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Common-Cause Failure Event Insights

Motor-Operated Valves

Idaho National Engineering and Environmental Laboratory

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
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ABSTRACT

This report documents a study performed on the set of common-cause failures (CCF) of motor-operated valves (MOV) from 1980 to 2000. The data studied here were derived from the NRC CCF database, which is based on US commercial nuclear power plant event data. This report is the result of an in-depth review of the MOV CCF data and presents several insights about the MOV CCF data. The objective of this document is to look beyond the CCF parameter estimates that can be obtained from the CCF data, to gain further understanding of why CCF events occur and what measures may be taken to prevent, or at least mitigate the effect of, MOV CCF events. This report presents quantitative presentation of the MOV CCF data and discussion of some engineering aspects of the MOV events.

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EXECUTIVE SUMMARY

This report provides insights related to motor-operated valve (MOV) common-cause failure (CCF) events. These events were obtained from the U.S. Nuclear Regulatory Commission's (USNRC) CCF Database. The MOV CCF data contains attributes about events that are of interest in the understanding of: completeness of the failures, occurrence rate trends of the events, MOV piece part affected, causal factors, coupling or linking factors, event detection methods, and MOV system. Distributions of these CCF characteristics and trends were analyzed and individual events were reviewed for insights.

General Insights. The study identified 149 events occurring at U.S. nuclear power plant units during the period from 1980 through 2000. Twenty-eight units each had one CCF event during the period; 42 units did not experience a CCF event. About 64 percent of the units had zero or one CCF event. Eleven percent of the units have experienced four or more MOV CCF events. Of the 149 events, 22 (15 percent) were Complete common-cause failures (failure events with all components failed due to a single cause in a short time).

Failure Modes. The events were classified as either fail-to-open or fail-to-close. The failure mode for the majority of the MOV CCF events is fail-to-open (60 percent). The fail-to-close failure mode accounted for the other 40 percent of the events. Most of the fail-to-close CCF events were caused by improper settings of the torque and limit switches that inhibited the full closure of the MOVs.

Trends. Figure ES-1 shows the trend for all MOV CCF events. The decreasing trend for all MOV CCF events is statistically significant with a p-value of 0.0001. Based on the review of failure data for this study, improved maintenance and operating procedures, as well as increased maintenance focus and emphasis on equipment reliability from initiatives throughout the industry (NRC, utilities, INPO, and EPRI), appear to be reasons for the observed reduction of the occurrence of CCF events over the 21 years of experience included in this study. The failure mode trends were both decreasing. The trend for the Complete events from 1980-2000 is decreasing and is statistically significant with a p-value = 0.0019.

Method of Discovery. When the method of discovery was investigated, Testing accounted for 61 events (41 percent), Demand for 57 events (38 percent), and 31 events (21 percent) were discovered during Inspection or during Maintenance activities. The high percentage of events discovered by demands appears to indicate weaknesses in the MOV testing programs. However, a review of MOV CCF by event dates and method of discovery shows that prior to 1990, 35 percent of events were discovered by Testing while 45 percent were discovered by Demands. Since 1990, 52 percent of events have been discovered by Testing while only 24 percent have been discovered by Demands. Therefore, it appears that industry MOV testing programs have increased the effectiveness of common-cause failure discovery via testing.

Sub-Component. The highest number of events occurred in the actuator sub-component (127 events or 85 percent). However, the fraction of Complete CCF events is similar between the actuator and valve sub-components. The torque switch piece part had the largest effect on the actuator. The limit

switch piece part had the second largest effect on the actuator. About half of the actuator CCF events were the result of problems with these two piece parts.

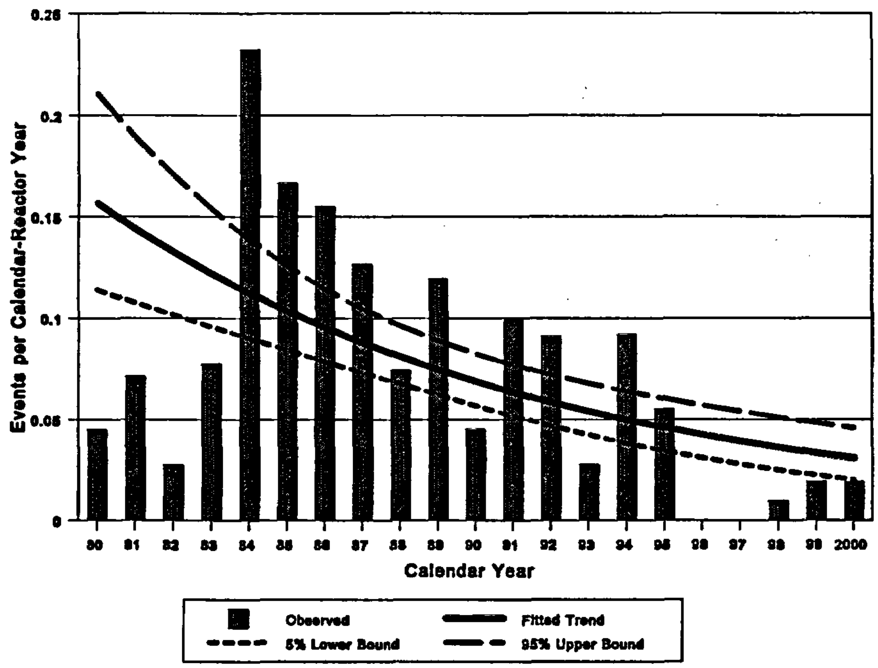

Figure ES-1. Trend for all MOV CCF events. The decreasing trend is statistically significant with a p-value = 0.0001.

Proximate Cause. As shown in Figure ES-2, the leading proximate cause groups are Operational/Human Error, Design/Construction/Installation/Manufacture Inadequacy, and Internal to Component. These three accounted for 27, 26, and 21 percent of the total events. The Operational/ Human Error cause group accounted contributed the largest number of Complete events (10 out of 22 Complete events, 45 percent).

The Operational/Human Error proximate cause group is the most likely for the MOV and represents causes related to errors of omission or commission on the part of plant staff or contractor staff. Included in this category are accidental actions, failures to follow the correct procedures or following inadequate procedures for construction, modification, operation, maintenance, calibration, and testing. This proximate cause group may also include deficient training.

The Design/Construction/Installation /Manufacture Inadequacy proximate cause group is the next most likely for the MOVs and encompasses events related to the design, construction, installation, and manufacture of components, both before and after the plant is operational. Included in this category are events resulting from errors in equipment and system specifications, material specifications, and calculations. Events related to maintenance activities are not included.

The Internal to Component proximate cause category is important for the MOVs and encompasses the malfunctioning of hardware internal to the component. Internal causes result from phenomena such as normal wear or other intrinsic failure mechanisms, which are influenced by the

ambient environment of the component. Specific mechanisms include erosion, corrosion, internal contamination, fatigue, wear-out, and end of life.

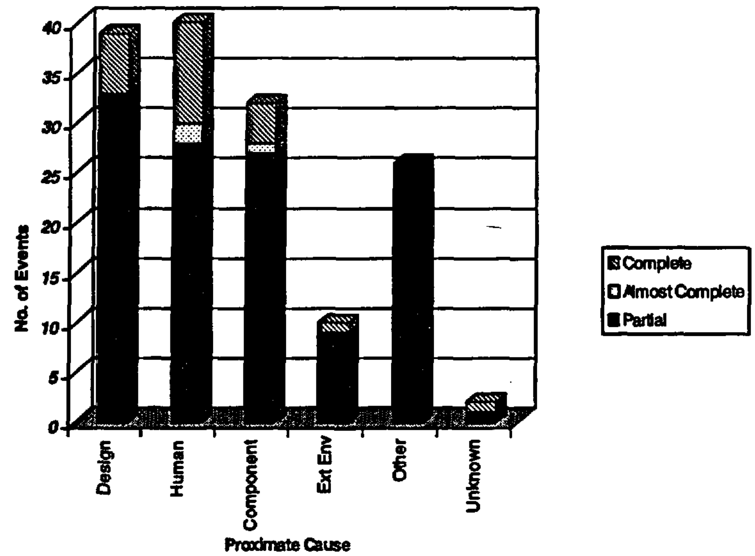

Figure ES-2. Proximate cause distribution for all MOV CCF events.

Coupling Factors. Maintenance is the leading coupling factor with 83 events (56 percent). Maintenance coupling factors result from common maintenance procedures, practices, and personnel. Design, with 42 events (28 percent), accounts for the majority of the remaining events. These two coupling factors account for the top 84 percent of the events.

System. Figure ES-3 shows the distribution of MOV CCF events by affected system. There were distinctly more events occurring in the BWR residual heat removal (RHR-B) system than any other system (29 percent). The high-pressure safety injection (HPI), auxiliary feedwater (AFW), PWR residual heat removal (RHR-P), and containment spray (CSS) systems have the bulk of the remaining events. The review of the data does not suggest that there is any specific causal relationship, other than the installed population of MOVs per system, between the systems and the number of observed CCFs.

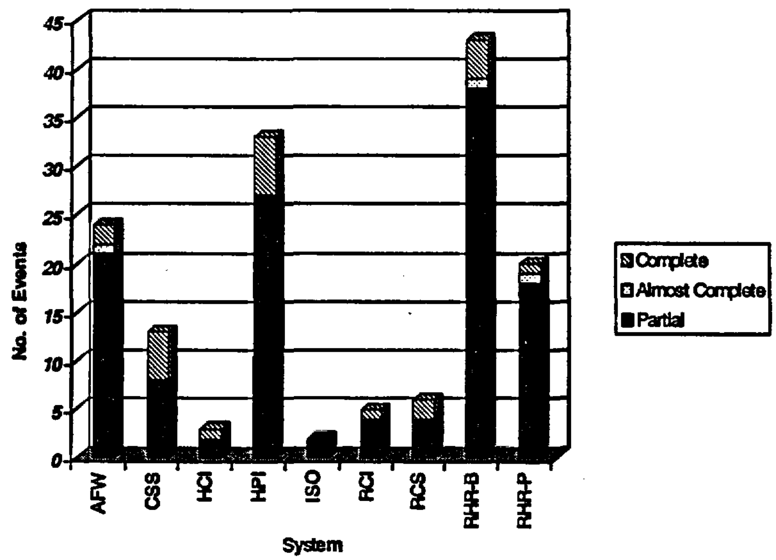

Figure ES-3. System distribution for all MOV CCF events.

FOREWORD

This report provides common-cause failure (CCF) event insights for motor-operated valves (MOVs). The results, findings, conclusions, and information contained in this study, the initiating event update study, and related system reliability studies conducted by the Office of Nuclear Regulatory Research support a variety of risk-informed NRC activities. These include providing information about relevant operating experience that can be used to enhance plant inspections of risk-important systems, and information used to support staff technical reviews of proposed license amendments, including risk-informed applications. In addition, this work will be used in the development of enhanced performance indicators that will be based largely on plant-specific system and equipment performance.

Findings and conclusions from the analyses of the MOV CCF data, which are based on 1980-2000 operating experience, are presented in the Executive Summary. High-level insights of all the MOV CCF data are presented in Section 3. Section 4 summarizes the events by sub-component. Section 5 presents MOV CCF insights by the MOV system. Section 6 provides information about how to obtain more detailed information for the MOV CCF events. The information to support risk-informed regulatory activities related to the MOV CCF data is summarized in Table F-1. This table provides a condensed index of risk-important data and results presented in discussions, tables, figures, and appendices.

Table F-1. Summary of Insights from Motor-Operated Valve Common-Cause Failure Events.

Item	Description	Text Reference	Page(s)	Data
1.	CCF trends overview	Section 3.2	12	Figure 3-1 – Figure 3-4
2.	CCF sub-component overview	Section 3.3	14	Figure 3-5
3.	CCF proximate cause overview	Section 3.4	15	Figure 3-6
4.	CCF coupling factor overview	Section 3.5	18	Figure 3-7
5.	CCF discovery method overview	Section 3.6	20	Figure 3-8 – Figure 3-9
6.	CCF system overview	Section 3.7	22	Figure 3-10
7.	Engineering Insights - Actuators	Section 4.2	27	Figure 4-1 – Figure 4-3
8.	Engineering Insights - Valves	Section 4.3	33	Figure 4-4 – Figure 4-6
9.	Engineering Insights - RHR (BWR) system	Section 5.2	37	Figure 5-1 – Figure 5-4
10.	Engineering Insights - HPI system	Section 5.3	40	Figure 5-5 – Figure 5-8
11.	Engineering Insights - AFW system	Section 5.4	42	Figure 5-9 – Figure 5-12
12.	Engineering Insights - RHR (PWR) system	Section 5.5	44	Figure 5-13 – Figure 5-16
13.	Engineering Insights - Cont. Spray system	Section 5.6	47	Figure 5-17 – Figure 5-20
14.	Complete Events - Actuators; Valves	Sections 4.2; 4.3	27; 33	Table 4-4; Table 4-6
15.	Piece Parts - Actuators; Valves	Section 4	25	Figure 4-3 and Figure 4-6
16.	Piece Parts - Systems	Section 5	37	Figure 5-3; Figure 5-7, Figure 5-11; Figure 5-15; Figure 5-19
17.	Data Summaries	Appendix A, B, and C		

The application of results to plant-specific applications may require a more detailed review of the relevant Licensee Event Report (LER) and Nuclear Plant Reliability Data System (NPRDS) or Equipment Performance Information and Exchange System (EPIX) data cited in this report. This review is needed to determine if generic experiences described in this report and specific aspects of the MOV CCF events documented in the LER and NPRDS failure records are applicable to the design and operational features at a specific plant or site. Factors such as system design, specific MOV components installed in the system, and test and maintenance practices would need to be considered in light of specific information provided in the LER and NPRDS failure records. Other documents such as logs, reports, and inspection reports that contain information about plant-specific experience (e.g., maintenance, operation, or surveillance testing) should be reviewed during plant inspections to supplement the information contained in this report.

Additional insights may be gained about plant-specific performance by examining the specific events in light of overall industry performance. In addition, a review of recent LERs and plant-specific component failure information in NPRDS or EPIX may yield indications of whether performance has undergone any significant change since the last year of this report. NPRDS archival data (through 1996) and EPIX failure data are proprietary information that can be obtained from the EPIX database through the Institute of Nuclear Power Operations (INPO). NRC staff and contractors can access that information through the EPIX database.

Common-cause failures used in this study were obtained from the common-cause failure database maintained for the NRC by the INEEL. NRC staff and contractors can access the plant-specific CCF information through the CCF database that is available on CD-ROM and has been provided to the NRC Regions and NRC Office of Nuclear Reactor Regulation (NRR). To obtain access to the NRC CCF Database, contact Dale Rasmuson [dmr@nrc.gov; (301) 415-7571] at the NRC or S. Ted Wood at the INEEL [stw@inel.gov; (208) 526-8729].

Periodic updates to the information in this report will be performed, as additional data become available. In the future, these insights will be available on the RES internal web page.

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ACRONYMS

AFW	auxiliary feedwater (PWR)
ASME	American society of mechanical engineers
BIT	boric acid injection tank
BWST	borated water storage tank
CCCG	common-cause failure component group
CCF	common-cause failure
CSS	containment spray (PWR)
d/p	differential pressure
ECCS	emergency core cooling system
EPIX	equipment performance and information exchange
FTC	fail-to-close
FTO	fail-to-open
GL	generic letter
HCI	high pressure coolant injection (BWR)
HPI	high pressure safety injection (PWR)
INEEL	Idaho National Engineering and Environmental Laboratory
INPO	Institute of Nuclear Power Operations
IPE	individual plant examination
ISLOCA	interfacing system loss of coolant accidents
ISO	isolation condenser (BWR)
LER	licensee event report
LLRT	local leak rate test
LOCA	loss of coolant accident
MCC	motor control center
MOV	motor-operated valve
NPP	nuclear power plant
NPRDS	Nuclear Plant Reliability Data System
NRC	Nuclear Regulatory Commission
OM	operation and maintenance
PM	preventative maintenance
PORV	power operated relief valve
PRA	probabilistic risk assessment
RCI	reactor core isolation cooling (BWR)

RCS	reactor coolant system
RHR-B	residual heat removal (BWR)
RHR-P	residual heat removal (PWR)
RWST	reactor water storage tank
SCSS	Sequence Coding and Search System
SI	safety injection

GLOSSARY

Application—A particular set of CCF events selected from the common-cause failure database for use in a specific study.

Average Impact Vector—An average over the impact vectors for different hypotheses regarding the number of components failed in an event.

Basic Event—An event in a reliability logic model that represents the state in which a component or group of components is unavailable and does not require further development in terms of contributing causes.

Common-cause Event—A dependent failure in which two or more component fault states exist simultaneously, or within a short time interval, and are a direct result of a shared cause.

Common-cause Basic Event—In system modeling, a basic event that represents the unavailability of a specific set of components because of shared causes that are not explicitly represented in the system logic model as other basic events.

Common-cause Component Group—A group of (usually similar [in mission, manufacturer, maintenance, environment, etc.]) components that are considered to have a high potential for failure due to the same cause or causes.

Common-cause Failure Model—The basis for quantifying the probability of common-cause events. Examples include the beta factor, alpha factor, basic parameter, and the binomial failure rate models.

Component—An element of plant hardware designed to provide a particular function.

Component Boundary—The component boundary encompasses the set of piece parts that are considered to form the component.

Component Degradation Value—The assessed probability ($0.0 \leq p \leq 1.0$) that a functionally- or physically-degraded component would fail to complete the mission.

Component State—Component state defines the component status in regard to its intended function. Two general categories of component states are defined, available, and unavailable.

> *Available*—The component is available if it is capable of performing its function according to a specified success criterion. (N.B., available is not the same as availability.)
>
> *Unavailable*—The component is unavailable if the component is unable to perform its intended function according to a stated success criterion. Two subsets of unavailable states are failure and functionally unavailable.

Coupling Factor/Mechanism—A set of causes and factors characterizing why and how a failure is systematically induced in several components.

Date—The date of the failure event, or date the failure was discovered.

Defense—Any operational, maintenance, and design measures taken to diminish the probability and/or consequences of common-cause failures.

Degree of Failure— The Degree of Failure category has three groups: Complete, Almost Complete, and Partial. The degree of failure is a categorization of a CCF event by the magnitude of three quantification parameters: component degradation value, shared cause factor, and timing factor. These parameters can be given values from zero to 1.0. The degree of failure categories are defined as follows:

> *Complete*—A common-cause failure in which all redundant components are failed simultaneously as a direct result of a shared cause; i.e., the component degradation value equals 1.0 for all components, and both the timing factor and the shared cause factor are equal to 1.0.
>
> *Almost Complete*—A common-cause failure in which one of the parameters is not equal to 1.0. Examples of events that would be termed Almost Complete are: events in which most components are completely failed and one component is degraded, or all components are completely failed but the time between failures is greater than one inspection interval.
>
> *Partial*—All other common-cause failures (i.e., more than one of the quantification parameters is not equal to 1.0.)

Dependent Basic Events—Two or more basic events, A and B, are statistically dependent if, and only if,

$$P[A \cap B] = P[B \mid A]P[A] = P[A \mid B]P[B] \neq P[A]P[B],$$

where P[X] denotes the probability of event X.

Event—An event is the occurrence of a component state or a group of component states.

Exposed Population—The set of components within the plant that are potentially affected by the common-cause failure event under consideration.

Failure—The component is not capable of performing its specified operation according to a success criterion.

Failure Mechanism—The history describing the events and influences leading to a given failure.

Failure Mode—A description of component failure in terms of the component function that was actually or potentially unavailable.

Failure Mode Applicability—The analyst's probability that the specified component failure mode for a given event is appropriate to the particular application.

Functionally Unavailable—The component is capable of operation, but the function normally provided by the component is unavailable due to lack of proper input, lack of support

function from a source outside the component (i.e., motive power, actuation signal), maintenance, testing, the improper interference of a person, etc.

Impact Vector—An assessment of the impact an event would have on a common-cause component group. The impact is usually measured as the number of failed components out of a set of similar components in the common-cause component group.

Independent Basic Events—Two basic events, A and B, are statistically independent if, and only if,

$$P[A \cap B] = P[A]P[B],$$

where P[X] denotes the probability of event X.

Mapping—The impact vector of an event must be "mapped up" or "mapped down" when the exposed population of the target plant is higher or lower than that of the original plant that experienced the common-cause failure. The result of mapping an impact vector is an adjusted impact vector applicable to the target plant.

Mapping Up Factor—A factor used to adjust the impact vector of an event when the exposed population of the target plan is higher than that of the original plant that experienced the common-cause failure.

P-Value—A p-value is a probability, that indicates a measure of statistical significance. The smaller the p-value, the greater the significance. A p-value of less than 0.05 is generally considered statistically significant.

Potentially Unavailable—The component is capable of performing its function according to a success criterion, but an incipient or degraded condition exists. (N.B., potentially unavailable is not synonymous with hypothetical.)

> *Degraded*—The component is in such a state that it exhibits reduced performance but insufficient degradation to declare the component unavailable according to the specified success criterion.
>
> *Incipient*—The component is in a condition that, if left un-remedied, could ultimately lead to a degraded or unavailable state.

Proximate Cause—A characterization of the condition that is readily identified as leading to failure of the component. It might alternatively be characterized as a symptom.

Reliability Logic Model—A logical representation of the combinations of component states that could lead to system failure. A fault tree is an example of a system logic model.

Root Cause—The most basic reason for a component failure, which, if corrected, could prevent recurrence. The identified root cause may vary depending on the particular defensive strategy adopted against the failure mechanism.

Shared-Cause Factor (c)—A number that reflects the analyst's uncertainty ($0.0 \leq c \leq 1.0$) about the existence of coupling among the failures of two or more components, i.e., whether a shared cause of failure can be clearly identified.

Shock—A shock is an event that occurs at a random point in time and acts on the system; i.e., all the components in the system simultaneously. There are two kinds of shocks distinguished by the potential impact of the shock event, i.e., lethal and nonlethal.

Statistically Significant—The term "statistically significant" means that the data are too closely correlated to be attributed to chances and consequently have a systematic relationship.

System—The entity that encompasses an interacting collection of components to provide a particular function or functions.

Timing Factor (q)—The probability $(0.0 \leq q \leq 1.0)$ that two or more component failures (or degraded states) separated in time represent a common-cause failure. This can be viewed as an indication of the strength-of-coupling in synchronizing failure times.

Common-Cause Failure Event Insights for Motor-Operated Valves

1. INTRODUCTION

This report presents insights about the common-cause events that have occurred in the motor-operated valve (MOV) system at operating nuclear power plants.

The insights for the U.S. plants are derived from information captured in the common-cause failure (CCF) database maintained for the Nuclear Regulatory Commission (NRC) by the Idaho National Engineering and Environmental Laboratory (INEEL). The database contains CCF-related events that have occurred in U.S. commercial nuclear power plants reported in licensee event reports (LERs) and reports to the Nuclear Plant Reliability Data System (NPRDS) and the Equipment Performance Information Exchange (EPIX) system maintained by the Institute for Nuclear Power Operations (INPO)

The information presented in this report is intended to help focus NRC inspections on the more risk-important aspects of MOV CCF events. Utilities can also use the information to help focus maintenance and test programs such that MOV CCF events are minimized.

1.1 Background

The following four criteria must be met for an event to be classified as resulting from a common-cause:

- Two or more individual components must fail or be degraded, including failures during demand, inservice testing, or from deficiencies that would have resulted in a failure if a demand signal had been received;
- Two or more individual components must fail or be degraded in a select period of time such that the probabilistic risk assessment (PRA) mission would not be certain;
- The component failures or degradations must result from a single shared cause and coupling mechanism; and
- The component failures are not due to the failure of equipment outside the established component boundary.

To help resolve NRC Generic Issue 145,[1] *Actions to Reduce Common-Cause Failures*, and to address deficiencies related to the availability and analysis of CCF data, the NRC and the INEEL developed a CCF database that codifies information on CCF-related events that have occurred in U.S. commercial nuclear power plants from 1980 to date. The data is derived from both licensee event reports (LERs) submitted to the NRC and equipment performance reports submitted to the INPO. Accompanying the development of the CCF database was the development of CCF analysis software for investigating the CCF aspect of system reliability analyses and related risk-informed applications.

The quantitative results of this CCF data collection effort are described in the four volumes of NUREG/CR-6268, *Common-Cause Failure Database and Analysis System*.[2,3,4,5] Some quantitative insights about the data for use in PRA studies were also published in NUREG/CR-5497,[6] *Common-Cause Failure Parameter Estimations*. Copies of the CCF database together with supporting technical

documentation and the analysis software are available from the NRC on CD-ROM to aid in system reliability analyses and risk-informed applications.

The CCF event data collected, classified, and compiled in the CCF database provide a unique opportunity to go beyond just estimation of CCF probabilities but to also gain more engineering insights into how and why CCF events occur. The data classification employed in the database was designed with this broader objective in mind. The data captured includes plant type, system component, piece parts, failure causes, mechanisms of propagation of failure to multiple components, and their functional and physical failure modes. Other important characteristics such as defenses that could have prevented the failures are also included.

Section 1.2 of Volume 3 of NUREG/CR-6268 (Reference 4) proposes methods for classifying common-cause failures using the concepts of causes, coupling factors, and defensive mechanisms. The methods suggest a causal picture of failure with an identification of a root cause, a means by which the cause is more likely to impact a number of components simultaneously (the coupling), and the failure of the defenses against such multiple failures. Utilizing these methods, the CCF data associated with MOV systems were analyzed to provide a better understanding of MOV CCFs. This report presents the results of this effort.

The data analyzed are derived from the CCF database. The coding and quality assurance (QA) process for entering data into the database is as follows: Each event is coded from an LER or an NPRDS or EPIX report by analysts at the INEEL. Each analyst has access to coding guidelines (NUREG/CR-6268), which provides specific direction to the analyst about what the required information means and how to enter the information into the database. Each analyst is knowledgeable about PRA and plant systems and operations. Each event is initially coded by one analyst and reviewed by another analyst with a comparable background. Any disagreement is resolved before coding of the event is considered completed. An additional review of the events is done by another person familiar with PRA and CCF concepts. An independent outside expert in CCF and PRA then reviews the coding. Any differences are resolved and the final coding changes made in the database. The data collection, analysis, independent review, and quality assurance process are described in more detail in NUREG/CR-6268, Volumes 1 and 3 (References 2 and 4).

1.2 Common-Cause Failure Event Concepts

CCFs can be thought of as resulting from the coexistence of two main factors: one that provides a susceptibility for components to fail or become unavailable due to a particular cause of failure and a coupling factor (or coupling mechanism) that creates the condition for multiple components to be affected by the same cause.

An example is a case where two relief valves fail-to-open at the required pressure due to set points being set too high. Because of personnel error (the proximate cause), each of the two valves fails due to an incorrect setpoint. What makes the two valves fail together, however, is a common calibration procedure and common maintenance personnel. These commonalties are the coupling factors of the failure event in this case.

Characterization of CCF events in terms of these key elements provides an effective means of performing engineering assessments of the CCF phenomenon including approaches to identification of plant vulnerabilities to CCFs and evaluation of the need for, and effectiveness of, defenses against them. It is equally effective in evaluation and classification of operational data and quantitative analysis of CCF frequencies.

It is evident that each component fails because of its susceptibility to the conditions created by the root cause, and the role of the coupling factor is to make those conditions common to several components. In analyzing failure events, the description of a failure in terms of the most obvious "cause" is often too simplistic. The sequence of events that constitute a particular failure mechanism is not necessarily simple. Many different paths by which this ultimate reason for failure could be reached exist. This chain can be characterized by two useful concepts— proximate cause and root cause.

The proximate cause of a failure event is the condition that is readily identifiable as leading to the failure. The proximate cause can be regarded as a symptom of the failure cause, and it does not in itself necessarily provide a full understanding of what led to that condition. As such, it may not be the most useful characterization of failure events for the purposes of identifying appropriate corrective actions. The proximate cause classification consists of six major categories:

- Design, construction, installation, and manufacture inadequacy causes,
- Operational and human-related causes (e.g. procedural errors, maintenance errors),
- Internal to the component, including hardware-related causes and internal environmental causes,
- External environmental causes,
- State of other component, and
- Other causes.

The causal chain can be long and, without applying a criterion identifying an event in the chain as a "root cause," is often arbitrary. Identifying root causes in relation to the implementation of defenses is a useful alternative. The root cause is therefore the most basic reason or reasons for the component failure, which if corrected, would prevent recurrence. Volume 3 of NUREG/CR-6268 (Reference 4) contains additional details on the cause categories and how CCF event causes are classified.

The coupling factor is a characteristic of a group of components or piece parts that identifies them as susceptible to the same causal mechanisms of failure – it is a characteristic that links the components. Such factors include similarity in design, location, environment, mission, and operational, maintenance, and test procedures. Coupling factors are categorized into the following five groups for analysis purposes:

- Hardware Quality,
- Hardware Design,
- Maintenance,
- Operations, and
- Environment.

Note that proximate causes of CCF events are no different from the proximate causes of single component failures.

The proximate causes and the coupling factors may appear to overlap because the same name is sometimes used as a proximate cause and as a coupling factor (e.g., design, maintenance). However, they are different. For example, maintenance, as a proximate cause, refers to errors and mistakes made during maintenance activities. As a coupling factor, maintenance refers to the similarity of maintenance among the components (e.g., same maintenance personnel, same maintenance procedures).

The defense or defensive mechanism is any operational, maintenance, or design measure taken to diminish the probability and/or consequences of a common-cause failure event. Three ways of defending against a CCF event are the following: (1) defend against the failure proximate cause, (2) defend against the coupling factor, or (3) defend against both the proximate cause and the coupling factor. As an example, consider two redundant components in the same room as a steam line. A barrier that separates the steam line from the components is an example of defending against the proximate cause. A barrier that separates the two components is an example of defending against the coupling factor (same location). Installing barriers around each component is an example of defending against both the cause and the coupling factor.

Proximate causes of CCF events are no different from the proximate causes of single component failures. This observation suggests that defending against single component failures can have an impact on CCFs as well. Most corrective actions usually attempt to reduce the frequency of failures (single or multiple). That is, very often the approach to defending against CCFs is to defend against the cause, not the coupling. Given that a defensive strategy is established based on reducing the number of failures by addressing proximate causes, it is reasonable to postulate that if fewer component failures occur, fewer CCF events would occur.

Defenses against causes result in improving the reliability of each component but do not necessarily reduce the fraction of failures that occur due to common-cause. They typically include design control, use of qualified equipment, testing and preventive maintenance programs, procedure review, personnel training, quality control, redundancy, diversity, and barriers. It is important to remember that the susceptibility of a system of redundant components to dependent failures as opposed to independent failures is determined by the presence of coupling factors.

The above cause-defense approach does not address the way that failures are coupled. Therefore, CCF events can occur, but at a lower probability. If a defensive strategy is developed using protection against a coupling factor as a basis, the relationship among the failures is eliminated. A search for coupling factors is primarily a search for similarities among components. A search for defenses against coupling, on the other hand, is primarily a search for dissimilarities among components, including differences in the components themselves (diversity); differences in the way they are installed, operated, and maintained; and in their environment and location.

During a CCF analysis, a defense based on a coupling factor is easier to assess because the coupling mechanism among failures is more readily apparent and therefore easier to interrupt. The following defenses are oriented toward eliminating or reducing the coupling among failures: diversity, physical or functional barriers, and testing and maintenance policies. A defensive strategy based on addressing both the proximate cause and coupling factor would be the most comprehensive.

A comprehensive review should include identification of the root causes, coupling factors, and defenses in place against them. However, as discussed in NUREG/CR-5460,[7] *A Cause-Defense Approach to the Understanding and Analysis of Common-Cause Failures*, given the rarity of common-cause events, current weaknesses of event reporting and other practical limitations, approaching the problem from the point of view of defenses is, perhaps, the most effective and practical. A good defense can prevent a whole class of CCFs for many types of components, and in this way, the application of a procedure based on this philosophy can provide a systematic approach to screening for potential CCF mechanisms.

1.3 Report Structure

This report presents an overview of the MOV CCF data and insights into the characteristics of that data. This report is organized as follows: Section 2 presents a description of the MOV, a short description of the associated sub-components, and a definition of the MOV failure modes. High level insights of all the MOV CCF data are presented in Section 3. Section 4 summarizes the events by sub-component. Section 5 presents MOV CCF insights by the MOV system. Section 6 provides information about how to obtain more detailed information for the MOV events. A glossary of terms used in this report is included in the front matter. Appendix A contains three listings of the MOV CCF events sorted by proximate cause, coupling factor, and discovery method. Appendix B contains a listing of the MOV CCF events sorted by the sub-component. Appendix C contains a listing of the MOV CCF events sorted by the system.

2. MOTOR-OPERATED VALVE COMPONENT DESCRIPTION

2.1 Introduction

MOVs are used in many safety-related systems at commercial nuclear utilities. MOVs provide the means to direct water flow to provide makeup for lost inventory, to provide cooling, to align suction sources to various pumps, and to bypass certain functions as conditions dictate. The systems with MOVs included in this insights study include:

- AFW — Auxiliary Feedwater System (PWR)
- CSS — Containment Spray (PWR)
- HCI — High Pressure Coolant Injection (BWR)
- HPI — High Pressure Safety Injection (PWR)
- ISO — Isolation Condenser (BWR)
- RHR-B — Residual Heat Removal (BWR)
- RHR-P — Residual Heat Removal (PWR)
- RCS — Reactor Coolant System (PWR)
- RCI — Reactor Core Isolation Cooling (BWR)

2.2 Risk Significance

The emergency core cooling system (ECCS) is designed to supply sufficient water to the reactor vessel and reactor coolant system (RCS) to keep the core covered and to remove decay heat in the event of a loss of coolant inventory or normal core cooling. Thus, the ECCS systems play significantly in transients with a loss of secondary cooling (including loss of off-site power and station blackout), and loss of coolant accidents (LOCAs).[8] While it is generally true that the motor-driven and turbine-driven pumps are the dominant risk contributors for the ECCS systems, MOVs must operate properly to initiate injection flow and shift from the injection to recirculation phase. In PWRs, MOVs are typically part of the design to separate and isolate low-pressure portions of ECCS systems from RCS pressure, mitigating interfacing system LOCAs (ISLOCAs). ISLOCAs typically do not contribute much to the core damage frequency, but are of interest because they bypass the containment and can be significant contributors to risk (Reference 8).

The AFW System in PWRs provides a means of removing decay heat using the secondary system when the normal feedwater system is not available. The most common demands for AFW are transients with loss of secondary heat removal and loss of off-site power (including station blackout), two prominent risk contributors in PWRs. Proper AFW actuation often requires operation of several dc-powered MOVs to direct flow to the steam generators. In cases where the condensate storage tanks are of insufficient capacity, alternate suction sources must be aligned using MOVs. Due to the level of redundancy, individual MOVs rarely (if ever) dominate AFW failure, but CCF of steam generator isolation valves is routinely one of the major contributors to AFW failure.[9]

2.3 Component Description and Boundary

The MOV component boundary is defined as the valve and motor actuator (including internal piece parts), motive and control power supplies (including the circuit breakers), and necessary control devices. Only sensors unique to the operation of the individual valve are included with the valve for CCF analysis. All MOVs have handwheels, which allow them to be manually operated. Failures involving the

handwheels are included. Figure 2-1 shows a cross-sectional view of a typical gate valve and motor actuator.

2.4 Sub-Component Description

The MOVs in this insights study operate under varying pressures, temperatures, and working fluids and may have different valve types. However, all the MOVs in this study share common generalized sub-components. This section contains a brief description of both sub-components that comprise the MOV.

2.4.1 Actuator

The MOV actuator provides motive power to move the valve disk in the open and closed directions. The actuator includes the motor, handwheel, gearbox (gears, clutch, bearings, torque switch, etc.), control devices and circuitry (limit switches, contactors, relays, fuses, etc.), power cables and circuit breaker.

2.4.2 Valve

The valve performs the function of allowing fluid to flow through the valve, throttling flow, or shutting off all flow. The valve includes the valve body, seating surface, disk or plug, yoke, stem, and packing.

2.5 Failure Modes

The functions of MOVs are to promote, restrict, or regulate flow. Depending on the system the MOV is installed in and the required function of the MOV, the MOV may be either normally open or closed. In either case, the direction of movement demanded of the valve at the time of failure was recorded. In some cases, the failure mechanism could cause the valve to fail in either direction. In those cases, the same event may be included twice, once for each possible failure mode. The failure modes used in evaluating the MOV data are:

Fail-to-Open (FTO) — The valve must fully open upon receipt of an open signal. Any position less than full open is considered a failure to open.

Fail-to-Close (FTC) — The valve must fully close on receipt of a close signal, or it is considered a failure to close. Minor leakage is not included in this failure mode, but gross leakage is.

Actuator sub-component failures are evaluated to determine the effect on MOV operability. Actuator failures include those failures that are caused by the motor actuator internals such as the motor, torque limiter, lubrication, handwheel, etc. The actuator also includes the power supply and controls. Typical failures of these include the circuit breaker, pressure switches, logic, etc. In addition, inadequate sizing or setting of piece parts in the actuator can result in the inability of the MOV to perform under design conditions. Failed position indication is included in the actuator sub-component events.

Valve sub-component failures are evaluated to determine the effect on MOV operability. Failures of the valve pieces include inadequate seating (gross leakage), packing leakage or binding, structural defects in the body, etc. In some cases, the design of the valve was inadequate or incorrect. If the design flaw was in the valve, then the failure was recorded under the valve sub-component.

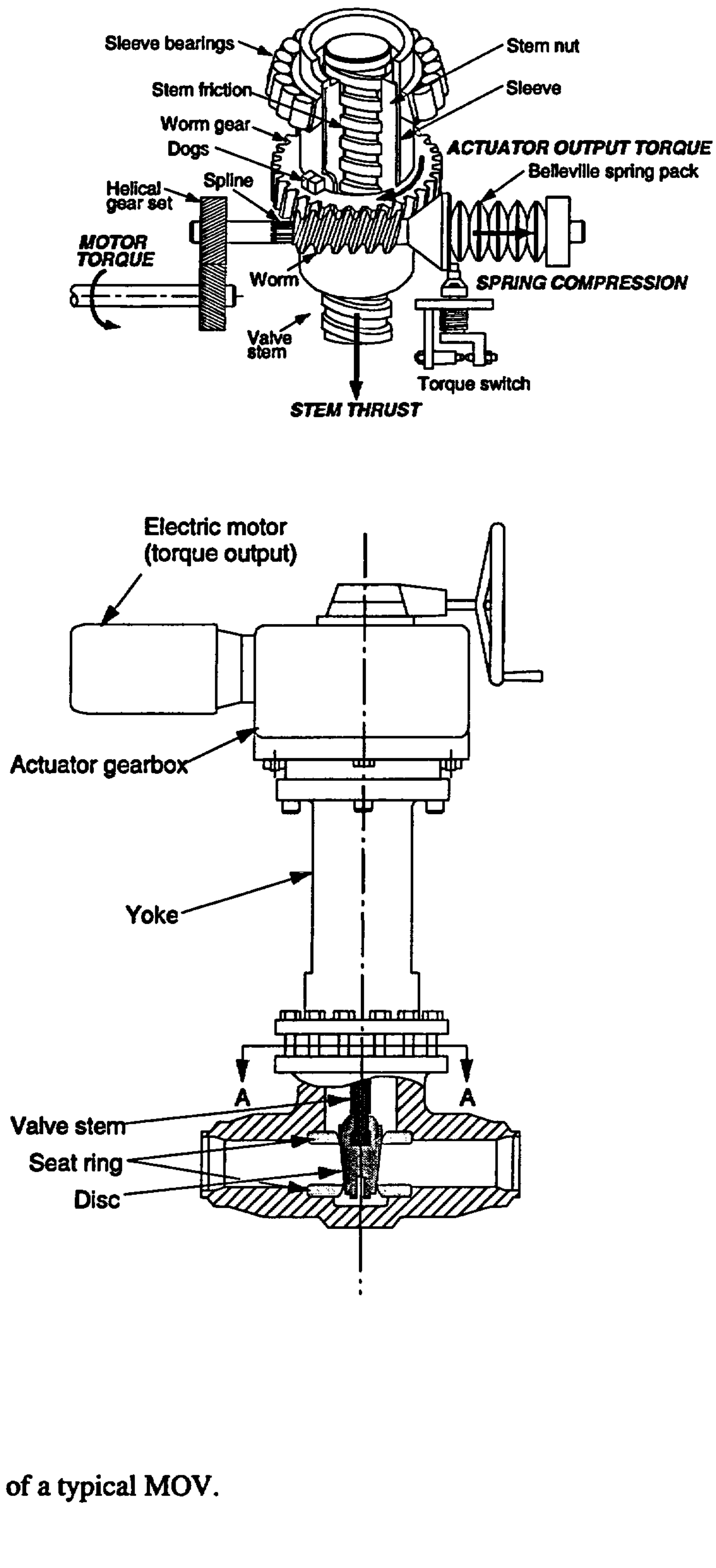

Figure 2-1. Cross-sectional view of a typical MOV.

3. HIGH LEVEL OVERVIEW OF MOTOR-OPERATED VALVE INSIGHTS

3.1 Introduction

This section provides an overview of CCF data for the MOV component that has been collected from the NRC CCF database. The set of MOV CCF events is based on industry data from 1980 to 2000. The MOV CCF data contains attributes about events that are of interest in the understanding of: degree of completeness, trends, MOV sub-component affected, the system affected, causal factors, linking or coupling factors, and event detection methods.

Not all MOV CCF events included in this study resulted in observed failures of multiple MOVs. Many of the events included in the database, in fact, describe degraded states of the MOVs where, given the conditions described, the MOVs may or may not perform as required. The CCF guidance documents (References 3 and 4) allow the use of three different quantification parameters (component degradation value, shared cause factor, and timing factor) to measure degree of failure for CCF events. Based on the values of these three parameters, a Degree of Failure was assigned to each MOV CCF event.

The Degree of Failure category has three groups—Complete, Almost Complete, and Partial. Complete CCF events are CCF events in which each component within the common-cause failure component group (CCCG) fails completely due to the same cause and within a short time interval (i.e., all quantification parameters equal 1.0). Complete events are important since they show us evidence of observed CCFs of all components in a common-cause group. Complete events also dominate the parameter estimates obtained from the CCF database. All other events are termed partial CCF events (i.e., at least one quantification parameter is not equal to 1.0). A subclass of partial CCF events are those that are Almost Complete CCF events. Examples of events that would be termed Almost Complete are: events in which most components are completely failed and one component is degraded, or all components are completely failed but the time between failures is greater than one inspection interval (i.e., all but one of the quantification parameters equal 1.0).

Table 3-1 summarizes, by failure mode and degree of failure, the MOV CCF events contained in this study. The majority of the MOV CCF events were fail-to-open (60 percent). Forty percent of the MOV CCF events involved fail-to-close. Of the 149 MOV CCF events identified from the database, 15 percent were Complete events. These events result in the loss of safety system function. Therefore, they are important because they circumvent the "defense-in-depth" strategy for reactor safety: the use of redundant and diverse components and systems to assure prevention or mitigation of reactor accidents. Complete events also dominate the parameter estimates used to calculate the CCF probability and impact the results of probabilistic risk analysis.

Table 3-1. Summary statistics of MOV data.

Failure Mode	Degree of Failure			Total
	Partial	Almost Complete	Complete	
Fail-to-Close (FTC)	55	2	3	60
Fail-to-Open (FTO)	69	1	19	89
Total	124	3	22	149

Most of the fail-to-close events (92 percent) were Partial CCF events caused by improper settings or failures of the torque and limit switches that prevented the subject MOVs from fully closing. In fact, regardless of the affected sub-component, the fail-to-close failure mode was dominated by events in which the valves failed to fully close. Specific events are listed in more detail in Appendix A of this report. The majority of the Complete events (86 percent) involved fail-to-open, likely because the majority of the subject MOVs are normally closed.

