO
			1	EDU
			1	EI
			2	ELA
			5	EMW
			1	HPM

TABLE F-57. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Auxiliary Feedwater System (continued)	Loss of Redundancy (continued)	Motor-Operated Valve	1	ECC
			4	EDB
			2	EDI
			1	EDU
			1	ELE
			1	ELW
			1	HPM
		Pneumatic-Operated Valve	1	DM
			1	EBF
			1	EBR
			5	EDB
			1	EDT
		Pressure Controller	1	EMW
		Pressure Switch	1	EDI
			8	EDT
			1	HPC
		Pressure Transmitter	1	EBR
			1	ELO
		Relay	1	DE
			1	ELW
		Relief Valve	1	EDI
		Solenoid Valve	1	EDI
		Speed Controller	1	ELF
		Turbine-Driven Pump	1	EBE
			1	EBF
			2	EBR
			1	ECC
			2	EDB
			1	EDI
			2	EVM
			1	HAM
			2	SPM
	Loss of Subsystem/Channel	Check Valve	6	DE
			33	EBR
			2	ECC
			2	EDB
			1	EDI
			7	HPM
		Circuit Breaker, AC	2	EBR
			1	EDI
			1	HPM
		Controller (Parameter not specified)	1	ELF
		Current Control Indicator	1	ELF
		Differential Pressure Controller	2	EDT
			1	EBM
			1	EDI
			1	EDT
			1	EV

TABLE F-57. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Auxiliary Feedwater System (continued)	Loss of Subsystem/Channel (continued)	Flow Control Indicator	1	HPM
		Flow Control Recorder	1	EDI
			4	EDT
		Flow Controller	1	EDI
			1	EDS
			3	EDT
			2	EL
			2	ELF
			2	HPM
		Flow Transmitter	4	DM
			1	EDS
			10	EDT
			2	ELF
		Hand Control Valve	6	EBR
		Hand Switch	1	EDI
		Hydraulic Valve	2	EDB
		Level Control Indicator	1	EBR
		Level Controller	1	EBF
			2	EDT
			2	ELF
			1	ELS
		Level Recorder	1	EDT
		Level Transmitter	1	ECC
			1	EDT
			1	ELO
		Motor-Driven Pump	1	DE
			3	EBR
			2	EDB
			1	EMW
			1	HPM
		Motor-Operated Valve	4	EDB
			3	EDI
			1	ELW
			1	HAM
			1	HPM
		Pneumatic-Operated Valve	3	EBE
			3	EBF
			17	EBR
			5	EDB
			6	EDI
			1	EDT
			2	EMW
			2	HAM
			2	HPM
		Pressure Control Recorder	1	EDT
		Pressure Controller	1	EDB
			2	EDT
			1	EMW

TABLE F-57. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Auxiliary Feedwater System (continued)	Loss of Subsystem/Channel (continued)	Pressure Switch	1	EDT
		Pressure Transmitter	6	EDT
		Relay	1	EBR
			2	ELI
			2	ELW
			1	HPC
			1	HPM
		Relief Valve	1	EBR
			1	EDS
		Snubber	2	EBR
			1	EI
		Solenoil Valve	2	EDI
			1	EDU
		Turbine-Driven Pump	1	EBM
			3	EBR
			4	EDB
			2	EDI
			1	HE
	Loss of System Function	Motor-Driven Pump	1	EBF
			1	EMW
		Motor-Operated Valve	1	EBE
	System Function Unaffected	Annunciator	1	ELF
		Check Valve	1	DM
			3	EBE
			12	EBR
			2	EDI
			2	EVM
			2	HPM
		Differential Pressure Controller	1	EDB
		Flow Control Indicator	1	ELF
		Flow Control Recorder	2	EBR
			2	EDT
		Flow Controller	1	EDB
			2	ELF
			1	ELK
		Flow Switch Indicator	1	EDI
		Flow Transmitter	1	EDB
			1	EDI
			2	EDT
			1	ELF
		Hand Control Valve	2	DM
			1	EBE
			4	EBR
			1	ECC
			1	EDB
			1	HPM