3.2 CCF Trends Overview

Figure 3-1 shows the yearly occurrence rate, the fitted trend, and its 90 percent uncertainty bounds for all MOV CCF events over the time span of this study. The decreasing trend is statistically significant[a] with a p-value[b] of 0.0001. Generic Letter (GL) 89-10, *Safety-Related Motor-Operated Valve Testing And Surveillance*[10] identified widespread problems with MOV operability and testing. This GL required design basis reviews by all licensees and extensive testing to verify MOV operability. GL 96-05, *Periodic Verification of Design-Basis Capability of Safety-Related Power-Operated Valves*[11] required continuing MOV surveillance programs along the line of GL 89-10 requirements. Additionally, GL 95-07, *Pressure Locking and Thermal Binding of Safety-Related Power-Operated Gate Valves*[12] identified several instances of MOV failures to open upon demand due to pressure locking and thermal binding. GL 95-07 required licensees to identify valves susceptible to these phenomena and to implement design changes to prevent failures. Since the mid-1990s, the industry experience regarding design basis requirements, surveillance and testing obtained from these regulatory requirements have been incorporated into the ASME Code Operation and Maintenance (OM) of Nuclear Power Plants. The OM Code contains testing and examination requirements for all safety-related MOVs, as mandated by 10CFR50.55a. Based on the review of failure data for this study, the improved maintenance and operating procedures as well as the improved testing and inspection requirements have facilitated the observed reduction of the occurrence of CCF events over the 21 years of experience included in this study.

Figure 3-2 through Figure 3-4 show trends for subsets of the MOV CCF events contained in Figure 3-1. Figure 3-2 shows the trend for Complete MOV CCF events. The overall trend from 1980 to 2000 is also statistically significant with a p-value of 0.0001. This indicates a dramatic decrease of Complete MOV CCF events, especially since the early-1990's. Figure 3-3 and Figure 3-4 show similar statistically significant decreasing trends for both the fail-to-close (p-value 0.0133) and the fail-to-open failure (p-value 0.0001) modes for all MOV CCF events. In Figure 3-2, the bars at approximately 0.01 events per calendar-reactor year correspond to a single Complete MOV CCF event in the year and the bars at approximately 0.02 correspond to two Complete MOV CCF events in the year.

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a. The term "statistically significant" means that the data are too closely correlated to be attributed to chances and consequently have a systematic relationship. A p-value of less than 0.05 is generally considered to be statistically significant.

b. A p-value is a probability, with a value between zero and one, which is a measure of statistical significance. The smaller the p-value, the greater the significance. A p-value of less than 0.05 is generally considered statistically significant. A p-value of less than 0.0001 is reported as 0.0001.

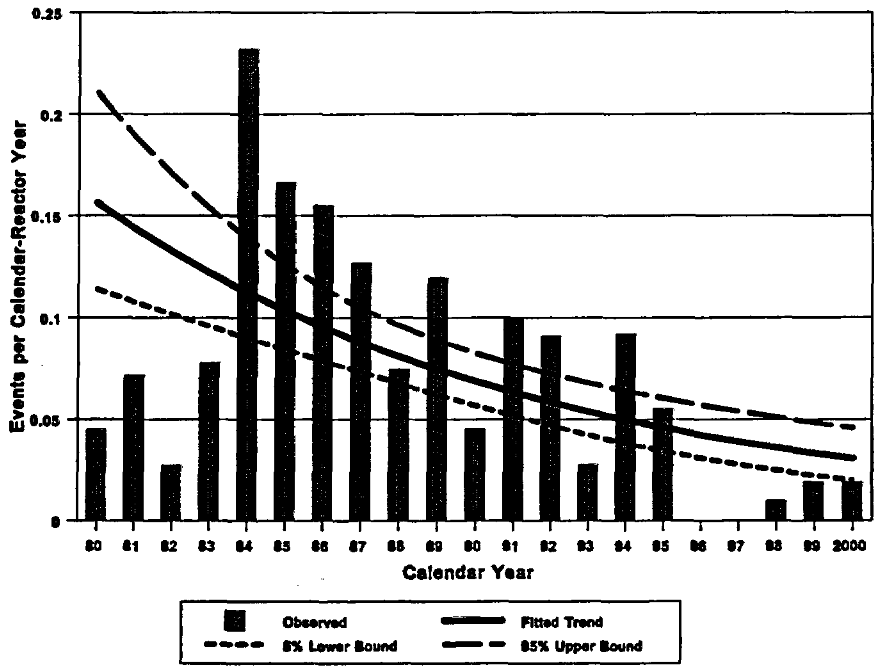

Figure 3-1. Trend for all MOV CCF events. The decreasing trend is statistically significant with a p-value = 0.0001.

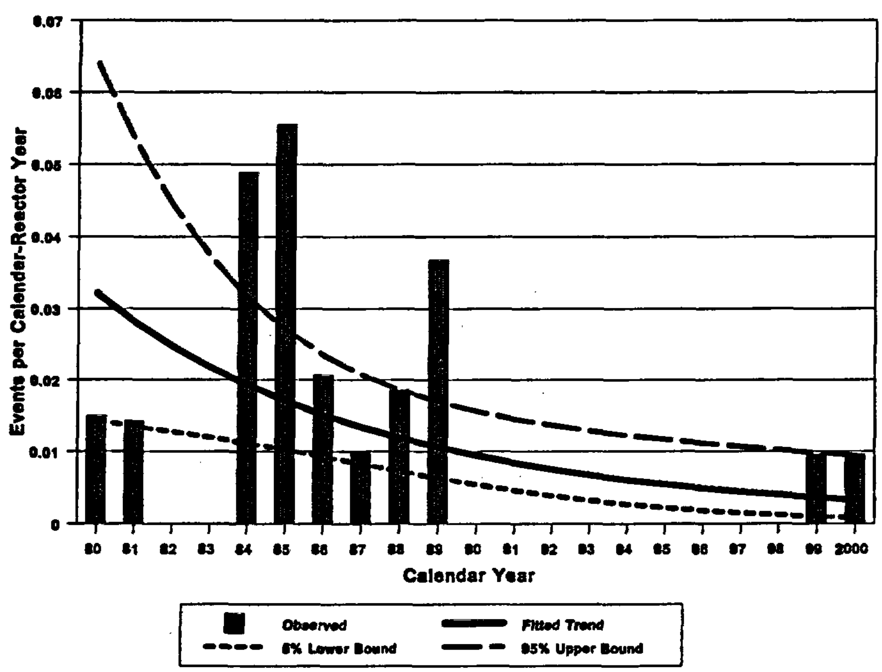

Figure 3-2. Trend for Complete MOV CCF events. The decreasing trend is statistically significant with a p-value = 0.0019.

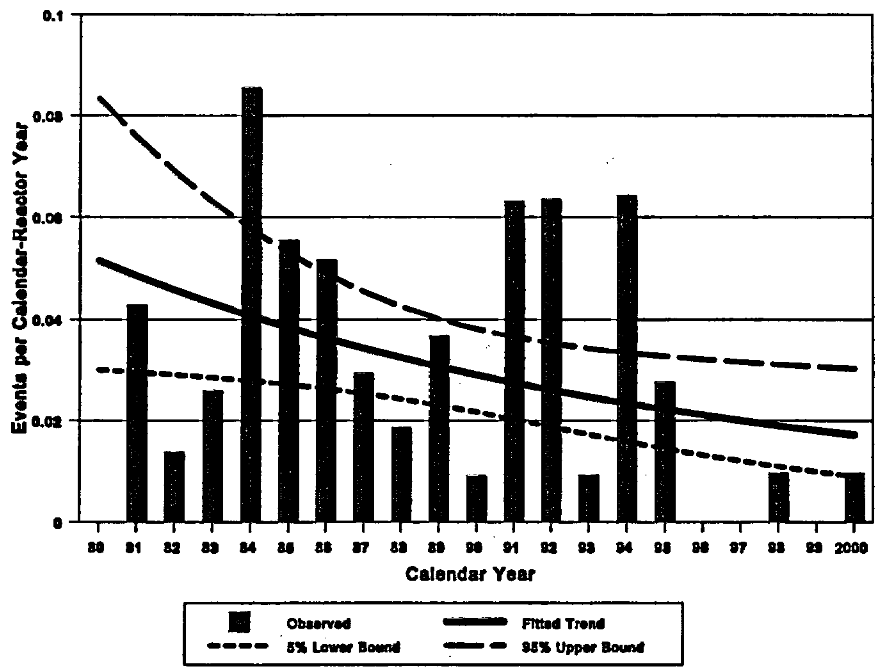

Figure 3-3. Trend for all MOV CCF events for the fail-to-close failure mode. The decreasing trend is statistically significant with a p-value = 0.0133

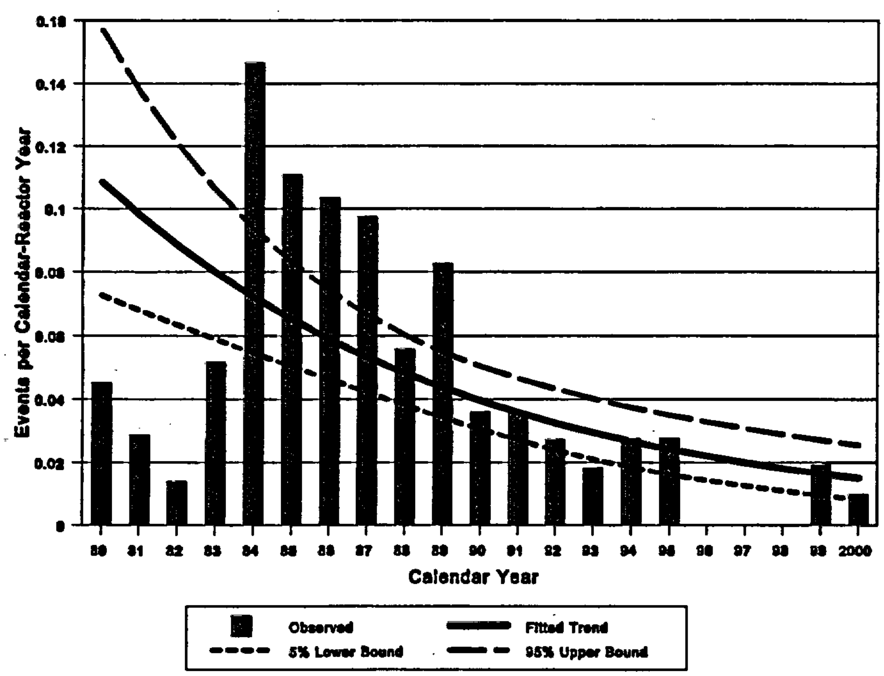

Figure 3-4. Trend for all MOV CCF events for the fail-to-open failure mode. The decreasing trend is statistically significant with a p-value = 0.0001.

3.3 CCF Sub-Component Overview

MOVs can easily be thought of as two sub-components, each with many piece parts. The MOV CCF data were reviewed to determine the affected sub-component and the affected piece part in that sub-

component. This was done to provide insights on which are the most vulnerable MOV sub-components for common-cause failure events. Section 2.4 describes these sub-components.

Figure 3-5 shows the distribution of the CCF events by MOV sub-component. The highest number of events occurred in the actuator sub-component (127 events or 85 percent). The torque switch was the failed component in 31 percent of the actuator events.

Section 4 of this report provides an in-depth analysis of the CCF events assigned to these two sub-components.

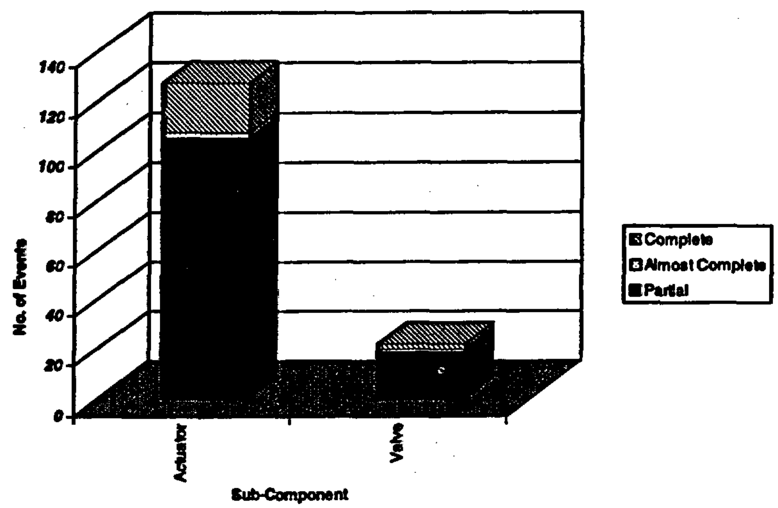

Figure 3-5. Sub-component distribution for all MOV CCF events.

3.4 CCF Proximate Cause

It is evident that each component fails because of its susceptibility to the conditions created by the root cause, and the role of the coupling factor is to make those conditions common to several components. In analyzing failure events, the description of a failure in terms of the most obvious "cause" is often too simplistic. The sequence of events that constitute a particular failure mechanism is not necessarily simple. Many different paths by which this ultimate reason for failure could be reached exist. This chain can be characterized by two useful concepts— proximate cause and root cause.

A **proximate cause** of a failure event is the condition that is readily identifiable as leading to the failure. The proximate cause can be regarded as a symptom of the failure cause, and it does not in itself necessarily provide a full understanding of what led to that condition. As such, it may not be the most useful characterization of failure events for the purposes of identifying appropriate corrective actions.

The proximate cause classification consists of six major groups or classes:

- Design/Construction/Installation/Manufacture Inadequacy
- Operational/Human Error

• Internal to the component, including hardware-related causes and internal environmental causes

• External environmental causes

• Other causes

• Unknown causes.

The causal chain can be long and, without applying a criterion, identifying a condition in the chain as a "root cause," is often arbitrary. Identifying root causes in relation to the implementation of defenses is a useful alternative. The root cause is therefore the most basic reason or reasons for the component failure, which if corrected, would prevent recurrence. (See Table 4-2 in Section 4.1 for a display of the major proximate cause categories and a short description.) Reference 4 contains additional details on the proximate cause categories, and how CCF event proximate causes are classified.

Figure 3-6 shows the distribution of CCF events by proximate cause. The two leading proximate causes were Human error and Design/Construction/Installation/Manufacture Inadequacy. Each accounted for about 27 percent of the total events. Internal to Component faults accounted for 21 percent of the total. To a lesser degree, External Environment and the Other proximate cause categories were assigned to the MOV component. The Other proximate cause category includes setpoint drift in the setting of the torque switches, limit switches, or overcurrent trip devices. There were many MOV CCF events caused by setpoint drift, which generally does not disable the component.

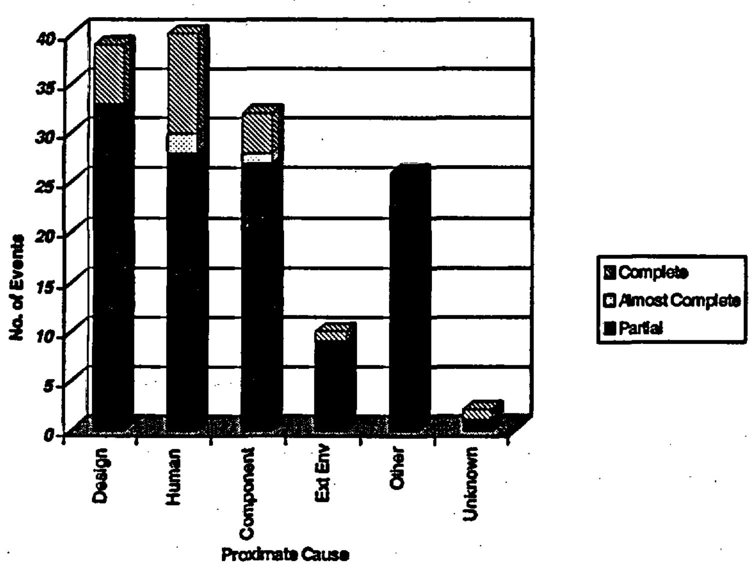

Figure 3-6. Proximate cause distribution for all MOV CCF events.

Table A-1 in Appendix A presents the entire data set of the MOV component, sorted by the proximate cause. This table can be referred to when reading the following discussions to see individual events described.

Design/Construction/Installation/Manufacture Inadequacy errors resulted in 39 events. The failure mode for 20 of these events is fail-to-open, and the remaining 19 events have fail-to-close as the failure mode. There were six Complete CCF events in this proximate cause group; four Complete events

were fail-to-open and two were fail-to-close. Five of the six Complete events were in the actuator sub-component.

The **Operational/Human Error** proximate cause group is the most likely for MOVs and represents causes related to errors of omission or commission on the part of plant staff or contractor staff. Included in this category are accidental actions, failures to follow the correct procedures or following inadequate procedures for construction, modification, operation, maintenance, calibration, and testing. This proximate cause group also includes deficient training. Operational/Human Error resulted in 40 MOV CCF events. The failure mode for 17 events was fail-to-close and 23 events had fail-to-open as the failure mode. There were ten Complete CCF events all fail-to-open; nine involved the actuator sub-component and one involved the valve sub-component. There are disproportionately more Complete events in this proximate cause category than in any other. This observation highlights the importance of maintenance and operations in the availability of MOVs.

These Human Actions include incorrect setting of the torque switches, contactors, and limit switches; installation of the wrong coupling pin in multiple breakers; MOV circuit breaker mis-positionings (breakers left tagged open, opening the wrong breakers, etc.); pulling the wrong control power fuse; and incorrect design calculations that led to installation of the wrong spring pack.

The **Design/Construction/Installation/Manufacture Inadequacy** proximate cause group is also one of the most likely for MOVs and encompasses events related to the design, construction, installation, and manufacture of components, both before and after the plant is operational. Included in this category are events resulting from errors in equipment and system specifications, material specifications, and calculations. Events related to maintenance activities are not included.

The **Internal to Component** proximate cause category is important for MOVs and encompasses the malfunctioning of hardware internal to the component. Internal causes result from phenomena such as normal wear or other intrinsic failure mechanisms that are influenced by the ambient environment of the component. Specific mechanisms include erosion, corrosion, internal contamination, fatigue, wear-out, and end of life. Internal to Component faults resulted in 32 events. Of these, 23 were classified as fail-to-open and nine were fail-to-close. There were four Complete failure events, all associated with the actuator sub-component.

The **External Environment** proximate cause category represents causes related to a harsh environment that is not within the component design specifications. Specific mechanisms include chemical reactions, electromagnetic interference, fire or smoke, impact loads, moisture (sprays, floods, etc.), radiation, abnormally high or low temperature, vibration load, and acts of nature (high wind, snow, etc.). This proximate cause had 10 events assigned to it. The failure mode for six events is fail-to-open, and four events have fail-to-close as the failure mode. There was one Complete CCF event, resulting in fail-to-open. The one complete event was due to excessive condensation shorting out the MOV actuators.

The **Other** proximate cause group is comprised of events that indicated setpoint drift and the state of other components as the basic causes. Twenty-six events were assigned to this category. The failure mode for seventeen events is fail-to-open and nine events have fail-to-close as the failure mode. There were no Complete CCF events in this category, and all of the events in this category are weak (i.e., small degradation values, weak coupling factors, and long time intervals among events).

Setpoint drift includes cases were the actuator output is found to be outside the specified output requirements. This occurrence is not limited to cases where the torque switch setting physically changes. Actuator output can change for a variety of reasons without any physical adjustment of the torque switch setting. For example, changes in the stem friction coefficient (caused by aging of the stem lubricant) can

result in a reduction in actuator output. The stem friction coefficient may also increase under design-basis conditions due to the high stem loads needed to operate the valve. This increase also results in a reduction in actuator output and can result in a demand failure, especially in the close direction. This variation in MOV output due to load is commonly known as "load sensitive behavior."

3.5 CCF Coupling Factor

Closely connected to the proximate cause is the concept of **coupling factor**. A coupling factor is a characteristic of a component group or piece parts that links them together so that they are more susceptible to the same causal mechanisms of failure. Such factors include similarity in design, location, environment, mission, and operational, maintenance, design, manufacturer, and test procedures. These factors have also been referred to as examples of coupling mechanisms, but because they really identify a potential for common susceptibility, it is preferable to think of these factors as characteristics of a common-cause component group. Reference 4 contains additional detail about the coupling factors.

The coupling factor classification consists of five major classes:

- Hardware Quality based coupling factors,
- Design-based coupling factors,
- Maintenance coupling factors,
- Operational coupling factors, and
- Environmental coupling factors.

Figure 3-7 shows the coupling factor distribution for the events. Maintenance is the leading coupling factor with 83 events (56 percent). Maintenance coupling factors result from common maintenance personnel, procedures, and equipment. Design with 42 events (28 percent) accounts for the majority of the remaining events. These two coupling factors account for the top 84 percent of the events. Operational, although a small part of the overall coupling factor distribution, has the highest percentage of Complete events. Again, highlighting the importance of operations in the MOV CCFs.

Table A-2 in Appendix A presents the entire MOV data set sorted by the coupling factor. This table can be referred to when reading the following discussions to see individual events described.

The dominance of the Maintenance coupling factor indicates that the maintenance frequency, procedures, or personnel provided the linkage between the component failures for the majority of the MOV CCF events. Five of the eighty-three MOV CCF events coupled by Maintenance were Complete events. Events with the proximate causes of Internal to Component, Human Action, and Other were predominantly coupled by Maintenance. Examples of the Internal to Component caused events coupled by Maintenance are:

- valve failures due to dirty contacts,
- a failed contactor due to the use of improper lubricant, and
- valve failures due to worn control switches.

Examples of events with the Human Action proximate cause coupled by Maintenance include:

- valve failures due to improper setting of limit switches, torque switches, and contactors; and
- failures due to the use of the wrong shaft coupling pins.

The events with the Other proximate cause coupled by Maintenance primarily involve setpoint drift (mostly limit and torque switches) where the failure coupling was maintenance frequency.

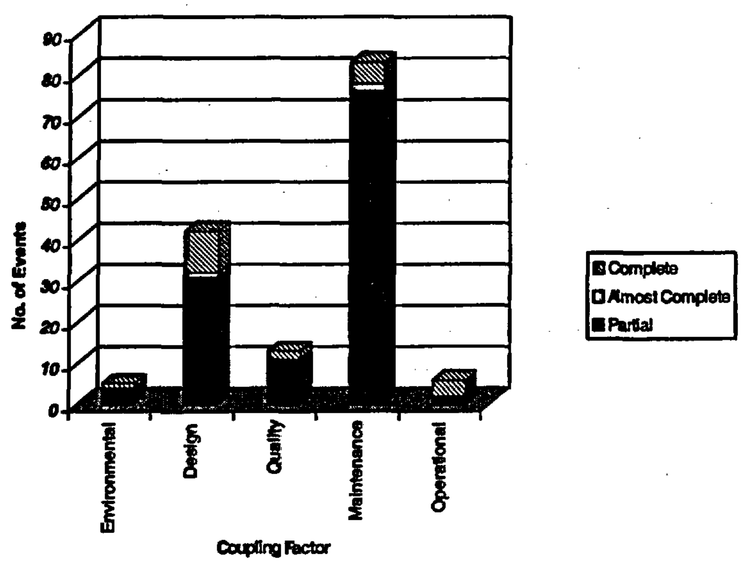

Figure 3-7. Coupling factor distribution for all MOV CCF events.

The **Design** coupling factor is most prevalent in the Design/Construction/Installation/ Manufacture Inadequacy proximate cause category. This means that the design was inadequate and was the link between the events. In most of the events in this proximate cause/coupling factor pair, the failures were coupled by the design of the component internal parts. In other words, common-cause failures occurred because of a design flaw or error involving the same internal piece part or sub-component for multiple MOVs. Examples of these events include:

- design calculations resulting in incorrect torque switch settings,
- valve pressure locking due to improper valve application (operating d/p greater than valve specifications),
- improper valve control circuit wiring due to errors in the valve logic diagrams, and
- wiring errors resulting in insufficient limit switch bypass duration.

The **Environment** coupling factors propagate a failure mechanism via identical external or internal environmental characteristics. Examples of observed environmental coupling factors are:

- steam condensation,

- flooding or water intrusion.

Quality based coupling factors propagate a failure mechanism among several components due to manufacturing and installation faults. An example of a Quality based coupling factor is the failure of several RHR pumps, because of the failure of identical pump air deflectors due to improper installation.

The **Operational** based coupling factors propagate a failure mechanism because of identical operational characteristics among several components. For example, failure of three redundant HPI pumps to start because the breakers for all three pumps were racked-out because of operator error. The Operational based coupling factors have the highest percentage of Complete events.

3.6 CCF Discovery Method Overview

An important facet of these CCF events is the way in which the failures were discovered. Each CCF event was reviewed and categorized into one of the four discovery categories: Test, Maintenance, Demand, or Inspection. These categories are defined as:

Test	The equipment failure was discovered either during the performance of a scheduled test or because of such a test. These tests are typically periodic surveillance tests, but may be any of the other tests performed at nuclear power plants, e.g., post-maintenance tests and special systems tests.
Maintenance	The equipment failure was discovered during maintenance activities. This typically occurs during preventative maintenance activities.
Demand	The equipment failure was discovered during an actual demand for the equipment. The demand can be in response to an automatic actuation of a safety system or during normal system operation.
Inspection	The equipment failure was discovered by personnel, typically during system tours or by operator observations.

Figure 3-8 shows the distribution of how the events were discovered or detected. Testing accounts for 61 events, (41 percent), Demand accounted for 57 events, (38 percent), and 16 events (11 percent) were discovered during Maintenance activities. Another 15 events (10 percent) were detected by inspection. Unlike a standby safety system such as the emergency diesel generators, MOVs have been shown to have more CCFs discovered during demand situations.

Table A-3 in Appendix A presents the entire MOV data set sorted by the discovery method. This table can be referred to when reading the following discussions to see individual events described.

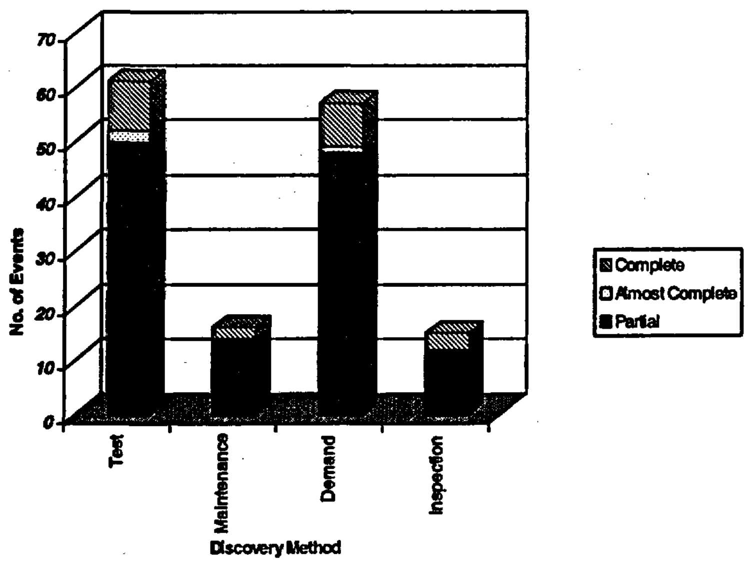

Figure 3-8. Discovery method distribution for all MOV CCF events.

The high percentage of events discovered by demands appears to indicate weaknesses in the MOV testing programs. However, a review of MOV CCF by event dates and method of discovery shows that prior to 1990, 35 percent of events were discovered by Testing while 45 percent were discovered by Demands (Figure 3-9). Since 1990, 52 percent of events have been discovered by Testing while only 24 percent have been discovered by Demands. Therefore, it appears that industry MOV testing programs (instituted as a result of GL 89-10, Reference 10) have increased the effectiveness of failure discovery via testing.

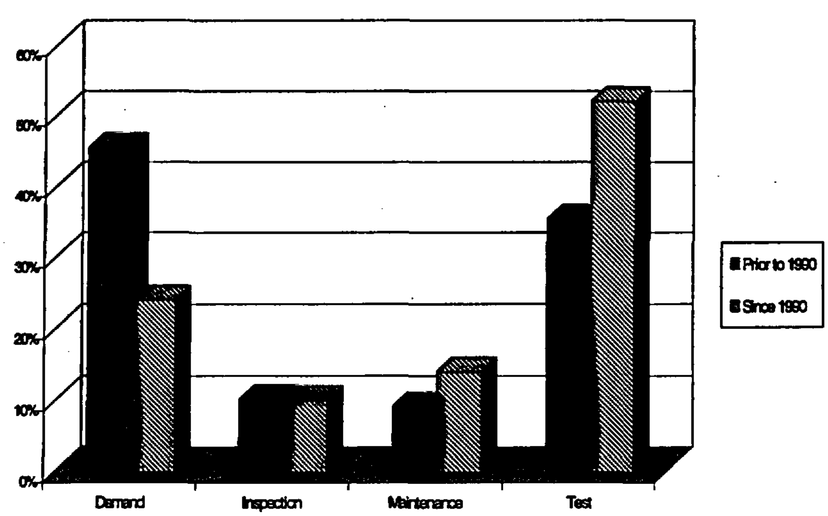

Figure 3-9. Method of discovery before and after 1990.

3.7 MOV CCF System Observations

Figure 3-10 displays the distribution of MOV CCF events by the system and failure degree. There were distinctly more events occurring in the RHR-B system than any other system (29 percent). The RHR-B, HPI, AFW, RHR-P, and CSS systems have the bulk of the events. It is not known if this is due to reporting, use, numbers of MOVs, or a combination of these factors. The review of the data does not suggest that there is any specific causal relationship, other than the installed population of MOVs per system, between the systems and the number of observed CCFs. Section 5 provides a more detailed look at the CCFs in these systems.

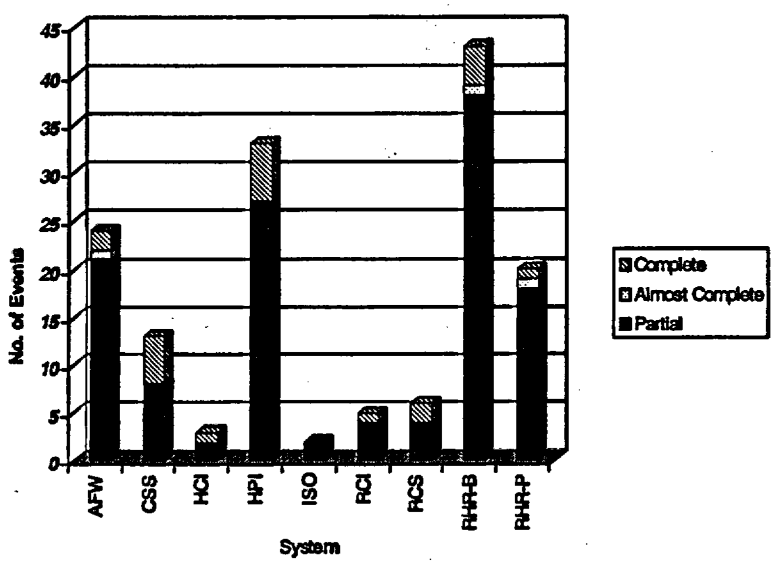

Figure 3-10. Distribution of MOV CCF events by system.

3.8 Other MOV CCF Observations

Figure 3-11 shows the distribution of MOV CCF events among the NPP units. The data are based on 109 NPP units represented in the insights CCF studies. The largest contribution (64 percent) consists of NPP units with either zero or one CCF event. This may indicate that the majority of the plants have maintenance and testing programs to identify possible MOV CCF events and work towards preventing either the first event or any repeat events. Eleven percent of the NPP units have experienced four or more MOV CCF events. Note that 36 percent of the NPP unit population accounts for 81 percent of the MOV CCF events.

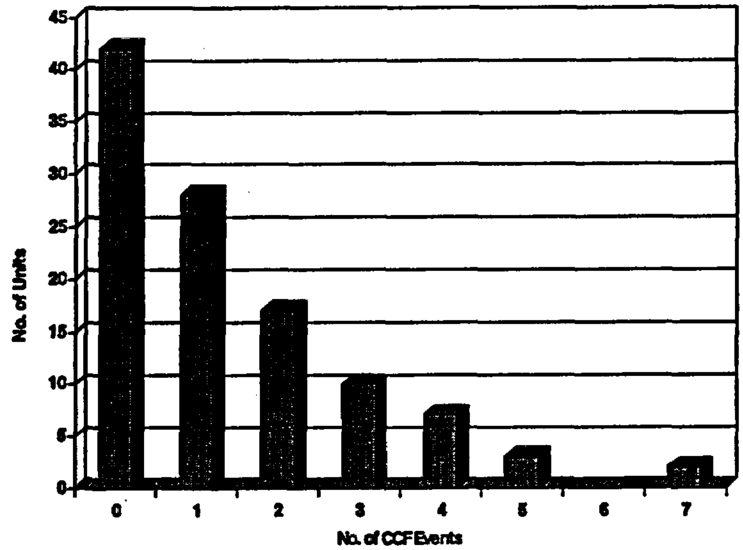

Figure 3-11. Distribution of NPP units experiencing a multiplicity of CCFs for all MOV CCF events.

4. ENGINEERING INSIGHTS BY MOTOR-OPERATED VALVE SUB-COMPONENT

4.1 Introduction

This section presents an overview of the CCF data for the MOV component that have been collected from the NRC CCF database, grouped by the affected sub-component. MOVs can easily be thought of as two sub-components, each with many piece parts. The MOV CCF data were reviewed to determine the affected sub-component and the affected piece part in that sub-component. This was done to provide insights into the most vulnerable areas of the MOV component to common-cause failure events. For the descriptions of the MOV and its sub-components, see Section 2.4.

Table 4-1 summarizes the CCF events by sub-component. Each discussion of an MOV sub-component summarizes selected attributes of that sub-component. A list of the MOV CCF Complete events follows; displaying the proximate cause, failure mode, and a short description of the event. For a listing of all MOV CCF events by sub-component, see Appendix B.

Table 4-1. Summary of sub-components.

Sub-Component	Sub-Section	Partial	Almost Complete	Complete	Total	Percent
Actuator	4.2	105	2	20	127	85.2%
Valve	4.3	19	1	2	22	14.8%
Total		124	3	22	149	100.0%

The majority of the MOV CCF events originated in the actuator sub-component. The torque switch is the most likely piece part to lead to a MOV CCF.

In this study, the proximate causes of the MOV CCF events in the NRC CCF database have been grouped into higher-order proximate cause categories to facilitate the graphical depiction of proximate causes. Table 4-2 contains a hierarchical mapping of the proximate causes of MOV CCF events into the higher-order groups. Since the graph x-axis labels are restricted in length, the proximate cause category names have been shortened and are shown in parenthesis in Table 4-2. Table 4-2 also describes each of these groups.

Table 4-2. Proximate cause hierarchy.

PROXIMATE CAUSE

- Design/Const./Install./Manufacture (Design)
  - Design Error
  - Manufacturing Error
  - Installation/Construction Error
  - Design Modification Error
- Operational/Human Error (Human)
  - Accidental Action
  - Inadequate/Incorrect Procedure
  - Failure to Follow Procedure
  - Inadquate Training
  - Inadequate Maintenance
- External Environment (Ext Env)
  - Fire/Smoke
  - Humidity/Moisture
  - High/Low Temperature
  - Electromagnetic Field
  - Radiation
  - Bio-organisms
  - Contamination/Dust/Dirt
  - Acts of Nature
    - Wind
    - Flood
    - Lightning
    - Snow/Ice
- Internal to Component (Component)
- Other
  - State of Other Component
  - Setpoint Drift
- Unknown

Design/Construction/Installation/Manufacture Inadequacy. This category encompasses actions and decisions taken during design, manufacture, or installation of components both before and after the plant is operational.

Operational/Human Error (Plant Staff Error). Represents causes related to errors of omission and commission on the part of plant staff. An example is a failure to follow the correct procedure. This category includes accidental actions, and failure to follow procedures for construction, modification, operation, maintenance, calibration, and testing. It also includes ambiguity, incompleteness, or error in procedures for operation and maintenance of equipment. This includes inadequacy in construction, modification, administrative, operational, maintenance, test, and calibration procedures.

External Environment. Represents causes related to a harsh external environment that is not within component design specifications. Specific mechanisms include electromagnetic interference, fire/ smoke, impact loads, moisture (sprays, floods, etc.), radiation, abnormally high or low temperature, and acts of nature.

Internal to Component. Is associated with the malfunctioning of hardware internal to the component. Internal causes result from phenomena such as normal wear or other intrinsic failure mechanisms. It includes the influence of the internal environment of a component. Specific mechanisms include erosion/ corrosion, vibration, internal contamination, fatigue, and wearout/ end of life.

Other. Represents other causes including the State of Another Component; The component is functionally unavailable because of failure of a supporting component or system and Setpoint Drift; The component is functional, but will not perform its function within required range due to a degraded piece-part.

Unknown. This cause category is used when the cause of the component state cannot be identified.

4.2 Actuator

One hundred and twenty-seven CCF events affected the actuator sub-component (see Table B-1 in Appendix B, items 1–127). Of these 127 events, 76 were fail-to-open and 51 were fail-to-close. Table 4-3 contains a summary of these events by proximate cause group and failure. Figure 4-1 shows that the most likely proximate cause groups are Design, Construction and Manufacture Inadequacies, Operational/Human Actions, and Internal to the Component. Twenty actuator MOV CCF events were Complete CCF events (see Table 4-4).

Most Actuator CCF events (50 percent) were the result of problems with the torque switch/spring pack or the valve limit switches. The remaining events were essentially evenly distributed among the remaining piece parts (breaker, circuit, motor, or transmission).

Table 4-3. CCF events in the actuator sub-component by cause group and degree of failure.

Proximate Cause Group	Complete	Almost Complete	Partial	Total	Percent
Design/Construction/Installation/ Manufacture Inadequacy	5		27	32	25.2%
Internal to Component	4	1	23	28	22.0%
Operational/Human	9	1	23	33	26.0%
External Environment	1		5	6	4.7%
Other			26	26	20.5%
Unknown	1		1	2	1.6%
Total	20	2	105	127	100.0%

The Design/Construction/Installation/Manufacture Inadequacy proximate cause group had 32 events (25 percent) of which five were Complete (see Table B-1 in Appendix B, items 1 –32). Affected piece parts included thermal overloads and logic and circuitry design. The main causes for this group included installing the wrong equipment, not installing the equipment correctly, and poor design of equipment. Several events involving inadequate thrust under design basis conditions due to under-sized motors, under gearing, incorrect spring packs, and improper torque switch settings were likely identified due to design reviews and testing as a result of GL 89-10, Reference 10. One would expect to see a reduction in these events, since all the reactor plants in the United States have now achieved closure from the NRC of their GL 89-10 programs and have implemented a continuing diagnostic testing program per GL 96-05, Reference 11.

The Internal to Component proximate cause group had 28 events (22 percent) of which four were Complete and one was Almost Complete (see Table B-1 in Appendix B, items 39 –66). Affected piece parts included the torque switch, circuits, limit switches, motors, and transmission. Most of these events were coupled by maintenance.

The Operational/Human Error proximate cause group contains 33 events (26 percent) of which nine were Complete and one was Almost Complete (see Table B-1 in Appendix B, items 67 –99). Affected piece parts included the torque switches, breakers, limit switches, transmission, and motor. Four Complete events were attributed to the breakers. In all these events, the breakers were open due to operator error. Most of these events were coupled by maintenance of equipment, poor maintenance,

performing testing incorrectly, and inattentive operators. This proximate cause group has the highest observed fraction (half) of Complete CCF events in the actuator sub-component. It is the combination of the susceptibility of the actuator sub-component to small errors and the ability of the human element to fail multiple components in a group that led to this result.

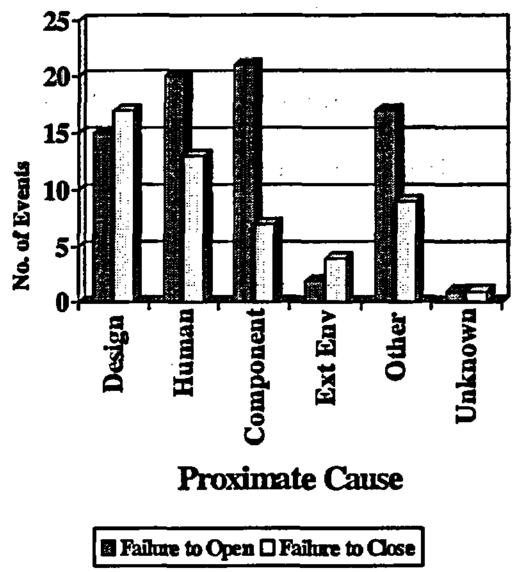

Figure 4-1. Distribution of proximate causes for the actuator sub-component.

The External Environment proximate cause group contains six events (5 percent) of which one was Complete (see Table B-1 in Appendix B, items 33 –38). Affected piece parts included the motor, torque switches, and transmission. External Environment was not a significant contributor to MOV CCF events. This is expected due to significant design and regulatory emphasis regarding component environmental qualification. The Complete event, which occurred in 1980, was due to excessive condensation shorting out the motor.

The Other proximate cause group contains 26 events (21 percent) of which none were Complete (see Table B-1 in Appendix B, items 100 –125). Affected piece parts included the torque switches, limit switches, circuit breakers, and various circuits. Most of these events were coupled by maintenance.

The Unknown proximate cause group has two events (see Table B-1 in Appendix B, items 126 – 127). One was a Complete event, in which the motor burned up, which was attributed to inadequate maintenance.

Testing and Demand were the most likely methods of discovery for actuator MOV events (101 out of the 127 actuator events) as shown in Figure 4-2. The most likely piece parts involved in CCF events were the torque switches and limit switches as shown in Figure 4-3. Four Complete events were attributed to the breakers. In all these events, the breakers were open due to operator error.

Table 4-4 lists the short descriptions by proximate cause for the Complete events, the events that failed all the MOVs in the group. The descriptions of all MOV CCF events can be found in Appendix B.

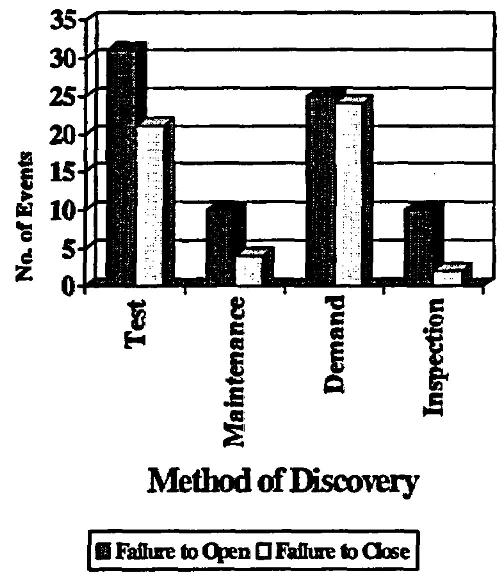

Figure 4-2. Distribution of the method of discovery for the actuator sub-component.

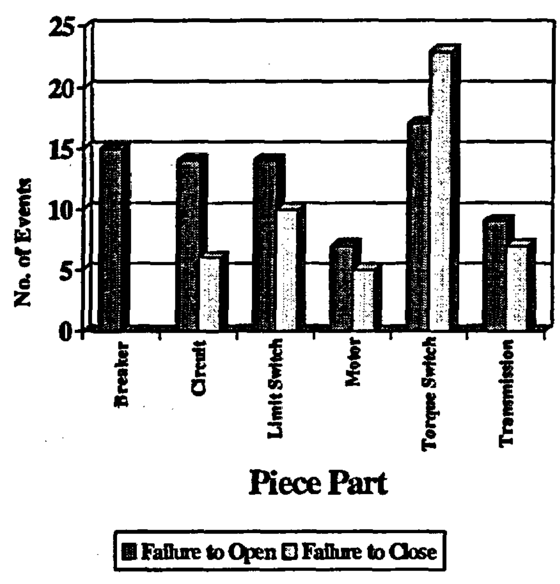

Figure 4-3. Distribution of the affected piece part for the actuator sub-component.

Table 4-4. Actuator sub-component event short descriptions for Complete events.

System	Proximate Cause Group	Failure Mode	Description
HPI	Operational/ Human Error	Failure to Open	Procedures allowed entry into operating mode where the system was required without directing operators to energize HPI MOV valve operators.
RHR-B	Design/ Construction/ Manufacture/ Installation Inadequacy	Failure to Close	Residual heat removal/low pressure coolant injection discharge to suppression pool minimum flow control valves did not close properly on demand. Incorrect logic design prevented valves from closing completely on demand. The new design provided for a seal-in contact with the automatic isolation signal. The seal-in contact allows torque closure of the valve even if the selector key lock switch is in the 'lock' position.
CSS	Design/ Construction/ Manufacture/ Installation Inadequacy	Failure to Open	During surveillance, two containment spray motor operated valves failed to open. The valves were stuck due to excess play in operator assembly, which allowed the open torque switch to disengage thereby shutting off the operator. The bypass limit switch was rewired to a separate rotor with a longer bypass duration per design change.
CSS	Design/ Construction/ Manufacture/ Installation Inadequacy	Failure to Close	During maintenance, testing it was determined that four containment spray MOVs wouldn't develop the required thrust. The failures were attributed to an improper spring pack installation and to an improper torque switch installation. The improper installations were due to incorrect engineering calculations of original design values.
RHR-P	Design/ Construction/ Manufacture/ Installation Inadequacy	Failure to Open	Thermal overloads for two valves tripped due to design deficiency. Consequently, the normal closure of the valve will trip the thermal overload heater some percentage of the time.
RHR-B	Operational/ Human Error	Failure to Open	When the control room operator proceeded to establish shutdown cooling, the suction valves to the system would not open. Investigation revealed that while applying a maintenance permit to the primary containment isolation system, a plant operator unknowingly removed the wrong fuse. This electrically blocked the residual heat removal system shutdown cooling suction valves and head spray isolation valves in the closed position. Investigation revealed that although the plant operator removed the fuse, which was labeled f2, as the permit required, this was not the correct fuse. Apparently, the label had slid down such that fuse f3 appeared to be f2.
RCI	Operational/ Human Error	Failure to Open	During the performance of a scheduled RCI system logic system functional test, an overpressurization of the system's suction piping occurred. The operators incorrectly positioned and/or inaccurately verified the positions of 6 circuit breakers to motor operated valves prior to (and for) the test. RCI system inoperable.

System	Proximate Cause Group	Failure Mode	Description
HPI	Operational/ Human Error	Failure to Open	Operator went to the wrong unit and de-energized a total of five SI valves.
RHR-B	Design/ Construction/ Manufacture/ Installation Inadequacy	Failure to Open	Both RHR-B injection MOVs would not open due to an error in the valve logic circuit diagrams and the removal of motor brakes for environmental qualification. This condition caused the valves to continuously try to close until both valve stems were damaged.
AFW	Operational/ Human Error	Failure to Open	The procedural deficiency that allowed for a low setting of the bypass limit switches on Limitorque valve operators prompted an evaluation of all MOVs. Using the motor operated valve analysis and test system; a review of the as-found conditions of 165 safety-related MOVs revealed that 17 valves were evaluated as inoperable for various reasons. These 17 valves included the auxiliary feedwater isolation valves. Further investigation revealed that Limitorque failed to supply adequate instructions on balancing of the torque switches. Torque switch unbalance resulted in three valves being unable to produce sufficient thrust to close against the design differential pressure.
HPI	Unknown	Failure to Open	The motor operators for 2 valves, which allow the chemical and volume control pumps to take suction from the refueling water storage tank when in the closed position or from the volume control tank when in the opened position, burned up in the closed position and had to be manually opened.
HPI	Operational/ Human Error	Failure to Open	While performing a surveillance test during refueling shutdown, the open contactor for HPI loop isolation valves did not close. The contactors were out of adjustment.
CSS	Operational/ Human Error	Failure to Open	During re-testing, technicians found that the containment sump isolation valve operator internal limit switches were incorrectly set. This prevented the containment spray suction valve from repositioning as required. During a plant modification, technicians incorrectly set the containment sump isolation valve operator's internal limit switch. The switch was set to be open, though drawings called for it to be closed. Due to inadequate functional verification, this error was not found during post modification testing.
HPI	Operational/ Human Error	Failure to Open	Incorrect engineering calculations resulted in spring pack setting that would not open the BIT isolation valves. The third valve, SI pump to accumulators, was discovered with the same failure.
RCS	Internal to Component	Failure to Close	The inlet block MOVs for the PORVs failed to close or open from the control room. This failure was due to the main control room switch for opening and closing the valve has erratic resistance reading as a result of wear and tear of the switch.

System	Proximate Cause Group	Failure Mode	Description
CSS	Internal to Component	Failure to Open	Routine surveillance disclosed that the containment recirculation sump to containment spray pump isolation valves would not open. The motors for valve operators burned up.
RCS	Internal to Component	Failure to Open	The inlet block MOVs for the PORVs failed to close or open from the control room. This failure was due to the main control room switch for opening and closing the valve has erratic resistance reading as a result of wear and tear of the switch.
AFW	Internal to Component	Failure to Open	Loose sliding link caused unplanned swap to LOCAL control. This also caused AFW suction auto swap capability to be blocked. Manual control apparently was still available.
HCI	External Environment	Failure to Open	While testing the torus suction valves, two MOVs failed when given an open signal. Both torus suction valves had shorted out due to excessive condensation in the HCI room area.
HPI	Operational/ Human Error	Failure to Open	The breakers for the high pressure injection suction valves from the BWST were inadvertently left tagged open after the reactor coolant system had been heated up to greater than 350F. The suction supply from the BWST to the HPI pumps was isolated and would not have opened automatically upon engineered safeguards actuation. The root cause is failure to perform an adequate review of the red tag logbook in accordance with the startup procedure.

4.3 Valve

Twenty-two MOV CCF events affected the valve sub-component, of which two events are Complete events (see Table B-2 in Appendix B, items 128–149). Thirteen events were fail-to-open and nine events were fail-to-close. The most likely proximate causes are Design/Construction/Installation /Manufacture Inadequacy, Operational/Human, and Internal to Component as shown in Figure 4-4. Table 4-5 contains a summary of these events by proximate cause group and failure.

Table 4-5. CCF events in valve sub-component by cause group and degree of failure.

Proximate Cause Group	Complete	Almost Complete	Partial	Total	Percent
Design/Construction/Installation/ Manufacture Inadequacy	1		6	7	31.8%
Internal to Component			4	4	18.2%
Operational/Human	1	1	5	7	31.8%
External Environment			4	4	18.2%
Other				0	0.0%
Total	2	1	19	22	100.0%

Of the 22 failures, two were Complete (see Table 4-6). One was human in nature, and was due to maintenance personnel erroneously installing the wrong coupling pin in a number of valves. Another Complete event was due to valve pressure locking. It was expected that pressure locking and thermal binding would have resulted in more than three CCF events since this was an industry generic issue. However, it may be that the low number of thermal binding pressure locking issues is due to the fact that the GL on this subject GL 95-07, Reference 12, was not issued until towards the end of the time period of this study.

The Design/Construction/Installation/Manufacture Inadequacy proximate cause group had seven events (32 percent) of which one was Complete (see Table B-2 in Appendix B, items 128 –134). Affected piece parts included valve disk, body, and stem. The main coupling factors were Design and Environmental.

The Internal to Component proximate cause group had four events (18 percent) of which none were Complete and none were Almost Complete (see Table B-2 in Appendix B, items 139 –142). Affected piece parts included valve disk, body, and packing. The main coupling factors were Design and Maintenance.

The Operational/Human Error proximate cause group contains seven events (32 percent) of which one was Complete and one was Almost Complete (see Table B-2 in Appendix B, items 143 –149). Affected piece parts included valve stem, body, and disk. The main coupling factor was Maintenance.

The External Environment proximate cause group contains four events (18 percent) of which none were Complete (see Table B-2 in Appendix B, items 135 –138). Affected piece parts included the body and the disk. External Environment was not a significant contributor to MOV CCF events. This is

expected due to significant design and regulatory emphasis regarding component environmental qualification.

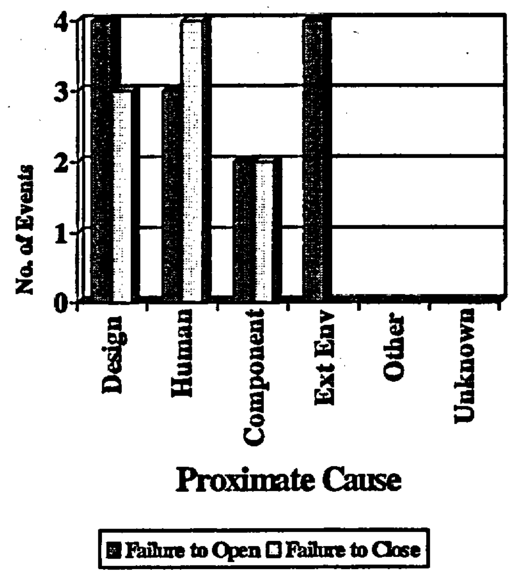

Figure 4-4. Distribution of proximate causes for the valve sub-component.

Demand and Testing were the most likely methods of discovery for the valve sub-component MOV events (17 out of the 22 events) as shown in Figure 4-5. The most likely piece parts involved in CCF events were the disk, stem, and body as shown in Figure 4-6.

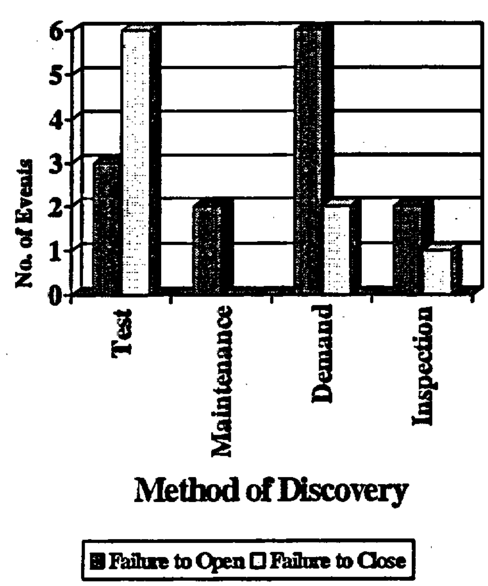

Figure 4-5. Distribution of the method of discovery for the valve sub-component.

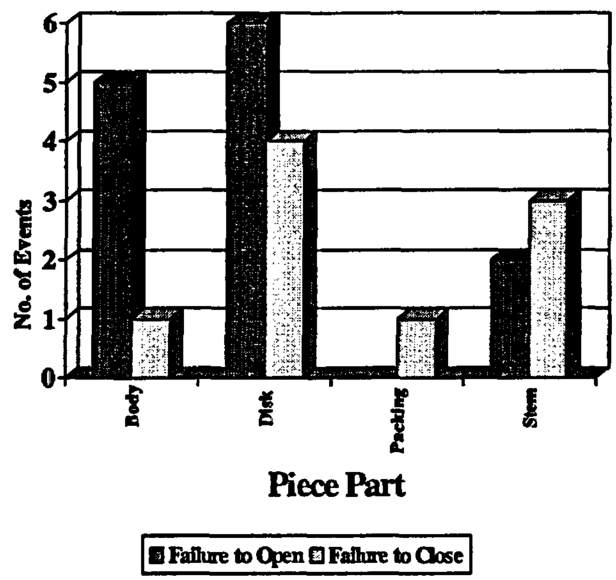

Figure 4-6. Distribution of the affected piece parts for the valve sub-component.

Table 4-6 lists the short descriptions by proximate cause for the Complete events, the events that failed all the MOVs in a group. The descriptions of all MOV CCF events can be found in Appendix B.

Table 4-6. Valve sub-component event short descriptions for Complete events.

System	Proximate Cause Group	Failure Mode	Description
CSS	Operational/ Human Error	Failure to Open	During surveillance tests, two recirculation spray pump suction valves were inoperable. The valve position lights in the control room indicated the valve cycled normally. However, the valve did not move from the closed position. Failure was caused by the shearing of the coupling pin due to inadvertently leaving the incorrect pin, a marlin pin, (tapered pin possibly used for alignment), in the valve operator coupling.
RHR-B	Design/ Construction/ Manufacture/ Installation Inadequacy	Failure to Open	Containment spray mode of RHR/RHR-B two MOV injection valve operator motors failed on overload when stroking valves due to trapped pressurized fluid between discs of the gate valve. This was caused by misinterpretation of valve purchase specifications by vendor.

5. ENGINEERING INSIGHTS BY MOTOR-OPERATED VALVE SYSTEM

5.1 Introduction

This section presents an overview of the CCF data for the MOV component that have been collected from the NRC CCF database, grouped by the system. Each discussion of a system summarizes selected attributes of that system. Table 5-1 shows the summary of the event counts by system and the degree of failure. For a listing of all MOV CCF events, by system, see Appendix C.

Table 5-1. Summary of systems.

System	Sub-Section	Partial	Almost Complete	Complete	Total	Percent
RHR-B	5.2	38	1	4	43	28.9%
HPI	5.3	27		6	33	22.1%
AFW	5.4	21	1	2	24	16.1%
RHR-P	5.5	18	1	1	20	13.4%
CSS	5.6	8		5	13	8.7%
RCS	5.7	4		2	6	4.0%
RCI	5.7	4		1	5	3.4%
HCI	5.7	2		1	3	2.0%
ISO	5.7	2			2	1.3%
Total		124	3	22	149	100.0%

5.2 Residual Heat Removal (BWR)

Forty-three events affected the RHR-B system (see Table C-1 in Appendix C, items 87–129). Figure 5-1 through Figure 5-4 show selected distributions graphically. The most likely proximate causes were the Design/Construction/Installation/ Manufacture Inadequacy and Internal to Component groups (35 and 26 percent of events, respectively). The Maintenance coupled events were mostly affected by maintenance/test schedules and maintenance staff errors. The Design coupled events were mostly affected by components having the same design and internal component parts. The most likely discovery methods were Demands (47 percent of events) and Testing (33 percent). Consistent with the overall results, most events were the result of failures in the Actuator sub-component.

Several events were attributed to fouling, due to sediment (Table C-1, Appendix C, items 102 and 103). These are the only events that could be attributed to the system configuration and environment. The other events are not unique to the RHR-B system. The distribution of proximate causes and coupling factors indicates that there is no single mechanism driving the CCF of RHR-B MOVs. The RHR-B system has the largest number of CCF events. This is primarily due to the large number of MOVs (approximately 20) installed.

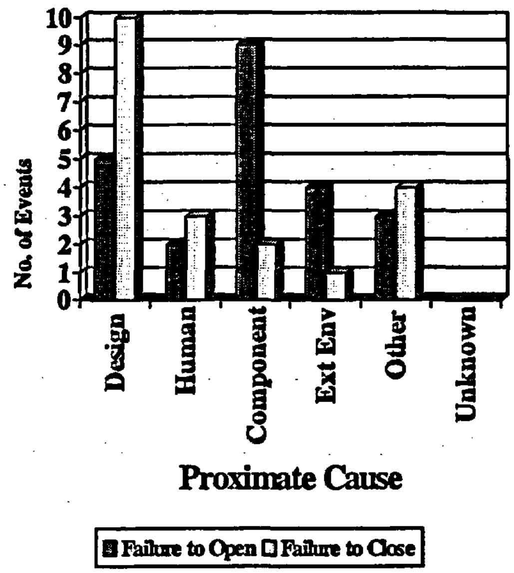

Figure 5-1. Proximate cause distribution for the RHR-B system.

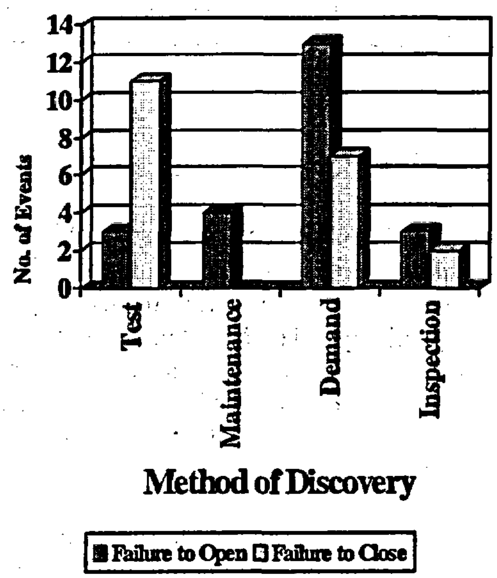

Figure 5-2. Method of discovery distribution for the RHR-B system.

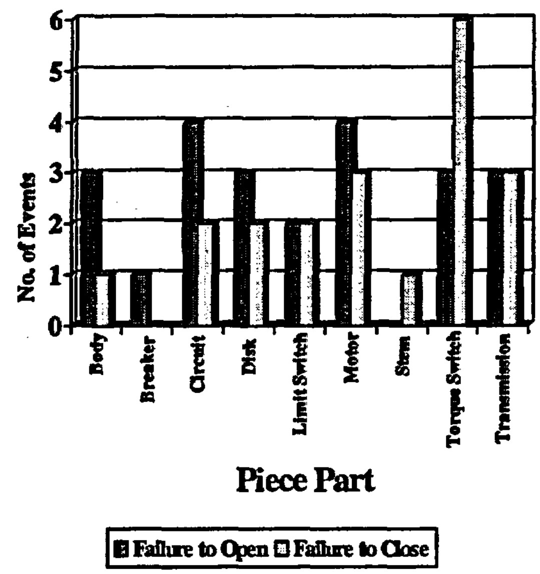

Figure 5-3. Piece part distribution for the RHR-B system.

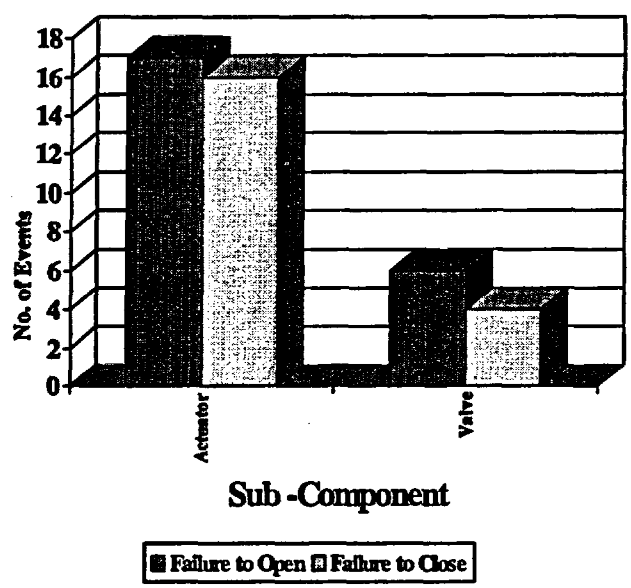

Figure 5-4. Sub-component distribution for the RHR-B system.

5.3 High Pressure Injection

Thirty-three events affected the HPI system (see Table C-1 in Appendix C, items 41–73). Figure 5-5 through Figure 5-8 show selected distributions graphically. The proximate causes for the HPI system events were rather evenly distributed amongst the Operational/Human Error, Other, Design/Construction/Installation/ Manufacture Inadequacy, and Internal to Component cause groups (30, 24, 21, and 15 percent respectively). The Maintenance coupled events were affected by maintenance/test schedules and inadequate procedures. The most likely discovery method was Testing (55 percent). The distribution of the events across the Actuator and Valve sub-components is consistent with the overall study.

None of these events were determined to be unique to the HPI system. The distribution of proximate causes and coupling factors indicates that there is no single mechanism driving the CCF of HPI MOVs.

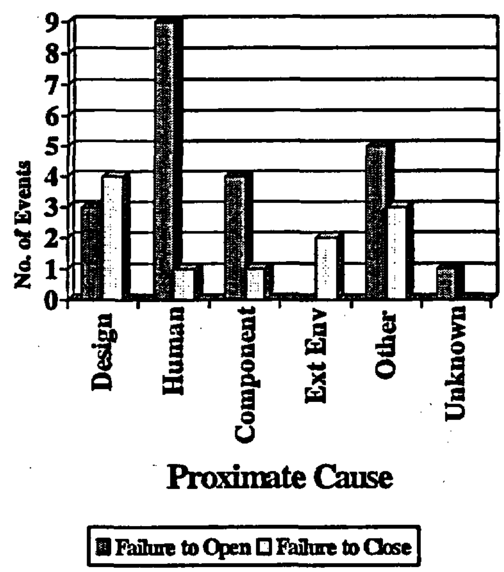

Figure 5-5. Proximate cause distribution for the HPI system.

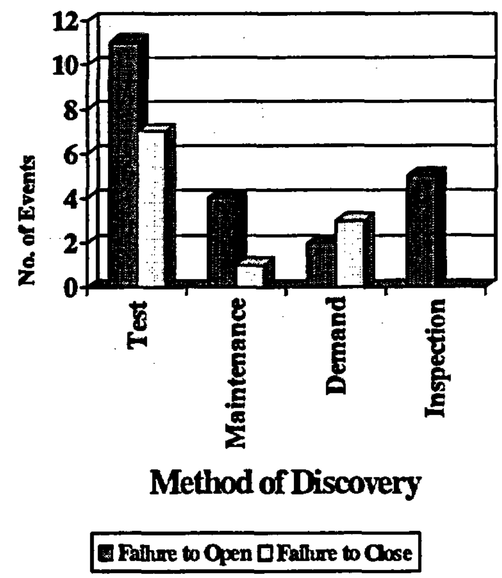

Figure 5-6. Method of discovery distribution for the HPI system.

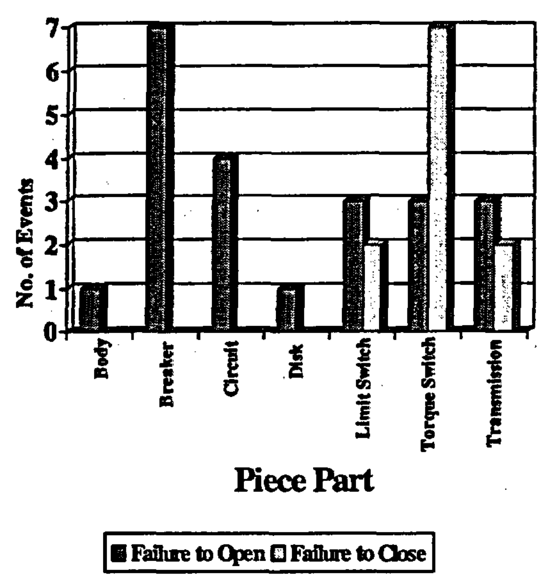

Figure 5-7. Piece part distribution for the HPI system.

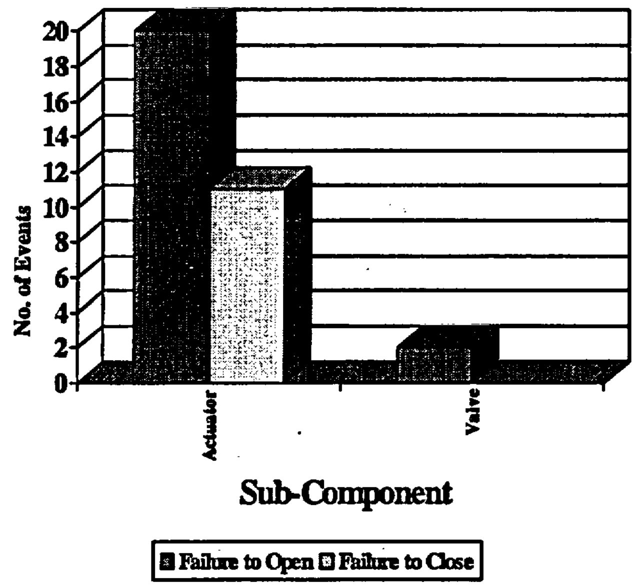

Figure 5-8. Sub-component distribution for the HPI system.

5.4 Auxiliary Feedwater

Twenty-four events affected the AFW system (see Table C-1 in Appendix C, items 1–24). Figure 5-9 through Figure 5-12 show selected distributions graphically. There were two Complete CCF events in the AFW system. The most likely proximate causes for the AFW system events were Operational/Human Error (38 percent), Design/ Construction/Installation/Manufacture Inadequacy (29 percent), and Internal to Component (25 percent). Specifically, most events were coupled by maintenance staff errors and maintenance/test schedules. The most likely discovery method was Demands; however, all these events except one occurred prior to 1990. None of these events were determined to be unique to the AFW system. The distribution of proximate causes and coupling factors indicates that there is no single mechanism driving the CCF of AFW MOVs.

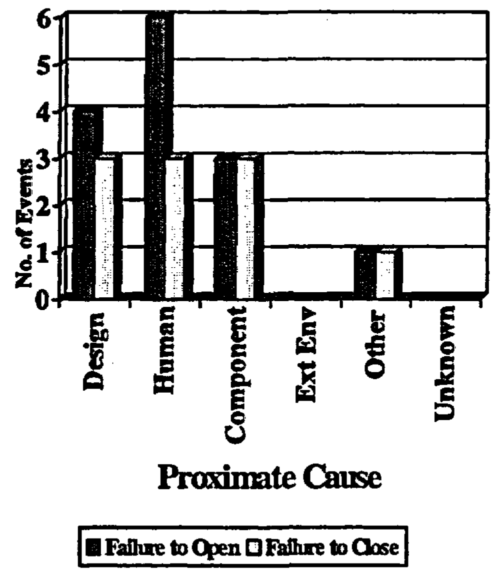

Figure 5-9. Proximate cause distribution for the AFW system.

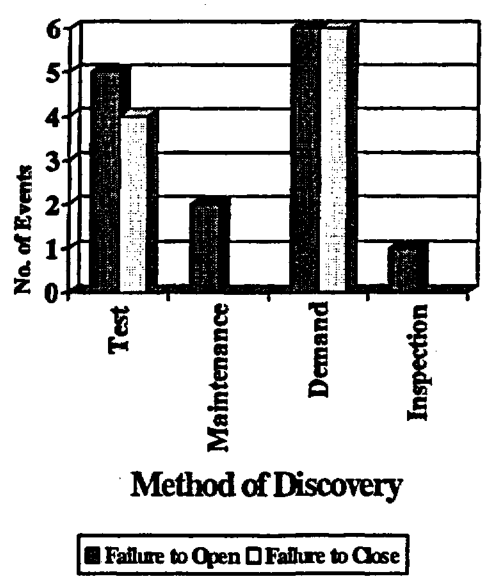

Figure 5-10. Method of discovery distribution for the AFW system.

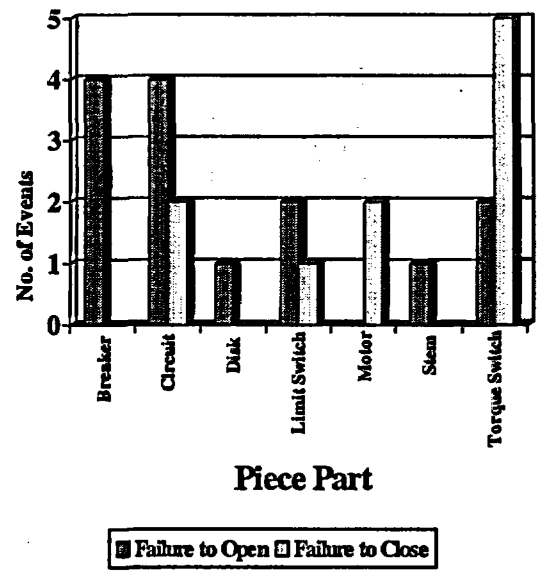

Figure 5-11. Piece part distribution for the AFW system.

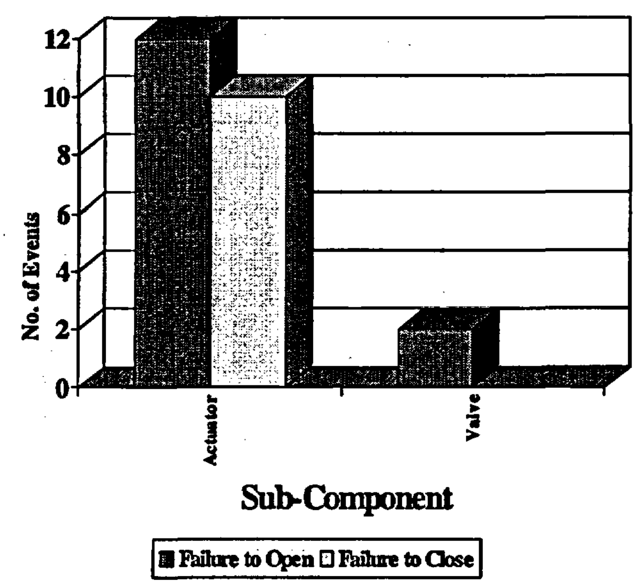

Figure 5-12. Sub-component distribution for the AFW system.

5.5 Residual Heat Removal (PWR)

Twenty events affected the RHR-P system (see Table C-1 in Appendix C, items 130–149). Figure 5-13 through Figure 5-16 show selected distributions graphically. The most likely proximate

causes were Other (35 percent) and Operational/Human Error (25 percent). The Maintenance coupled events were mostly affected by maintenance/test schedules and maintenance/procedures. The Design coupled events were all affected by components having the same design and internal component parts. The most likely discovery methods were Demands (60 percent of events) and Testing (35 percent). Consistent with the overall results, most events were the result of failures in the Actuator sub-component.

The RHR-P MOV events where the valve disks were fouled due to boric acid buildup and where torque switch settings were impacted by vibrations were the only events that could be attributed to the system configuration and environment (Table C-1, Appendix C, items 134 and 135). The majority of the events that occurred with RHR-P system MOVs are not unique to the RHR-P system. The distribution of proximate causes and coupling factors indicates that there is no single mechanism driving the CCF of RHR-P MOVs.

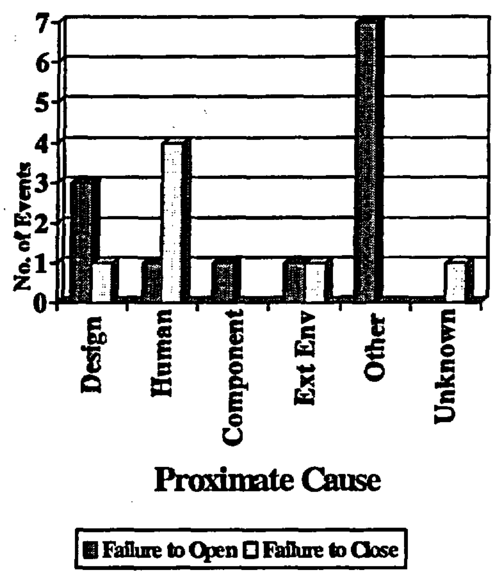

Figure 5-13. Proximate cause distribution for the RHR-P system.

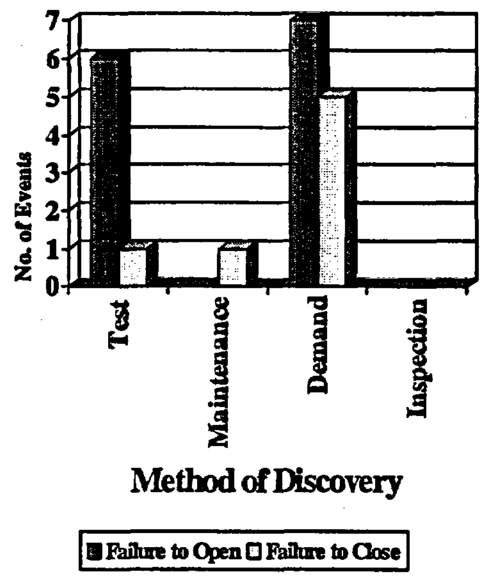

Figure 5-14. Method of discovery distribution for the RHR-P system.

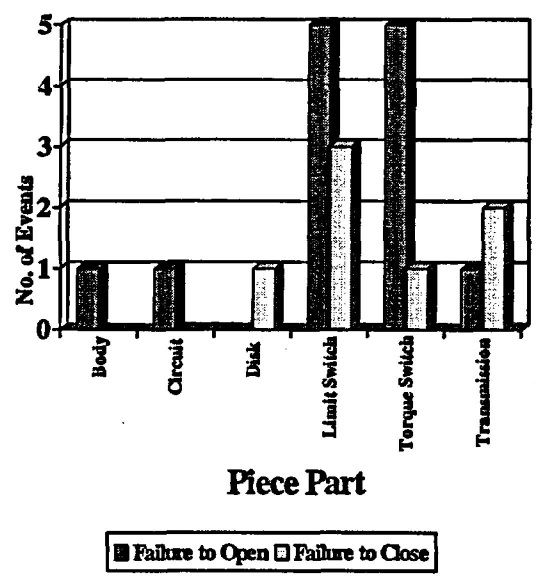

Figure 5-15. Piece part distribution for the RHR-P system.

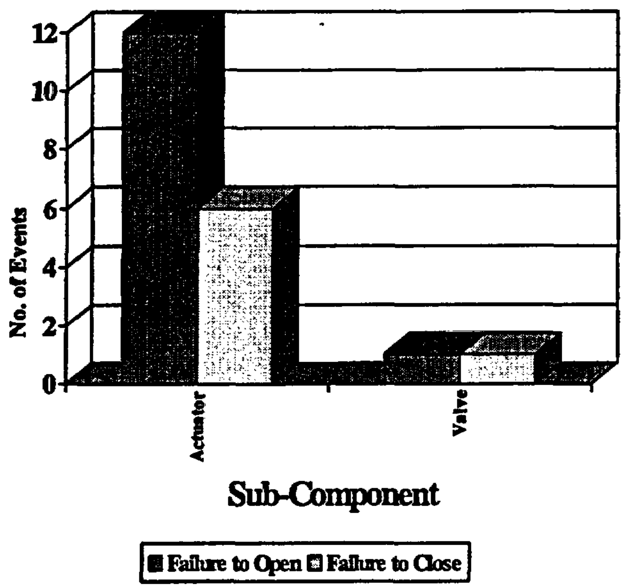

Figure 5-16. Sub-component distribution for the RHR-P system.

5.6 Containment Spray System

Thirteen events affected the CSS system (see Table C-1 in Appendix C, items 25–37). Figure 5-17 through Figure 5-20 show selected distributions graphically. The CSS system had 38 percent of its CCF events classified as Complete. This is the highest fraction of Complete events in the systems studied. The proximate causes for the CSS system events were approximately evenly distributed amongst the Operational/Human Error, Design/Construction/ Installation/Manufacture Inadequacy, and Internal to Component cause groups (31, 31, and 23 percent, respectively). The Maintenance coupled events were affected by maintenance staff errors and maintenance/test schedules. The Design coupled events were affected by components having the same design and internal component parts. Most events were discovered by Testing (62 percent). No events were discovered by Demands. The distribution of the events across the Actuator and Valve sub-components is consistent with the overall study. None of these events are unique to the CSS system. The distribution of proximate causes and coupling factors indicates that there is no single mechanism driving the CCF of CSS MOVs.

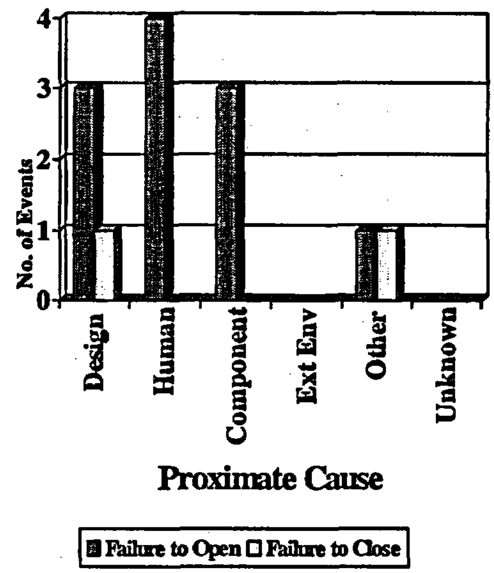

Figure 5-17. Proximate cause distribution for the CSS system.

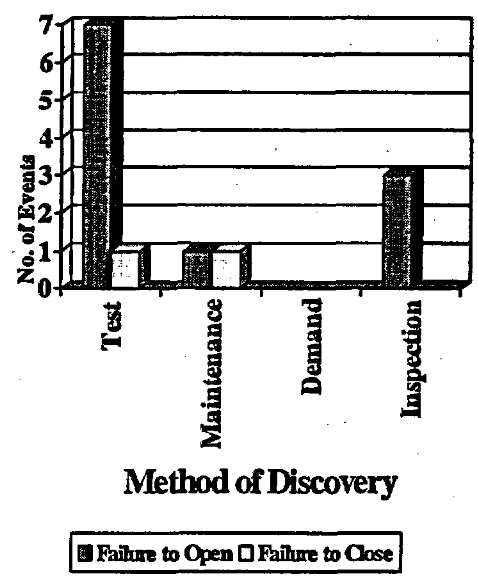

Figure 5-18. Method of discovery distribution for the CSS system.

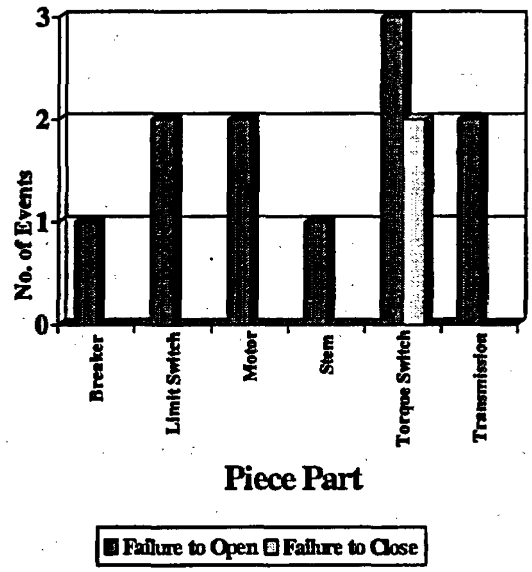

Figure 5-19. Piece part distribution for the CSS system.

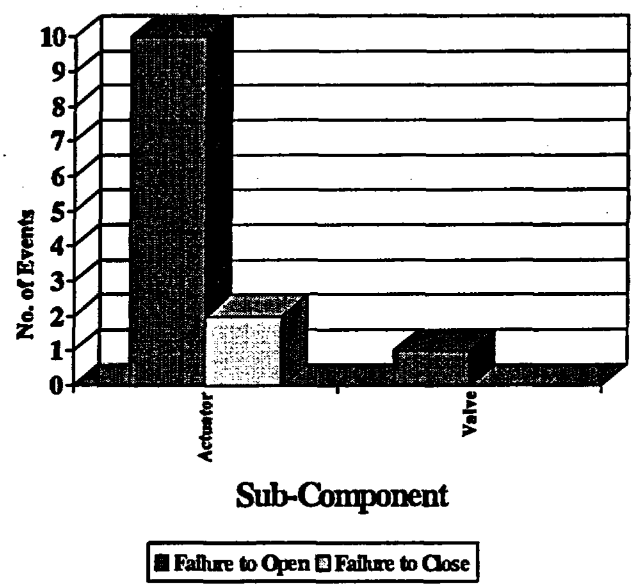

Figure 5-20. Sub-component distribution for the CSS system.

5.7 Other Systems

Sixteen events affected the RCS, HCI, RCI, and ISO systems. Since these systems have so few events, no charts will be presented. Events in these systems are summarized in this section.

5.7.1 Reactor Coolant System Event Summary

Six events affected the RCS system (see Table C-1 in Appendix C, items 81–86). Two of these CCF events were Complete. Both of these events were at the same NPP unit and were coded as both fail-to-open and fail-to-close because the RCS power operated relief valve (PORV) inlet block MOVs control switch would not control the valves in either the open or close direction. The rest of the events were fail to fully close events. There are very few RCS MOV events in the database. This is most likely due to the small number of valves in the RCS system.

5.7.2 High Pressure Coolant Injection System Event Summary

Three events affected the HCI system (see Table C-1 in Appendix C, items 38–40). One of these events was Complete. The Complete event was due to a steam leak, causing both HCI suction valves to fail.

5.7.3 Reactor Coolant Injection System Event Summary

Five events affected the RCI system (see Table C-1 in Appendix C, items 76–80). The one Complete event was due to mis-positioning six RCI MOV breakers.

5.7.4 Isolation Condenser System Event Summary

Two events affected the ISO system (see Table C-1 in Appendix C, items 74–75). Neither of these events were Complete. Both of these events were at the same NPP unit. Thermal binding and damaged stem nuts were the causes. There are very few ISO MOV events in the database. This due to the small number of valves in the ISO system and because very few NPP units have the ISO system.

6. HOW TO OBTAIN MORE DETAILED INFORMATION

The MOV CCF insights for the U.S. plants are derived from information contained in the CCF Database maintained for the NRC by the INEEL. The database contains CCF-related events that have occurred in U.S. commercial nuclear power plants reported in LERs, NPRDS failure records, and EPIX failure records. The NPRDS and EPIX information is proprietary. Thus, the information presented in the report has been presented in such a way to keep the information proprietary.

The subset of the CCF database presented in this volume is based on the MOV component data from 1980 through 2000. The information contained in the CCF Database consists of coded fields and a descriptive narrative taken verbatim from LERs or NPRDS/EPIX failure records. The database was searched on component type (MOV) and failure mode. The failure modes selected were fail-to-open and fail-to-close. The additional fields, (e.g., proximate cause, coupling factor, shared cause factor, and component degradation values), along with the information contained in the narrative, were used to glean the insights presented in this report. The detailed records and narratives can be obtained from the CCF Database and from respective LERs and NPRDS/EPIX failure records.

The CCF Database was designed so that information can be easily obtained by defining searches. Searches can be made on any coded fields. That is, plant, date, component type, system, proximate cause, coupling factor, shared cause factor, reactor type, reactor vendor, CCCG size, defensive mechanism, degree of failure, or any combination of these coded fields. The results for most of the figures in the report can be obtained or a subset of the information can be obtained by selecting specific values for the fields of interest. The identified records can then be reviewed and reports generated if desired. To obtain access to the NRC CCF Database, contact Dale Rasmuson at the NRC or Ted Wood at the INEEL.

7. REFERENCES

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11. U.S. Nuclear Regulatory Commission, *Periodic Verification of Design-Basis Capability of Safety-Related Power-Operated Valves*, Generic Letter 96-05.

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Appendix A

Data Summary

Appendix A

Data Summary

This appendix is a summary of the data evaluated in the common-cause failure (CCF) data collection effort for MOVs. The tables in this appendix support the charts in Chapter 3. Each table is sorted alphabetically, by the first four columns.

Appendix A

Table A-1. MOV CCF events sorted by proximate cause.

Item	Proximate Cause	Sub-Component	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
1	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Demand	Circuit	AFW	Maintenance	1984	Failure to Open	Partial	Aux. feedwater flow control valves would not open. On one the motor control contactor was not contacting due to 2 loose connections; and the other the torque close setting was misadjusted, causing contacts to open too soon.
2	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Demand	Circuit	RHR-B	Design	1984	Failure to Open	Complete	Both LCI injection MOVs would not open due to an error in the valve logic circuit diagrams and the removal of motor brakes for environmental qualification. This condition caused the valves to continuously try to close until both valve stems were damaged.
3	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Demand	Circuit	RHR-B	Design	1986	Failure to Close	Complete	Residual heat removal/low pressure coolant injection discharge to suppression pool minimum flow control valves did not close properly on demand. Incorrect logic design prevented valves from closing completely on demand. The new design provided for a seal-in contact with the automatic isolation signal. The seal-in contact allows torque closure of the valve even if the selector key lock switch is in the 'lock' position.
4	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Demand	Circuit	RHR-P	Design	1999	Failure to Open	Complete	Thermal overloads for two valves tripped due to design deficiency. Consequently, the normal closure of the valve will trip the thermal overload heater some percentage of the time.
5	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Demand	Limit Switch	RHR-P	Design	1985	Failure to Close	Partial	Shutdown cooling system heat exchanger isolation valves were not fully closed. The condition resulted from premature actuation of valve motor operator position indication limit switches and control room indication of the valves being in the closed position. A change is being implemented for these valves to separate the torque switch bypass limit switch and the valve position indicating limit switch by rewiring the position indicating rotors.
6	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Demand	Motor	RHR-B	Design	1991	Failure to Close	Partial	RHR test return valves failed to seat tightly due to friction related problems. Replaced valve operators.
7	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Demand	Motor	AFW	Design	1989	Failure to Close	Partial	AFW MOVs would not fully close under high d/p conditions until the valve actuators were setup at the highest torque switch setting allowed by the tolerances.
8	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Demand	Motor	RHR-B	Design	1987	Failure to Open	Partial	Suppression pool cooling valves (one in each loop) failed to open. As long as the RHR pump was operating, the valves could not be opened and the thermal overloads would trip. Cause was an incorrectly sized motor.