TABLE F-57. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Chemical and Volume Control System	Degraded System Operations	Heat Tracing Heater	2	ELH
		Level Control Indicator	3	EDB
			1	EDT
			3	ELF
		Level Control Recorder	1	ELF
		Level Controller	1	EDT
			5	ELF
		Level Transmitter	1	EBF
			2	ELF
		Mechanical Valve	2	EDB
		Motor-Driven Pump	4	DE
			13	EBR
			3	EDT
			1	EL
		Motor-Operated Valve	8	EBR
			1	EDB
			1	EDI
			1	ELS
			1	HPO
			4	EBR
			1	ECC
			3	EDB
			1	EDI
			1	HPM
		Pipe	1	EBE
			1	EBW
			2	EDB
		Pneumatic-Operated Valve	1	EBE
			1	EBF
			12	EBR
			3	EDB
			3	EDI
			3	EDU
			1	ELS
			1	EMW
			1	HEO
			1	HPM
		Pressure Control Recorder	1	EDT
		Pressure Controller	1	EDI
			1	EDT
		Pressure Switch	1	EDI
			1	EDT
			1	EL
		Pressure Transmitter	1	EBM
			3	EDT
			1	ELF
			2	HPC
			1	HPO
			1	SPM

TABLE F-57. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Chemical and Volume Control System (continued)	Degraded System Operations (continued)	Relay	1	EDS
		Relief Valve	1	EDS
		Snubber	3	EBR
			1	H
		Support	4	EBW
			1	EI
		Turbine-Driven Pump	1	EBE
			8	EBR
			1	EDI
			1	HPM
			2	HPO
	Loss of Redundancy	Circuit Breaker, AC	1	EL
			1	ELW
		Heat Tracing Heater	1	ELH
			2	ELO
			1	HAM
		Level Controller	1	EBF
			2	EDI
		Level Transmitter	1	ELF
		Motor-Driven Pump	1	DE
			8	EBR
			1	EDU
		Motor-Operated Valve	3	EBR
			2	EDB
	Loss of Subsystem/Channel	Circuit Breaker, AC	1	EBF
			2	EDB
		Heat Tracing Heater	1	ECC
		Level Controller	1	EDT
		Level Transmitter	4	EDI
			3	EDT
			1	HPO
		Motor-Driven Pump	3	EBR
			1	EDI
		Motor-Operated Valve	3	EDB
			1	EDI
		Relief Valve	1	EBR
		Temperature Switch	1	EDI
	Loss of System Function	Motor-Driven Pump	2	EDI

TABLE F-57. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Chemical and Volume Control System (continued)	System Function Unaffected	Check Valve	1	EBR
		Flow Transmitter	1	EDT
		Hand Control Valve	2	EBR
		Heat Tracing Heater	1	ELD
			1	HAM
		Level Control Recorder	1	EDT
		Level Controller	1	EDI
			2	EDT
		Level Switch	1	EDT
		Level Transmitter	8	EDT
		Mechanical Valve	1	EDB
		Motor-Driven Pump	10	EBR
			1	EVM
			2	HPM
		Motor-Operated Valve	3	EBE
			16	EBR
			1	ECC
			4	EDB
			2	EDI
			1	EDU
		Pneumatic-Operated Valve	1	EBR
			1	HPM
		Temperature Switch	3	EDT
Class 1E Electrical Power Distribution System				
Instrument & Uninterruptible Power Subsystem	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
	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

TABLE F-57. (continued)

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

TABLE F-57. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Class 1E Electrical Power Distribution System (continued)				
Emergency On-Site Power Supply Subsystem	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
	Loss of Redundancy	Circuit Breaker, AC	1	EBR
		Diesel Generator	2	DEI
			2	DM
			6	EBR
			1	EDB
			1	EDI
			1	EDU
			1	EEN
			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

TABLE F-57. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Class 1E Electrical Power Distribution System (continued)				
Emergency On-Site Power Supply Subsystem (continued)	System Function 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
Low-Voltage Power Subsystem	Degraded System Operations	Circuit Breaker, AC	1	ELO
	Loss of Redundancy	Bus	1	HEM
	Loss of Subsystem/Channel	Relay	1	DEI
			1	ELS
	System Function Unaffected	Circuit Breaker, AC	2	ELT
		Relay	1	SPC
Medium-Voltage Power Subsystem	Degraded System Operations	Cable	1	ELI
		Circuit Breaker, AC	1	ELE
		Transformer	1	ELI
	Loss of Redundancy	Circuit Breaker, AC	1	HPM
	Loss of Subsystem/Channel	Circuit Breaker, AC	1	ELC
		Transformer	1	EMW
			1	HEM
	System Function Unaffected	Circuit Breaker, AC	1	HPM
		Transformer	1	EBR
High Pressure Injection System	Degraded System Operations	Check Valve	3	DE
			7	EBR
			1	EDB
			1	HPM
		Circuit Breaker, AC	1	EBR
			1	ELK
		Flow Transmitter	1	EBM
			1	EDB
			1	EDT
		Hand Control Valve	2	DM
			1	EBR
			1	EDU

TABLE F-57. (continued)

System	System Effect	Component	Count[b]	Failure Cause
High Pressure Injection System (continued)	Degraded System Operations (continued)	Heat Tracing Heater	1	ELE
		Level Transmitter	1	EDT
		Load Sequence Controller	1	EDI
		Motor-Driven Pump	1	EBR
			1	EDI
		Motor-Operated Valve	1	DE
			4	EBR
			7	EDB
			2	EDI
			1	EDU
			1	ELK
			1	ELS
			1	SC
		Pneumatic-Operated Valve	1	EBE
		Relief Valve	5	EDS
	Loss of Redundancy	Circuit Breaker, AC	1	EBF
			1	EDB
			1	ELF
			1	HPM
		Flow Transmitter	1	EDT
		Heat Tracing Heater	1	ECC
			1	EDB
			5	ELH
			3	ELO
			1	ELS
			2	ELW
			3	HAM
			1	SC
		Level Transmitter	6	EDT
		Load Sequence Controller	1	DE
			2	ELF
			1	HPM
		Motor-Driven Pump	1	EDB
			1	HMM
			1	HPM
		Motor-Operated Valve	3	EBR
			1	EDB
			1	EDI
			2	EDU
			4	HPM
		Pipe	2	ECC
		Pressure Switch	1	ELS
		Relief Valve	1	EBR
			1	HPM

TABLE F-57. (continued)

System	System Effect	Component	Count[b]	Failure Cause
High Pressure Injection System (continued)	Loss of Subsystem/Channel	Check Valve	1	EBR
		Circuit Breaker, AC	2	EBF
			1	EBR
			1	EI
		Flow Modifier	1	EDT
		Flow Transmitter	1	EBM
			3	EDT
		Hand Control Valve	1	ECC
			1	EDI
			1	HPM
		Heat Tracing Heater	2	HAM
			1	HPM
		Load Sequence Controller	1	EDI
			1	ELL
			1	HEM
		Motor-Driven Pump	2	EDB
			2	EDO
			1	HPO
			1	SPO
		Motor-Operated Valve	1	EBF
			4	EBR
			1	ECC
			2	EDB
			2	EDI
			1	EDU
			1	HCO
			1	HPM
		Pneumatic-Operated Valve	1	EDB
			1	ELW
		Pressure Transmitter	1	EDS
		Relief Valve	2	EDI
			2	EDS
			1	SPM
		Snubber	2	ETH
	Loss of System Function	Hydraulic Valve	2	DE
		Motor-Driven Pump	1	EDI
	System Function Unaffected	Check Valve	3	EBR
			2	EDI
		Circuit Breaker, AC	1	ELK
		Current Switch	1	EDS
		Flow Transmitter	1	EBF
			2	EBR
			6	EDT

TABLE F-57. (continued)

System	System Effect	Component	Count[b]	Failure Cause
High Pressure Injection System (continued)	System Function Unaffected (continued)	Hand Control Valve	1	DE
			2	EBR
			1	EDB
			1	EDI
		Hydraulic Valve	2	EBR
		Level Transmitter	12	EDT
			1	ELF
			1	HE
		Load Sequence Controller	1	EL
			1	ELF
		Mechanical Valve	1	EBE
		Motor-Driven Pump	4	EBR
			1	HP
		Motor-Operated Valve	2	DE
			9	EBR
			4	EDB
			3	EDI
			1	EDO
			2	EDU
			2	ELS
			1	EVM
			4	HPM
		Orifice	1	ECC
		Pipe	1	EVM
			1	H
		Pneumatic-Operated Valve	2	EBF
			4	EBR
			1	EDB
		Pressure Control Recorder	2	EDT
		Pressure Controller	1	EDT
		Pressure Modifier	1	EDT
		Pressure Transmitter	2	EDS
			3	EDT
		Relief Valve	1	EBR
			1	ECC
			2	EDI
			2	EDS
		Snubber	2	EBR
			1	EDB
			3	ETH
			2	HPM
Service Water System	Degraded System Operations	Check Valve	2	EBE
			4	EBR
		Circuit Breaker, AC	1	EBR
			1	EDB
			1	EDI
			1	HEM

TABLE F-57. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Service Water System (continued)	Degraded System Operations (continued)	Differential Pressure Switch	1	EDI
		Flow Indicator	2	ELT
		Flow Switch	3	ELD
			1	ELI
			1	ELT
		Hand Control Valve	1	EBR
			1	ECC
			1	HEM
			2	HEO
		Motor	1	ELC
		Motor-Driven Pump	10	EBR
			6	EDB
			5	EDI
			1	EI
			1	EVM
			1	HAM
			1	HPM
			1	SPM
			1	SPO
		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
			1	ELR
			1	ELS
			1	EMW
		Overcurrent Relay (DC)	1	ELO
		Pipe	1	EBE
			1	ECC
		Pneumatic-Operated Valve	6	EBR
			4	EDB
			2	EDI
			1	ELD
			3	EVM
		Pressure Switch	1	EDI
			1	ELD
		Relay	1	DE
		Relief Valve	1	EBE
		Strainer	1	EDI
			1	HAM
		Temperature Control Indicator	1	EDB