Item	Proximate Cause	Sub-Component	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
9	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Demand	Torque Switch	HPI	Maintenance	1985	Failure to Close	Partial	Motor torque switches were out of adjustment and did not allow full closure.
10	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Demand	Transmission	RHR-P	Design	1991	Failure to Open	Partial	The motor operator for cold leg isolation valve electricallyengaged while the valve was being manually stroked open during post-modification testing. The motor operator electrically engaged and closed the valve (short stroking). Investigation determined that this electrical short stroking of the valve caused the motor pinion key to shear. Other safety-related motor operators were inspected. The motor operators were identified as having failed keys similar to the failed key identified earlier. Further investigation revealed small cracks emanating from both corners of the keyway on the motor shaft. The root cause of the sheared motor pinion gear was that the key material was inadequate.
11	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Inspection	Breaker	HPI	Quality	1980	Failure to Open	Partial	Power leads were found reversed to two safety injection valve operators. Root cause was poor administrative control.
12	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Inspection	Breaker	AFW	Quality	1989	Failure to Open	Partial	The 125 vdc breakers for motor-operated valves in the turbine driven auxiliary feedwater pump system were not the proper size.
13	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Inspection	Transmission	RHR-B	Maintenance	1992	Failure to Close	Partial	LCI MOV motor pinion key replacements were supposed to be performed in 1982 to change the keys to an appropriate material key. This replacement was not performed and was discovered in 1992, as 3 valve keys were found sheared or nearly sheared.
14	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Inspection	Transmission	RHR-B	Design	1990	Failure to Close	Partial	Investigating failure of motor operated valve to achieve minimum required closing thrust. Actuator for inboard isolation valve not geared to supply specified 110% design thrust. Outboard isolation valve and 6 other motor operated valves (2 in RHR) had same actuator problems due to failure to consider design capabilities prior to establishing diagnostic testing criteria.
15	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Inspection	Transmission	CSS	Design	1993	Failure to Open	Partial	The motor pinion key for a Containment Spray header isolation valve was sheared. Subsequent motor pinion key failures occurred on October 18, 1993, March 23, 1994, and April 13, 1994. The evaluations for these events determined that the failures were due to improper key material.
16	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Maintenance	Breaker	AFW	Quality	1989	Failure to Open	Partial	The trip coils installed in the power supply feeder breakers for the motor actuator for two AFW MOVs were incorrect.

Item	Proximate Cause	Sub-Component	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
17	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Maintenance	Transmission	RHR-B	Quality	1990	Failure to Open	Partial	Normal maintenance on suppression chamber cooling Loop B throttle valve. Suppression chamber cooling Loop B throttle valve motor pinion key sheared and Loop A throttle valve motor pinion key deformed. Keys were found to be of the wrong material due to vendor inadequacies and utility programmatic deficiencies.
18	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Test	Circuit	AFW	Quality	1982	Failure to Open	Partial	It was determined that a train of AFW MOV's would not open on a steam generator low-low level. Some of the wiring to be done for design a change was incomplete upon completion of the design change.
19	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Test	Limit Switch	RHR-B	Maintenance	1988	Failure to Close	Partial	During surveillance testing of the RHR shutdown cooling isolation valves revealed that each loop injection valve failed to close as required. The failure was due to a wiring error on the limit switches associated with RHR suction valves. An incorrect limit switch was used for both valves, which made a slight mis-operation of the switches capable of affecting the close circuitry of the isolation valves.
20	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Test	Motor	RHR-B	Design	1992	Failure to Close	Partial	Due to the original valve operator selection criteria using less conservative factors, the outboard primary containment spray isolation valves had an inadequate torque and thrust capability. Design requirement is 134 ft-lbs; available is 100 ft-lbs.
21	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Test	Motor	RHR-B	Design	1989	Failure to Close	Partial	Due to incorrectly sized operator the Torus cooling valves would not completely close against full differential pressure.
22	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Test	Torque Switch	RHR-B	Design	1987	Failure to Close	Partial	During operability test of RHR, a loop isolation valve would not close against system operating pressure due to an undersized washer spring pack in valve operator, supplied to the plant in actuators by the vendor not in accordance with purchase specifications. Similar problem found on the other loop isolation valve.
23	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Test	Torque Switch	AFW	Design	1989	Failure to Close	Partial	Seven AFW valves would open but would not fully close electrically. The cause of failure was that the valve operator and valve were previously changed out on a modification and passed the post modification test. Upon investigation of the valve failure it was determined that the design engineers had the thrust values wrong and the torque switch was reflecting a 1085 psi system when in fact the system is 1600 psi.
24	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Test	Torque Switch	AFW	Design	1994	Failure to Close	Partial	Auxiliary Feedwater Pumps to Steam Generator Isolations were determined to be past inoperable. Differential pressure testing conducted during the outage revealed the valves would not sufficiently close against design basis system conditions to isolate flow.
25	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Test	Torque Switch	HPI	Design	1994	Failure to Close	Partial	HPI MOVs failed to fully close. Engineering determined that the recommended close thrust was insufficient to close valve during worst case failure.

Item	Proximate Cause	Sub-Component	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
26	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Test	Torque Switch	CSS	Design	1985	Failure to Open	Partial	During maintenance, testing it was determined that four containment spray MOVs wouldn't develop the required thrust. The failures were attributed to an improper spring pack installation and to an improper torque switch installation. The improper installations were due to incorrect engineering calculations of original design values.
27	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Test	Torque Switch	CSS	Design	1984	Failure to Open	Complete	During surveillance, two containment spray motor operated valves failed to open. The valves were stuck due to excess play in operator assembly, which allowed the open torque switch to disengage thereby shutting off the operator. The bypass limit switch was rewired to a separate rotor with a longer bypass duration per design change.
28	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Test	Torque Switch	CSS	Design	1985	Failure to Close	Complete	During maintenance, testing it was determined that four containment spray MOVs wouldn't develop the required thrust. The failures were attributed to an improper spring pack installation and to an improper torque switch installation. The improper installations were due to incorrect engineering calculations of original design values.
29	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Test	Torque Switch	RHR-P	Design	1985	Failure to Open	Partial	During maintenance testing it was determined several residual heat removal MOVs wouldn't develop the required thrust as specified by the motor operated valve testing program. The failure was attributed to an improper torque switch installation due to incorrect engineering calculations of original design values. The appropriate torque switch was installed, adjusted per the revised engineering values, tested, and returned to service.
30	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Test	Torque Switch	HPI	Maintenance	1991	Failure to Close	Partial	The high pressure safety injection system flow control containment isolation valves failed to completely close because total close thrust was not sufficient to close valve under dynamic stroke. A thrust value beyond the recommended maximum total close thrust would be needed to completely close the valve. Engineering evaluation determined a higher thrust value would be acceptable.
31	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Test	Transmission	HPI	Quality	1992	Failure to Close	Partial	A safety injection recirculation MOV failed to close. It was discovered that the valve had a broken anti-rotation device (key). This prompted an inspection of the remaining globe valves that found the safety injection to reactor coolant system cold leg injection valves also had a broken key.
32	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Test	Transmission	HPI	Design	1987	Failure to Open	Partial	While testing the high pressure injection control valves, the motor operator overthrusted while going in the open direction. Valve operator overthrusted due to a design deficiency in the torque switch spring pack that allowed a buildup of grease between the Belleville washers, which resulted in hydraulic lockup when the valve was operated. After discussion with component manufacturer, a plant modification was performed that machined notches in the ends of the motor operator torque limiting sleeve. These notches will provide a better grease relief path.
33	Design/ Construction/ Manufacture/ Installation Inadequacy	Valve	Demand	Body	RHR-B	Design	1991	Failure to Open	Partial	Inboard LCI valve failed to open due to failed actuator motor caused by sustained operation at locked-rotor current due to hydraulic locking of the valve bonnet. Modifications performed on both LCI inboard valves and both core spray inboard valves.

Item	Proximate Cause	Sub-Component	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
34	Design/ Construction/ Manufacture/ Installation Inadequacy	Valve	Demand	Disk	ISO	Design	1989	Failure to Open	Partial	Isolation condenser dc outlet MOVs failed to open. Both valve failures are attributed to thermal binding, which is identified as a recurring design condition.
35	Design/ Construction/ Manufacture/ Installation Inadequacy	Valve	Inspection	Disk	RCI	Design	1998	Failure to Close	Partial	RCI steam line isolation valves did not have the required seat/disk chamfer necessary to assure that the valves would close under design basis conditions.
36	Design/ Construction/ Manufacture/ Installation Inadequacy	Valve	Maintenance	Disk	RHR-B	Design	1988	Failure to Open	Complete	Containment spray mode of RHR/LCI two MOV injection valve operator motors failed on overload when stroking valves due to trapped pressurized fluid between discs of the gate valve. This was caused by misinterpretation of valve purchase specifications by vendor.
37	Design/ Construction/ Manufacture/ Installation Inadequacy	Valve	Test	Body	RHR-B	Design	1992	Failure to Close	Partial	Original construction design error resulted in pump minimum flow valves not being installed with the valve stem in the vertical, pointing upward orientation. Since these valves do not have wedge springs they have potential to prematurely seat failing to fully close.
38	Design/ Construction/ Manufacture/ Installation Inadequacy	Valve	Test	Disk	RHR-B	Design	1992	Failure to Close	Partial	The test valves to the suppression pool failed to stroke full closed. Root cause analysis revealed that the failure was the result of a gate valve in a globe valve application.
39	Design/ Construction/ Manufacture/ Installation Inadequacy	Valve	Test	Disk	HPI	Quality	1990	Failure to Open	Partial	While testing the high pressure injection system, it was discovered that the flow rate was unbalanced and below the minimum allowed by the units technical specifications. The previous replacement of the plugs in the MOVs with a plug that had been manufactured to the wrong dimensions, due to an error in a vendor drawing, caused unbalanced and low flow.
40	External Environment	Actuator	Demand	Torque Switch	RHR-P	Design	1983	Failure to Close	Partial	Two RHR MOVs were not giving remote indication in the full close position of valve. Torque switch inoperative, not rotating on closing stroke. The torque switch setting screw was found loose most likely due to valve vibration.
41	External Environment	Actuator	Demand	Transmission	HPI	Environmental	1995	Failure to Close	Partial	When a close signal was initiated from the control room, two Refueling Water Tank valves failed to close. They only stroked 2 pct. and gave dual indication. Inspection of actuator internals found rust, corrosion, and water intrusion. The cause was due to water ingress through an actuator penetration in the stem protector resulting in rust and corrosion to actuator parts.
42	External Environment	Actuator	Inspection	Motor	RHR-B	Environmental	1985	Failure to Open	Partial	The ECCS pump room was inadvertently flooded with water, inundating the RHR system minimum flow valve and a pump suction isolation valve. The valve operator motor windings were grounded as a result of the water intrusion.
43	External Environment	Actuator	Test	Motor	HCI	Environmental	1980	Failure to Open	Complete	While testing the torus suction valves, two MOVs failed when given an open signal. Both torus suction valves had shorted out due to excessive condensation in the HCI room area.

Item	Proximate Cause	Sub-Component	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
44	External Environment	Actuator	Test	Torque Switch	HPI	Design	1991	Failure to Close	Partial	Compression springs in the HPI MOV torque switch assembly were weakened by vibration.
45	External Environment	Actuator	Test	Transmission	RHR-B	Environmental	1991	Failure to Close	Partial	One of the two primary containment isolation valves in both residual heat removal low pressure coolant injection subsystems to be inoperable. One valve operator torque switch tripped in both directions preventing both full closure and full opening. The other valve had excessive seat leakage. The threads of the gate valve stem nut in the motor operator were worn and broken causing the valve to lock in a partially open position. Analysis determined stem nut wear out may have been accelerated by mechanical overload caused by high differential pressure across the valve. The valve stem failed due to vibration causing cyclic fatigue.
46	External Environment	Valve	Demand	Body	RHR-P	Maintenance	1985	Failure to Open	Partial	Shutdown cooling isolation valves wouldn't fully open. One was attributed to boric acid buildup and the other cause is unknown.
47	External Environment	Valve	Demand	Disk	RHR-B	Maintenance	1986	Failure to Open	Partial	MOVs failed to open after being closed. Valves are the residual heat removal suppression pool suction valves. Torque switch prevented motor burn-out. Valve disk was found struck closed. Mud was found in the valve seat, which caused the disk to wedge into the seat upon closing and prevented it from opening. Mud in MOVs believed to be from construction activities of plant
48	External Environment	Valve	Demand	Disk	RHR-B	Maintenance	1986	Failure to Open	Partial	The suppression pool (residual heat removal) pump suction valves failed to open electrically. The motor was subjected to locked-rotor current for about 2 minutes, resulting in overheating. Sediment accumulations (non-ferrous) that would squeeze out between the disc and the seat and lock them together was the root cause. The suppression pool sediment most likely occurred during construction.
49	External Environment	Valve	Inspection	Body	RHR-B	Environmental	1981	Failure to Open	Partial	Motor operated valves (chemwaste receiver tank isolation) and (Torus Injection Isolation) operators found with loose and broken cap screws anchoring motors to valves due to vibration induced loosening of the hold-down bolts.
50	Internal to Component	Actuator	Demand	Circuit	RHR-B	Maintenance	1993	Failure to Open	Partial	RHR MOVs failed when an aux relay open contactor failed to operate. Cause was attributed to inappropriate use of cramolin spray to clean relay, which caused it to become sticky.
51	Internal to Component	Actuator	Demand	Circuit	RHR-B	Maintenance	1993	Failure to Close	Partial	RHR MOVs failed when an aux relay open contactor failed to operate. Cause was attributed to inappropriate use of cramolin spray to clean relay, which caused it to become sticky.
52	Internal to Component	Actuator	Demand	Circuit	AFW	Maintenance	1985	Failure to Close	Partial	While removing an AFW train from service, the pump discharge valves to two steam generators did not close. The closing coils in the motor controller failed, due to unknown cause.
53	Internal to Component	Actuator	Demand	Circuit	RCS	Maintenance	1989	Failure to Close	Complete	The inlet block MOVs for the PORVs failed to close or open from the control room. This failure was due to the main control room switch for opening and closing the valve has erratic resistance reading as a result of wear and tear of the switch.
54	Internal to Component	Actuator	Demand	Circuit	RCS	Maintenance	1989	Failure to Open	Complete	The inlet block MOVs for the PORVs failed to close or open from the control room. This failure was due to the main control room switch for opening and closing the valve has erratic resistance reading as a result of wear and tear of the switch.
55	Internal to Component	Actuator	Demand	Limit Switch	RHR-B	Maintenance	1980	Failure to Open	Partial	Extinguished valve indicating lights on RHR pump suction valves. MOVs would not operate due to broken limit switch rotors caused by loose limit switch finger bases.

Item	Proximate Cause	Sub-Component	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
56	Internal to Component	Actuator	Demand	Limit Switch	RHR-B	Maintenance	1995	Failure to Open	Partial	RHR system suppression pool valves failed to operate on demand (open). The limit switch on the MOV failed to operate, thus not allowing the valve to cycle on command. The cause of the failure was normal wear and service conditions of the limit switch resulting in failure.
57	Internal to Component	Actuator	Demand	Torque Switch	HCI	Quality	1986	Failure to Open	Partial	After an attempt to reposition a HCI MOV (the recirc loop pump suction valve), The valve failed to open upon a signal from the control room. An investigation into the cause of the valve's failure determined that a hydraulic lockup of the MOV's spring pack prevented the torque switch from opening causing the motor to fail. This lock-up was due to: 1) the replacement of less viscous new grease, into the operator, which was recommended by the manufacturer and 2) the failure of the manufacturer to provide information regarding the need to install a retrofit grease relief kit.
58	Internal to Component	Actuator	Demand	Torque Switch	RHR-B	Quality	1986	Failure to Open	Partial	An electrical fire was discovered in an MCC. The cause of this event was a personnel error, which resulted in an incorrect field wiring installation on HCI MOVs. The error was complicated by unsuccessful detection of the error during subsequent testing or inspections. As corrective actions, the wiring error was corrected. Additionally, all other motor operators, which were replaced for environmental qualification purposes during this period were modified to preclude this failure.
59	Internal to Component	Actuator	Demand	Transmission	RHR-B	Maintenance	1984	Failure to Open	Partial	Torus suction valves (Both loops) clutch lever would not engage.
60	Internal to Component	Actuator	Inspection	Transmission	HPI	Maintenance	1986	Failure to Open	Partial	During a special inspection, a limit switch terminal block was found cracked and a bevel gear stripped on safety injection system high pressure header shutoff valves. The cause of failure has not been determined but inadequate maintenance is suspected. The limit switch terminal block and the bevel gear were replaced.
61	Internal to Component	Actuator	Inspection	Transmission	CSS	Maintenance	1989	Failure to Open	Partial	Oil leaks identified on handwheel of motor operated actuator for containment spray header isolation valves. Internal seals and o-ring for mating surface of handwheel and gear box had failed. Failure attributed to unexpected abnormal wear.
62	Internal to Component	Actuator	Maintenance	Breaker	RCI	Maintenance	1999	Failure to Open	Partial	Valve operations were not within specified time limits due to faulty contactors. Inadequate PM.
63	Internal to Component	Actuator	Maintenance	Limit Switch	RCS	Quality	1983	Failure to Close	Partial	The Limitorque valve operator for the pressurizer isolation valves found to have cracks on the geared limit switch.
64	Internal to Component	Actuator	Maintenance	Motor	RHR-B	Maintenance	1989	Failure to Open	Partial	Grounds were found on 2 of 4 LCI Injection valves. Probable cause was determined to be insulation breakdown.
65	Internal to Component	Actuator	Maintenance	Torque Switch	HPI	Maintenance	1994	Failure to Close	Partial	High Head Safety Injection System motor operated isolation valves would not open fully. Technicians investigated and found grease on torque switch contacts, which prevented contacts from closing circuit. Improper greasing resulted in excessive grease accumulation on torque switch contacts.
66	Internal to Component	Actuator	Maintenance	Torque Switch	HPI	Maintenance	1994	Failure to Open	Partial	After completion of mechanical rework on HPI MOV actuator, technician was attempting to setup and stroke motor operated valves. While stroking valve electrically found the torque switch would not open, resulting in valve travel not being stopped. Technicians investigated and found torque switch defective and rotor on limit switch to not be turning fully to proper position.
67	Internal to Component	Actuator	Test	Breaker	CSS	Maintenance	1990	Failure to Open	Partial	The 480 Vac circuit breakers for recirculation sump to containment spray pump isolation valves would not trip on an instantaneous trip test within specified current limits.

Item	Proximate Cause	Sub-Component	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
68	Internal to Component	Actuator	Test	Circuit	AFW	Design	2000	Failure to Open	Complete	Loose sliding link caused unplanned swap to LOCAL control. This also caused AFW suction auto swap capability to be blocked. Manual control apparently still available.
69	Internal to Component	Actuator	Test	Circuit	HPI	Maintenance	1986	Failure to Open	Partial	Dirty contacts and loose connections resulted in valves failing to open.
70	Internal to Component	Actuator	Test	Limit Switch	AFW	Maintenance	1992	Failure to Open	Partial	The AFW pump supply to steam generator control valves stopped at an intermediate position and did not fully open. Local verification based on stem travel verified the valve stopped at an intermediate position. The valve operators limit switch was out of adjustment.
71	Internal to Component	Actuator	Test	Motor	AFW	Maintenance	1992	Failure to Close	Partial	The maximum d/p previously used in earlier testing and evaluation was determined to not represent worst case conditions. Further testing revealed that none of the AFW block valves would full close against the calculated worst case d/p. The root cause of the inability of the valves to close is attributed to valve condition due to normal wear.
72	Internal to Component	Actuator	Test	Motor	RHR-B	Maintenance	1985	Failure to Open	Partial	Burned out motors (one LCI and one Torus cooling) due to aging.
73	Internal to Component	Actuator	Test	Motor	CSS	Design	1986	Failure to Open	Complete	Routine surveillance disclosed that the containment recirculation sump to containment spray pump isolation valves would not open. The motor for valve operators burned up.
74	Internal to Component	Actuator	Test	Torque Switch	RHR-P	Maintenance	1986	Failure to Open	Partial	While the unit was in shutdown for refueling, the BWST outlet valve operator failed to open during motor operated valve actuation testing. The torque switch was out of balance.
75	Internal to Component	Actuator	Test	Torque Switch	AFW	Design	1986	Failure to Close	Almost Complete	During MOV actuator testing, the close torque limits on the operator to the emergency feedwater pump discharge valves to the steam generators were found to be below minimum. The torque switches were out of adjustment.
76	Internal to Component	Actuator	Test	Torque Switch	HPI	Maintenance	1991	Failure to Open	Partial	A fuse failed in the first event due to aging and washers in the spring pack of the second valve came loose and grounded the motor. Root cause was inadequate maintenance.
77	Internal to Component	Actuator	Test	Transmission	RHR-B	Maintenance	1983	Failure to Open	Partial	RHR inboard injection valve would not open due to a locking nut on the worm gear shaft having backed off allowing the worm gear to back out of the bearing and the spring pack. The opposite train valve had failed 2 months previously for the same cause.
78	Internal to Component	Valve	Inspection	Body	RHR-B	Design	1992	Failure to Open	Partial	On 4/29/92, the Torus cooling injection motor-operated valve was found to have cracks in the valve yoke. On 8/7/92, the Torus cooling injection MOV in the redundant loop was also discovered with cracks in the yoke.
79	Internal to Component	Valve	Maintenance	Disk	AFW	Maintenance	1988	Failure to Open	Partial	Plug nut welds were broken on the auxiliary feedwater pump discharge isolation valves. This would allow the disc to come off. Exact cause was unknown but suspect age and wearing.
80	Internal to Component	Valve	Test	Disk	RHR-B	Maintenance	1994	Failure to Close	Partial	RHR MOVs failed the surveillance test with gross seat leakage. Investigation revealed wear on the disc guides and some scratches on the seat. The cause is normal wear and aging.
81	Internal to Component	Valve	Test	Packing	HCI	Design	1994	Failure to Close	Partial	High Pressure Coolant valves failed to fully close. The cause of the failure appeared to be high packing load that caused mechanical binding preventing the operator from fully closing the valves.
82	Operational/ Human Error	Actuator	Demand	Breaker	AFW	Maintenance	1987	Failure to Open	Partial	The isolation valves to the steam generator from the steam driven auxiliary feedwater pump failed to open when demanded from the main control board switch. The dc circuit breaker for the motor operated valves were found to have loose (unplugged) connections on the terminal block inside the breaker. It appears that the connectors are easily unplugged by moving the cables in the cable run compartment adjoining the breaker.

Item	Proximate Cause	Sub-Component	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
83	Operational/ Human Error	Actuator	Demand	Breaker	AFW	Design	1988	Failure to Open	Partial	The motor operated containment isolation valves for the turbine driven feedwater pump supply to steam generator failed to respond during stroke test from the main control board. The motor leads in the dc breaker were found disconnected. This is a plug-in type connector unique to the 480 vdc breakers. After evaluation, it was determined that personnel were working in the cable run compartment adjacent to the breaker and as they moved cables around in the cable run, tension was applied to the connectors causing them to pull out
84	Operational/ Human Error	Actuator	Demand	Circuit	RCI	Maintenance	2000	Failure to Close	Partial	The instruments that signal the RCI steam supply valves to close in the event of a steam line break were rendered inoperable due to human error and work package change errors.
85	Operational/ Human Error	Actuator	Demand	Circuit	RHR-B	Design	1985	Failure to Open	Complete	When the control room operator proceeded to establish shutdown cooling, the suction valves to the system would not open. Investigation revealed that while applying a maintenance permit to the primary containment isolation system, a plant operator unknowingly removed the wrong fuse. This electrically blocked the residual heat removal system shutdown cooling suction valves and head spray isolation valves in the closed position. Investigation revealed that although the plant operator removed the fuse, which was labeled f2, as the permit required, this was not the correct fuse. Apparently, the label had slid down such that fuse f3 appeared to be f2.
86	Operational/ Human Error	Actuator	Demand	Limit Switch	AFW	Maintenance	1984	Failure to Close	Partial	Feedwater from the motor driven auxiliary feed pumps to steam generators, failed upon a feedwater flow retention signal. Normal operation upon a retention signal is to actuate to a preset position. Inspection of the Limitorque operator revealed the limit switch was improperly positioned. An investigation could not determine cause of improper adjustment.
87	Operational/ Human Error	Actuator	Demand	Limit Switch	AFW	Maintenance	1984	Failure to Open	Partial	Feedwater from the motor driven auxiliary feed pumps to steam generators, failed upon a feedwater flow retention signal. Normal operation upon a retention signal is to actuate to a preset position. Inspection of the Limitorque operator revealed the limit switch was improperly positioned. An investigation could not determine cause of improper adjustment.
88	Operational/ Human Error	Actuator	Demand	Torque Switch	RHR-B	Maintenance	1991	Failure to Close	Partial	First failure was a torque switch out of adjustment. Second failure was a mis-positioned motor lead holding a torque switch open. Inadequate maintenance.
89	Operational/ Human Error	Actuator	Demand	Torque Switch	RCS	Maintenance	1981	Failure to Close	Partial	The pressurizer PORV block valves did not fully shut on demand. The cause of this event was due to maintenance practices problems.
90	Operational/ Human Error	Actuator	Demand	Torque Switch	AFW	Quality	1985	Failure to Open	Complete	The procedural deficiency that allowed for a low setting of the bypass limit switches on Limitorque valve operators prompted an evaluation of all MOVs. Using the motor operated valve analysis and test system; a review of the as found conditions of 165 safety related MOVs revealed that 17 valves were evaluated as inoperable for various reasons. These 17 valves included the auxiliary feedwater isolation valves. Further investigation revealed that Limitorque failed to supply adequate instructions on balancing of the torque switches. Torque switch unbalance resulted in three valves being unable to produce sufficient thrust to close against the design differential pressure.
91	Operational/ Human Error	Actuator	Demand	Torque Switch	RCI	Design	1986	Failure to Close	Partial	An electrical fire was discovered in an MCC. The cause of this event was a personnel error, which resulted in an incorrect field wiring installation on HCI MOVs. The error was complicated by unsuccessful detection of the error during subsequent testing or inspections. As corrective actions, the wiring error was corrected. Additionally, all other motor operators, which were replaced for environmental qualification purposes during this period were modified to preclude this failure.

Item	Proximate Cause	Sub-Component	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
92	Operational/ Human Error	Actuator	Demand	Torque Switch	RHR-B	Maintenance	1987	Failure to Close	Partial	The residual heat removal suppression pool full flow discharge isolation valve and the torus spray isolation valve would not fully close upon demand. The cause of the failure is improper previous maintenance activities set the torque switch setting on the valve operator incorrectly low.
93	Operational/ Human Error	Actuator	Demand	Torque Switch	RHR-P	Maintenance	1983	Failure to Open	Almost Complete	Shutdown cooling system heat exchanger isolation valves could not be remotely opened from the control room. The inability of the valves to remotely open was attributed to incorrect open sequence torque and limit switch settings. The incorrect settings caused the motor on the valves to stop before the valves had come off their seats.
94	Operational/ Human Error	Actuator	Demand	Torque Switch	AFW	Maintenance	1995	Failure to Close	Partial	AFW steam supply valves torque switch setpoints were incorrectly calculated for the type of valve.
95	Operational/ Human Error	Actuator	Demand	Torque Switch	AFW	Maintenance	1988	Failure to Close	Partial	Operator tried to close motor driven auxiliary feedwater pump discharge header to steam generator isolation valves against pump flow and they would not fully close. Valves failed to close due to the torque switch opening. These being caused by the increased torque during intermittent throttling near the full closed position where differential pressure is maximum.
96	Operational/ Human Error	Actuator	Demand	Transmission	RHR-P	Operational	1995	Failure to Close	Partial	Low Pressure Injection valves were overtorqued open in error during manual backseating after past packing leaks. Excessive force was applied when disengaged from electric operation, causing clutch ring to bind-up when electric operation was re-initiated.
97	Operational/ Human Error	Actuator	Inspection	Breaker	HPI	Operational	1989	Failure to Open	Complete	Procedures allowed entry into operating mode where the system was required without directing operators to energize HPI MOV valve operators.
98	Operational/ Human Error	Actuator	Inspection	Breaker	HPI	Operational	1987	Failure to Open	Complete	The breakers for the high pressure injection suction valves from the BWST were inadvertently left tagged open after the reactor coolant system had been heated up to greater than 350F. The suction supply from the BWST to the HPI pumps was isolated and would not have opened automatically upon engineered safeguards actuation. The root cause is failure to perform an adequate review of the red tag logbook in accordance with the startup procedure.
99	Operational/ Human Error	Actuator	Inspection	Breaker	HPI	Operational	1981	Failure to Open	Complete	Operator went to the wrong unit and de-energized a total of five SI valves.
100	Operational/ Human Error	Actuator	Inspection	Motor	CSS	Maintenance	1987	Failure to Open	Partial	Containment spray MOVs were rendered inoperable by maintenance staff error. Lubrication for the pinion gear housings was put in the motor housings.
101	Operational/ Human Error	Actuator	Maintenance	Limit Switch	HPI	Design	1985	Failure to Open	Complete	Incorrect engineering calculations resulted in spring pack setting that would not open the BIT isolation valves. The third valve, SI pump to accumulators was discovered with the same failure.
102	Operational/ Human Error	Actuator	Maintenance	Limit Switch	RHR-P	Maintenance	1986	Failure to Close	Partial	Low pressure safety injection flow control containment isolation valves' stroke travel was greater than allowable. The cause was open limit switches out of adjustment.
103	Operational/ Human Error	Actuator	Maintenance	Torque Switch	RHR-B	Maintenance	1983	Failure to Open	Partial	Improper wiring and connections on torque switches and limit switches.
104	Operational/ Human Error	Actuator	Test	Breaker	HPI	Maintenance	1994	Failure to Open	Partial	RWST to Charging Pump Suction Isolation Valve failed to open. Troubleshooting subsequently determined that the MOV had two lifted leads. Further investigation revealed that another Charging Pump Suction Isolation Valve also had two lifted leads. The cause of the event was personnel error.

Item	Proximate Cause	Sub-Component	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
105	Operational/ Human Error	Actuator	Test	Breaker	RCI	Operational	1989	Failure to Open	Complete	During the performance of a scheduled RCI system logic system functional test, an overpressurization of the system's suction piping occurred. The operators incorrectly positioned and/or inaccurately verified the positions of 6 circuit breakers to motor operated valves prior to (and for) the test. RCI system inoperable.
106	Operational/ Human Error	Actuator	Test	Circuit	HPI	Maintenance	1984	Failure to Open	Complete	While performing a surveillance test during refueling shutdown, the open contactor for HPI loop isolation valves did not close. The contactors were out of adjustment.
107	Operational/ Human Error	Actuator	Test	Circuit	HPI	Maintenance	1986	Failure to Open	Partial	Two ECCS MOVs had wire grounded under valve operator cover. Both failures were attributed to previous maintenance.
108	Operational/ Human Error	Actuator	Test	Limit Switch	CSS	Quality	1988	Failure to Open	Complete	During re-testing, technicians found that the containment sump isolation valve operator internal limit switches were incorrectly set. This prevented the containment spray suction valve from repositioning as required. During a plant modification, technicians incorrectly set the containment sump isolation valve operator's internal limit switch. The switch was set to be open, though drawings called for it to be closed. Due to inadequate functional verification, this error was not found during post modification testing.
109	Operational/ Human Error	Actuator	Test	Limit Switch	CSS	Maintenance	1985	Failure to Open	Partial	Redundant discharge valves on a containment spray pump would not open. Valve would torque out before going open due to improperly adjusted limit switch.
110	Operational/ Human Error	Actuator	Test	Limit Switch	RHR-P	Maintenance	1991	Failure to Close	Partial	LPI MOVs failed to open. Incorrect setpoints of the valve operator limit switches. Root cause was insufficient control of setpoints.
111	Operational/ Human Error	Actuator	Test	Limit Switch	RCS	Maintenance	1984	Failure to Close	Partial	In performance of surveillance testing, pressurizer power operated relief valves, failed to close properly. Loose connections within the Limitorque operator. Long term measures to eliminate this recurring problem include changes to maintenance procedures requiring periodic examinations of all switch contacts within Limitorque operators.
112	Operational/ Human Error	Actuator	Test	Torque Switch	HPI	Maintenance	1981	Failure to Close	Partial	Makeup pump recirculation valves did not fully close due to low torque values. The torque switch settings were set with no system pressure.
113	Operational/ Human Error	Actuator	Test	Torque Switch	AFW	Maintenance	1987	Failure to Open	Partial	Auxiliary feedwater regulating isolation MOVs were observed to stick and jam during motor operated valve actuation testing because the testing loosened the valve coupling on the drive shaft, throwing the limit switches out. The cause of the coupling coming loose was the torque of the operator exceeding the potential of the coupling, thus unscrewing it. This resulted from too high a setting on the torque switch, and the setup of the control circuitry.
114	Operational/ Human Error	Actuator	Test	Transmission	HPI	Maintenance	1987	Failure to Open	Partial	The high pressure safety injection header to loop injection MOV operator spring packs were found with excess grease during surveillance testing causing valve to torque out mid stroke. The spring pack was inoperable due to excessive grease caused by improper maintenance.
115	Operational/ Human Error	Valve	Demand	Body	HPI	Operational	1988	Failure to Open	Partial	Safety injection isolation motor operated valves responded to an open signal from control room only after the valves were cracked open manually. The valve operators thermal overloads failed to trip after the valve remained energized for 30 minutes. No problems with the operator were discovered. It is suspected that the practice of manually seating the valve during refueling tagouts overtorqued the valve and prevented it from opening.
116	Operational/ Human Error	Valve	Demand	Disk	RHR-P	Quality	1987	Failure to Close	Partial	The residual heat removal system safety injection to reactor coolant loop isolation MOVs were leaking through while closed and could not be isolated. Valve split disks were reversed during initial installation and were 180 degrees out from the proper orientation. This caused seat leakage due to lack of seating contact.

Item	Proximate Cause	Sub-Component	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
117	Operational/ Human Error	Valve	Demand	Stem	ISO	Maintenance	1981	Failure to Close	Partial	The isolation condenser valves failed to properly operate. The stem nuts of the MOV operators were found to be damaged.
118	Operational/ Human Error	Valve	Test	Stem	AFW	Maintenance	1984	Failure to Open	Partial	Aux feedwater pump discharge/header isolation valves found damaged during special inspection. One valve did not open during surveillance test; the other three were not operated, but probably would not have opened due to excessive damage, (bent stem). All damage was determined to be due to over-torquing the torque switch.
119	Operational/ Human Error	Valve	Test	Stem	RCS	Maintenance	1992	Failure to Close	Partial	The pressurizer's power operated relief valve's isolation valve operator's output thrust was below the minimum required to fully close the valve on demand. The valve's stem to stem nut nickel based lubricant was the cause.
120	Operational/ Human Error	Valve	Test	Stem	CSS	Maintenance	1984	Failure to Open	Complete	During surveillance tests, two recirculation spray pump suction valves were inoperable. The valve position lights in the control room indicated the valve cycled normally. However, the valve did not move from the closed position. Failure was caused by the shearing of the coupling pin due to inadvertently leaving the incorrect pin, a marlin pin, (tapered pin possibly used for alignment), in the valve operator coupling.
121	Operational/ Human Error	Valve	Test	Stem	RHR-B	Maintenance	1986	Failure to Close	Almost Complete	While testing the high pressure injection control valves, the motor operator overthrusted while going in the open direction. The valve operator overthrusted due to a design deficiency in the torque switch spring pack that allowed a buildup of grease between the Belleville washers which resulted in hydraulic lockup when the valve was operated. After discussion with component manufacturer, a plant modification was performed that machined notches in the ends of the motor operator torque limiting sleeve. These notches will provide a better grease relief path.
122	Other	Actuator	Demand	Circuit	RHR-B	Design	1987	Failure to Open	Partial	Failure of the auxiliary contact block assembly of valve motor close contactor (failed in open position) prevented energizing valve motor open contactor. Occurred on Unit 2/1 cross-connect isolation valve and on Unit 1 RHR isolation injection valve. The contacts failed in the open position, thereby preventing energization of the valve motor open contactor.
123	Other	Actuator	Demand	Circuit	AFW	Maintenance	1984	Failure to Open	Partial	During automatic actuation of the AFW system, the motor operator flow control valves to SG's did not operate properly on a flow retention signal.
124	Other	Actuator	Demand	Circuit	AFW	Maintenance	1984	Failure to Close	Partial	During automatic actuation of the AFW system, the motor operator flow control valves to SG's did not operate properly on a flow retention signal.
125	Other	Actuator	Demand	Limit Switch	RHR-P	Maintenance	1987	Failure to Open	Partial	Residual heat removal pump suctions from feedwater storage tank valve and containment sump would not operate from control room. Cause of valve's failure to operate was limit switches out of adjustment.
126	Other	Actuator	Demand	Limit Switch	RHR-P	Maintenance	1983	Failure to Open	Partial	MOV motor torqued out on start of open/close cycle. Limit switches out of adjustment.
127	Other	Actuator	Demand	Limit Switch	HPI	Maintenance	1982	Failure to Close	Partial	Close limit switch out of adjustment. After adjustment, valve closed correctly.
128	Other	Actuator	Demand	Torque Switch	RHR-B	Maintenance	1984	Failure to Open	Partial	Residual heat removal suction from suppression pool and shutdown cooling inboard isolation suction valve would trip thermal overload when attempting to open from closed position and failed to close completely. Torque switch setting was to high and limit switch settings were incorrect. Reset limit and torque switches.
129	Other	Actuator	Demand	Torque Switch	RHR-B	Maintenance	1984	Failure to Close	Partial	Both LCI loop's full flow test valves failed to go full closed due to a faulty torque switch.

Item	Proximate Cause	Sub-Component	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
130	Other	Actuator	Demand	Torque Switch	RHR-B	Maintenance	1984	Failure to Close	Partial	Residual heat removal suction from suppression pool and shutdown cooling inboard isolation suction valve would trip thermal overload when attempting to open from closed position and failed to close completely. Torque switch setting was to high and limit switch settings were incorrect. Reset limit and torque switches.
131	Other	Actuator	Demand	Torque Switch	RHR-P	Maintenance	1987	Failure to Open	Partial	RHR pump suction MOV isolation valves would not fully open on demand. The cause of this failure was due to both torque switches were out of adjustment. Both valves could be closed on repeated attempts but not reopened completely.
132	Other	Actuator	Maintenance	Breaker	HPI	Maintenance	1992	Failure to Open	Partial	The 480-volt circuit breakers for three safety injection to cold leg motor operated isolation valves were found out specification high on two phases. The degraded component had no significant effect on the system or the plant, but could have caused damage to the valve actuator motors since the overcurrent protection was degraded.
133	Other	Actuator	Maintenance	Breaker	HPI	Maintenance	1988	Failure to Open	Partial	A 480 Vac circuit breaker for a safety injection control valve failed to trip within its set tolerance. The cause of the failure was attributed to a defective circuit breaker.
134	Other	Actuator	Maintenance	Torque Switch	CSS	Maintenance	1991	Failure to Close	Partial	The as found available open and close thrusts were below the recommended minimum. It was determined that the MOVs were inoperable in the open direction, the safety function of the MOV, and operable in the closed direction under worst case design basis conditions as found. Suspect it was due to setpoint drift and or cyclic loading.
135	Other	Actuator	Maintenance	Torque Switch	CSS	Maintenance	1991	Failure to Open	Partial	While maintaining the containment sump isolation valve operators, it was noted that the as found available open and close thrusts were below the recommended minimum. It was determined that the MOVs were inoperable in the open direction, the safety function of the MOVs, and operable in the closed direction under worst case design basis conditions as found. Cause of valve thrusts below minimum recommended was unknown. Suspect it was due to setpoint drift or a cyclic loading.
136	Other	Actuator	Test	Breaker	RHR-B	Maintenance	1986	Failure to Open	Partial	LCI test valve and LCI torus suction valve would not open upon demand and would trip the breaker upon movement. Found auxiliary contacts on breaker in open circuit not making up.
137	Other	Actuator	Test	Limit Switch	HPI	Maintenance	1994	Failure to Close	Partial	Limit switches being out of adjustment resulted in contained leakage. One had both open and closed limit switches out of adjustment. The other valve had only the closed limit switches out of adjustment.
138	Other	Actuator	Test	Limit Switch	HPI	Maintenance	1989	Failure to Open	Partial	The high pressure safety injection pump long term cooling containment isolation MOVs failed to achieve minimum flow requirements. The cause of failure was attributed to the limit switch rotor being out of mechanical adjustment.
139	Other	Actuator	Test	Limit Switch	RHR-P	Maintenance	1990	Failure to Open	Partial	Stem travel was excessive on low pressure safety injection flow control containment isolation valves. The opening travel was excessive, due to limit switch out of adjustment.
140	Other	Actuator	Test	Limit Switch	RHR-B	Maintenance	1984	Failure to Close	Partial	During a LCI operability test, full flow test valves were closed by position indication. However, the valves were not fully seated, and the LCI discharge piping drained. Valve position indication was out of adjustment.
141	Other	Actuator	Test	Limit Switch	HPI	Design	1984	Failure to Open	Partial	The HPI header flow rate was not within technical specification requirements. No direct cause could be found for the apparent drift of the valve operators.
142	Other	Actuator	Test	Limit Switch	RHR-P	Design	1995	Failure to Open	Partial	LPI throttle valves failed to stroke fully open. As a result, minimum flow for LPSI injection legs were below the minimum design basis flow.
143	Other	Actuator	Test	Limit Switch	RHR-P	Design	1995	Failure to Open	Partial	LPI throttle valves over traveled in the open direction by approximately 1/2 inch. This resulted in LPI flow exceeding Tech spec limits..

Item	Proximate Cause	Sub-Component	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
144	Other	Actuator	Test	Torque Switch	RHR-P	Maintenance	1984	Failure to Open	Partial	While performing sump valve stroke test two MOVs failed to re-open after being stroked closed. The cause of the failures has been determined to be that the bypass circuit time was too short. This prevented the valves from opening until the control switch had been operated several times.
145	Other	Actuator	Test	Torque Switch	HPI	Maintenance	1994	Failure to Open	Partial	Motor Operated Valve for High Pressure Safety Injection would not stroke fully open. Electricians found oxidation on the open torque switch contacts, causing the motor to stop valve movement before the valve was fully open. Oxidation is an expected occurrence over time in this atmosphere.
146	Other	Actuator	Test	Torque Switch	HPI	Maintenance	1994	Failure to Close	Partial	High Pressure Safety Injection to Loop MOV would not stroke fully open. Electricians found oxidation on the open torque switch contacts, causing the motor to stop valve movement before the valve was fully open. Oxidation is an expected occurrence over time in this atmosphere
147	Other	Actuator	Test	Torque Switch	RHR-B	Maintenance	1984	Failure to Close	Partial	LLRT failures on Torus Suction valves due to torque switch misadjustment.
148	Unknown	Actuator	Demand	Circuit	HPI	Maintenance	1985	Failure to Open	Complete	The motor operators for 2 valves, which allow the chemical and volume control pumps to take suction from the refueling water storage tank when in the closed position or from the volume control tank when in the opened position, burned up in the closed position and had to be manually opened.
149	Unknown	Actuator	Demand	Transmission	RHR-P	Maintenance	1985	Failure to Close	Partial	Low pressure injection supply from the borated water storage tank isolation valves would not close due to broken worm shaft clutch gear on valve operator.

Table A-2. MOV CCF events sorted by coupling factor.

Item	Coupling Factor	Proximate Cause	Discovery Method	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
1	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Actuator	Circuit	RHR-B	1984	Failure to Open	Complete	Both LCI injection MOVs would not open due to an error in the valve logic circuit diagrams and the removal of motor brakes for environmental qualification. This condition caused the valves to continuously try to close until both valve stems were damaged.
2	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Actuator	Motor	AFW	1989	Failure to Close	Partial	AFW MOVs would not fully close under high d/p conditions until the valve actuators were setup at the highest torque switch setting allowed by the tolerances.
3	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Actuator	Circuit	RHR-P	1999	Failure to Open	Complete	Thermal overloads for two valves tripped due to design deficiency. Consequently, the normal closure of the valve will trip the thermal overload heater some percentage of the time.
4	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Actuator	Motor	RHR-B	1991	Failure to Close	Partial	RHR test return valves failed to seat tightly due to friction related problems. Replaced valve operators.
5	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Actuator	Limit Switch	RHR-P	1985	Failure to Close	Partial	Shutdown cooling system heat exchanger isolation valves were not fully closed. The condition resulted from premature actuation of valve motor operator position indication limit switches and control room indication of the valves being in the closed position. A change is being implemented for these valves to separate the torque switch bypass limit switch and the valve position indicating limit switch by rewiring the position indicating rotors.
6	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Actuator	Transmission	RHR-P	1991	Failure to Open	Partial	The motor operator for cold leg isolation valve electricallyengaged while the valve was being manually stroked open during post-modification testing. The motor operator electrically engaged and closed the valve (short stroking). Investigation determined that this electrical short stroking of the valve caused the motor pinion key to shear. Other safety-related motor operators were inspected. The motor operators were identified as having failed keys similar to the failed key identified earlier. Further investigation revealed small cracks emanating from both corners of the keyway on the motor shaft. The root cause of the sheared motor pinion gear was that the key material was inadequate.
7	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Actuator	Circuit	RHR-B	1986	Failure to Close	Complete	Residual heat removal/low pressure coolant injection discharge to suppression pool minimum flow control valves did not close properly on demand. Incorrect logic design prevented valves from closing completely on demand. The new design provided for a seal-in contact with the automatic isolation signal. The seal-in contact allows torque closure of the valve even if the selector key lock switch is in the 'lock' position.

Item	Coupling Factor	Proximate Cause	Discovery Method	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
8	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Actuator	Motor	RHR-B	1987	Failure to Open	Partial	Suppression pool cooling valves (one in each loop) failed to open. As long as the RHR pump was operating, the valves could not be opened and the thermal overloads would trip. Cause was an incorrectly sized motor.
9	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Valve	Disk	ISO	1989	Failure to Open	Partial	Isolation condenser dc outlet MOVs failed to open. Both valve failures are attributed to thermal binding, which is identified as a recurring design condition.
10	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Valve	Body	RHR-B	1991	Failure to Open	Partial	Inboard LCI valve failed to open due to failed actuator motor caused by sustained operation at locked-rotor current due to hydraulic locking of the valve bonnet. Modifications performed on both LCI inboard valves and both core spray inboard valves.
11	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Inspection	Actuator	Transmission	CSS	1993	Failure to Open	Partial	The motor pinion key for a Containment Spray header isolation valve was sheared. Subsequent motor pinion key failures occurred on October 18, 1993, March 23, 1994, and April 13, 1994. The evaluations for these events determined that the failures were due to improper key material.
12	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Inspection	Actuator	Transmission	RHR-B	1990	Failure to Close	Partial	Investigating failure of motor operated valve to achieve minimum required closing thrust. Actuator for inboard isolation valve not geared to supply specified 110% design thrust. Outboard isolation valve and 6 other motor operated valves (2 in RHR) had same actuator problems due to failure to consider design capabilities prior to establishing diagnostic testing criteria.
13	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Inspection	Valve	Disk	RCI	1998	Failure to Close	Partial	RCI steam line isolation valves did not have the required seat/disk chamfer necessary to assure that the valves would close under design basis conditions.
14	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Maintenance	Valve	Disk	RHR-B	1988	Failure to Open	Complete	Containment spray mode of RHR/LCI two MOV injection valve operator motors failed on overload when stroking valves due to trapped pressurized fluid between discs of the gate valve. This was caused by misinterpretation of valve purchase specifications by vendor.
15	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Actuator	Torque Switch	AFW	1989	Failure to Close	Partial	Seven AFW valves would open but would not fully close electrically. The cause of failure was that the valve operator and valve were previously changed out on a modification and passed the post modification test. Upon investigation of the valve failure it was determined that the design engineers had the thrust values wrong and the torque switch was reflecting a 1085 psi system when in fact the system is 1600 psi.
16	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Actuator	Torque Switch	AFW	1994	Failure to Close	Partial	Auxiliary Feedwater Pumps to Steam Generator Isolations were determined to be past inoperable. Differential pressure testing conducted during the outage revealed the valves would not sufficiently close against design basis system conditions to isolate flow.

Item	Coupling Factor	Proximate Cause	Discovery Method	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
17	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Actuator	Torque Switch	HPI	1994	Failure to Close	Partial	HPI MOVs failed to fully close. Engineering determined that the recommended close thrust was insufficient to close valve during worst case failure.
18	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Actuator	Torque Switch	RHR-B	1987	Failure to Close	Partial	During operability test of RHR, a loop isolation valve would not close against system operating pressure due to an undersized washer spring pack in valve operator, supplied to the plant in actuators by the vendor not in accordance with purchase specifications. Similar problem found on the other loop isolation valve.
19	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Actuator	Torque Switch	RHR-P	1985	Failure to Open	Partial	During maintenance testing it was determined several residual heat removal MOVs wouldn't develop the required thrust as specified by the motor operated valve testing program. The failure was attributed to an improper torque switch installation due to incorrect engineering calculations of original design values. The appropriate torque switch was installed, adjusted per the revised engineering values, tested, and returned to service.
20	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Actuator	Motor	RHR-B	1992	Failure to Close	Partial	Due to the original valve operator selection criteria using less conservative factors, the outboard primary containment spray isolation valves had an inadequate torque and thrust capability. Design requirement is 134 ft-lbs; available is 100 ft-lbs.
21	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Actuator	Torque Switch	CSS	1984	Failure to Open	Complete	During surveillance, two containment spray motor operated valves failed to open. The valves were stuck due to excess play in operator assembly, which allowed the open torque switch to disengage thereby shutting off the operator. The bypass limit switch was rewired to a separate rotor with a longer bypass duration per design change.
22	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Actuator	Transmission	HPI	1987	Failure to Open	Partial	While testing the high pressure injection control valves, the motor operator overthrusted while going in the open direction. Valve operator overthrusted due to a design deficiency in the torque switch spring pack that allowed a buildup of grease between the Belleville washers, which resulted in hydraulic lockup when the valve was operated. After discussion with component manufacturer, a plant modification was performed that machined notches in the ends of the motor operator torque limiting sleeve. These notches will provide a better grease relief path.
23	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Actuator	Torque Switch	CSS	1985	Failure to Open	Partial	During maintenance, testing it was determined that four containment spray MOVs wouldn't develop the required thrust. The failures were attributed to an improper spring pack installation and to an improper torque switch installation. The improper installations were due to incorrect engineering calculations of original design values.
24	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Actuator	Torque Switch	CSS	1985	Failure to Close	Complete	During maintenance, testing it was determined that four containment spray MOVs wouldn't develop the required thrust. The failures were attributed to an improper spring pack installation and to an improper torque switch installation. The improper installations were due to incorrect engineering calculations of original design values.

Item	Coupling Factor	Proximate Cause	Discovery Method	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
25	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Actuator	Motor	RHR-B	1989	Failure to Close	Partial	Due to incorrectly sized operator the Torus cooling valves would not completely close against full differential pressure.
26	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Valve	Body	RHR-B	1992	Failure to Close	Partial	Original construction design error resulted in pump minimum flow valves not being installed with the valve stem in the vertical, pointing upward orientation. Since these valves do not have wedge springs they have potential to prematurely seat failing to fully close.
27	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Valve	Disk	RHR-B	1992	Failure to Close	Partial	The test valves to the suppression pool failed to stroke full closed. Root cause analysis revealed that the failure was the result of a gate valve in a globe valve application.
28	Design	External Environment	Demand	Actuator	Torque Switch	RHR-P	1983	Failure to Close	Partial	Two RHR MOVs were not giving remote indication in the full close position of valve. Torque switch inoperative, not rotating on closing stroke. The torque switch setting screw was found loose most likely due to valve vibration.
29	Design	External Environment	Test	Actuator	Torque Switch	HPI	1991	Failure to Close	Partial	Compression springs in the HPI MOV torque switch assembly were weakened by vibration.
30	Design	Internal to Component	Inspection	Valve	Body	RHR-B	1992	Failure to Open	Partial	On 4/29/92, the Torus cooling injection motor-operated valve was found to have cracks in the valve yoke. On 8/7/92, the Torus cooling injection MOV in the redundant loop was also discovered with cracks in the yoke.
31	Design	Internal to Component	Test	Actuator	Torque Switch	AFW	1986	Failure to Close	Almost Complete	During MOV actuator testing, the close torque limits on the operator to the emergency feedwater pump discharge valves to the steam generators were found to be below minimum. The torque switches were out of adjustment.
32	Design	Internal to Component	Test	Actuator	Motor	CSS	1986	Failure to Open	Complete	Routine surveillance disclosed that the containment recirculation sump to containment spray pump isolation valves would not open. The motor for valve operators burned up.
33	Design	Internal to Component	Test	Actuator	Circuit	AFW	2000	Failure to Open	Complete	Loose sliding link caused unplanned swap to LOCAL control. This also caused AFW suction auto swap capability to be blocked. Manual control apparently still available.
34	Design	Internal to Component	Test	Valve	Packing	HCI	1994	Failure to Close	Partial	High Pressure Coolant valves failed to fully close. The cause of the failure appeared to be high packing load that caused mechanical binding preventing the operator from fully closing the valves.
35	Design	Operational/ Human Error	Demand	Actuator	Breaker	AFW	1988	Failure to Open	Partial	The motor operated containment isolation valves for the turbine driven feedwater pump supply to steam generator failed to respond during stroke test from the main control board. The motor leads in the dc breaker were found disconnected. This is a plug-in type connector unique to the 480 vdc breakers. After evaluation, it was determined that personnel were working in the cable run compartment adjacent to the breaker and as they moved cables around in the cable run, tension was applied to the connectors causing them to pull out.

Item	Coupling Factor	Proximate Cause	Discovery Method	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
36	Design	Operational/ Human Error	Demand	Actuator	Torque Switch	RCI	1986	Failure to Close	Partial	An electrical fire was discovered in an MCC. The cause of this event was a personnel error, which resulted in an incorrect field wiring installation on HCI MOVs. The error was complicated by unsuccessful detection of the error during subsequent testing or inspections. As corrective actions, the wiring error was corrected. Additionally, all other motor operators, which were replaced for environmental qualification purposes during this period were modified to preclude this failure.
37	Design	Operational/ Human Error	Demand	Actuator	Circuit	RHR-B	1985	Failure to Open	Complete	When the control room operator proceeded to establish shutdown cooling, the suction valves to the system would not open. Investigation revealed that while applying a maintenance permit to the primary containment isolation system, a plant operator unknowingly removed the wrong fuse. This electrically blocked the residual heat removal system shutdown cooling suction valves and head spray isolation valves in the closed position. Investigation revealed that although the plant operator removed the fuse, which was labeled f2, as the permit required, this was not the correct fuse. Apparently, the label had slid down such that fuse f3 appeared to be f2.
38	Design	Operational/ Human Error	Maintenance	Actuator	Limit Switch	HPI	1985	Failure to Open	Complete	Incorrect engineering calculations resulted in spring pack setting that would not open the BIT isolation valves. The third valve, SI pump to accumulators was discovered with the same failure.
39	Design	Other	Demand	Actuator	Circuit	RHR-B	1987	Failure to Open	Partial	Failure of the auxiliary contact block assembly of valve motor close contactor (failed in open position) prevented energizing valve motor open contactor. Occurred on Unit 2/1 cross-connect isolation valve and on Unit 1 RHR isolation injection valve. The contacts failed in the open position, thereby preventing energization of the valve motor open contactor.
40	Design	Other	Test	Actuator	Limit Switch	RHR-P	1995	Failure to Open	Partial	LPI throttle valves over traveled in the open direction by approximately 1/2 inch. This resulted in LPI flow exceeding Tech spec limits..
41	Design	Other	Test	Actuator	Limit Switch	RHR-P	1995	Failure to Open	Partial	LPI throttle valves failed to stroke fully open. As a result, minimum flow for LPSI injection legs were below the minimum design basis flow.
42	Design	Other	Test	Actuator	Limit Switch	HPI	1984	Failure to Open	Partial	The HPI header flow rate was not within technical specification requirements. No direct cause could be found for the apparent drift of the valve operators.
43	Environmental	External Environment	Demand	Actuator	Transmission	HPI	1995	Failure to Close	Partial	When a close signal was initiated from the control room, two Refueling Water Tank valves failed to close. They only stroked 2 pct. and gave dual indication. Inspection of actuator internals found rust, corrosion, and water intrusion. The cause was due to water ingress through an actuator penetration in the stem protector resulting in rust and corrosion to actuator parts.
44	Environmental	External Environment	Inspection	Actuator	Motor	RHR-B	1985	Failure to Open	Partial	The ECCS pump room was inadvertently flooded with water, inundating the RHR system minimum flow valve and a pump suction isolation valve. The valve operator motor windings were grounded as a result of the water intrusion.
45	Environmental	External Environment	Inspection	Valve	Body	RHR-B	1981	Failure to Open	Partial	Motor operated valves (chemwaste receiver tank isolation) and (Torus Injection Isolation) operators found with loose and broken cap screws anchoring motors to valves due to vibration induced loosening of the hold-down bolts.
46	Environmental	External Environment	Test	Actuator	Motor	HCI	1980	Failure to Open	Complete	While testing the torus suction valves, two MOVs failed when given an open signal. Both torus suction valves had shorted out due to excessive condensation in the HCI room area.

Item	Coupling Factor	Proximate Cause	Discovery Method	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
47	Environmental	External Environment	Test	Actuator	Transmission	RHR-B	1991	Failure to Close	Partial	One of the two primary containment isolation valves in both residual heat removal low pressure coolant injection subsystems to be inoperable. One valve operator torque switch tripped in both directions preventing both full closure and full opening. The other valve had excessive seat leakage. The threads of the gate valve stem nut in the motor operator were worn and broken causing the valve to lock in a partially open position. Analysis determined stem nut wear out may have been accelerated by mechanical overload caused by high differential pressure across the valve. The valve stem failed due to vibration causing cyclic fatigue.
48	Maintenance	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Actuator	Torque Switch	HPI	1985	Failure to Close	Partial	Motor torque switches were out of adjustment and did not allow full closure.
49	Maintenance	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Actuator	Circuit	AFW	1984	Failure to Open	Partial	Aux. feedwater flow control valves would not open. On one the motor control contactor was not contacting due to 2 loose connections; and the other the torque close setting was misadjusted, causing contacts to open too soon.
50	Maintenance	Design/ Construction/ Manufacture/ Installation Inadequacy	Inspection	Actuator	Transmission	RHR-B	1992	Failure to Close	Partial	LCI MOV motor pinion key replacements were supposed to be performed in 1982 to change the keys to an appropriate material key. This replacement was not performed and was discovered in 1992, as 3 valve keys were found sheared or nearly sheared.
51	Maintenance	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Actuator	Torque Switch	HPI	1991	Failure to Close	Partial	The high pressure safety injection system flow control containment isolation valves failed to completely close because total close thrust was not sufficient to close valve under dynamic stroke. A thrust value beyond the recommended maximum total close thrust would be needed to completely close the valve. Engineering evaluation determined a higher thrust value would be acceptable.
52	Maintenance	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Actuator	Limit Switch	RHR-B	1988	Failure to Close	Partial	During surveillance testing of the RHR shutdown cooling isolation valves revealed that each loop injection valve failed to close as required. The failure was due to a wiring error on the limit switches associated with RHR suction valves. An incorrect limit switch was used for both valves, which made a slight mis-operation of the switches capable of affecting the close circuitry of the isolation valves.
53	Maintenance	External Environment	Demand	Valve	Disk	RHR-B	1986	Failure to Open	Partial	The suppression pool (residual heat removal) pump suction valves failed to open electrically. The motor was subjected to locked-rotor current for about 2 minutes, resulting in overheating. Sediment accumulations (non-ferrous) that would squeeze out between the disc and the seat and lock them together was the root cause. The suppression pool sediment most likely occurred during construction.
54	Maintenance	External Environment	Demand	Valve	Body	RHR-P	1985	Failure to Open	Partial	Shutdown cooling isolation valves wouldn't fully open. One was attributed to boric acid buildup and the other cause is unknown.
55	Maintenance	External Environment	Demand	Valve	Disk	RHR-B	1986	Failure to Open	Partial	MOVs failed to open after being closed. Valves are the residual heat removal suppression pool suction valves. Torque switch prevented motor burn-out. Valve disk was found struck closed. Mud was found in the valve seat, which caused the disk to wedge into the seat upon closing and prevented it from opening. Mud in MOVs believed to be from construction activities of plant

Item	Coupling Factor	Proximate Cause	Discovery Method	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
56	Maintenance	Internal to Component	Demand	Actuator	Circuit	RHR-B	1993	Failure to Open	Partial	RHR MOVs failed when an aux relay open contactor failed to operate. Cause was attributed to inappropriate use of cramolin spray to clean relay, which caused it to become sticky.
57	Maintenance	Internal to Component	Demand	Actuator	Limit Switch	RHR-B	1980	Failure to Open	Partial	Extinguished valve indicating lights on RHR pump suction valves. MOVs would not operate due to broken limit switch rotors caused by loose limit switch finger bases.
58	Maintenance	Internal to Component	Demand	Actuator	Circuit	RHR-B	1993	Failure to Close	Partial	RHR MOVs failed when an aux relay open contactor failed to operate. Cause was attributed to inappropriate use of cramolin spray to clean relay, which caused it to become sticky.
59	Maintenance	Internal to Component	Demand	Actuator	Circuit	RCS	1989	Failure to Open	Complete	The inlet block MOVs for the PORVs failed to close or open from the control room. This failure was due to the main control room switch for.opening and closing the valve has erratic resistance reading as a result of wear and tear of the switch.
60	Maintenance	Internal to Component	Demand	Actuator	Transmission	RHR-B	1984	Failure to Open	Partial	Torus suction valves (Both loops) clutch lever would not engage.
61	Maintenance	Internal to Component	Demand	Actuator	Limit Switch	RHR-B	1995	Failure to Open	Partial	RHR system suppression pool valves failed to operate on demand (open). The limit switch on the MOV failed to operate, thus not allowing the valve to cycle on command. The cause of the failure was normal wear and service conditions of the limit switch resulting in failure.
62	Maintenance	Internal to Component	Demand	Actuator	Circuit	AFW	1985	Failure to Close	Partial	While removing an AFW train from service, the pump discharge valves to two steam generators did not close. The closing coils in the motor controller failed, due to unknown cause.
63	Maintenance	Internal to Component	Demand	Actuator	Circuit	RCS	1989	Failure to Close	Complete	The inlet block MOVs for the PORVs failed to close or open from the control room. This failure was due to the main control room switch for opening and closing the valve has erratic resistance reading as a result of wear and tear of the switch.
64	Maintenance	Internal to Component	Inspection	Actuator	Transmission	CSS	1989	Failure to Open	Partial	Oil leaks identified on handwheel of motor operated actuator for containment spray header isolation valves. Internal seals and o-ring for mating surface of handwheel and gear box had failed. Failure attributed to unexpected abnormal wear.
65	Maintenance	Internal to Component	Inspection	Actuator	Transmission	HPI	1986	Failure to Open	Partial	During a special inspection, a limit switch terminal block was found cracked and a bevel gear stripped on safety injection system high pressure header shutoff valves. The cause of failure has not been determined but inadequate maintenance is suspected. The limit switch terminal block and the bevel gear were replaced.
66	Maintenance	Internal to Component	Maintenance	Actuator	Breaker	RCI	1999	Failure to Open	Partial	Valve operations were not within specified time limits due to faulty contactors. Inadequate PM.
67	Maintenance	Internal to Component	Maintenance	Actuator	Torque Switch	HPI	1994	Failure to Open	Partial	After completion of mechanical rework on HPI MOV actuator, technician was attempting to setup and stroke motor operated valves. While stroking valve electrically found the torque switch would not open, resulting in valve travel not being stopped. Technicians investigated and found torque switch defective and rotor on limit switch to not be turning fully to proper position.
68	Maintenance	Internal to Component	Maintenance	Actuator	Torque Switch	HPI	1994	Failure to Close	Partial	High Head Safety Injection System motor operated isolation valves would not open fully. Technicians investigated and found grease on torque switch contacts, which prevented contacts from closing circuit. Improper greasing resulted in excessive grease accumulation on torque switch contacts.
69	Maintenance	Internal to Component	Maintenance	Actuator	Motor	RHR-B	1989	Failure to Open	Partial	Grounds were found on 2 of 4 LCI Injection valves. Probable cause was determined to be insulation breakdown.

Item	Coupling Factor	Proximate Cause	Discovery Method	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
70	Maintenance	Internal to Component	Maintenance	Valve	Disk	AFW	1988	Failure to Open	Partial	Plug nut welds were broken on the auxiliary feedwater pump discharge isolation valves. This would allow the disc to come off. Exact cause was unknown but suspect age and wearing.
71	Maintenance	Internal to Component	Test	Actuator	Motor	RHR-B	1985	Failure to Open	Partial	Burned out motors (one LCI and one Torus cooling) due to aging.
72	Maintenance	Internal to Component	Test	Actuator	Torque Switch	HPI	1991	Failure to Open	Partial	A fuse failed in the first event due to aging and washers in the spring pack of the second valve came loose and grounded the motor. Root cause was inadequate maintenance.
73	Maintenance	Internal to Component	Test	Actuator	Torque Switch	RHR-P	1986	Failure to Open	Partial	While the unit was in shutdown for refueling, the BWST outlet valve operator failed to open during motor operated valve actuation testing. The torque switch was out of balance.
74	Maintenance	Internal to Component	Test	Actuator	Breaker	CSS	1990	Failure to Open	Partial	The 480 Vac circuit breakers for recirculation sump to containment spray pump isolation valves would not trip on an instantaneous trip test within specified current limits.
75	Maintenance	Internal to Component	Test	Actuator	Circuit	HPI	1986	Failure to Open	Partial	Dirty contacts and loose connections resulted in valves failing to open.
76	Maintenance	Internal to Component	Test	Actuator	Limit Switch	AFW	1992	Failure to Open	Partial	The AFW pump supply to steam generator control valves stopped at an intermediate position and did not fully open. Local verification based on stem travel verified the valve stopped at an intermediate position. The valve operators limit switch was out of adjustment.
77	Maintenance	Internal to Component	Test	Actuator	Transmission	RHR-B	1983	Failure to Open	Partial	RHR inboard injection valve would not open due to a locking nut on the worm gear shaft having backed off allowing the worm gear to back out of the bearing and the spring pack. The opposite train valve had failed 2 months previously for the same cause.
78	Maintenance	Internal to Component	Test	Actuator	Motor	AFW	1992	Failure to Close	Partial	The maximum d/p previously used in earlier testing and evaluation was determined to not represent worst case conditions. Further testing revealed that none of the AFW block valves would full close against the calculated worst case d/p. The root cause of the inability of the valves to close is attributed to valve condition due to normal wear.
79	Maintenance	Internal to Component	Test	Valve	Disk	RHR-B	1994	Failure to Close	Partial	RHR MOVs failed the surveillance test with gross seat leakage. Investigation revealed wear on the disc guides and some scratches on the seat. The cause is normal wear and aging.
80	Maintenance	Operational/ Human Error	Demand	Actuator	Limit Switch	AFW	1984	Failure to Open	Partial	Feedwater from the motor driven auxiliary feed pumps to steam generators, failed upon a feedwater flow retention signal. Normal operation upon a retention signal is to actuate to a preset position. Inspection of the Limitorque operator revealed the limit switch was improperly positioned. An investigation could not determine cause of improper adjustment.
81	Maintenance	Operational/ Human Error	Demand	Actuator	Torque Switch	AFW	1995	Failure to Close	Partial	AFW steam supply valves torque switch setpoints were incorrectly calculated for the type of valve.
82	Maintenance	Operational/ Human Error	Demand	Actuator	Breaker	AFW	1987	Failure to Open	Partial	The isolation valves to the steam generator from the steam driven auxiliary feedwater pump failed to open when demanded from the main control board switch. The dc circuit breaker for the motor operated valves were found to have loose (unplugged) connections on the terminal block inside the breaker. It appears that the connectors are easily unplugged by moving the cables in the cable run compartment adjoining the breaker.
83	Maintenance	Operational/ Human Error	Demand	Actuator	Torque Switch	RHR-P	1983	Failure to Open	Almost Complete	Shutdown cooling system heat exchanger isolation valves could not be remotely opened from the control room. The inability of the valves to remotely open was attributed to incorrect open sequence torque and limit switch settings. The incorrect settings caused the motor on the valves to stop before the valves had come off their seats.
84	Maintenance	Operational/ Human Error	Demand	Actuator	Circuit	RCI	2000	Failure to Close	Partial	The instruments that signal the RCI steam supply valves to close in the event of a steam line break were rendered inoperable due to human error and work package change errors.

Item	Coupling Factor	Proximate Cause	Discovery Method	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
85	Maintenance	Operational/ Human Error	Demand	Actuator	Torque Switch	AFW	1988	Failure to Close	Partial	Operator tried to close motor driven auxiliary feedwater pump discharge header to steam generator isolation valves against pump flow and they would not fully close. Valves failed to close due to the torque switch opening. These being caused by the increased torque during intermittent throttling near the full closed position where differential pressure is maximum.
86	Maintenance	Operational/ Human Error	Demand	Actuator	Torque Switch	RCS	1981	Failure to Close	Partial	The pressurizer PORV block valves did not fully shut on demand. The cause of this event was due to maintenance practices problems.
87	Maintenance	Operational/ Human Error	Demand	Actuator	Torque Switch	RHR-B	1987	Failure to Close	Partial	The residual heat removal suppression pool full flow discharge isolation valve and the torus spray isolation valve would not fully close upon demand. The cause of the failure is improper previous maintenance activities set the torque switch setting on the valve operator incorrectly low.
88	Maintenance	Operational/ Human Error	Demand	Actuator	Torque Switch	RHR-B	1991	Failure to Close	Partial	First failure was a torque switch out of adjustment. Second failure was a mis-positioned motor lead holding a torque switch open. Inadequate maintenance.
89	Maintenance	Operational/ Human Error	Demand	Actuator	Limit Switch	AFW	1984	Failure to Close	Partial	Feedwater from the motor driven auxiliary feed pumps to steam generators, failed upon a feedwater flow retention signal. Normal operation upon a retention signal is to actuate to a preset position. Inspection of the Limitorque operator revealed the limit switch was improperly positioned. An investigation could not determine cause of improper adjustment.
90	Maintenance	Operational/ Human Error	Demand	Valve	Stem	ISO	1981	Failure to Close	Partial	The isolation condenser valves failed to properly operate. The stem nuts of the MOV operators were found to be damaged.
91	Maintenance	Operational/ Human Error	Inspection	Actuator	Motor	CSS	1987	Failure to Open	Partial	Containment spray MOVs were rendered inoperable by maintenance staff error. Lubrication for the pinion gear housings was put in the motor housings.
92	Maintenance	Operational/ Human Error	Maintenance	Actuator	Limit Switch	RHR-P	1986	Failure to Close	Partial	Low pressure safety injection flow control containment isolation valves' stroke travel was greater than allowable. The cause was open limit switches out of adjustment.
93	Maintenance	Operational/ Human Error	Maintenance	Actuator	Torque Switch	RHR-B	1983	Failure to Open	Partial	Improper wiring and connections on torque switches and limit switches.
94	Maintenance	Operational/ Human Error	Test	Actuator	Transmission	HPI	1987	Failure to Open	Partial	The high pressure safety injection header to loop injection MOV operator spring packs were found with excess grease during surveillance testing causing valve to torque out mid stroke. The spring pack was inoperable due to excessive grease caused by improper maintenance.
95	Maintenance	Operational/ Human Error	Test	Actuator	Limit Switch	RCS	1984	Failure to Close	Partial	In performance of surveillance testing, pressurizer power operated relief valves, failed to close properly. Loose connections within the Limitorque operator. Long term measures to eliminate this recurring problem include changes to maintenance procedures requiring periodic examinations of all switch contacts within Limitorque operators.
96	Maintenance	Operational/ Human Error	Test	Actuator	Limit Switch	CSS	1985	Failure to Open	Partial	Redundant discharge valves on a containment spray pump would not open. Valve would torque out before going open due to improperly adjusted limit switch.
97	Maintenance	Operational/ Human Error	Test	Actuator	Limit Switch	RHR-P	1991	Failure to Close	Partial	LPI MOVs failed to open. Incorrect setpoints of the valve operator limit switches. Root cause was insufficient control of setpoints.
98	Maintenance	Operational/ Human Error	Test	Actuator	Breaker	HPI	1994	Failure to Open	Partial	RWST to Charging Pump Suction Isolation Valve failed to open. Troubleshooting subsequently determined that the MOV had two lifted leads. Further investigation revealed that another Charging Pump Suction Isolation Valve also had two lifted leads. The cause of the event was personnel error.
99	Maintenance	Operational/ Human Error	Test	Actuator	Circuit	HPI	1984	Failure to Open	Complete	While performing a surveillance test during refueling shutdown, the open contactor for HPI loop isolation valves did not close. The contactors were out of adjustment.

Item	Coupling Factor	Proximate Cause	Discovery Method	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
100	Maintenance	Operational/ Human Error	Test	Actuator	Circuit	HPI	1986	Failure to Open	Partial	Two ECCS MOVs had wire grounded under valve operator cover. Both failures were attributed to previous maintenance.
101	Maintenance	Operational/ Human Error	Test	Actuator	Torque Switch	HPI	1981	Failure to Close	Partial	Makeup pump recirculation valves did not fully close due to low torque values. The torque switch settings were set with no system pressure.
102	Maintenance	Operational/ Human Error	Test	Actuator	Torque Switch	AFW	1987	Failure to Open	Partial	Auxiliary feedwater regulating isolation MOVs were observed to stick and jam during motor operated valve actuation testing because the testing loosened the valve coupling on the drive shaft, throwing the limit switches out. The cause of the coupling coming loose was the torque of the operator exceeding the potential of the coupling, thus unscrewing it. This resulted from too high a setting on the torque switch, and the setup of the control circuitry.
103	Maintenance	Operational/ Human Error	Test	Valve	Stem	RCS	1992	Failure to Close	Partial	The pressurizer's power operated relief valve's isolation valve operator's output thrust was below the minimum required to fully close the valve on demand. The valve's stem to stem nut nickel based lubricant was the cause.
104	Maintenance	Operational/ Human Error	Test	Valve	Stem	RHR-B	1986	Failure to Close	Almost Complete	While testing the high pressure injection control valves, the motor operator overthrusted while going in the open direction. The valve operator overthrusted due to a design deficiency in the torque switch spring pack that allowed a buildup of grease between the Belleville washers which resulted in hydraulic lockup when the valve was operated. After discussion with component manufacturer, a plant modification was performed that machined notches in the ends of the motor operator torque limiting sleeve. These notches will provide a better grease relief path.
105	Maintenance	Operational/ Human Error	Test	Valve	Stem	CSS	1984	Failure to Open	Complete	During surveillance tests, two recirculation spray pump suction valves were inoperable. The valve position lights in the control room indicated the valve cycled normally. However, the valve did not move from the closed position. Failure was caused by the shearing of the coupling pin due to inadvertently leaving the incorrect pin, a marlin pin, (tapered pin possibly used for alignment), in the valve operator coupling.
106	Maintenance	Operational/ Human Error	Test	Valve	Stem	AFW	1984	Failure to Open	Partial	Aux feedwater pump discharge/header isolation valves found damaged during special inspection. One valve did not open during surveillance test; the other three were not operated, but probably would not have opened due to excessive damage, (bent stem). All damage was determined to be due to over-torquing the torque switch.
107	Maintenance	Other	Demand	Actuator	Limit Switch	RHR-P	1983	Failure to Open	Partial	MOV motor torqued out on start of open/close cycle. Limit switches out of adjustment.
108	Maintenance	Other	Demand	Actuator	Circuit	AFW	1984	Failure to Close	Partial	During automatic actuation of the AFW system, the motor operator flow control valves to SG's did not operate properly on a flow retention signal.
109	Maintenance	Other	Demand	Actuator	Circuit	AFW	1984	Failure to Open	Partial	During automatic actuation of the AFW system, the motor operator flow control valves to SG's did not operate properly on a flow retention signal.
110	Maintenance	Other	Demand	Actuator	Limit Switch	RHR-P	1987	Failure to Open	Partial	Residual heat removal pump suctions from feedwater storage tank valve and containment sump would not operate from control room. Cause of valve's failure to operate was limit switches out of adjustment.
111	Maintenance	Other	Demand	Actuator	Torque Switch	RHR-B	1984	Failure to Close	Partial	Residual heat removal suction from suppression pool and shutdown cooling inboard isolation suction valve would trip thermal overload when attempting to open from closed position and failed to close completely. Torque switch setting was to high and limit switch settings were incorrect. Reset limit and torque switches.
112	Maintenance	Other	Demand	Actuator	Torque Switch	RHR-B	1984	Failure to Close	Partial	Both LCI loop's full flow test valves failed to go full closed due to a faulty torque switch.

Item	Coupling Factor	Proximate Cause	Discovery Method	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
113	Maintenance	Other	Demand	Actuator	Torque Switch	RHR-B	1984	Failure to Open	Partial	Residual heat removal suction from suppression pool and shutdown cooling inboard isolation suction valve would trip thermal overload when attempting to open from closed position and failed to close completely. Torque switch setting was to high and limit switch settings were incorrect. Reset limit and torque switches.
114	Maintenance	Other	Demand	Actuator	Torque Switch	RHR-P	1987	Failure to Open	Partial	RHR pump suction MOV isolation valves would not fully open on demand. The cause of this failure was due to both torque switches were out of adjustment. Both valves could be closed on repeated attempts but not reopened completely.
115	Maintenance	Other	Demand	Actuator	Limit Switch	HPI	1982	Failure to Close	Partial	Close limit switch out of adjustment. After adjustment, valve closed correctly.
116	Maintenance	Other	Maintenance	Actuator	Torque Switch	CSS	1991	Failure to Open	Partial	While maintaining the containment sump isolation valve operators, it was noted that the as found available open and close thrusts were below the recommended minimum. It was determined that the MOVs were inoperable in the open direction, the safety function of the MOVs, and operable in the closed direction under worst case design basis conditions as found. Cause of valve thrusts below minimum recommended was unknown. Suspect it was due to setpoint drift or a cyclic loading.
117	Maintenance	Other	Maintenance	Actuator	Torque Switch	CSS	1991	Failure to Close	Partial	The as found available open and close thrusts were below the recommended minimum. It was determined that the MOVs were inoperable in the open direction, the safety function of the MOV, and operable in the closed direction under worst case design basis conditions as found. Suspect it was due to setpoint drift and or cyclic loading.
118	Maintenance	Other	Maintenance	Actuator	Breaker	HPI	1988	Failure to Open	Partial	A 480 Vac circuit breaker for a safety injection control valve failed to trip within its set tolerance. The cause of the failure was attributed to a defective circuit breaker.
119	Maintenance	Other	Maintenance	Actuator	Breaker	HPI	1992	Failure to Open	Partial	The 480-volt circuit breakers for three safety injection to cold leg motor operated isolation valves were found out specification high on two phases. The degraded component had no significant effect on the system or the plant, but could have caused damage to the valve actuator motors since the overcurrent protection was degraded.
120	Maintenance	Other	Test	Actuator	Torque Switch	RHR-B	1984	Failure to Close	Partial	LLRT failures on Torus Suction valves due to torque switch misadjustment.
121	Maintenance	Other	Test	Actuator	Torque Switch	RHR-P	1984	Failure to Open	Partial	While performing sump valve stroke test two MOVs failed to re-open after being stroked closed. The cause of the failures has been determined to be that the bypass circuit time was too short. This prevented the valves from opening until the control switch had been operated several times.
122	Maintenance	Other	Test	Actuator	Torque Switch	HPI	1994	Failure to Open	Partial	Motor Operated Valve for High Pressure Safety Injection would not stroke fully open. Electricians found oxidation on the open torque switch contacts, causing the motor to stop valve movement before the valve was fully open. Oxidation is an expected occurrence over time in this atmosphere.
123	Maintenance	Other	Test	Actuator	Limit Switch	HPI	1989	Failure to Open	Partial	The high pressure safety injection pump long term cooling containment isolation MOVs failed to achieve minimum flow requirements. The cause of failure was attributed to the limit switch rotor being out of mechanical adjustment.
124	Maintenance	Other	Test	Actuator	Limit Switch	HPI	1994	Failure to Close	Partial	Limit switches being out of adjustment resulted in contained leakage. One had both open and closed limit switches out of adjustment. The other valve had only the closed limit switches out of adjustment.

Item	Coupling Factor	Proximate Cause	Discovery Method	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
125	Maintenance	Other	Test	Actuator	Torque Switch	HPI	1994	Failure to Close	Partial	High Pressure Safety Injection to Loop MOV would not stroke fully open. Electricians found oxidation on the open torque switch contacts, causing the motor to stop valve movement before the valve was fully open. Oxidation is an expected occurrence over time in this atmosphere
126	Maintenance	Other	Test	Actuator	Breaker	RHR-B	1986	Failure to Open	Partial	LCI test valve and LCI torus suction valve would not open upon demand and would trip the breaker upon movement. Found auxiliary contacts on breaker in open circuit not making up.
127	Maintenance	Other	Test	Actuator	Limit Switch	RHR-P	1990	Failure to Open	Partial	Stem travel was excessive on low pressure safety injection flow control containment isolation valves. The opening travel was excessive, due to limit switch out of adjustment.
128	Maintenance	Other	Test	Actuator	Limit Switch	RHR-B	1984	Failure to Close	Partial	During a LCI operability test, full flow test valves were closed by position indication. However, the valves were not fully seated, and the LCI discharge piping drained. Valve position indication was out of adjustment.
129	Maintenance	Unknown	Demand	Actuator	Circuit	HPI	1985	Failure to Open	Complete	The motor operators for 2 valves, which allow the chemical and volume control pumps to take suction from the refueling water storage tank when in the closed position or from the volume control tank when in the opened position, burned up in the closed position and had to be manually opened.
130	Maintenance	Unknown	Demand	Actuator	Transmission	RHR-P	1985	Failure to Close	Partial	Low pressure injection supply from the borated water storage tank isolation valves would not close due to broken worm shaft clutch gear on valve operator.
131	Operational	Operational/ Human Error	Demand	Actuator	Transmission	RHR-P	1995	Failure to Close	Partial	Low Pressure Injection valves were overtorqued open in error during manual backseating after past packing leaks. Excessive force was applied when disengaged from electric operation, causing clutch ring to bind-up when electric operation was re-initiated.
132	Operational	Operational/ Human Error	Demand	Valve	Body	HPI	1988	Failure to Open	Partial	Safety injection isolation motor operated valves responded to an open signal from control room only after the valves were cracked open manually. The valve operators thermal overloads failed to trip after the valve remained energized for 30 minutes. No problems with the operator were discovered. It is suspected that the practice of manually seating the valve during refueling tagouts overtorqued the valve and prevented it from opening.
133	Operational	Operational/ Human Error	Inspection	Actuator	Breaker	HPI	1989	Failure to Open	Complete	Procedures allowed entry into operating mode where the system was required without directing operators to energize HPI MOV valve operators.
134	Operational	Operational/ Human Error	Inspection	Actuator	Breaker	HPI	1987	Failure to Open	Complete	The breakers for the high pressure injection suction valves from the BWST were inadvertently left tagged open after the reactor coolant system had been heated up to greater than 350F. The suction supply from the BWST to the HPI pumps was isolated and would not have opened automatically upon engineered safeguards actuation. The root cause is failure to perform an adequate review of the red tag logbook in accordance with the startup procedure.
135	Operational	Operational/ Human Error	Inspection	Actuator	Breaker	HPI	1981	Failure to Open	Complete	Operator went to the wrong unit and de-energized a total of five SI valves.
136	Operational	Operational/ Human Error	Test	Actuator	Breaker	RCI	1989	Failure to Open	Complete	During the performance of a scheduled RCI system logic system functional test, an overpressurization of the system's suction piping occurred. The operators incorrectly positioned and/or inaccurately verified the positions of 6 circuit breakers to motor operated valves prior to (and for) the test. RCI system inoperable.

Item	Coupling Factor	Proximate Cause	Discovery Method	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
137	Quality	Design/ Construction/ Manufacture/ Installation Inadequacy	Inspection	Actuator	Breaker	HPI	1980	Failure to Open	Partial	Power leads were found reversed to two safety injection valve operators. Root cause was poor administrative control.
138	Quality	Design/ Construction/ Manufacture/ Installation Inadequacy	Inspection	Actuator	Breaker	AFW	1989	Failure to Open	Partial	The 125 vdc breakers for motor-operated valves in the turbine driven auxiliary feedwater pump system were not the proper size.
139	Quality	Design/ Construction/ Manufacture/ Installation Inadequacy	Maintenance	Actuator	Breaker	AFW	1989	Failure to Open	Partial	The trip coils installed in the power supply feeder breakers for the motor actuator for two AFW MOVs were incorrect.
140	Quality	Design/ Construction/ Manufacture/ Installation Inadequacy	Maintenance	Actuator	Transmission	RHR-B	1990	Failure to Open	Partial	Normal maintenance on suppression chamber cooling Loop B throttle valve. Suppression chamber cooling Loop B throttle valve motor pinion key sheared and Loop A throttle valve motor pinion key deformed. Keys were found to be of the wrong material due to vendor inadequacies and utility programmatic deficiencies.
141	Quality	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Actuator	Circuit	AFW	1982	Failure to Open	Partial	It was determined that a train of AFW MOV's would not open on a steam generator low-low level. Some of the wiring to be done for design a change was incomplete upon completion of the design change.
142	Quality	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Actuator	Transmission	HPI	1992	Failure to Close	Partial	A safety injection recirculation MOV failed to close. It was discovered that the valve had a broken anti-rotation device (key). This prompted an inspection of the remaining globe valves that found the safety injection to reactor coolant system cold leg injection valves also had a broken key.
143	Quality	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Valve	Disk	HPI	1990	Failure to Open	Partial	While testing the high pressure injection system, it was discovered that the flow rate was unbalanced and below the minimum allowed by the units technical specifications. The previous replacement of the plugs in the MOVs with a plug that had been manufactured to the wrong dimensions, due to an error in a vendor drawing, caused unbalanced and low flow.
144	Quality	Internal to Component	Demand	Actuator	Torque Switch	RHR-B	1986	Failure to Open	Partial	An electrical fire was discovered in an MCC. The cause of this event was a personnel error, which resulted in an incorrect field wiring installation on HCI MOVs. The error was complicated by unsuccessful detection of the error during subsequent testing or inspections. As corrective actions, the wiring error was corrected. Additionally, all other motor operators, which were replaced for environmental qualification purposes during this period were modified to preclude this failure.