TABLE F-57. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Service Water System (continued)	Loss of Redundancy	Check Valve	1	DCI
			1	DE
			2	EBR
			1	ECC
		Circuit Breaker, AC	1	EBM
			2	EDB
		Differential Pressure Control Recorder	1	EDI
		Electric Power Supply	1	ELE
		Flow Indicator	1	EDI
		Flow Modifier	1	ELD
		Hand Control Valve	1	ECC
			1	EDB
			1	EDI
		Motor	1	ELS
		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
		Motor-Operated Valve	2	EBR
			5	EDB
			1	EL
			1	ELO
			1	EMW
		Pneumatic-Operated Valve	1	ECC
			1	EDB
			1	EDI
		Pressure Switch	1	ECC
			1	EL
		Relay	1	ELC
		Strainer	4	EBR
	Loss of Subsystem/Channel	Check Valve	5	EBR
			3	ECC
		Circuit Breaker, AC	2	EBF
			1	EDI
			2	ELW
			1	SPC
		Differential Pressure Control Recorder	1	EBR
		Differential Pressure Switch	1	EBR
		Flow Switch	1	EDI

TABLE F-57. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Service Water System (continued)	Loss of Subsystem/Channel (continued)	Hand Control Valve	1	ECC
			1	EDB
		Motor	1	EDI
		Motor-Driven Pump	1	DCI
			1	EBE
			25	EBR
			2	ECC
			15	EDI
			1	ELI
			1	ELO
			1	EVM
			1	HAM
			1	HEO
		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
		Pipe	1	ECC
			1	EMI
		Pneumatic-Operated Valve	4	EBR
			3	EDB
			3	EDI
			1	EVM
		Pressure Indicator	1	EDI
			2	EDT
		Relief Valve	1	EBR
			1	EDI
		Safety/Relief Valve	1	EDB
		Snubber	1	D
			1	EDI
		Strainer	2	EAO
			1	EBR
			1	ECC
			2	EDI
			1	HPM
		Support	1	DEI
			1	EBR
		Temperature Switch	1	ELT
		Thermowell	1	ECC

TABLE F-57. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Service Water Systems (continued)	System Function Unaffected	Check Valve	2	EBE
			3	EBR
			3	ECC
			1	EDB
			2	EDI
			1	HPM
		Circuit Breaker, AC	1	EBR
			2	EDI
			1	ELE
		Differential Pressure Switch	2	ELD
		Flow Indicator	1	ELF
			1	ELT
		Flow Switch	10	ELD
		Hand Control Valve	1	EBE
			2	EBR
			2	ECC
			2	HEO
		Level Switch	1	EMW
		Level Transmitter	1	EDI
		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
		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

TABLE F-57. (continued)

System	System Effect	Component	Count[b]	Failure Cause
Service Water Systems (continued)	System Function Unaffected (continued)	Pneumatic-Operated Valve	1	EBB
			1	EBF
			9	EBR
			1	ECC
			1	EDB
			1	EDI
			1	EDU
			1	EVM
			1	HA
		Position-Limit Switch	1	EBR
		Pressure Indicator	1	EDI
			1	EDT
			1	ELT
		Relay	1	EBR
		Snubber	1	DCI
			1	ECC
		Strainer	3	EBR
			2	ECC
			3	EDI
		Temperature Indicator	2	ELT
		Vent Valve	1	EBE
			1	EDB
		Zone Modifier	1	EDB

a. Table summary does not contain data for any failure categorized unclassified (Table F-3).

b. Total counts: 1713

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This report describes the methods, analyses, results, and conclusions of two different aging studies. The first study consists of a survey of light water reactor component failures associated with 15 selected safety and support systems. Analysts used computerized sorting techniques to classify component failures into generic failure categories. The second study consists of careful examination of component failure records to identify and categorize the reported cause of component failures. The systems evaluated in the failure-cause analysis were the auxiliary feedwater, Class 1E electrical power distribution, high-pressure injection, and service water. Tables and figures are presented, indicating the systems and the components within those systems most affected by aging. Also provided are engineering insights drawn from the data. This report is the second of two volumes and presents all of the Volume 1 data from FY-86 combined with the data gathered in FY-87.

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