Item	Coupling Factor	Proximate Cause	Discovery Method	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
145	Quality	Internal to Component	Demand	Actuator	Torque Switch	HCI	1986	Failure to Open	Partial	After an attempt to reposition a HCI MOV (the recirc loop pump suction valve), The valve failed to open upon a signal from the control room. An investigation into the cause of the valve's failure determined that a hydraulic lockup of the MOV's spring pack prevented the torque switch from opening causing the motor to fail. This lock-up was due to: 1) the replacement of less viscous new grease, into the operator, which was recommended by the manufacturer and 2) the failure of the manufacturer to provide information regarding the need to install a retrofit grease relief kit.
146	Quality	Internal to Component	Maintenance	Actuator	Limit Switch	RCS	1983	Failure to Close	Partial	The Limitorque valve operator for the pressurizer isolation valves found to have cracks on the geared limit switch.
147	Quality	Operational/ Human Error	Demand	Actuator	Torque Switch	AFW	1985	Failure to Open	Complete	The procedural deficiency that allowed for a low setting of the bypass limit switches on Limitorque valve operators prompted an evaluation of all MOVs. Using the motor operated valve analysis and test system; a review of the as found conditions of 165 safety related MOVs revealed that 17 valves were evaluated as inoperable for various reasons. These 17 valves included the auxiliary feedwater isolation valves. Further investigation revealed that Limitorque failed to supply adequate instructions on balancing of the torque switches. Torque switch unbalance resulted in three valves being unable to produce sufficient thrust to close against the design differential pressure.
148	Quality	Operational/ Human Error	Demand	Valve	Disk	RHR-P	1987	Failure to Close	Partial	The residual heat removal system safety injection to reactor coolant loop isolation MOVs were leaking through while closed and could not be isolated. Valve split disks were reversed during initial installation and were 180 degrees out from the proper orientation. This caused seat leakage due to lack of seating contact.
149	Quality	Operational/ Human Error	Test	Actuator	Limit Switch	CSS	1988	Failure to Open	Complete	During re-testing, technicians found that the containment sump isolation valve operator internal limit switches were incorrectly set. This prevented the containment spray suction valve from repositioning as required. During a plant modification, technicians incorrectly set the containment sump isolation valve operator's internal limit switch. The switch was set to be open, though drawings called for it to be closed. Due to inadequate functional verification, this error was not found during post modification testing.

Table A-3. MOV CCF events sorted by discovery method.

Item	Discovery Method	Coupling Factor	Proximate Cause	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
1	Demand	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Circuit	RHR-B	1986	Failure to Close	Complete	Residual heat removal/low pressure coolant injection discharge to suppression pool minimum flow control valves did not close properly on demand. Incorrect logic design prevented valves from closing completely on demand. The new design provided for a seal-in contact with the automatic isolation signal. The seal-in contact allows torque closure of the valve even if the selector key lock switch is in the 'lock' position.
2	Demand	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Transmission	RHR-P	1991	Failure to Open	Partial	The motor operator for cold leg isolation valve electrically engaged while the valve was being manually stroked open during post-modification testing. The motor operator electrically engaged and closed the valve (short stroking). Investigation determined that this electrical short stroking of the valve caused the motor pinion key to shear. Other safety-related motor operators were inspected. The motor operators were identified as having failed keys similar to the failed key identified earlier. Further investigation revealed small cracks emanating from both corners of the keyway on the motor shaft. The root cause of the sheared motor pinion gear was that the key material was inadequate.
3	Demand	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Motor	AFW	1989	Failure to Close	Partial	AFW MOVs would not fully close under high d/p conditions until the valve actuators were setup at the highest torque switch setting allowed by the tolerances.
4	Demand	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Motor	RHR-B	1991	Failure to Close	Partial	RHR test return valves failed to seat tightly due to friction related problems. Replaced valve operators.
5	Demand	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Limit Switch	RHR-P	1985	Failure to Close	Partial	Shutdown cooling system heat exchanger isolation valves were not fully closed. The condition resulted from premature actuation of valve motor operator position indication limit switches and control room indication of the valves being in the closed position. A change is being implemented for these valves to separate the torque switch bypass limit switch and the valve position indicating limit switch by rewiring the position indicating rotors.
6	Demand	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Motor	RHR-B	1987	Failure to Open	Partial	Suppression pool cooling valves (one in each loop) failed to open. As long as the RHR pump was operating, the valves could not be opened and the thermal overloads would trip. Cause was an incorrectly sized motor.
7	Demand	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Circuit	RHR-B	1984	Failure to Open	Complete	Both LCI injection MOVs would not open due to an error in the valve logic circuit diagrams and the removal of motor brakes for environmental qualification. This condition caused the valves to continuously try to close until both valve stems were damaged.

Item	Discovery Method	Coupling Factor	Proximate Cause	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
8	Demand	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Circuit	RHR-P	1999	Failure to Open	Complete	Thermal overloads for two valves tripped due to design deficiency. Consequently, the normal closure of the valve will trip the thermal overload heater some percentage of the time.
9	Demand	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Valve	Body	RHR-B	1991	Failure to Open	Partial	Inboard LCI valve failed to open due to failed actuator motor caused by sustained operation at locked-rotor current due to hydraulic locking of the valve bonnet. Modifications performed on both LCI inboard valves and both core spray inboard valves.
10	Demand	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Valve	Disk	ISO	1989	Failure to Open	Partial	Isolation condenser dc outlet MOVs failed to open. Both valve failures are attributed to thermal binding, which is identified as a recurring design condition.
11	Demand	Design	External Environment	Actuator	Torque Switch	RHR-P	1983	Failure to Close	Partial	Two RHR MOVs were not giving remote indication in the full close position of valve. Torque switch inoperative, not rotating on closing stroke. The torque switch setting screw was found loose most likely due to valve vibration.
12	Demand	Design	Operational/ Human Error	Actuator	Breaker	AFW	1988	Failure to Open	Partial	The motor operated containment isolation valves for the turbine driven feedwater pump supply to steam generator failed to respond during stroke test from the main control board. The motor leads in the dc breaker were found disconnected. This is a plug-in type connector unique to the 480 vdc breakers. After evaluation, it was determined that personnel were working in the cable run compartment adjacent to the breaker and as they moved cables around in the cable run, tension was applied to the connectors causing them to pull out.
13	Demand	Design	Operational/ Human Error	Actuator	Torque Switch	RCI	1986	Failure to Close	Partial	An electrical fire was discovered in an MCC. The cause of this event was a personnel error, which resulted in an incorrect field wiring installation on HCI MOVs. The error was complicated by unsuccessful detection of the error during subsequent testing or inspections. As corrective actions, the wiring error was corrected. Additionally, all other motor operators, which were replaced for environmental qualification purposes during this period were modified to preclude this failure.
14	Demand	Design	Operational/ Human Error	Actuator	Circuit	RHR-B	1985	Failure to Open	Complete	When the control room operator proceeded to establish shutdown cooling, the suction valves to the system would not open. Investigation revealed that while applying a maintenance permit to the primary containment isolation system, a plant operator unknowingly removed the wrong fuse. This electrically blocked the residual heat removal system shutdown cooling suction valves and head spray isolation valves in the closed position. Investigation revealed that although the plant operator removed the fuse, which was labeled f2, as the permit required, this was not the correct fuse. Apparently, the label had slid down such that fuse f3 appeared to be f2.
15	Demand	Design	Other	Actuator	Circuit	RHR-B	1987	Failure to Open	Partial	Failure of the auxiliary contact block assembly of valve motor close contactor (failed in open position) prevented energizing valve motor open contactor. Occurred on Unit 2/1 cross-connect isolation valve and on Unit 1 RHR isolation injection valve. The contacts failed in the open position, thereby preventing energization of the valve motor open contactor.

Item	Discovery Method	Coupling Factor	Proximate Cause	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
16	Demand	Environmental	External Environment	Actuator	Transmission	HPI	1995	Failure to Close	Partial	When a close signal was initiated from the control room, two Refueling Water Tank valves failed to close. They only stroked 2 pct. and gave dual indication. Inspection of actuator internals found rust, corrosion, and water intrusion. The cause was due to water ingress through an actuator penetration in the stem protector resulting in rust and corrosion to actuator parts.
17	Demand	Maintenance	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Circuit	AFW	1984	Failure to Open	Partial	Aux. feedwater flow control valves would not open. On one the motor control contactor was not contacting due to 2 loose connections; and the other the torque close setting was misadjusted, causing contacts to open too soon.
18	Demand	Maintenance	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Torque Switch	HPI	1985	Failure to Close	Partial	Motor torque switches were out of adjustment and did not allow full closure.
19	Demand	Maintenance	External Environment	Valve	Disk	RHR-B	1986	Failure to Open	Partial	MOVs failed to open after being closed. Valves are the residual heat removal suppression pool suction valves. Torque switch prevented motor burn-out. Valve disk was found struck closed. Mud was found in the valve seat, which caused the disk to wedge into the seat upon closing and prevented it from opening. Mud in MOVs believed to be from construction activities of plant
20	Demand	Maintenance	External Environment	Valve	Body	RHR-P	1985	Failure to Open	Partial	Shutdown cooling isolation valves wouldn't fully open. One was attributed to boric acid buildup and the other cause is unknown.
21	Demand	Maintenance	External Environment	Valve	Disk	RHR-B	1986	Failure to Open	Partial	The suppression pool (residual heat removal) pump suction valves failed to open electrically. The motor was subjected to locked-rotor current for about 2 minutes, resulting in overheating. Sediment accumulations (non-ferrous) that would squeeze out between the disc and the seat and lock them together was the root cause. The suppression pool sediment most likely occurred during construction.
22	Demand	Maintenance	Internal to Component	Actuator	Circuit	RCS	1989	Failure to Open	Complete	The inlet block MOVs for the PORVs failed to close or open from the control room. This failure was due to the main control room switch for opening and closing the valve has erratic resistance reading as a result of wear and tear of the switch.
23	Demand	Maintenance	Internal to Component	Actuator	Circuit	AFW	1985	Failure to Close	Partial	While removing an AFW train from service, the pump discharge valves to two steam generators did not close. The closing coils in the motor controller failed, due to unknown cause.
24	Demand	Maintenance	Internal to Component	Actuator	Circuit	RCS	1989	Failure to Close	Complete	The inlet block MOVs for the PORVs failed to close or open from the control room. This failure was due to the main control room switch for opening and closing the valve has erratic resistance reading as a result of wear and tear of the switch.
25	Demand	Maintenance	Internal to Component	Actuator	Limit Switch	RHR-B	1995	Failure to Open	Partial	RHR system suppression pool valves failed to operate on demand (open). The limit switch on the MOV failed to operate, thus not allowing the valve to cycle on command. The cause of the failure was normal wear and service conditions of the limit switch resulting in failure.
26	Demand	Maintenance	Internal to Component	Actuator	Circuit	RHR-B	1993	Failure to Open	Partial	RHR MOVs failed when an aux relay open contactor failed to operate. Cause was attributed to inappropriate use of cramolin spray to clean relay, which caused it to become sticky.

Item	Discovery Method	Coupling Factor	Proximate Cause	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
27	Demand	Maintenance	Internal to Component	Actuator	Circuit	RHR-B	1993	Failure to Close	Partial	RHR MOVs failed when an aux relay open contactor failed to operate. Cause was attributed to inappropriate use of cramolin spray to clean relay, which caused it to become sticky.
28	Demand	Maintenance	Internal to Component	Actuator	Limit Switch	RHR-B	1980	Failure to Open	Partial	Extinguished valve indicating lights on RHR pump suction valves. MOVs would not operate due to broken limit switch rotors caused by loose limit switch finger bases.
29	Demand	Maintenance	Internal to Component	Actuator	Transmission	RHR-B	1984	Failure to Open	Partial	Torus suction valves (Both loops) clutch lever would not engage.
30	Demand	Maintenance	Operational/ Human Error	Actuator	Torque Switch	AFW	1988	Failure to Close	Partial	Operator tried to close motor driven auxiliary feedwater pump discharge header to steam generator isolation valves against pump flow and they would not fully close. Valves failed to close due to the torque switch opening. These being caused by the increased torque during intermittent throttling near the full closed position where differential pressure is maximum.
31	Demand	Maintenance	Operational/ Human Error	Actuator	Torque Switch	AFW	1995	Failure to Close	Partial	AFW steam supply valves torque switch setpoints were incorrectly calculated for the type of valve.
32	Demand	Maintenance	Operational/ Human Error	Actuator	Torque Switch	RHR-B	1991	Failure to Close	Partial	First failure was a torque switch out of adjustment. Second failure was a mis-positioned motor lead holding a torque switch open. Inadequate maintenance.
33	Demand	Maintenance	Operational/ Human Error	Actuator	Torque Switch	RHR-B	1987	Failure to Close	Partial	The residual heat removal suppression pool full flow discharge isolation valve and the torus spray isolation valve would not fully close upon demand. The cause of the failure is improper previous maintenance activities set the torque switch setting on the valve operator incorrectly low.
34	Demand	Maintenance	Operational/ Human Error	Actuator	Circuit	RCI	2000	Failure to Close	Partial	The instruments that signal the RCI steam supply valves to close in the event of a steam line break were rendered inoperable due to human error and work package change errors.
35	Demand	Maintenance	Operational/ Human Error	Actuator	Limit Switch	AFW	1984	Failure to Close	Partial	Feedwater from the motor driven auxiliary feed pumps to steam generators, failed upon a feedwater flow retention signal. Normal operation upon a retention signal is to actuate to a preset position. Inspection of the Limitorque operator revealed the limit switch was improperly positioned. An investigation could not determine cause of improper adjustment.
36	Demand	Maintenance	Operational/ Human Error	Actuator	Torque Switch	RHR-P	1983	Failure to Open	Almost Complete	Shutdown cooling system heat exchanger isolation valves could not be remotely opened from the control room. The inability of the valves to remotely open was attributed to incorrect open sequence torque and limit switch settings. The incorrect settings caused the motor on the valves to stop before the valves had come off their seats.
37	Demand	Maintenance	Operational/ Human Error	Actuator	Limit Switch	AFW	1984	Failure to Open	Partial	Feedwater from the motor driven auxiliary feed pumps to steam generators, failed upon a feedwater flow retention signal. Normal operation upon a retention signal is to actuate to a preset position. Inspection of the Limitorque operator revealed the limit switch was improperly positioned. An investigation could not determine cause of improper adjustment.
38	Demand	Maintenance	Operational/ Human Error	Actuator	Torque Switch	RCS	1981	Failure to Close	Partial	The pressurizer PORV block valves did not fully shut on demand. The cause of this event was due to maintenance practices problems.
39	Demand	Maintenance	Operational/ Human Error	Actuator	Breaker	AFW	1987	Failure to Open	Partial	The isolation valves to the steam generator from the steam driven auxiliary feedwater pump failed to open when demanded from the main control board switch. The dc circuit breaker for the motor operated valves were found to have loose (unplugged) connections on the terminal block inside the breaker. It appears that the connectors are easily unplugged by moving the cables in the cable run compartment adjoining the breaker.
40	Demand	Maintenance	Operational/ Human Error	Valve	Stem	ISO	1981	Failure to Close	Partial	The isolation condenser valves failed to properly operate. The stem nuts of the MOV operators were found to be damaged.

Item	Discovery Method	Coupling Factor	Proximate Cause	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
41	Demand	Maintenance	Other	Actuator	Circuit	AFW	1984	Failure to Open	Partial	During automatic actuation of the AFW system, the motor operator flow control valves to SG's did not operate properly on a flow retention signal.
42	Demand	Maintenance	Other	Actuator	Torque Switch	RHR-B	1984	Failure to Close	Partial	Both LCI loop's full flow test valves failed to go full closed due to a faulty torque switch.
43	Demand	Maintenance	Other	Actuator	Limit Switch	HPI	1982	Failure to Close	Partial	Close limit switch out of adjustment. After adjustment, valve closed correctly.
44	Demand	Maintenance	Other	Actuator	Torque Switch	RHR-B	1984	Failure to Close	Partial	Residual heat removal suction from suppression pool and shutdown cooling inboard isolation suction valve would trip thermal overload when attempting to open from closed position and failed to close completely. Torque switch setting was to high and limit switch settings were incorrect. Reset limit and torque switches.
45	Demand	Maintenance	Other	Actuator	Torque Switch	RHR-B	1984	Failure to Open	Partial	Residual heat removal suction from suppression pool and shutdown cooling inboard isolation suction valve would trip thermal overload when attempting to open from closed position and failed to close completely. Torque switch setting was to high and limit switch settings were incorrect. Reset limit and torque switches.
46	Demand	Maintenance	Other	Actuator	Limit Switch	RHR-P	1987	Failure to Open	Partial	Residual heat removal pump suctions from feedwater storage tank valve and containment sump would not operate from control room. Cause of valve's failure to operate was limit switches out of adjustment.
47	Demand	Maintenance	Other	Actuator	Limit Switch	RHR-P	1983	Failure to Open	Partial	MOV motor torqued out on start of open/close cycle. Limit switches out of adjustment.
48	Demand	Maintenance	Other	Actuator	Torque Switch	RHR-P	1987	Failure to Open	Partial	RHR pump suction MOV isolation valves would not fully open on demand. The cause of this failure was due to both torque switches were out of adjustment. Both valves could be closed on repeated attempts but not reopened completely.
49	Demand	Maintenance	Other	Actuator	Circuit	AFW	1984	Failure to Close	Partial	During automatic actuation of the AFW system, the motor operator flow control valves to SG's did not operate properly on a flow retention signal.
50	Demand	Maintenance	Unknown	Actuator	Circuit	HPI	1985	Failure to Open	Complete	The motor operators for 2 valves, which allow the chemical and volume control pumps to take suction from the refueling water storage tank when in the closed position or from the volume control tank when in the opened position, burned up in the closed position and had to be manually opened.
51	Demand	Maintenance	Unknown	Actuator	Transmission	RHR-P	1985	Failure to Close	Partial	Low pressure injection supply from the borated water storage tank isolation valves would not close due to broken worm shaft clutch gear on valve operator.
52	Demand	Operational	Operational/ Human Error	Actuator	Transmission	RHR-P	1995	Failure to Close	Partial	Low Pressure Injection valves were overtorqued open in error during manual backseating after past packing leaks. Excessive force was applied when disengaged from electric operation, causing clutch ring to bind-up when electric operation was re-initiated.
53	Demand	Operational	Operational/ Human Error	Valve	Body	HPI	1988	Failure to Open	Partial	Safety injection isolation motor operated valves responded to an open signal from control room only after the valves were cracked open manually. The valve operators thermal overloads failed to trip after the valve remained energized for 30 minutes. No problems with the operator were discovered. It is suspected that the practice of manually seating the valve during refueling tagouts overtorqued the valve and prevented it from opening.
54	Demand	Quality	Internal to Component	Actuator	Torque Switch	RHR-B	1986	Failure to Open	Partial	An electrical fire was discovered in an MCC. The cause of this event was a personnel error, which resulted in an incorrect field wiring installation on HCI MOVs. The error was complicated by unsuccessful detection of the error during subsequent testing or inspections. As corrective actions, the wiring error was corrected. Additionally, all other motor operators, which were replaced for environmental qualification purposes during this period were modified to preclude this failure.

Item	Discovery Method	Coupling Factor	Proximate Cause	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
55	Demand	Quality	Internal to Component	Actuator	Torque Switch	HCI	1986	Failure to Open	Partial	After an attempt to reposition a HCI MOV (the recirc loop pump suction valve), The valve failed to open upon a signal from the control room. An investigation into the cause of the valve's failure determined that a hydraulic lockup of the MOV's spring pack prevented the torque switch from opening causing the motor to fail. This lock-up was due to: 1) the replacement of less viscous new grease, into the operator, which was recommended by the manufacturer and 2) the failure of the manufacturer to provide information regarding the need to install a retrofit grease relief kit.
56	Demand	Quality	Operational/ Human Error	Actuator	Torque Switch	AFW	1985	Failure to Open	Complete	The procedural deficiency that allowed for a low setting of the bypass limit switches on Limitorque valve operators prompted an evaluation of all MOVs. Using the motor operated valve analysis and test system; a review of the as found conditions of 165 safety related MOVs revealed that 17 valves were evaluated as inoperable for various reasons. These 17 valves included the auxiliary feedwater isolation valves. Further investigation revealed that Limitorque failed to supply adequate instructions on balancing of the torque switches. Torque switch unbalance resulted in three valves being unable to produce sufficient thrust to close against the design differential pressure.
57	Demand	Quality	Operational/ Human Error	Valve	Disk	RHR-P	1987	Failure to Close	Partial	The residual heat removal system safety injection to reactor coolant loop isolation MOVs were leaking through while closed and could not be isolated. Valve split disks were reversed during initial installation and were 180 degrees out from the proper orientation. This caused seat leakage due to lack of seating contact.
58	Inspection	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Transmission	CSS	1993	Failure to Open	Partial	The motor pinion key for a Containment Spray header isolation valve was sheared. Subsequent motor pinion key failures occurred on October 18, 1993, March 23, 1994, and April 13, 1994. The evaluations for these events determined that the failures were due to improper key material.
59	Inspection	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Transmission	RHR-B	1990	Failure to Close	Partial	Investigating failure of motor operated valve to achieve minimum required closing thrust. Actuator for inboard isolation valve not geared to supply specified 110% design thrust. Outboard isolation valve and 6 other motor operated valves (2 in RHR) had same actuator problems due to failure to consider design capabilities prior to establishing diagnostic testing criteria.
60	Inspection	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Valve	Disk	RCI	1998	Failure to Close	Partial	RCI steam line isolation valves did not have the required seat/disk chamfer necessary to assure that the valves would close under design basis conditions.
61	Inspection	Design	Internal to Component	Valve	Body	RHR-B	1992	Failure to Open	Partial	On 4/29/92, the Torus cooling injection motor-operated valve was found to have cracks in the valve yoke. On 8/7/92, the Torus cooling injection MOV in the redundant loop was also discovered with cracks in the yoke.
62	Inspection	Environmental	External Environment	Actuator	Motor	RHR-B	1985	Failure to Open	Partial	The ECCS pump room was inadvertently flooded with water, inundating the RHR system minimum flow valve and a pump suction isolation valve. The valve operator motor windings were grounded as a result of the water intrusion.
63	Inspection	Environmental	External Environment	Valve	Body	RHR-B	1981	Failure to Open	Partial	Motor operated valves (chemwaste receiver tank isolation) and (Torus Injection Isolation) operators found with loose and broken cap screws anchoring motors to valves due to vibration induced loosening of the hold-down bolts.

Item	Discovery Method	Coupling Factor	Proximate Cause	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
64	Inspection	Maintenance	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Transmission	RHR-B	1992	Failure to Close	Partial	LCI MOV motor pinion key replacements were supposed to be performed in 1982 to change the keys to an appropriate material key. This replacement was not performed and was discovered in 1992, as 3 valve keys were found sheared or nearly sheared.
65	Inspection	Maintenance	Internal to Component	Actuator	Transmission	CSS	1989	Failure to Open	Partial	Oil leaks identified on handwheel of motor operated actuator for containment spray header isolation valves. Internal seals and o-ring for mating surface of handwheel and gear box had failed. Failure attributed to unexpected abnormal wear.
66	Inspection	Maintenance	Internal to Component	Actuator	Transmission	HPI	1986	Failure to Open	Partial	During a special inspection, a limit switch terminal block was found cracked and a bevel gear stripped on safety injection system high pressure header shutoff valves. The cause of failure has not been determined but inadequate maintenance is suspected. The limit switch terminal block and the bevel gear were replaced.
67	Inspection	Maintenance	Operational/ Human Error	Actuator	Motor	CSS	1987	Failure to Open	Partial	Containment spray MOVs were rendered inoperable by maintenance staff error. Lubrication for the pinion gear housings was put in the motor housings.
68	Inspection	Operational	Operational/ Human Error	Actuator	Breaker	HPI	1981	Failure to Open	Complete	Operator went to the wrong unit and de-energized a total of five SI valves.
69	Inspection	Operational	Operational/ Human Error	Actuator	Breaker	HPI	1987	Failure to Open	Complete	The breakers for the high pressure injection suction valves from the BWST were inadvertently left tagged open after the reactor coolant system had been heated up to greater than 350F. The suction supply from the BWST to the HPI pumps was isolated and would not have opened automatically upon engineered safeguards actuation. The root cause is failure to perform an adequate review of the red tag logbook in accordance with the startup procedure.
70	Inspection	Operational	Operational/ Human Error	Actuator	Breaker	HPI	1989	Failure to Open	Complete	Procedures allowed entry into operating mode where the system was required without directing operators to energize HPI MOV valve operators.
71	Inspection	Quality	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Breaker	AFW	1989	Failure to Open	Partial	The 125 vdc breakers for motor-operated valves in the turbine driven auxiliary feedwater pump system were not the proper size.
72	Inspection	Quality	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Breaker	HPI	1980	Failure to Open	Partial	Power leads were found reversed to two safety injection valve operators. Root cause was poor administrative control.
73	Maintenance	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Valve	Disk	RHR-B	1988	Failure to Open	Complete	Containment spray mode of RHR/LCI two MOV injection valve operator motors failed on overload when stroking valves due to trapped pressurized fluid between discs of the gate valve. This was caused by misinterpretation of valve purchase specifications by vendor.
74	Maintenance	Design	Operational/ Human Error	Actuator	Limit Switch	HPI	1985	Failure to Open	Complete	Incorrect engineering calculations resulted in spring pack setting that would not open the BIT isolation valves. The third valve, SI pump to accumulators was discovered with the same failure.
75	Maintenance	Maintenance	Internal to Component	Actuator	Breaker	RCI	1999	Failure to Open	Partial	Valve operations were not within specified time limits due to faulty contactors. Inadequate PM.

Item	Discovery Method	Coupling Factor	Proximate Cause	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
76	Maintenance	Maintenance	Internal to Component	Actuator	Motor	RHR-B	1989	Failure to Open	Partial	Grounds were found on 2 of 4 LCI Injection valves. Probable cause was determined to be insulation breakdown.
77	Maintenance	Maintenance	Internal to Component	Actuator	Torque Switch	HPI	1994	Failure to Close	Partial	High Head Safety Injection System motor operated isolation valves would not open fully. Technicians investigated and found grease on torque switch contacts, which prevented contacts from closing circuit. Improper greasing resulted in excessive grease accumulation on torque switch contacts.
78	Maintenance	Maintenance	Internal to Component	Actuator	Torque Switch	HPI	1994	Failure to Open	Partial	After completion of mechanical rework on HPI MOV actuator, technician was attempting to setup and stroke motor operated valves. While stroking valve electrically found the torque switch would not open, resulting in valve travel not being stopped. Technicians investigated and found torque switch defective and rotor on limit switch to not be turning fully to proper position.
79	Maintenance	Maintenance	Internal to Component	Valve	Disk	AFW	1988	Failure to Open	Partial	Plug nut welds were broken on the auxiliary feedwater pump discharge isolation valves. This would allow the disc to come off. Exact cause was unknown but suspect age and wearing.
80	Maintenance	Maintenance	Operational/ Human Error	Actuator	Limit Switch	RHR-P	1986	Failure to Close	Partial	Low pressure safety injection flow control containment isolation valves' stroke travel was greater than allowable. The cause was open limit switches out of adjustment.
81	Maintenance	Maintenance	Operational/ Human Error	Actuator	Torque Switch	RHR-B	1983	Failure to Open	Partial	Improper wiring and connections on torque switches and limit switches.
82	Maintenance	Maintenance	Other	Actuator	Breaker	HPI	1988	Failure to Open	Partial	A 480 Vac circuit breaker for a safety injection control valve failed to trip within its set tolerance. The cause of the failure was attributed to a defective circuit breaker.
83	Maintenance	Maintenance	Other	Actuator	Torque Switch	CSS	1991	Failure to Open	Partial	While maintaining the containment sump isolation valve operators, it was noted that the as found available open and close thrusts were below the recommended minimum. It was determined that the MOVs were inoperable in the open direction, the safety function of the MOVs, and operable in the closed direction under worst case design basis conditions as found. Cause of valve thrusts below minimum recommended was unknown. Suspect it was due to setpoint drift or a cyclic loading.
84	Maintenance	Maintenance	Other	Actuator	Breaker	HPI	1992	Failure to Open	Partial	The 480-volt circuit breakers for three safety injection to cold leg motor operated isolation valves were found out specification high on two phases. The degraded component had no significant effect on the system or the plant, but could have caused damage to the valve actuator motors since the overcurrent protection was degraded.
85	Maintenance	Maintenance	Other	Actuator	Torque Switch	CSS	1991	Failure to Close	Partial	The as found available open and close thrusts were below the recommended minimum. It was determined that the MOVs were inoperable in the open direction, the safety function of the MOV, and operable in the closed direction under worst case design basis conditions as found. Suspect it was due to setpoint drift and or cyclic loading.
86	Maintenance	Quality	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Breaker	AFW	1989	Failure to Open	Partial	The trip coils installed in the power supply feeder breakers for the motor actuator for two AFW MOVs were incorrect.
87	Maintenance	Quality	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Transmission	RHR-B	1990	Failure to Open	Partial	Normal maintenance on suppression chamber cooling Loop B throttle valve. Suppression chamber cooling Loop B throttle valve motor pinion key sheared and Loop A throttle valve motor pinion key deformed. Keys were found to be of the wrong material due to vendor inadequacies and utility programmatic deficiencies.

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88	Maintenance	Quality	Internal to Component	Actuator	Limit Switch	RCS	1983	Failure to Close	Partial	The Limitorque valve operator for the pressurizer isolation valves found to have cracks on the geared limit switch.
89	Test	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Torque Switch	AFW	1994	Failure to Close	Partial	Auxiliary Feedwater Pumps to Steam Generator Isolations were determined to be past inoperable. Differential pressure testing conducted during the outage revealed the valves would not sufficiently close against design basis system conditions to isolate flow.
90	Test	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Torque Switch	RHR-B	1987	Failure to Close	Partial	During operability test of RHR, a loop isolation valve would not close against system operating pressure due to an undersized washer spring pack in valve operator, supplied to the plant in actuators by the vendor not in accordance with purchase specifications. Similar problem found on the other loop isolation valve.
91	Test	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Torque Switch	CSS	1985	Failure to Close	Complete	During maintenance, testing it was determined that four containment spray MOVs wouldn't develop the required thrust. The failures were attributed to an improper spring pack installation and to an improper torque switch installation. The improper installations were due to incorrect engineering calculations of original design values.
92	Test	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Torque Switch	RHR-P	1985	Failure to Open	Partial	During maintenance testing it was determined several residual heat removal MOVs wouldn't develop the required thrust as specified by the motor operated valve testing program. The failure was attributed to an improper torque switch installation due to incorrect engineering calculations of original design values. The appropriate torque switch was installed, adjusted per the revised engineering values, tested, and returned to service.
93	Test	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Torque Switch	CSS	1984	Failure to Open	Complete	During surveillance, two containment spray motor operated valves failed to open. The valves were stuck due to excess play in operator assembly, which allowed the open torque switch to disengage thereby shutting off the operator. The bypass limit switch was rewired to a separate rotor with a longer bypass duration per design change.
94	Test	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Torque Switch	AFW	1989	Failure to Close	Partial	Seven AFW valves would open but would not fully close electrically. The cause of failure was that the valve operator and valve were previously changed out on a modification and passed the post modification test. Upon investigation of the valve failure it was determined that the design engineers had the thrust values wrong and the torque switch was reflecting a 1085 psi system when in fact the system is 1600 psi.
95	Test	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Transmission	HPI	1987	Failure to Open	Partial	While testing the high pressure injection control valves, the motor operator overthrusted while going in the open direction. Valve operator overthrusted due to a design deficiency in the torque switch spring pack that allowed a buildup of grease between the Belleville washers, which resulted in hydraulic lockup when the valve was operated. After discussion with component manufacturer, a plant modification was performed that machined notches in the ends of the motor operator torque limiting sleeve. These notches will provide a better grease relief path.
96	Test	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Torque Switch	HPI	1994	Failure to Close	Partial	HPI MOVs failed to fully close. Engineering determined that the recommended close thrust was insufficient to close valve during worst case failure.

Item	Discovery Method	Coupling Factor	Proximate Cause	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
97	Test	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Motor	RHR-B	1989	Failure to Close	Partial	Due to incorrectly sized operator the Torus cooling valves would not completely close against full differential pressure.
98	Test	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Motor	RHR-B	1992	Failure to Close	Partial	Due to the original valve operator selection criteria using less conservative factors, the outboard primary containment spray isolation valves had an inadequate torque and thrust capability. Design requirement is 134 ft-lbs; available is 100 ft-lbs.
99	Test	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Torque Switch	CSS	1985	Failure to Open	Partial	During maintenance, testing it was detemined that four containment spray MOVs wouldn't develop the required thrust. The failures were attributed to an improper spring pack installation and to an improper torque switch installation. The improper installations were due to incorrect engineering calculations of original design values.
100	Test	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Valve	Disk	RHR-B	1992	Failure to Close	Partial	The test valves to the suppression pool failed to stroke full closed. Root cause analysis revealed that the failure was the result of a gate valve in a globe valve application.
101	Test	Design	Design/ Construction/ Manufacture/ Installation Inadequacy	Valve	Body	RHR-B	1992	Failure to Close	Partial	Original construction design error resulted in pump minimum flow valves not being installed with the valve stem in the vertical, pointing upward orientation. Since these valves do not have wedge springs they have potential to prematurely seat failing to fully close.
102	Test	Design	External Environment	Actuator	Torque Switch	HPI	1991	Failure to Close	Partial	Compression springs in the HPI MOV torque switch assembly were weakened by vibration.
103	Test	Design	Internal to Component	Actuator	Motor	CSS	1986	Failure to Open	Complete	Routine surveillance disclosed that the containment recirculation sump to containment spray pump isolation valves would not open. The motor for valve operators burned up.
104	Test	Design	Internal to Component	Actuator	Circuit	AFW	2000	Failure to Open	Complete	Loose sliding link caused unplanned swap to LOCAL control. This also caused AFW suction auto swap capability to be blocked. Manual control apparently still available.
105	Test	Design	Internal to Component	Actuator	Torque Switch	AFW	1986	Failure to Close	Almost Complete	During MOV actuator testing, the close torque limits on the operator to the emergency feedwater pump discharge valves to the steam generators were found to be below minimum. The torque switches were out of adjustment.
106	Test	Design	Internal to Component	Valve	Packing	HCI	1994	Failure to Close	Partial	High Pressure Coolant valves failed to fully close. The cause of the failure appeared to be high packing load that caused mechanical binding preventing the operator from fully closing the valves.
107	Test	Design	Other	Actuator	Limit Switch	HPI	1984	Failure to Open	Partial	The HPI header flow rate was not within technical specification requirements. No direct cause could be found for the apparent drift of the valve operators.
108	Test	Design	Other	Actuator	Limit Switch	RHR-P	1995	Failure to Open	Partial	LPI throttle valves failed to stroke fully open. As a result, minimum flow for LPSI injection legs were below the minimum design basis flow.
109	Test	Design	Other	Actuator	Limit Switch	RHR-P	1995	Failure to Open	Partial	LPI throttle valves over traveled in the open direction by approximately 1/2 inch. This resulted in LPI flow exceeding Tech spec limits..

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110	Test	Environmental	External Environment	Actuator	Transmission	RHR-B	1991	Failure to Close	Partial	One of the two primary containment isolation valves in both residual heat removal low pressure coolant injection subsystems to be inoperable. One valve operator torque switch tripped in both directions preventing both full closure and full opening. The other valve had excessive seat leakage. The threads of the gate valve stem nut in the motor operator were worn and broken causing the valve to lock in a partially open position. Analysis determined stem nut wear out may have been accelerated by mechanical overload caused by high differential pressure across the valve. The valve stem failed due to vibration causing cyclic fatigue.
111	Test	Environmental	External Environment	Actuator	Motor	HCI	1980	Failure to Open	Complete	While testing the torus suction valves, two MOVs failed when given an open signal. Both torus suction valves had shorted out due to excessive condensation in the HCI room area.
112	Test	Maintenance	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Limit Switch	RHR-B	1988	Failure to Close	Partial	During surveillance testing of the RHR shutdown cooling isolation valves revealed that each loop injection valve failed to close as required. The failure was due to a wiring error on the limit switches associated with RHR suction valves. An incorrect limit switch was used for both valves, which made a slight mis-operation of the switches capable of affecting the close circuitry of the isolation valves.
113	Test	Maintenance	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Torque Switch	HPI	1991	Failure to Close	Partial	The high pressure safety injection system flow control containment isolation valves failed to completely close because total close thrust was not sufficient to close valve under dynamic stroke. A thrust value beyond the recommended maximum total close thrust would be needed to completely close the valve. Engineering evaluation determined a higher thrust value would be acceptable.
114	Test	Maintenance	Internal to Component	Actuator	Torque Switch	RHR-P	1986	Failure to Open	Partial	While the unit was in shutdown for refueling, the BWST outlet valve operator failed to open during motor operated valve actuation testing. The torque switch was out of balance.
115	Test	Maintenance	Internal to Component	Actuator	Limit Switch	AFW	1992	Failure to Open	Partial	The AFW pump supply to steam generator control valves stopped at an intermediate position and did not fully open. Local verification based on stem travel verified the valve stopped at an intermediate position. The valve operators limit switch was out of adjustment.
116	Test	Maintenance	Internal to Component	Actuator	Motor	RHR-B	1985	Failure to Open	Partial	Burned out motors (one LCI and one Torus cooling) due to aging.
117	Test	Maintenance	Internal to Component	Actuator	Transmission	RHR-B	1983	Failure to Open	Partial	RHR inboard injection valve would not open due to a locking nut on the worm gear shaft having backed off allowing the worm gear to back out of the bearing and the spring pack. The opposite train valve had failed 2 months previously for the same cause.
118	Test	Maintenance	Internal to Component	Actuator	Circuit	HPI	1986	Failure to Open	Partial	Dirty contacts and loose connections resulted in valves failing to open.
119	Test	Maintenance	Internal to Component	Actuator	Motor	AFW	1992	Failure to Close	Partial	The maximum d/p previously used in earlier testing and evaluation was determined to not represent worst case conditions. Further testing revealed that none of the AFW block valves would full close against the calculated worst case d/p. The root cause of the inability of the valves to close is attributed to valve condition due to normal wear.
120	Test	Maintenance	Internal to Component	Actuator	Breaker	CSS	1990	Failure to Open	Partial	The 480 Vac circuit breakers for recirculation sump to containment spray pump isolation valves would not trip on an instantaneous trip test within specified current limits.
121	Test	Maintenance	Internal to Component	Actuator	Torque Switch	HPI	1991	Failure to Open	Partial	A fuse failed in the first event due to aging and washers in the spring pack of the second valve came loose and grounded the motor. Root cause was inadequate maintenance.
122	Test	Maintenance	Internal to Component	Valve	Disk	RHR-B	1994	Failure to Close	Partial	RHR MOVs failed the surveillance test with gross seat leakage. Investigation revealed wear on the disc guides and some scratches on the seat. The cause is normal wear and aging.

Item	Discovery Method	Coupling Factor	Proximate Cause	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
123	Test	Maintenance	Operational/ Human Error	Actuator	Breaker	HPI	1994	Failure to Open	Partial	RWST to Charging Pump Suction Isolation Valve failed to open. Troubleshooting subsequently determined that the MOV had two lifted leads. Further investigation revealed that another Charging Pump Suction Isolation Valve also had two lifted leads. The cause of the event was personnel error.
124	Test	Maintenance	Operational/ Human Error	Actuator	Torque Switch	AFW	1987	Failure to Open	Partial	Auxiliary feedwater regulating isolation MOVs were observed to stick and jam during motor operated valve actuation testing because the testing loosened the valve coupling on the drive shaft, throwing the limit switches out. The cause of the coupling coming loose was the torque of the operator exceeding the potential of the coupling, thus unscrewing it. This resulted from too high a setting on the torque switch, and the setup of the control circuitry.
125	Test	Maintenance	Operational/ Human Error	Actuator	Torque Switch	HPI	1981	Failure to Close	Partial	Makeup pump recirculation valves did not fully close due to low torque values. The torque switch settings were set with no system pressure.
126	Test	Maintenance	Operational/ Human Error	Actuator	Limit Switch	RHR-P	1991	Failure to Close	Partial	LPI MOVs failed to open. Incorrect setpoints of the valve operator limit switches. Root cause was insufficient control of setpoints.
127	Test	Maintenance	Operational/ Human Error	Actuator	Limit Switch	RCS	1984	Failure to Close	Partial	In performance of surveillance testing, pressurizer power operated relief valves, failed to close properly. Loose connections within the Limitorque operator. Long term measures to eliminate this recurring problem include changes to maintenance procedures requiring periodic examinations of all switch contacts within Limitorque operators.
128	Test	Maintenance	Operational/ Human Error	Actuator	Transmission	HPI	1987	Failure to Open	Partial	The high pressure safety injection header to loop injection MOV operator spring packs were found with excess grease during surveillance testing causing valve to torque out mid stroke. The spring pack was inoperable due to excessive grease caused by improper maintenance.
129	Test	Maintenance	Operational/ Human Error	Actuator	Limit Switch	CSS	1985	Failure to Open	Partial	Redundant discharge valves on a containment spray pump would not open. Valve would torque out before going open due to improperly adjusted limit switch.
130	Test	Maintenance	Operational/ Human Error	Actuator	Circuit	HPI	1984	Failure to Open	Complete	While performing a surveillance test during refueling shutdown, the open contactor for HPI loop isolation valves did not close. The contactors were out of adjustment.
131	Test	Maintenance	Operational/ Human Error	Actuator	Circuit	HPI	1986	Failure to Open	Partial	Two ECCS MOVs had wire grounded under valve operator cover. Both failures were attributed to previous maintenance.
132	Test	Maintenance	Operational/ Human Error	Valve	Stem	RHR-B	1986	Failure to Close	Almost Complete	While testing the high pressure injection control valves, the motor operator overthrusted while going in the open direction. The valve operator overthrusted due to a design deficiency in the torque switch spring pack that allowed a buildup of grease between the Belleville washers which resulted in hydraulic lockup when the valve was operated. After discussion with component manufacturer, a plant modification was performed that machined notches in the ends of the motor operator torque limiting sleeve. These notches will provide a better grease relief path.
133	Test	Maintenance	Operational/ Human Error	Valve	Stem	RCS	1992	Failure to Close	Partial	The pressurizer's power operated relief valve's isolation valve operator's output thrust was below the minimum required to fully close the valve on demand. The valve's stem to stem nut nickel based lubricant was the cause.
134	Test	Maintenance	Operational/ Human Error	Valve	Stem	AFW	1984	Failure to Open	Partial	Aux feedwater pump discharge/header isolation valves found damaged during special inspection. One valve did not open during surveillance test; the other three were not operated, but probably would not have opened due to excessive damage, (bent stem). All damage was determined to be due to over-torquing the torque switch.

Item	Discovery Method	Coupling Factor	Proximate Cause	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
135	Test	Maintenance	Operational/ Human Error	Valve	Stem	CSS	1984	Failure to Open	Complete	During surveillance tests, two recirculation spray pump suction valves were inoperable. The valve position lights in the control room indicated the valve cycled normally. However, the valve did not move from the closed position. Failure was caused by the shearing of the coupling pin due to inadvertently leaving the incorrect pin, a marlin pin, (tapered pin possibly used for alignment), in the valve operator coupling.
136	Test	Maintenance	Other	Actuator	Breaker	RHR-B	1986	Failure to Open	Partial	LCI test valve and LCI torus suction valve would not open upon demand and would trip the breaker upon movement. Found auxiliary contacts on breaker in open circuit not making up.
137	Test	Maintenance	Other	Actuator	Torque Switch	HPI	1994	Failure to Close	Partial	High Pressure Safety Injection to Loop MOV would not stroke fully open. Electricians found oxidation on the open torque switch contacts, causing the motor to stop valve movement before the valve was fully open. Oxidation is an expected occurrence over time in this atmosphere
138	Test	Maintenance	Other	Actuator	Limit Switch	HPI	1994	Failure to Close	Partial	Limit switches being out of adjustment resulted in contained leakage. One had both open and closed limit switches out of adjustment. The other valve had only the closed limit switches out of adjustment.
139	Test	Maintenance	Other	Actuator	Limit Switch	HPI	1989	Failure to Open	Partial	The high pressure safety injection pump long term cooling containment isolation MOVs failed to achieve minimum flow requirements. The cause of failure was attributed to the limit switch rotor being out of mechanical adjustment.
140	Test	Maintenance	Other	Actuator	Torque Switch	RHR-B	1984	Failure to Close	Partial	LLRT failures on Torus Suction valves due to torque switch misadjustment.
141	Test	Maintenance	Other	Actuator	Torque Switch	HPI	1994	Failure to Open	Partial	Motor Operated Valve for High Pressure Safety Injection would not stroke fully open. Electricians found oxidation on the open torque switch contacts, causing the motor to stop valve movement before the valve was fully open. Oxidation is an expected occurrence over time in this atmosphere.
142	Test	Maintenance	Other	Actuator	Limit Switch	RHR-B	1984	Failure to Close	Partial	During a LCI operability test, full flow test valves were closed by position indication. However, the valves were not fully seated, and the LCI discharge piping drained. Valve position indication was out of adjustment.
143	Test	Maintenance	Other	Actuator	Torque Switch	RHR-P	1984	Failure to Open	Partial	While performing sump valve stroke test two MOVs failed to re-open after being stroked closed. The cause of the failures has been determined to be that the bypass circuit time was too short. This prevented the valves from opening until the control switch had been operated several times.
144	Test	Maintenance	Other	Actuator	Limit Switch	RHR-P	1990	Failure to Open	Partial	Stem travel was excessive on low pressure safety injection flow control containment isolation valves. The opening travel was excessive, due to limit switch out of adjustment.
145	Test	Operational	Operational/ Human Error	Actuator	Breaker	RCI	1989	Failure to Open	Complete	During the performance of a scheduled RCI system logic system functional test, an overpressurization of the system's suction piping occurred. The operators incorrectly positioned and/or inaccurately verified the positions of 6 circuit breakers to motor operated valves prior to (and for) the test. RCI system inoperable.
146	Test	Quality	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Transmission	HPI	1992	Failure to Close	Partial	A safety injection recirculation MOV failed to close. It was discovered that the valve had a broken anti-rotation device (key). This prompted an inspection of the remaining globe valves that found the safety injection to reactor coolant system cold leg injection valves also had a broken key.

Item	Discovery Method	Coupling Factor	Proximate Cause	Sub-Component	Piece Part	System	Year	Failure Mode	Degree of Failure	Description
147	Test	Quality	Design/ Construction/ Manufacture/ Installation Inadequacy	Actuator	Circuit	AFW	1982	Failure to Open	Partial	It was determined that a train of AFW MOV's would not open on a steam generator low-low level. Some of the wiring to be done for design a change was incomplete upon completion of the design change.
148	Test	Quality	Design/ Construction/ Manufacture/ Installation Inadequacy	Valve	Disk	HPI	1990	Failure to Open	Partial	While testing the high pressure injection system, it was discovered that the flow rate was unbalanced and below the minimum allowed by the units technical specifications. The previous replacement of the plugs in the MOVs with a plug that had been manufactured to the wrong dimensions, due to an error in a vendor drawing, caused unbalanced and low flow.
149	Test	Quality	Operational/ Human Error	Actuator	Limit Switch	CSS	1988	Failure to Open	Complete	During re-testing, technicians found that the containment sump isolation valve operator internal limit switches were incorrectly set. This prevented the containment spray suction valve from repositioning as required. During a plant modification, technicians incorrectly set the containment sump isolation valve operator's internal limit switch. The switch was set to be open, though drawings called for it to be closed. Due to inadequate functional verification, this error was not found during post modification testing.

Appendix B

Data Summary by Sub-Component

Appendix B

Data Summary by Sub-Component

This appendix is a summary of the data evaluated in the common-cause failure (CCF) data collection effort for MOVs. The tables in this appendix support the sections in Chapter 4. Each table is sorted alphabetically, by the first four columns.

Appendix B

Table B-1. MOV actuator sub-component CCF event summary.

Item	Sub-Component	Proximate Cause	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
1	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Circuit	RHR-B	Design	1984	Failure to Open	Complete	Both LCI injection MOVs would not open due to an error in the valve logic circuit diagrams and the removal of motor brakes for environmental qualification. This condition caused the valves to continuously try to close until both valve stems were damaged.
2	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Circuit	RHR-B	Design	1986	Failure to Close	Complete	Residual heat removal/low pressure coolant injection discharge to suppression pool minimum flow control valves did not close properly on demand. Incorrect logic design prevented valves from closing completely on demand. The new design provided for a seal-in contact with the automatic isolation signal. The seal-in contact allows torque closure of the valve even if the selector key lock switch is in the 'lock' position.
3	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Circuit	AFW	Maintenance	1984	Failure to Open	Partial	Aux. feedwater flow control valves would not open. On one the motor control contactor was not contacting due to 2 loose connections; and the other the torque close setting was misadjusted, causing contacts to open too soon.
4	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Circuit	RHR-P	Design	1999	Failure to Open	Complete	Thermal overloads for two valves tripped due to design deficiency. Consequently, the normal closure of the valve will trip the thermal overload heater some percentage of the time.
5	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Limit Switch	RHR-P	Design	1985	Failure to Close	Partial	Shutdown cooling system heat exchanger isolation valves were not fully closed. The condition resulted from premature actuation of valve motor operator position indication limit switches and control room indication of the valves being in the closed position. A change is being implemented for these valves to separate the torque switch bypass limit switch and the valve position indicating limit switch by rewiring the position indicating rotors.
6	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Motor	RHR-B	Design	1987	Failure to Open	Partial	Suppression pool cooling valves (one in each loop) failed to open. As long as the RHR pump was operating, the valves could not be opened and the thermal overloads would trip. Cause was an incorrectly sized motor.
7	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Motor	AFW	Design	1989	Failure to Close	Partial	AFW MOVs would not fully close under high d/p conditions until the valve actuators were setup at the highest torque switch setting allowed by the tolerances.
8	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Motor	RHR-B	Design	1991	Failure to Close	Partial	RHR test return valves failed to seat tightly due to friction related problems. Replaced valve operators.

Item	Sub-Component	Proximate Cause	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
9	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Torque Switch	HPI	Maintenance	1985	Failure to Close	Partial	Motor torque switches were out of adjustment and did not allow full closure.
10	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Transmission	RHR-P	Design	1991	Failure to Open	Partial	The motor operator for cold leg isolation valve electricallyengaged while the valve was being manually stroked open during post-modification testing. The motor operator electrically engaged and closed the valve (short stroking). Investigation determined that this electrical short stroking of the valve caused the motor pinion key to shear. Other safety-related motor operators were inspected. The motor operators were identified as having failed keys similar to the failed key identified earlier. Further investigation revealed small cracks emanating from both corners of the keyway on the motor shaft. The root cause of the sheared motor pinion gear was that the key material was inadequate.
11	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Inspection	Breaker	HPI	Quality	1980	Failure to Open	Partial	Power leads were found reversed to two safety injection valve operators. Root cause was poor administrative control.
12	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Inspection	Breaker	AFW	Quality	1989	Failure to Open	Partial	The 125 vdc breakers for motor-operated valves in the turbine driven auxiliary feedwater pump system were not the proper size.
13	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Inspection	Transmission	CSS	Design	1993	Failure to Open	Partial	The motor pinion key for a Containment Spray header isolation valve was sheared. Subsequent motor pinion key failures occurred on October 18, 1993, March 23, 1994, and April 13, 1994. The evaluations for these events determined that the failures were due to improper key material.
14	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Inspection	Transmission	RHR-B	Design	1990	Failure to Close	Partial	Investigating failure of motor operated valve to achieve minimum required closing thrust. Actuator for inboard isolation valve not geared to supply specified 110% design thrust. Outboard isolation valve and 6 other motor operated valves (2 in RHR) had same actuator problems due to failure to consider design capabilities prior to establishing diagnostic testing criteria.
15	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Inspection	Transmission	RHR-B	Maintenance	1992	Failure to Close	Partial	LCI MOV motor pinion key replacements were supposed to be performed in 1982 to change the keys to an appropriate material key. This replacement was not performed and was discovered in 1992, as 3 valve keys were found sheared or nearly sheared.
16	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Maintenance	Breaker	AFW	Quality	1989	Failure to Open	Partial	The trip coils installed in the power supply feeder breakers for the motor actuator for two AFW MOVs were incorrect.

Item	Sub-Component	Proximate Cause	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
17	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Maintenance	Transmission	RHR-B	Quality	1990	Failure to Open	Partial	Normal maintenance on suppression chamber cooling Loop B throttle valve. Suppression chamber cooling Loop B throttle valve motor pinion key sheared and Loop A throttle valve motor pinion key deformed. Keys were found to be of the wrong material due to vendor inadequacies and utility programmatic deficiencies.
18	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Circuit	AFW	Quality	1982	Failure to Open	Partial	It was determined that a train of AFW MOV's would not open on a steam generator low-low level. Some of the wiring to be done for design a change was incomplete upon completion of the design change.
19	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Limit Switch	RHR-B	Maintenance	1988	Failure to Close	Partial	During surveillance testing of the RHR shutdown cooling isolation valves revealed that each loop injection valve failed to close as required. The failure was due to a wiring error on the limit switches associated with RHR suction valves. An incorrect limit switch was used for both valves, which made a slight mis-operation of the switches capable of affecting the close circuitry of the isolation valves.
20	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Motor	RHR-B	Design	1992	Failure to Close	Partial	Due to the original valve operator selection criteria using less conservative factors, the outboard primary containment spray isolation valves had an inadequate torque and thrust capability. Design requirement is 134 ft-lbs; available is 100 ft-lbs.
21	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Motor	RHR-B	Design	1989	Failure to Close	Partial	Due to incorrectly sized operator the Torus cooling valves would not completely close against full differential pressure.
22	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Torque Switch	AFW	Design	1994	Failure to Close	Partial	Auxiliary Feedwater Pumps to Steam Generator Isolations were determined to be past inoperable. Differential pressure testing conducted during the outage revealed the valves would not sufficiently close against design basis system conditions to isolate flow.
23	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Torque Switch	AFW	Design	1989	Failure to Close	Partial	Seven AFW valves would open but would not fully close electrically. The cause of failure was that the valve operator and valve were previously changed out on a modification and passed the post modification test. Upon investigation of the valve failure it was determined that the design engineers had the thrust values wrong and the torque switch was reflecting a 1085 psi system when in fact the system is 1600 psi.
24	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Torque Switch	CSS	Design	1984	Failure to Open	Complete	During surveillance, two containment spray motor operated valves failed to open. The valves were stuck due to excess play in operator assembly, which allowed the open torque switch to disengage thereby shutting off the operator. The bypass limit switch was rewired to a separate rotor with a longer bypass duration per design change.
25	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Torque Switch	HPI	Design	1994	Failure to Close	Partial	HPI MOVs failed to fully close. Engineering determined that the recommended close thrust was insufficient to close valve during worst case failure.

Item	Sub-Component	Proximate Cause	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
26	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Torque Switch	RHR-B	Design	1987	Failure to Close	Partial	During operability test of RHR, a loop isolation valve would not close against system operating pressure due to an undersized washer spring pack in valve operator, supplied to the plant in actuators by the vendor not in accordance with purchase specifications. Similar problem found on the other loop isolation valve.
27	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Torque Switch	HPI	Maintenance	1991	Failure to Close	Partial	The high pressure safety injection system flow control containment isolation valves failed to completely close because total close thrust was not sufficient to close valve under dynamic stroke. A thrust value beyond the recommended maximum total close thrust would be needed to completely close the valve. Engineering evaluation determined a higher thrust value would be acceptable.
28	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Torque Switch	RHR-P	Design	1985	Failure to Open	Partial	During maintenance testing it was determined several residual heat removal MOVs wouldn't develop the required thrust as specified by the motor operated valve testing program. The failure was attributed to an improper torque switch installation due to incorrect engineering calculations of original design values. The appropriate torque switch was installed, adjusted per the revised engineering values, tested, and returned to service.
29	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Torque Switch	CSS	Design	1985	Failure to Open	Partial	During maintenance, testing it was determined that four containment spray MOVs wouldn't develop the required thrust. The failures were attributed to an improper spring pack installation and to an improper torque switch installation. The improper installations were due to incorrect engineering calculations of original design values.
30	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Torque Switch	CSS	Design	1985	Failure to Close	Complete	During maintenance, testing it was determined that four containment spray MOVs wouldn't develop the required thrust. The failures were attributed to an improper spring pack installation and to an improper torque switch installation. The improper installations were due to incorrect engineering calculations of original design values.
31	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Transmission	HPI	Quality	1992	Failure to Close	Partial	A safety injection recirculation MOV failed to close. It was discovered that the valve had a broken anti-rotation device (key). This prompted an inspection of the remaining globe valves that found the safety injection to reactor coolant system cold leg injection valves also had a broken key.
32	Actuator	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Transmission	HPI	Design	1987	Failure to Open	Partial	While testing the high pressure injection control valves, the motor operator overthrusted while going in the open direction. Valve operator overthrusted due to a design deficiency in the torque switch spring pack that allowed a buildup of grease between the Belleville washers, which resulted in hydraulic lockup when the valve was operated. After discussion with component manufacturer, a plant modification was performed that machined notches in the ends of the motor operator torque limiting sleeve. These notches will provide a better grease relief path.
33	Actuator	External Environment	Demand	Torque Switch	RHR-P	Design	1983	Failure to Close	Partial	Two RHR MOVs were not giving remote indication in the full close position of valve. Torque switch inoperative, not rotating on closing stroke. The torque switch setting screw was found loose most likely due to valve vibration.
34	Actuator	External Environment	Demand	Transmission	HPI	Environmental	1995	Failure to Close	Partial	When a close signal was initiated from the control room, two Refueling Water Tank valves failed to close. They only stroked 2 pct. and gave dual indication. Inspection of actuator internals found rust, corrosion, and water intrusion. The cause was due to water ingress through an actuator penetration in the stem protector resulting in rust and corrosion to actuator parts.

Item	Sub-Component	Proximate Cause	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
35	Actuator	External Environment	Inspection	Motor	RHR-B	Environmental	1985	Failure to Open	Partial	The ECCS pump room was inadvertently flooded with water, inundating the RHR system minimum flow valve and a pump suction isolation valve. The valve operator motor windings were grounded as a result of the water intrusion.
36	Actuator	External Environment	Test	Motor	HCI	Environmental	1980	Failure to Open	Complete	While testing the torus suction valves, two MOVs failed when given an open signal. Both torus suction valves had shorted out due to excessive condensation in the HCI room area.
37	Actuator	External Environment	Test	Torque Switch	HPI	Design	1991	Failure to Close	Partial	Compression springs in the HPI MOV torque switch assembly were weakened by vibration.
38	Actuator	External Environment	Test	Transmission	RHR-B	Environmental	1991	Failure to Close	Partial	One of the two primary containment isolation valves in both residual heat removal low pressure coolant injection subsystems to be inoperable. One valve operator torque switch tripped in both directions preventing both full closure and full opening. The other valve had excessive seat leakage. The threads of the gate valve stem nut in the motor operator were worn and broken causing the valve to lock in a partially open position. Analysis determined stem nut wear out may have been accelerated by mechanical overload caused by high differential pressure across the valve. The valve stem failed due to vibration causing cyclic fatigue.
39	Actuator	Internal to Component	Demand	Circuit	RCS	Maintenance	1989	Failure to Close	Complete	The inlet block MOVs for the PORVs failed to close or open from the control room. This failure was due to the main control room switch for opening and closing the valve has erratic resistance reading as a result of wear and tear of the switch.
40	Actuator	Internal to Component	Demand	Circuit	RCS	Maintenance	1989	Failure to Open	Complete	The inlet block MOVs for the PORVs failed to close or open from the control room. This failure was due to the main control room switch for opening and closing the valve has erratic resistance reading as a result of wear and tear of the switch.
41	Actuator	Internal to Component	Demand	Circuit	AFW	Maintenance	1985	Failure to Close	Partial	While removing an AFW train from service, the pump discharge valves to two steam generators did not close. The closing coils in the motor controller failed, due to unknown cause.
42	Actuator	Internal to Component	Demand	Circuit	RHR-B	Maintenance	1993	Failure to Close	Partial	RHR MOVs failed when an aux relay open contactor failed to operate. Cause was attributed to inappropriate use of cramolin spray to clean relay, which caused it to become sticky.
43	Actuator	Internal to Component	Demand	Circuit	RHR-B	Maintenance	1993	Failure to Open	Partial	RHR MOVs failed when an aux relay open contactor failed to operate. Cause was attributed to inappropriate use of cramolin spray to clean relay, which caused it to become sticky.
44	Actuator	Internal to Component	Demand	Limit Switch	RHR-B	Maintenance	1980	Failure to Open	Partial	Extinguished valve indicating lights on RHR pump suction valves. MOVs would not operate due to broken limit switch rotors caused by loose limit switch finger bases.
45	Actuator	Internal to Component	Demand	Limit Switch	RHR-B	Maintenance	1995	Failure to Open	Partial	RHR system suppression pool valves failed to operate on demand (open). The limit switch on the MOV failed to operate, thus not allowing the valve to cycle on command. The cause of the failure was normal wear and service conditions of the limit switch resulting in failure.
46	Actuator	Internal to Component	Demand	Torque Switch	RHR-B	Quality	1986	Failure to Open	Partial	An electrical fire was discovered in an MCC. The cause of this event was a personnel error, which resulted in an incorrect field wiring installation on HCI MOVs. The error was complicated by unsuccessful detection of the error during subsequent testing or inspections. As corrective actions, the wiring error was corrected. Additionally, all other motor operators, which were replaced for environmental qualification purposes during this period were modified to preclude this failure.

Item	Sub-Component	Proximate Cause	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
47	Actuator	Internal to Component	Demand	Torque Switch	HCI	Quality	1986	Failure to Open	Partial	After an attempt to reposition a HCI MOV (the recirc loop pump suction valve), The valve failed to open upon a signal from the control room. An investigation into the cause of the valve's failure determined that a hydraulic lockup of the MOV's spring pack prevented the torque switch from opening causing the motor to fail. This lock-up was due to: 1) the replacement of less viscous new grease, into the operator, which was recommended by the manufacturer and 2) the failure of the manufacturer to provide information regarding the need to install a retrofit grease relief kit.
48	Actuator	Internal to Component	Demand	Transmission	RHR-B	Maintenance	1984	Failure to Open	Partial	Torus suction valves (Both loops) clutch lever would not engage.
49	Actuator	Internal to Component	Inspection	Transmission	HPI	Maintenance	1986	Failure to Open	Partial	During a special inspection, a limit switch terminal block was found cracked and a bevel gear stripped on safety injection system high pressure header shutoff valves. The cause of failure has not been determined but inadequate maintenance is suspected. The limit switch terminal block and the bevel gear were replaced.
50	Actuator	Internal to Component	Inspection	Transmission	CSS	Maintenance	1989	Failure to Open	Partial	Oil leaks identified on handwheel of motor operated actuator for containment spray header isolation valves. Internal seals and o-ring for mating surface of handwheel and gear box had failed. Failure attributed to unexpected abnormal wear.
51	Actuator	Internal to Component	Maintenance	Breaker	RCI	Maintenance	1999	Failure to Open	Partial	Valve operations were not within specified time limits due to faulty contactors. Inadequate PM.
52	Actuator	Internal to Component	Maintenance	Limit Switch	RCS	Quality	1983	Failure to Close	Partial	The Limitorque valve operator for the pressurizer isolation valves found to have cracks on the geared limit switch.
53	Actuator	Internal to Component	Maintenance	Motor	RHR-B	Maintenance	1989	Failure to Open	Partial	Grounds were found on 2 of 4 LCI Injection valves. Probable cause was determined to be insulation breakdown.
54	Actuator	Internal to Component	Maintenance	Torque Switch	HPI	Maintenance	1994	Failure to Open	Partial	After completion of mechanical rework on HPI MOV actuator, technician was attempting to setup and stroke motor operated valves. While stroking valve electrically found the torque switch would not open, resulting in valve travel not being stopped. Technicians investigated and found torque switch defective and rotor on limit switch to not be turning fully to proper position.
55	Actuator	Internal to Component	Maintenance	Torque Switch	HPI	Maintenance	1994	Failure to Close	Partial	High Head Safety Injection System motor operated isolation valves would not open fully. Technicians investigated and found grease on torque switch contacts, which prevented contacts from closing circuit. Improper greasing resulted in excessive grease accumulation on torque switch contacts.
56	Actuator	Internal to Component	Test	Breaker	CSS	Maintenance	1990	Failure to Open	Partial	The 480 Vac circuit breakers for recirculation sump to containment spray pump isolation valves would not trip on an instantaneous trip test within specified current limits.
57	Actuator	Internal to Component	Test	Circuit	HPI	Maintenance	1986	Failure to Open	Partial	Dirty contacts and loose connections resulted in valves failing to open.
58	Actuator	Internal to Component	Test	Circuit	AFW	Design	2000	Failure to Open	Complete	Loose sliding link caused unplanned swap to LOCAL control. This also caused AFW suction auto swap capability to be blocked. Manual control apparently still available.
59	Actuator	Internal to Component	Test	Limit Switch	AFW	Maintenance	1992	Failure to Open	Partial	The AFW pump supply to steam generator control valves stopped at an intermediate position and did not fully open. Local verification based on stem travel verified the valve stopped at an intermediate position. The valve operators limit switch was out of adjustment.
60	Actuator	Internal to Component	Test	Motor	AFW	Maintenance	1992	Failure to Close	Partial	The maximum d/p previously used in earlier testing and evaluation was determined to not represent worst case conditions. Further testing revealed that none of the AFW block valves would full close against the calculated worst case d/p. The root cause of the inability of the valves to close is attributed to valve condition due to normal wear.

Item	Sub-Component	Proximate Cause	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
61	Actuator	Internal to Component	Test	Motor	RHR-B	Maintenance	1985	Failure to Open	Partial	Burned out motors (one LCI and one Torus cooling) due to aging.
62	Actuator	Internal to Component	Test	Motor	CSS	Design	1986	Failure to Open	Complete	Routine surveillance disclosed that the containment recirculation sump to containment spray pump isolation valves would not open. The motor for valve operators burned up.
63	Actuator	Internal to Component	Test	Torque Switch	AFW	Design	1986	Failure to Close	Almost Complete	During MOV actuator testing, the close torque limits on the operator to the emergency feedwater pump discharge valves to the steam generators were found to be below minimum. The torque switches were out of adjustment.
64	Actuator	Internal to Component	Test	Torque Switch	RHR-P	Maintenance	1986	Failure to Open	Partial	While the unit was in shutdown for refueling, the BWST outlet valve operator failed to open during motor operated valve actuation testing. The torque switch was out of balance.
65	Actuator	Internal to Component	Test	Torque Switch	HPI	Maintenance	1991	Failure to Open	Partial	A fuse failed in the first event due to aging and washers in the spring pack of the second valve came loose and grounded the motor. Root cause was inadequate maintenance.
66	Actuator	Internal to Component	Test	Transmission	RHR-B	Maintenance	1983	Failure to Open	Partial	RHR inboard injection valve would not open due to a locking nut on the worm gear shaft having backed off allowing the worm gear to back out of the bearing and the spring pack. The opposite train valve had failed 2 months previously for the same cause.
67	Actuator	Operational/ Human Error	Demand	Breaker	AFW	Maintenance	1987	Failure to Open	Partial	The isolation valves to the steam generator from the steam driven auxiliary feedwater pump failed to open when demanded from the main control board switch. The dc circuit breaker for the motor operated valves were found to have loose (unplugged) connections on the terminal block inside the breaker. It appears that the connectors are easily unplugged by moving the cables in the cable run compartment adjoining the breaker.
68	Actuator	Operational/ Human Error	Demand	Breaker	AFW	Design	1988	Failure to Open	Partial	The motor operated containment isolation valves for the turbine driven feedwater pump supply to steam generator failed to respond during stroke test from the main control board. The motor leads in the dc breaker were found disconnected. This is a plug-in type connector unique to the 480 vdc breakers. After evaluation, it was determined that personnel were working in the cable run compartment adjacent to the breaker and as they moved cables around in the cable run, tension was applied to the connectors causing them to pull out.
69	Actuator	Operational/ Human Error	Demand	Circuit	RCI	Maintenance	2000	Failure to Close	Partial	The instruments that signal the RCI steam supply valves to close in the event of a steam line break were rendered inoperable due to human error and work package change errors.
70	Actuator	Operational/ Human Error	Demand	Circuit	RHR-B	Design	1985	Failure to Open	Complete	When the control room operator proceeded to establish shutdown cooling, the suction valves to the system would not open. Investigation revealed that while applying a maintenance permit to the primary containment isolation system, a plant operator unknowingly removed the wrong fuse. This electrically blocked the residual heat removal system shutdown cooling suction valves and head spray isolation valves in the closed position. Investigation revealed that although the plant operator removed the fuse, which was labeled f2, as the permit required, this was not the correct fuse. Apparently, the label had slid down such that fuse f3 appeared to be f2.
71	Actuator	Operational/ Human Error	Demand	Limit Switch	AFW	Maintenance	1984	Failure to Close	Partial	Feedwater from the motor driven auxiliary feed pumps to steam generators, failed upon a feedwater flow retention signal. Normal operation upon a retention signal is to actuate to a preset position. Inspection of the Limitorque operator revealed the limit switch was improperly positioned. An investigation could not determine cause of improper adjustment.
72	Actuator	Operational/ Human Error	Demand	Limit Switch	AFW	Maintenance	1984	Failure to Open	Partial	Feedwater from the motor driven auxiliary feed pumps to steam generators, failed upon a feedwater flow retention signal. Normal operation upon a retention signal is to actuate to a preset position. Inspection of the Limitorque operator revealed the limit switch was improperly positioned. An investigation could not determine cause of improper adjustment.

Item	Sub-Component	Proximate Cause	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
73	Actuator	Operational/ Human Error	Demand	Torque Switch	RHR-B	Maintenance	1987	Failure to Close	Partial	The residual heat removal suppression pool full flow discharge isolation valve and the torus spray isolation valve would not fully close upon demand. The cause of the failure is improper previous maintenance activities set the torque switch setting on the valve operator incorrectly low.
74	Actuator	Operational/ Human Error	Demand	Torque Switch	RCI	Design	1986	Failure to Close	Partial	An electrical fire was discovered in an MCC. The cause of this event was a personnel error, which resulted in an incorrect field wiring installation on HCI MOVs. The error was complicated by unsuccessful detection of the error during subsequent testing or inspections. As corrective actions, the wiring error was corrected. Additionally, all other motor operators, which were replaced for environmental qualification purposes during this period were modified to preclude this failure.
75	Actuator	Operational/ Human Error	Demand	Torque Switch	RHR-P	Maintenance	1983	Failure to Open	Almost Complete	Shutdown cooling system heat exchanger isolation valves could not be remotely opened from the control room. The inability of the valves to remotely open was attributed to incorrect open sequence torque and limit switch settings. The incorrect settings caused the motor on the valves to stop before the valves had come off their seats.
76	Actuator	Operational/ Human Error	Demand	Torque Switch	AFW	Maintenance	1995	Failure to Close	Partial	AFW steam supply valves torque switch setpoints were incorrectly calculated for the type of valve.
77	Actuator	Operational/ Human Error	Demand	Torque Switch	AFW	Maintenance	1988	Failure to Close	Partial	Operator tried to close motor driven auxiliary feedwater pump discharge header to steam generator isolation valves against pump flow and they would not fully close. Valves failed to close due to the torque switch opening. These being caused by the increased torque during intermittent throttling near the full closed position where differential pressure is maximum.
78	Actuator	Operational/ Human Error	Demand	Torque Switch	AFW	Quality	1985	Failure to Open	Complete	The procedural deficiency that allowed for a low setting of the bypass limit switches on Limitorque valve operators prompted an evaluation of all MOVs. Using the motor operated valve analysis and test system; a review of the as found conditions of 165 safety related MOVs revealed that 17 valves were evaluated as inoperable for various reasons. These 17 valves included the auxiliary feedwater isolation valves. Further investigation revealed that Limitorque failed to supply adequate instructions on balancing of the torque switches. Torque switch unbalance resulted in three valves being unable to produce sufficient thrust to close against the design differential pressure.
79	Actuator	Operational/ Human Error	Demand	Torque Switch	RCS	Maintenance	1981	Failure to Close	Partial	The pressurizer PORV block valves did not fully shut on demand. The cause of this event was due to maintenance practices problems.
80	Actuator	Operational/ Human Error	Demand	Torque Switch	RHR-B	Maintenance	1991	Failure to Close	Partial	First failure was a torque switch out of adjustment. Second failure was a mis-positioned motor lead holding a torque switch open. Inadequate maintenance.
81	Actuator	Operational/ Human Error	Demand	Transmission	RHR-P	Operational	1995	Failure to Close	Partial	Low Pressure Injection valves were overtorqued open in error during manual backseating after past packing leaks. Excessive force was applied when disengaged from electric operation, causing clutch ring to bind-up when electric operation was re-initiated.
82	Actuator	Operational/ Human Error	Inspection	Breaker	HPI	Operational	1981	Failure to Open	Complete	Operator went to the wrong unit and de-energized a total of five SI valves.
83	Actuator	Operational/ Human Error	Inspection	Breaker	HPI	Operational	1987	Failure to Open	Complete	The breakers for the high pressure injection suction valves from the BWST were inadvertently left tagged open after the reactor coolant system had been heated up to greater than 350F. The suction supply from the BWST to the HPI pumps was isolated and would not have opened automatically upon engineered safeguards actuation. The root cause is failure to perform an adequate review of the red tag logbook in accordance with the startup procedure.

Item	Sub-Component	Proximate Cause	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
84	Actuator	Operational/ Human Error	Inspection	Breaker	HPI	Operational	1989	Failure to Open	Complete	Procedures allowed entry into operating mode where the system was required without directing operators to energize HPI MOV valve operators.
85	Actuator	Operational/ Human Error	Inspection	Motor	CSS	Maintenance	1987	Failure to Open	Partial	Containment spray MOVs were rendered inoperable by maintenance staff error. Lubrication for the pinion gear housings was put in the motor housings.
86	Actuator	Operational/ Human Error	Maintenance	Limit Switch	HPI	Design	1985	Failure to Open	Complete	Incorrect engineering calculations resulted in spring pack setting that would not open the BIT isolation valves. The third valve, SI pump to accumulators was discovered with the same failure.
87	Actuator	Operational/ Human Error	Maintenance	Limit Switch	RHR-P	Maintenance	1986	Failure to Close	Partial	Low pressure safety injection flow control containment isolation valves' stroke travel was greater than allowable. The cause was open limit switches out of adjustment.
88	Actuator	Operational/ Human Error	Maintenance	Torque Switch	RHR-B	Maintenance	1983	Failure to Open	Partial	Improper wiring and connections on torque switches and limit switches.
89	Actuator	Operational/ Human Error	Test	Breaker	HPI	Maintenance	1994	Failure to Open	Partial	RWST to Charging Pump Suction Isolation Valve failed to open. Troubleshooting subsequently determined that the MOV had two lifted leads. Further investigation revealed that another Charging Pump Suction Isolation Valve also had two lifted leads. The cause of the event was personnel error.
90	Actuator	Operational/ Human Error	Test	Breaker	RCI	Operational	1989	Failure to Open	Complete	During the performance of a scheduled RCI system logic system functional test, an overpressurization of the system's suction piping occurred. The operators incorrectly positioned and/or inaccurately verified the positions of 6 circuit breakers to motor operated valves prior to (and for) the test. RCI system inoperable.
91	Actuator	Operational/ Human Error	Test	Circuit	HPI	Maintenance	1986	Failure to Open	Partial	Two ECCS MOVs had wire grounded under valve operator cover. Both failures were attributed to previous maintenance.
92	Actuator	Operational/ Human Error	Test	Circuit	HPI	Maintenance	1984	Failure to Open	Complete	While performing a surveillance test during refueling shutdown, the open contactor for HPI loop isolation valves did not close. The contactors were out of adjustment.
93	Actuator	Operational/ Human Error	Test	Limit Switch	RHR-P	Maintenance	1991	Failure to Close	Partial	LPI MOVs failed to open. Incorrect setpoints of the valve operator limit switches. Root cause was insufficient control of setpoints.
94	Actuator	Operational/ Human Error	Test	Limit Switch	RCS	Maintenance	1984	Failure to Close	Partial	In performance of surveillance testing, pressurizer power operated relief valves, failed to close properly. Loose connections within the Limitorque operator. Long term measures to eliminate this recurring problem include changes to maintenance procedures requiring periodic examinations of all switch contacts within Limitorque operators.
95	Actuator	Operational/ Human Error	Test	Limit Switch	CSS	Quality	1988	Failure to Open	Complete	During re-testing, technicians found that the containment sump isolation valve operator internal limit switches were incorrectly set. This prevented the containment spray suction valve from repositioning as required. During a plant modification, technicians incorrectly set the containment sump isolation valve operator's internal limit switch. The switch was set to be open, though drawings called for it to be closed. Due to inadequate functional verification, this error was not found during post modification testing.
96	Actuator	Operational/ Human Error	Test	Limit Switch	CSS	Maintenance	1985	Failure to Open	Partial	Redundant discharge valves on a containment spray pump would not open. Valve would torque out before going open due to improperly adjusted limit switch.
97	Actuator	Operational/ Human Error	Test	Torque Switch	AFW	Maintenance	1987	Failure to Open	Partial	Auxiliary feedwater regulating isolation MOVs were observed to stick and jam during motor operated valve actuation testing because the testing loosened the valve coupling on the drive shaft, throwing the limit switches out. The cause of the coupling coming loose was the torque of the operator exceeding the potential of the coupling, thus unscrewing it. This resulted from too high a setting on the torque switch, and the setup of the control circuitry.

Item	Sub-Component	Proximate Cause	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
98	Actuator	Operational/ Human Error	Test	Torque Switch	HPI	Maintenance	1981	Failure to Close	Partial	Makeup pump recirculation valves did not fully close due to low torque values. The torque switch settings were set with no system pressure.
99	Actuator	Operational/ Human Error	Test	Transmission	HPI	Maintenance	1987	Failure to Open	Partial	The high pressure safety injection header to loop injection MOV operator spring packs were found with excess grease during surveillance testing causing valve to torque out mid stroke. The spring pack was inoperable due to excessive grease caused by improper maintenance.
100	Actuator	Other	Demand	Circuit	RHR-B	Design	1987	Failure to Open	Partial	Failure of the auxiliary contact block assembly of valve motor close contactor (failed in open position) prevented energizing valve motor open contactor. Occurred on Unit 2/1 cross-connect isolation valve and on Unit 1 RHR isolation injection valve. The contacts failed in the open position, thereby preventing energization of the valve motor open contactor.
101	Actuator	Other	Demand	Circuit	AFW	Maintenance	1984	Failure to Close	Partial	During automatic actuation of the AFW system, the motor operator flow control valves to SG's did not operate properly on a flow retention signal.
102	Actuator	Other	Demand	Circuit	AFW	Maintenance	1984	Failure to Open	Partial	During automatic actuation of the AFW system, the motor operator flow control valves to SG's did not operate properly on a flow retention signal.
103	Actuator	Other	Demand	Limit Switch	RHR-P	Maintenance	1987	Failure to Open	Partial	Residual heat removal pump suctions from feedwater storage tank valve and containment sump would not operate from control room. Cause of valve's failure to operate was limit switches out of adjustment.
104	Actuator	Other	Demand	Limit Switch	HPI	Maintenance	1982	Failure to Close	Partial	Close limit switch out of adjustment. After adjustment, valve closed correctly.
105	Actuator	Other	Demand	Limit Switch	RHR-P	Maintenance	1983	Failure to Open	Partial	MOV motor torqued out on start of open/close cycle. Limit switches out of adjustment.
106	Actuator	Other	Demand	Torque Switch	RHR-B	Maintenance	1984	Failure to Close	Partial	Both LCI loop's full flow test valves failed to go full closed due to a faulty torque switch.
107	Actuator	Other	Demand	Torque Switch	RHR-B	Maintenance	1984	Failure to Close	Partial	Residual heat removal suction from suppression pool and shutdown cooling inboard isolation suction valve would trip thermal overload when attempting to open from closed position and failed to close completely. Torque switch setting was to high and limit switch settings were incorrect. Reset limit and torque switches.
108	Actuator	Other	Demand	Torque Switch	RHR-P	Maintenance	1987	Failure to Open	Partial	RHR pump suction MOV isolation valves would not fully open on demand. The cause of this failure was due to both torque switches were out of adjustment. Both valves could be closed on repeated attempts but not reopened completely.
109	Actuator	Other	Demand	Torque Switch	RHR-B	Maintenance	1984	Failure to Open	Partial	Residual heat removal suction from suppression pool and shutdown cooling inboard isolation suction valve would trip thermal overload when attempting to open from closed position and failed to close completely. Torque switch setting was to high and limit switch settings were incorrect. Reset limit and torque switches.
110	Actuator	Other	Maintenance	Breaker	HPI	Maintenance	1992	Failure to Open	Partial	The 480-volt circuit breakers for three safety injection to cold leg motor operated isolation valves were found out specification high on two phases. The degraded component had no significant effect on the system or the plant, but could have caused damage to the valve actuator motors since the overcurrent protection was degraded.
111	Actuator	Other	Maintenance	Breaker	HPI	Maintenance	1988	Failure to Open	Partial	A 480 Vac circuit breaker for a safety injection control valve failed to trip within its set tolerance. The cause of the failure was attributed to a defective circuit breaker.

Item	Sub-Component	Proximate Cause	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
112	Actuator	Other	Maintenance	Torque Switch	CSS	Maintenance	1991	Failure to Close	Partial	The as found available open and close thrusts were below the recommended minimum. It was determined that the MOVs were inoperable in the open direction, the safety function of the MOV, and operable in the closed direction under worst case design basis conditions as found. Suspect it was due to setpoint drift and or cyclic loading.
113	Actuator	Other	Maintenance	Torque Switch	CSS	Maintenance	1991	Failure to Open	Partial	While maintaining the containment sump isolation valve operators, it was noted that the as found available open and close thrusts were below the recommended minimum. It was determined that the MOVs were inoperable in the open direction, the safety function of the MOVs, and operable in the closed direction under worst case design basis conditions as found. Cause of valve thrusts below minimum recommended was unknown. Suspect it was due to setpoint drift or a cyclic loading.
114	Actuator	Other	Test	Breaker	RHR-B	Maintenance	1986	Failure to Open	Partial	LCI test valve and LCI torus suction valve would not open upon demand and would trip the breaker upon movement. Found auxiliary contacts on breaker in open circuit not making up.
115	Actuator	Other	Test	Limit Switch	HPI	Maintenance	1989	Failure to Open	Partial	The high pressure safety injection pump long term cooling containment isolation MOVs failed to achieve minimum flow requirements. The cause of failure was attributed to the limit switch rotor being out of mechanical adjustment.
116	Actuator	Other	Test	Limit Switch	RHR-B	Maintenance	1984	Failure to Close	Partial	During a LCI operability test, full flow test valves were closed by position indication. However, the valves were not fully seated, and the LCI discharge piping drained. Valve position indication was out of adjustment.
117	Actuator	Other	Test	Limit Switch	HPI	Maintenance	1994	Failure to Close	Partial	Limit switches being out of adjustment resulted in contained leakage. One had both open and closed limit switches out of adjustment. The other valve had only the closed limit switches out of adjustment.
118	Actuator	Other	Test	Limit Switch	RHR-P	Design	1995	Failure to Open	Partial	LPI throttle valves over traveled in the open direction by approximately 1/2 inch. This resulted in LPI flow exceeding Tech spec limits..
119	Actuator	Other	Test	Limit Switch	HPI	Design	1984	Failure to Open	Partial	The HPI header flow rate was not within technical specification requirements. No direct cause could be found for the apparent drift of the valve operators.
120	Actuator	Other	Test	Limit Switch	RHR-P	Design	1995	Failure to Open	Partial	LPI throttle valves failed to stroke fully open. As a result, minimum flow for LPSI injection legs were below the minimum design basis flow.
121	Actuator	Other	Test	Limit Switch	RHR-P	Maintenance	1990	Failure to Open	Partial	Stem travel was excessive on low pressure safety injection flow control containment isolation valves. The opening travel was excessive, due to limit switch out of adjustment.
122	Actuator	Other	Test	Torque Switch	HPI	Maintenance	1994	Failure to Open	Partial	Motor Operated Valve for High Pressure Safety Injection would not stroke fully open. Electricians found oxidation on the open torque switch contacts, causing the motor to stop valve movement before the valve was fully open. Oxidation is an expected occurrence over time in this atmosphere.
123	Actuator	Other	Test	Torque Switch	HPI	Maintenance	1994	Failure to Close	Partial	High Pressure Safety Injection to Loop MOV would not stroke fully open. Electricians found oxidation on the open torque switch contacts, causing the motor to stop valve movement before the valve was fully open. Oxidation is an expected occurrence over time in this atmosphere
124	Actuator	Other	Test	Torque Switch	RHR-B	Maintenance	1984	Failure to Close	Partial	LLRT failures on Torus Suction valves due to torque switch misadjustment.
125	Actuator	Other	Test	Torque Switch	RHR-P	Maintenance	1984	Failure to Open	Partial	While performing sump valve stroke test two MOVs failed to re-open after being stroked closed. The cause of the failures has been determined to be that the bypass circuit time was too short. This prevented the valves from opening until the control switch had been operated several times.

Item	Sub-Component	Proximate Cause	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
126	Actuator	Unknown	Demand	Circuit	HPI	Maintenance	1985	Failure to Open	Complete	The motor operators for 2 valves, which allow the chemical and volume control pumps to take suction from the refueling water storage tank when in the closed position or from the volume control tank when in the opened position, burned up in the closed position and had to be manually opened.
127	Actuator	Unknown	Demand	Transmission	RHR-P	Maintenance	1985	Failure to Close	Partial	Low pressure injection supply from the borated water storage tank isolation valves would not close due to broken worm shaft clutch gear on valve operator.

Table B-2. MOV valve sub-component CCF event summary.

Item	Sub-Component	Proximate Cause	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
128	Valve	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Body	RHR-B	Design	1991	Failure to Open	Partial	Inboard LCI valve failed to open due to failed actuator motor caused by sustained operation at locked-rotor current due to hydraulic locking of the valve bonnet. Modifications performed on both LCI inboard valves and both core spray inboard valves.
129	Valve	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Disk	ISO	Design	1989	Failure to Open	Partial	Isolation condenser dc outlet MOVs failed to open. Both valve failures are attributed to thermal binding, which is identified as a recurring design condition.
130	Valve	Design/ Construction/ Manufacture/ Installation Inadequacy	Inspection	Disk	RCI	Design	1998	Failure to Close	Partial	RCI steam line isolation valves did not have the required seat/disk chamfer necessary to assure that the valves would close under design basis conditions.
131	Valve	Design/ Construction/ Manufacture/ Installation Inadequacy	Maintenance	Disk	RHR-B	Design	1988	Failure to Open	Complete	Containment spray mode of RHR/LCI two MOV injection valve operator motors failed on overload when stroking valves due to trapped pressurized fluid between discs of the gate valve. This was caused by misinterpretation of valve purchase specifications by vendor.
132	Valve	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Body	RHR-B	Design	1992	Failure to Close	Partial	Original construction design error resulted in pump minimum flow valves not being installed with the valve stem in the vertical, pointing upward orientation. Since these valves do not have wedge springs they have potential to prematurely seat failing to fully close.
133	Valve	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Disk	HPI	Quality	1990	Failure to Open	Partial	While testing the high pressure injection system, it was discovered that the flow rate was unbalanced and below the minimum allowed by the units technical specifications. The previous replacement of the plugs in the MOVs with a plug that had been manufactured to the wrong dimensions, due to an error in a vendor drawing, caused unbalanced and low flow.
134	Valve	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Disk	RHR-B	Design	1992	Failure to Close	Partial	The test valves to the suppression pool failed to stroke full closed. Root cause analysis revealed that the failure was the result of a gate valve in a globe valve application.
135	Valve	External Environment	Demand	Body	RHR-P	Maintenance	1985	Failure to Open	Partial	Shutdown cooling isolation valves wouldn't fully open. One was attributed to boric acid buildup and the other cause is unknown.
136	Valve	External Environment	Demand	Disk	RHR-B	Maintenance	1986	Failure to Open	Partial	The suppression pool (residual heat removal) pump suction valves failed to open electrically. The motor was subjected to locked-rotor current for about 2 minutes, resulting in overheating. Sediment accumulations (non-ferrous) that would squeeze out between the disc and the seat and lock them together was the root cause. The suppression pool sediment most likely occurred during construction.

Item	Sub-Component	Proximate Cause	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
137	Valve	External Environment	Demand	Disk	RHR-B	Maintenance	1986	Failure to Open	Partial	MOVs failed to open after being closed. Valves are the residual heat removal suppression pool suction valves. Torque switch prevented motor burn-out. Valve disk was found struck closed. Mud was found in the valve seat, which caused the disk to wedge into the seat upon closing and prevented it from opening. Mud in MOVs believed to be from construction activities of plant
138	Valve	External Environment	Inspection	Body	RHR-B	Environmental	1981	Failure to Open	Partial	Motor operated valves (chemwaste receiver tank isolation) and (Torus Injection Isolation) operators found with loose and broken cap screws anchoring motors to valves due to vibration induced loosening of the hold-down bolts.
139	Valve	Internal to Component	Inspection	Body	RHR-B	Design	1992	Failure to Open	Partial	On 4/29/92, the Torus cooling injection motor-operated valve was found to have cracks in the valve yoke. On 8/7/92, the Torus cooling injection MOV in the redundant loop was also discovered with cracks in the yoke.
140	Valve	Internal to Component	Maintenance	Disk	AFW	Maintenance	1988	Failure to Open	Partial	Plug nut welds were broken on the auxiliary feedwater pump discharge isolation valves. This would allow the disc to come off. Exact cause was unknown but suspect age and wearing.
141	Valve	Internal to Component	Test	Disk	RHR-B	Maintenance	1994	Failure to Close	Partial	RHR MOVs failed the surveillance test with gross seat leakage. Investigation revealed wear on the disc guides and some scratches on the seat. The cause is normal wear and aging.
142	Valve	Internal to Component	Test	Packing	HCI	Design	1994	Failure to Close	Partial	High Pressure Coolant valves failed to fully close. The cause of the failure appeared to be high packing load that caused mechanical binding preventing the operator from fully closing the valves.
143	Valve	Operational/ Human Error	Demand	Body	HPI	Operational	1988	Failure to Open	Partial	Safety injection isolation motor operated valves responded to an open signal from control room only after the valves were cracked open manually. The valve operators thermal overloads failed to trip after the valve remained energized for 30 minutes. No problems with the operator were discovered. It is suspected that the practice of manually seating the valve during refueling tagouts overtorqued the valve and prevented it from opening.
144	Valve	Operational/ Human Error	Demand	Disk	RHR-P	Quality	1987	Failure to Close	Partial	The residual heat removal system safety injection to reactor coolant loop isolation MOVs were leaking through while closed and could not be isolated. Valve split disks were reversed during initial installation and were 180 degrees out from the proper orientation. This caused seat leakage due to lack of seating contact.
145	Valve	Operational/ Human Error	Demand	Stem	ISO	Maintenance	1981	Failure to Close	Partial	The isolation condenser valves failed to properly operate. The stem nuts of the MOV operators were found to be damaged.
146	Valve	Operational/ Human Error	Test	Stem	RCS	Maintenance	1992	Failure to Close	Partial	The pressurizer's power operated relief valve's isolation valve operator's output thrust was below the minimum required to fully close the valve on demand. The valve's stem to stem nut nickel based lubricant was the cause.
147	Valve	Operational/ Human Error	Test	Stem	RHR-B	Maintenance	1986	Failure to Close	Almost Complete	While testing the high pressure injection control valves, the motor operator overthrusted while going in the open direction. The valve operator overthrusted due to a design deficiency in the torque switch spring pack that allowed a buildup of grease between the Belleville washers which resulted in hydraulic lockup when the valve was operated. After discussion with component manufacturer, a plant modification was performed that machined notches in the ends of the motor operator torque limiting sleeve. These notches will provide a better grease relief path.
148	Valve	Operational/ Human Error	Test	Stem	AFW	Maintenance	1984	Failure to Open	Partial	Aux feedwater pump discharge/header isolation valves found damaged during special inspection. One valve did not open during surveillance test; the other three were not operated, but probably would not have opened due to excessive damage, (bent stem). All damage was determined to be due to over-torquing the torque switch.

Item	Sub-Component	Proximate Cause	Discovery Method	Piece Part	System	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
149	Valve	Operational/ Human Error	Test	Stem	CSS	Maintenance	1984	Failure to Open	Complete	During surveillance tests, two recirculation spray pump suction valves were inoperable. The valve position lights in the control room indicated the valve cycled normally. However, the valve did not move from the closed position. Failure was caused by the shearing of the coupling pin due to inadvertently leaving the incorrect pin, a marlin pin, (tapered pin possibly used for alignment), in the valve operator coupling.

Appendix C

Data Summary by System

Appendix C

Data Summary by System

This appendix is a summary of the data evaluated in the common-cause failure (CCF) data collection effort for MOVs. The data has been sorted by system to facilitate review of these events with Chapter 5 of the report. Each table is sorted alphabetically, by the first four columns.

Table C-1. MOV CCF data summary by system.

Item	System	Proximate Cause	Discovery Method	Piece Part	Sub-Component	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
1	AFW	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Circuit	Actuator	Maintenance	1984	Failure to Open	Partial	Aux. feedwater flow control valves would not open. On one the motor control contactor was not contacting due to 2 loose connections; and the other the torque close setting was misadjusted, causing contacts to open too soon.
2	AFW	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Motor	Actuator	Design	1989	Failure to Close	Partial	AFW MOVs would not fully close under high d/p conditions until the valve actuators were setup at the highest torque switch setting allowed by the tolerances.
3	AFW	Design/ Construction/ Manufacture/ Installation Inadequacy	Inspection	Breaker	Actuator	Quality	1989	Failure to Open	Partial	The 125 vdc breakers for motor-operated valves in the turbine driven auxiliary feedwater pump system were not the proper size.
4	AFW	Design/ Construction/ Manufacture/ Installation Inadequacy	Maintenance	Breaker	Actuator	Quality	1989	Failure to Open	Partial	The trip coils installed in the power supply feeder breakers for the motor actuator for two AFW MOVs were incorrect.
5	AFW	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Circuit	Actuator	Quality	1982	Failure to Open	Partial	It was determined that a train of AFW MOV's would not open on a steam generator low-low level. Some of the wiring to be done for design a change was incomplete upon completion of the design change.
6	AFW	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Torque Switch	Actuator	Design	1994	Failure to Close	Partial	Auxiliary Feedwater Pumps to Steam Generator Isolations were determined to be past inoperable. Differential pressure testing conducted during the outage revealed the valves would not sufficiently close against design basis system conditions to isolate flow.
7	AFW	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Torque Switch	Actuator	Design	1989	Failure to Close	Partial	Seven AFW valves would open but would not fully close electrically. The cause of failure was that the valve operator and valve were previously changed out on a modification and passed the post modification test. Upon investigation of the valve failure it was determined that the design engineers had the thrust values wrong and the torque switch was reflecting a 1085 psi system when in fact the system is 1600 psi.
8	AFW	Internal to Component	Demand	Circuit	Actuator	Maintenance	1985	Failure to Close	Partial	While removing an AFW train from service, the pump discharge valves to two steam generators did not close. The closing coils in the motor controller failed, due to unknown cause.
9	AFW	Internal to Component	Maintenance	Disk	Valve	Maintenance	1988	Failure to Open	Partial	Plug nut welds were broken on the auxiliary feedwater pump discharge isolation valves. This would allow the disc to come off. Exact cause was unknown but suspect age and wearing.
10	AFW	Internal to Component	Test	Circuit	Actuator	Design	2000	Failure to Open	Complete	Loose sliding link caused unplanned swap to LOCAL control. This also caused AFW suction auto swap capability to be blocked. Manual control apparently still available.

Item	System	Proximate Cause	Discovery Method	Piece Part	Sub-Component	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
11	AFW	Internal to Component	Test	Limit Switch	Actuator	Maintenance	1992	Failure to Open	Partial	The AFW pump supply to steam generator control valves stopped at an intermediate position and did not fully open. Local verification based on stem travel verified the valve stopped at an intermediate position. The valve operators limit switch was out of adjustment.
12	AFW	Internal to Component	Test	Motor	Actuator	Maintenance	1992	Failure to Close	Partial	The maximum d/p previously used in earlier testing and evaluation was determined to not represent worst case conditions. Further testing revealed that none of the AFW block valves would full close against the calculated worst case d/p. The root cause of the inability of the valves to close is attributed to valve condition due to normal wear.
13	AFW	Internal to Component	Test	Torque Switch	Actuator	Design	1986	Failure to Close	Almost Complete	During MOV actuator testing, the close torque limits on the operator to the emergency feedwater pump discharge valves to the steam generators were found to be below minimum. The torque switches were out of adjustment.
14	AFW	Operational/ Human Error	Demand	Breaker	Actuator	Maintenance	1987	Failure to Open	Partial	The isolation valves to the steam generator from the steam driven auxiliary feedwater pump failed to open when demanded from the main control board switch. The dc circuit breaker for the motor operated valves were found to have loose (unplugged) connections on the terminal block inside the breaker. It appears that the connectors are easily unplugged by moving the cables in the cable run compartment adjoining the breaker.
15	AFW	Operational/ Human Error	Demand	Breaker	Actuator	Design	1988	Failure to Open	Partial	The motor operated containment isolation valves for the turbine driven feedwater pump supply to steam generator failed to respond during stroke test from the main control board. The motor leads in the dc breaker were found disconnected. This is a plug-in type connector unique to the 480 vdc breakers. After evaluation, it was determined that personnel were working in the cable run compartment adjacent to the breaker and as they moved cables around in the cable run, tension was applied to the connectors causing them to pull out.
16	AFW	Operational/ Human Error	Demand	Limit Switch	Actuator	Maintenance	1984	Failure to Close	Partial	Feedwater from the motor driven auxiliary feed pumps to steam generators, failed upon a feedwater flow retention signal. Normal operation upon a retention signal is to actuate to a preset position. Inspection of the Limitorque operator revealed the limit switch was improperly positioned. An investigation could not determine cause of improper adjustment.
17	AFW	Operational/ Human Error	Demand	Limit Switch	Actuator	Maintenance	1984	Failure to Open	Partial	Feedwater from the motor driven auxiliary feed pumps to steam generators, failed upon a feedwater flow retention signal. Normal operation upon a retention signal is to actuate to a preset position. Inspection of the Limitorque operator revealed the limit switch was improperly positioned. An investigation could not determine cause of improper adjustment.
18	AFW	Operational/ Human Error	Demand	Torque Switch	Actuator	Maintenance	1995	Failure to Close	Partial	AFW steam supply valves torque switch setpoints were incorrectly calculated for the type of valve.
19	AFW	Operational/ Human Error	Demand	Torque Switch	Actuator	Quality	1985	Failure to Open	Complete	The procedural deficiency that allowed for a low setting of the bypass limit switches on Limitorque valve operators prompted an evaluation of all MOVs. Using the motor operated valve analysis and test system; a review of the as found conditions of 165 safety related MOVs revealed that 17 valves were evaluated as inoperable for various reasons. These 17 valves included the auxiliary feedwater isolation valves. Further investigation revealed that Limitorque failed to supply adequate instructions on balancing of the torque switches. Torque switch unbalance resulted in three valves being unable to produce sufficient thrust to close against the design differential pressure.
20	AFW	Operational/ Human Error	Demand	Torque Switch	Actuator	Maintenance	1988	Failure to Close	Partial	Operator tried to close motor driven auxiliary feedwater pump discharge header to steam generator isolation valves against pump flow and they would not fully close. Valves failed to close due to the torque switch opening. These being caused by the increased torque during intermittent throttling near the full closed position where differential pressure is maximum.

Item	System	Proximate Cause	Discovery Method	Piece Part	Sub-Component	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
21	AFW	Operational/ Human Error	Test	Stem	Valve	Maintenance	1984	Failure to Open	Partial	Aux feedwater pump discharge/header isolation valves found damaged during special inspection. One valve did not open during surveillance test; the other three were not operated, but probably would not have opened due to excessive damage, (bent stem). All damage was determined to be due to over-torquing the torque switch.
22	AFW	Operational/ Human Error	Test	Torque Switch	Actuator	Maintenance	1987	Failure to Open	Partial	Auxiliary feedwater regulating isolation MOVs were observed to stick and jam during motor operated valve actuation testing because the testing loosened the valve coupling on the drive shaft, throwing the limit switches out. The cause of the coupling coming loose was the torque of the operator exceeding the potential of the coupling, thus unscrewing it. This resulted from too high a setting on the torque switch, and the setup of the control circuitry.
23	AFW	Other	Demand	Circuit	Actuator	Maintenance	1984	Failure to Close	Partial	During automatic actuation of the AFW system, the motor operator flow control valves to SG's did not operate properly on a flow retention signal.
24	AFW	Other	Demand	Circuit	Actuator	Maintenance	1984	Failure to Open	Partial	During automatic actuation of the AFW system, the motor operator flow control valves to SG's did not operate properly on a flow retention signal.
25	CSS	Design/ Construction/ Manufacture/ Installation Inadequacy	Inspection	Transmission	Actuator	Design	1993	Failure to Open	Partial	The motor pinion key for a Containment Spray header isolation valve was sheared. Subsequent motor pinion key failures occurred on October 18, 1993, March 23, 1994, and April 13, 1994. The evaluations for these events determined that the failures were due to improper key material.
26	CSS	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Torque Switch	Actuator	Design	1984	Failure to Open	Complete	During surveillance, two containment spray motor operated valves failed to open. The valves were stuck due to excess play in operator assembly, which allowed the open torque switch to disengage thereby shutting off the operator. The bypass limit switch was rewired to a separate rotor with a longer bypass duration per design change.
27	CSS	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Torque Switch	Actuator	Design	1985	Failure to Close	Complete	During maintenance, testing it was determined that four containment spray MOVs wouldn't develop the required thrust. The failures were attributed to an improper spring pack installation and to an improper torque switch installation. The improper installations were due to incorrect engineering calculations of original design values.
28	CSS	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Torque Switch	Actuator	Design	1985	Failure to Open	Partial	During maintenance, testing it was determined that four containment spray MOVs wouldn't develop the required thrust. The failures were attributed to an improper spring pack installation and to an improper torque switch installation. The improper installations were due to incorrect engineering calculations of original design values.
29	CSS	Internal to Component	Inspection	Transmission	Actuator	Maintenance	1989	Failure to Open	Partial	Oil leaks identified on handwheel of motor operated actuator for containment spray header isolation valves. Internal seals and o-ring for mating surface of handwheel and gear box had failed. Failure attributed to unexpected abnormal wear.
30	CSS	Internal to Component	Test	Breaker	Actuator	Maintenance	1990	Failure to Open	Partial	The 480 Vac circuit breakers for recirculation sump to containment spray pump isolation valves would not trip on an instantaneous trip test within specified current limits.
31	CSS	Internal to Component	Test	Motor	Actuator	Design	1986	Failure to Open	Complete	Routine surveillance disclosed that the containment recirculation sump to containment spray pump isolation valves would not open. The motor for valve operators burned up.
32	CSS	Operational/ Human Error	Inspection	Motor	Actuator	Maintenance	1987	Failure to Open	Partial	Containment spray MOVs were rendered inoperable by maintenance staff error. Lubrication for the pinion gear housings was put in the motor housings.

Item	System	Proximate Cause	Discovery Method	Piece Part	Sub-Component	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
33	CSS	Operational/ Human Error	Test	Limit Switch	Actuator	Maintenance	1985	Failure to Open	Partial	Redundant discharge valves on a containment spray pump would not open. Valve would torque out before going open due to improperly adjusted limit switch.
34	CSS	Operational/ Human Error	Test	Limit Switch	Actuator	Quality	1988	Failure to Open	Complete	During re-testing, technicians found that the containment sump isolation valve operator internal limit switches were incorrectly set. This prevented the containment spray suction valve from repositioning as required. During a plant modification, technicians incorrectly set the containment sump isolation valve operator's internal limit switch. The switch was set to be open, though drawings called for it to be closed. Due to inadequate functional verification, this error was not found during post modification testing.
35	CSS	Operational/ Human Error	Test	Stem	Valve	Maintenance	1984	Failure to Open	Complete	During surveillance tests, two recirculation spray pump suction valves were inoperable. The valve position lights in the control room indicated the valve cycled normally. However, the valve did not move from the closed position. Failure was caused by the shearing of the coupling pin due to inadvertently leaving the incorrect pin, a marlin pin, (tapered pin possibly used for alignment), in the valve operator coupling.
36	CSS	Other	Maintenance	Torque Switch	Actuator	Maintenance	1991	Failure to Close	Partial	The as found available open and close thrusts were below the recommended minimum. It was determined that the MOVs were inoperable in the open direction, the safety function of the MOV, and operable in the closed direction under worst case design basis conditions as found. Suspect it was due to setpoint drift and or cyclic loading.
37	CSS	Other	Maintenance	Torque Switch	Actuator	Maintenance	1991	Failure to Open	Partial	While maintaining the containment sump isolation valve operators, it was noted that the as found available open and close thrusts were below the recommended minimum. It was determined that the MOVs were inoperable in the open direction, the safety function of the MOVs, and operable in the closed direction under worst case design basis conditions as found. Cause of valve thrusts below minimum recommended was unknown. Suspect it was due to setpoint drift or a cyclic loading.
38	HCI	External Environment	Test	Motor	Actuator	Environmental	1980	Failure to Open	Complete	While testing the torus suction valves, two MOVs failed when given an open signal. Both torus suction valves had shorted out due to excessive condensation in the HCI room area.
39	HCI	Internal to Component	Demand	Torque Switch	Actuator	Quality	1986	Failure to Open	Partial	After an attempt to reposition a HCI MOV (the recirc loop pump suction valve), The valve failed to open upon a signal from the control room. An investigation into the cause of the valve's failure determined that a hydraulic lockup of the MOV's spring pack prevented the torque switch from opening causing the motor to fail. This lock-up was due to: 1) the replacement of less viscous new grease, into the operator, which was recommended by the manufacturer and 2) the failure of the manufacturer to provide information regarding the need to install a retrofit grease relief kit.
40	HCI	Internal to Component	Test	Packing	Valve	Design	1994	Failure to Close	Partial	High Pressure Coolant valves failed to fully close. The cause of the failure appeared to be high packing load that caused mechanical binding preventing the operator from fully closing the valves.
41	HPI	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Torque Switch	Actuator	Maintenance	1985	Failure to Close	Partial	Motor torque switches were out of adjustment and did not allow full closure.
42	HPI	Design/ Construction/ Manufacture/ Installation Inadequacy	Inspection	Breaker	Actuator	Quality	1980	Failure to Open	Partial	Power leads were found reversed to two safety injection valve operators. Root cause was poor administrative control.

Item	System	Proximate Cause	Discovery Method	Piece Part	Sub-Component	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
43	HPI	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Disk	Valve	Quality	1990	Failure to Open	Partial	While testing the high pressure injection system, it was discovered that the flow rate was unbalanced and below the minimum allowed by the units technical specifications. The previous replacement of the plugs in the MOVs with a plug that had been manufactured to the wrong dimensions, due to an error in a vendor drawing, caused unbalanced and low flow.
44	HPI	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Torque Switch	Actuator	Maintenance	1991	Failure to Close	Partial	The high pressure safety injection system flow control containment isolation valves failed to completely close because total close thrust was not sufficient to close valve under dynamic stroke. A thrust value beyond the recommended maximum total close thrust would be needed to completely close the valve. Engineering evaluation determined a higher thrust value would be acceptable.
45	HPI	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Torque Switch	Actuator	Design	1994	Failure to Close	Partial	HPI MOVs failed to fully close. Engineering determined that the recommended close thrust was insufficient to close valve during worst case failure.
46	HPI	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Transmission	Actuator	Quality	1992	Failure to Close	Partial	A safety injection recirculation MOV failed to close. It was discovered that the valve had a broken anti-rotation device (key). This prompted an inspection of the remaining globe valves that found the safety injection to reactor coolant system cold leg injection valves also had a broken key.
47	HPI	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Transmission	Actuator	Design	1987	Failure to Open	Partial	While testing the high pressure injection control valves, the motor operator overthrusted while going in the open direction. Valve operator overthrusted due to a design deficiency in the torque switch spring pack that allowed a buildup of grease between the Belleville washers, which resulted in hydraulic lockup when the valve was operated. After discussion with component manufacturer, a plant modification was performed that machined notches in the ends of the motor operator torque limiting sleeve. These notches will provide a better grease relief path.
48	HPI	External Environment	Demand	Transmission	Actuator	Environmental	1995	Failure to Close	Partial	When a close signal was initiated from the control room, two Refueling Water Tank valves failed to close. They only stroked 2 pct. and gave dual indication. Inspection of actuator internals found rust, corrosion, and water intrusion. The cause was due to water ingress through an actuator penetration in the stem protector resulting in rust and corrosion to actuator parts.
49	HPI	External Environment	Test	Torque Switch	Actuator	Design	1991	Failure to Close	Partial	Compression springs in the HPI MOV torque switch assembly were weakened by vibration.
50	HPI	Internal to Component	Inspection	Transmission	Actuator	Maintenance	1986	Failure to Open	Partial	During a special inspection, a limit switch terminal block was found cracked and a bevel gear stripped on safety injection system high pressure header shutoff valves. The cause of failure has not been determined but inadequate maintenance is suspected. The limit switch terminal block and the bevel gear were replaced.
51	HPI	Internal to Component	Maintenance	Torque Switch	Actuator	Maintenance	1994	Failure to Open	Partial	After completion of mechanical rework on HPI MOV actuator, technician was attempting to setup and stroke motor operated valves. While stroking valve electrically found the torque switch would not open, resulting in valve travel not being stopped. Technicians investigated and found torque switch defective and rotor on limit switch to not be turning fully to proper position.

Item	System	Proximate Cause	Discovery Method	Piece Part	Sub-Component	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
52	HPI	Internal to Component	Maintenance	Torque Switch	Actuator	Maintenance	1994	Failure to Close	Partial	High Head Safety Injection System motor operated isolation valves would not open fully. Technicians investigated and found grease on torque switch contacts, which prevented contacts from closing circuit. Improper greasing resulted in excessive grease accumulation on torque switch contacts.
53	HPI	Internal to Component	Test	Circuit	Actuator	Maintenance	1986	Failure to Open	Partial	Dirty contacts and loose connections resulted in valves failing to open.
54	HPI	Internal to Component	Test	Torque Switch	Actuator	Maintenance	1991	Failure to Open	Partial	A fuse failed in the first event due to aging and washers in the spring pack of the second valve came loose and grounded the motor. Root cause was inadequate maintenance.
55	HPI	Operational/ Human Error	Demand	Body	Valve	Operational	1988	Failure to Open	Partial	Safety injection isolation motor operated valves responded to an open signal from control room only after the valves were cracked open manually. The valve operators thermal overloads failed to trip after the valve remained energized for 30 minutes. No problems with the operator were discovered. It is suspected that the practice of manually seating the valve during refueling tagouts overtorqued the valve and prevented it from opening.
56	HPI	Operational/ Human Error	Inspection	Breaker	Actuator	Operational	1987	Failure to Open	Complete	The breakers for the high pressure injection suction valves from the BWST were inadvertently left tagged open after the reactor coolant system had been heated up to greater than 350F. The suction supply from the BWST to the HPI pumps was isolated and would not have opened automatically upon engineered safeguards actuation. The root cause is failure to perform an adequate review of the red tag logbook in accordance with the startup procedure.
57	HPI	Operational/ Human Error	Inspection	Breaker	Actuator	Operational	1989	Failure to Open	Complete	Procedures allowed entry into operating mode where the system was required without directing operators to energize HPI MOV valve operators.
58	HPI	Operational/ Human Error	Inspection	Breaker	Actuator	Operational	1981	Failure to Open	Complete	Operator went to the wrong unit and de-energized a total of five SI valves.
59	HPI	Operational/ Human Error	Maintenance	Limit Switch	Actuator	Design	1985	Failure to Open	Complete	Incorrect engineering calculations resulted in spring pack setting that would not open the BIT isolation valves. The third valve, SI pump to accumulators was discovered with the same failure.
60	HPI	Operational/ Human Error	Test	Breaker	Actuator	Maintenance	1994	Failure to Open	Partial	RWST to Charging Pump Suction Isolation Valve failed to open. Troubleshooting subsequently determined that the MOV had two lifted leads. Further investigation revealed that another Charging Pump Suction Isolation Valve also had two lifted leads. The cause of the event was personnel error.
61	HPI	Operational/ Human Error	Test	Circuit	Actuator	Maintenance	1984	Failure to Open	Complete	While performing a surveillance test during refueling shutdown, the open contactor for HPI loop isolation valves did not close. The contactors were out of adjustment.
62	HPI	Operational/ Human Error	Test	Circuit	Actuator	Maintenance	1986	Failure to Open	Partial	Two ECCS MOVs had wire grounded under valve operator cover. Both failures were attributed to previous maintenance.
63	HPI	Operational/ Human Error	Test	Torque Switch	Actuator	Maintenance	1981	Failure to Close	Partial	Makeup pump recirculation valves did not fully close due to low torque values. The torque switch settings were set with no system pressure.
64	HPI	Operational/ Human Error	Test	Transmission	Actuator	Maintenance	1987	Failure to Open	Partial	The high pressure safety injection header to loop injection MOV operator spring packs were found with excess grease during surveillance testing causing valve to torque out mid stroke. The spring pack was inoperable due to excessive grease caused by improper maintenance.
65	HPI	Other	Demand	Limit Switch	Actuator	Maintenance	1982	Failure to Close	Partial	Close limit switch out of adjustment. After adjustment, valve closed correctly.

Item	System	Proximate Cause	Discovery Method	Piece Part	Sub-Component	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
66	HPI	Other	Maintenance	Breaker	Actuator	Maintenance	1992	Failure to Open	Partial	The 480-volt circuit breakers for three safety injection to cold leg motor operated isolation valves were found out specification high on two phases. The degraded component had no significant effect on the system or the plant, but could have caused damage to the valve actuator motors since the overcurrent protection was degraded.
67	HPI	Other	Maintenance	Breaker	Actuator	Maintenance	1988	Failure to Open	Partial	A 480 Vac circuit breaker for a safety injection control valve failed to trip within its set tolerance. The cause of the failure was attributed to a defective circuit breaker.
68	HPI	Other	Test	Limit Switch	Actuator	Maintenance	1994	Failure to Close	Partial	Limit switches being out of adjustment resulted in contained leakage. One had both open and closed limit switches out of adjustment. The other valve had only the closed limit switches out of adjustment.
69	HPI	Other	Test	Limit Switch	Actuator	Design	1984	Failure to Open	Partial	The HPI header flow rate was not within technical specification requirements. No direct cause could be found for the apparent drift of the valve operators.
70	HPI	Other	Test	Limit Switch	Actuator	Maintenance	1989	Failure to Open	Partial	The high pressure safety injection pump long term cooling containment isolation MOVs failed to achieve minimum flow requirements. The cause of failure was attributed to the limit switch rotor being out of mechanical adjustment.
71	HPI	Other	Test	Torque Switch	Actuator	Maintenance	1994	Failure to Open	Partial	Motor Operated Valve for High Pressure Safety Injection would not stroke fully open. Electricians found oxidation on the open torque switch contacts, causing the motor to stop valve movement before the valve was fully open. Oxidation is an expected occurrence over time in this atmosphere.
72	HPI	Other	Test	Torque Switch	Actuator	Maintenance	1994	Failure to Close	Partial	High Pressure Safety Injection to Loop MOV would not stroke fully open. Electricians found oxidation on the open torque switch contacts, causing the motor to stop valve movement before the valve was fully open. Oxidation is an expected occurrence over time in this atmosphere
73	HPI	Unknown	Demand	Circuit	Actuator	Maintenance	1985	Failure to Open	Complete	The motor operators for 2 valves, which allow the chemical and volume control pumps to take suction from the refueling water storage tank when in the closed position or from the volume control tank when in the opened position, burned up in the closed position and had to be manually opened.
74	ISO	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Disk	Valve	Design	1989	Failure to Open	Partial	Isolation condenser dc outlet MOVs failed to open. Both valve failures are attributed to thermal binding, which is identified as a recurring design condition.
75	ISO	Operational/ Human Error	Demand	Stem	Valve	Maintenance	1981	Failure to Close	Partial	The isolation condenser valves failed to properly operate. The stem nuts of the MOV operators were found to be damaged.
76	RCI	Design/ Construction/ Manufacture/ Installation Inadequacy	Inspection	Disk	Valve	Design	1998	Failure to Close	Partial	RCI steam line isolation valves did not have the required seat/disk chamfer necessary to assure that the valves would close under design basis conditions.
77	RCI	Internal to Component	Maintenance	Breaker	Actuator	Maintenance	1999	Failure to Open	Partial	Valve operations were not within specified time limits due to faulty contactors. Inadequate PM.
78	RCI	Operational/ Human Error	Demand	Circuit	Actuator	Maintenance	2000	Failure to Close	Partial	The instruments that signal the RCI steam supply valves to close in the event of a steam line break were rendered inoperable due to human error and work package change errors.

Item	System	Proximate Cause	Discovery Method	Piece Part	Sub-Component	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
79	RCI	Operational/ Human Error	Demand	Torque Switch	Actuator	Design	1986	Failure to Close	Partial	An electrical fire was discovered in an MCC. The cause of this event was a personnel error, which resulted in an incorrect field wiring installation on HCI MOVs. The error was complicated by unsuccessful detection of the error during subsequent testing or inspections. As corrective actions, the wiring error was corrected. Additionally, all other motor operators, which were replaced for environmental qualification purposes during this period were modified to preclude this failure.
80	RCI	Operational/ Human Error	Test	Breaker	Actuator	Operational	1989	Failure to Open	Complete	During the performance of a scheduled RCI system logic system functional test, an overpressurization of the system's suction piping occurred. The operators incorrectly positioned and/or inaccurately verified the positions of 6 circuit breakers to motor operated valves prior to (and for) the test. RCI system inoperable.
81	RCS	Internal to Component	Demand	Circuit	Actuator	Maintenance	1989	Failure to Close	Complete	The inlet block MOVs for the PORVs failed to close or open from the control room. This failure was due to the main control room switch for opening and closing the valve has erratic resistance reading as a result of wear and tear of the switch.
82	RCS	Internal to Component	Demand	Circuit	Actuator	Maintenance	1989	Failure to Open	Complete	The inlet block MOVs for the PORVs failed to close or open from the control room. This failure was due to the main control room switch for opening and closing the valve has erratic resistance reading as a result of wear and tear of the switch.
83	RCS	Internal to Component	Maintenance	Limit Switch	Actuator	Quality	1983	Failure to Close	Partial	The Limitorque valve operator for the pressurizer isolation valves found to have cracks on the geared limit switch.
84	RCS	Operational/ Human Error	Demand	Torque Switch	Actuator	Maintenance	1981	Failure to Close	Partial	The pressurizer PORV block valves did not fully shut on demand. The cause of this event was due to maintenance practices problems.
85	RCS	Operational/ Human Error	Test	Limit Switch	Actuator	Maintenance	1984	Failure to Close	Partial	In performance of surveillance testing, pressurizer power operated relief valves, failed to close properly. Loose connections within the Limitorque operator. Long term measures to eliminate this recurring problem include changes to maintenance procedures requiring periodic examinations of all switch contacts within Limitorque operators.
86	RCS	Operational/ Human Error	Test	Stem	Valve	Maintenance	1992	Failure to Close	Partial	The pressurizer's power operated relief valve's isolation valve operator's output thrust was below the minimum required to fully close the valve on demand. The valve's stem to stem nut nickel based lubricant was the cause.
87	RHR-B	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Body	Valve	Design	1991	Failure to Open	Partial	Inboard LCI valve failed to open due to failed actuator motor caused by sustained operation at locked-rotor current due to hydraulic locking of the valve bonnet. Modifications performed on both LCI inboard valves and both core spray inboard valves.
88	RHR-B	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Circuit	Actuator	Design	1984	Failure to Open	Complete	Both LCI injection MOVs would not open due to an error in the valve logic circuit diagrams and the removal of motor brakes for environmental qualification. This condition caused the valves to continuously try to close until both valve stems were damaged.
89	RHR-B	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Circuit	Actuator	Design	1986	Failure to Close	Complete	Residual heat removal/low pressure coolant injection discharge to suppression pool minimum flow control valves did not close properly on demand. Incorrect logic design prevented valves from closing completely on demand. The new design provided for a seal-in contact with the automatic isolation signal. The seal-in contact allows torque closure of the valve even if the selector key lock switch is in the 'lock' position.

Item	System	Proximate Cause	Discovery Method	Piece Part	Sub-Component	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
90	RHR-B	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Motor	Actuator	Design	1987	Failure to Open	Partial	Suppression pool cooling valves (one in each loop) failed to open. As long as the RHR pump was operating, the valves could not be opened and the thermal overloads would trip. Cause was an incorrectly sized motor.
91	RHR-B	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Motor	Actuator	Design	1991	Failure to Close	Partial	RHR test return valves failed to seat tightly due to friction related problems. Replaced valve operators.
92	RHR-B	Design/ Construction/ Manufacture/ Installation Inadequacy	Inspection	Transmission	Actuator	Design	1990	Failure to Close	Partial	Investigating failure of motor operated valve to achieve minimum required closing thrust. Actuator for inboard isolation valve not geared to supply specified 110% design thrust. Outboard isolation valve and 6 other motor operated valves (2 in RHR) had same actuator problems due to failure to consider design capabilities prior to establishing diagnostic testing criteria.
93	RHR-B	Design/ Construction/ Manufacture/ Installation Inadequacy	Inspection	Transmission	Actuator	Maintenance	1992	Failure to Close	Partial	LCI MOV motor pinion key replacements were supposed to be performed in 1982 to change the keys to an appropriate material key. This replacement was not performed and was discovered in 1992, as 3 valve keys were found sheared or nearly sheared.
94	RHR-B	Design/ Construction/ Manufacture/ Installation Inadequacy	Maintenance	Disk	Valve	Design	1988	Failure to Open	Complete	Containment spray mode of RHR/LCI two MOV injection valve operator motors failed on overload when stroking valves due to trapped pressurized fluid between discs of the gate valve. This was caused by misinterpretation of valve purchase specifications by vendor.
95	RHR-B	Design/ Construction/ Manufacture/ Installation Inadequacy	Maintenance	Transmission	Actuator	Quality	1990	Failure to Open	Partial	Normal maintenance on suppression chamber cooling Loop B throttle valve. Suppression chamber cooling Loop B throttle valve motor pinion key sheared and Loop A throttle valve motor pinion key deformed. Keys were found to be of the wrong material due to vendor inadequacies and utility programmatic deficiencies.
96	RHR-B	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Body	Valve	Design	1992	Failure to Close	Partial	Original construction design error resulted in pump minimum flow valves not being installed with the valve stem in the vertical, pointing upward orientation. Since these valves do not have wedge springs they have potential to prematurely seat failing to fully close.
97	RHR-B	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Disk	Valve	Design	1992	Failure to Close	Partial	The test valves to the suppression pool failed to stroke full closed. Root cause analysis revealed that the failure was the result of a gate valve in a globe valve application.
98	RHR-B	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Limit Switch	Actuator	Maintenance	1988	Failure to Close	Partial	During surveillance testing of the RHR shutdown cooling isolation valves revealed that each loop injection valve failed to close as required. The failure was due to a wiring error on the limit switches associated with RHR suction valves. An incorrect limit switch was used for both valves, which made a slight mis-operation of the switches capable of affecting the close circuitry of the isolation valves.

Item	System	Proximate Cause	Discovery Method	Piece Part	Sub-Component	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
99	RHR-B	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Motor	Actuator	Design	1992	Failure to Close	Partial	Due to the original valve operator selection criteria using less conservative factors, the outboard primary containment spray isolation valves had an inadequate torque and thrust capability. Design requirement is 134 ft-lbs; available is 100 ft-lbs.
100	RHR-B	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Motor	Actuator	Design	1989	Failure to Close	Partial	Due to incorrectly sized operator the Torus cooling valves would not completely close against full differential pressure.
101	RHR-B	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Torque Switch	Actuator	Design	1987	Failure to Close	Partial	During operability test of RHR, a loop isolation valve would not close against system operating pressure due to an undersized washer spring pack in valve operator, supplied to the plant in actuators by the vendor not in accordance with purchase specifications. Similar problem found on the other loop isolation valve.
102	RHR-B	External Environment	Demand	Disk	Valve	Maintenance	1986	Failure to Open	Partial	MOVs failed to open after being closed. Valves are the residual heat removal suppression pool suction valves. Torque switch prevented motor burn-out. Valve disk was found struck closed. Mud was found in the valve seat, which caused the disk to wedge into the seat upon closing and prevented it from opening. Mud in MOVs believed to be from construction activities of plant
103	RHR-B	External Environment	Demand	Disk	Valve	Maintenance	1986	Failure to Open	Partial	The suppression pool (residual heat removal) pump suction valves failed to open electrically. The motor was subjected to locked-rotor current for about 2 minutes, resulting in overheating. Sediment accumulations (non-ferrous) that would squeeze out between the disc and the seat and lock them together was the root cause. The suppression pool sediment most likely occurred during construction.
104	RHR-B	External Environment	Inspection	Body	Valve	Environmental	1981	Failure to Open	Partial	Motor operated valves (chemwaste receiver tank isolation) and (Torus Injection Isolation) operators found with loose and broken cap screws anchoring motors to valves due to vibration induced loosening of the hold-down bolts.
105	RHR-B	External Environment	Inspection	Motor	Actuator	Environmental	1985	Failure to Open	Partial	The ECCS pump room was inadvertently flooded with water, inundating the RHR system minimum flow valve and a pump suction isolation valve. The valve operator motor windings were grounded as a result of the water intrusion.
106	RHR-B	External Environment	Test	Transmission	Actuator	Environmental	1991	Failure to Close	Partial	One of the two primary containment isolation valves in both residual heat removal low pressure coolant injection subsystems to be inoperable. One valve operator torque switch tripped in both directions preventing both full closure and full opening. The other valve had excessive seat leakage. The threads of the gate valve stem nut in the motor operator were worn and broken causing the valve to lock in a partially open position. Analysis determined stem nut wear out may have been accelerated by mechanical overload caused by high differential pressure across the valve. The valve stem failed due to vibration causing cyclic fatigue.
107	RHR-B	Internal to Component	Demand	Circuit	Actuator	Maintenance	1993	Failure to Close	Partial	RHR MOVs failed when an aux relay open contactor failed to operate. Cause was attributed to inappropriate use of cramolin spray to clean relay, which caused it to become sticky.
108	RHR-B	Internal to Component	Demand	Circuit	Actuator	Maintenance	1993	Failure to Open	Partial	RHR MOVs failed when an aux relay open contactor failed to operate. Cause was attributed to inappropriate use of cramolin spray to clean relay, which caused it to become sticky.

Item	System	Proximate Cause	Discovery Method	Piece Part	Sub-Component	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
109	RHR-B	Internal to Component	Demand	Limit Switch	Actuator	Maintenance	1980	Failure to Open	Partial	Extinguished valve indicating lights on RHR pump suction valves. MOVs would not operate due to broken limit switch rotors caused by loose limit switch finger bases.
110	RHR-B	Internal to Component	Demand	Limit Switch	Actuator	Maintenance	1995	Failure to Open	Partial	RHR system suppression pool valves failed to operate on demand (open). The limit switch on the MOV failed to operate, thus not allowing the valve to cycle on command. The cause of the failure was normal wear and service conditions of the limit switch resulting in failure.
111	RHR-B	Internal to Component	Demand	Torque Switch	Actuator	Quality	1986	Failure to Open	Partial	An electrical fire was discovered in an MCC. The cause of this event was a personnel error, which resulted in an incorrect field wiring installation on HCI MOVs. The error was complicated by unsuccessful detection of the error during subsequent testing or inspections. As corrective actions, the wiring error was corrected. Additionally, all other motor operators, which were replaced for environmental qualification purposes during this period were modified to preclude this failure.
112	RHR-B	Internal to Component	Demand	Transmission	Actuator	Maintenance	1984	Failure to Open	Partial	Torus suction valves (Both loops) clutch lever would not engage.
113	RHR-B	Internal to Component	Inspection	Body	Valve	Design	1992	Failure to Open	Partial	On 4/29/92, the Torus cooling injection motor-operated valve was found to have cracks in the valve yoke. On 8/7/92, the Torus cooling injection MOV in the redundant loop was also discovered with cracks in the yoke.
114	RHR-B	Internal to Component	Maintenance	Motor	Actuator	Maintenance	1989	Failure to Open	Partial	Grounds were found on 2 of 4 LCI Injection valves. Probable cause was determined to be insulation breakdown.
115	RHR-B	Internal to Component	Test	Disk	Valve	Maintenance	1994	Failure to Close	Partial	RHR MOVs failed the surveillance test with gross seat leakage. Investigation revealed wear on the disc guides and some scratches on the seat. The cause is normal wear and aging.
116	RHR-B	Internal to Component	Test	Motor	Actuator	Maintenance	1985	Failure to Open	Partial	Burned out motors (one LCI and one Torus cooling) due to aging.
117	RHR-B	Internal to Component	Test	Transmission	Actuator	Maintenance	1983	Failure to Open	Partial	RHR inboard injection valve would not open due to a locking nut on the worm gear shaft having backed off allowing the worm gear to back out of the bearing and the spring pack. The opposite train valve had failed 2 months previously for the same cause.
118	RHR-B	Operational/ Human Error	Demand	Circuit	Actuator	Design	1985	Failure to Open	Complete	When the control room operator proceeded to establish shutdown cooling, the suction valves to the system would not open. Investigation revealed that while applying a maintenance permit to the primary containment isolation system, a plant operator unknowingly removed the wrong fuse. This electrically blocked the residual heat removal system shutdown cooling suction valves and head spray isolation valves in the closed position. Investigation revealed that although the plant operator removed the fuse, which was labeled f2, as the permit required, this was not the correct fuse. Apparently, the label had slid down such that fuse f3 appeared to be f2.
119	RHR-B	Operational/ Human Error	Demand	Torque Switch	Actuator	Maintenance	1991	Failure to Close	Partial	First failure was a torque switch out of adjustment. Second failure was a mis-positioned motor lead holding a torque switch open. Inadequate maintenance.
120	RHR-B	Operational/ Human Error	Demand	Torque Switch	Actuator	Maintenance	1987	Failure to Close	Partial	The residual heat removal suppression pool full flow discharge isolation valve and the torus spray isolation valve would not fully close upon demand. The cause of the failure is improper previous maintenance activities set the torque switch setting on the valve operator incorrectly low.
121	RHR-B	Operational/ Human Error	Maintenance	Torque Switch	Actuator	Maintenance	1983	Failure to Open	Partial	Improper wiring and connections on torque switches and limit switches.

Item	System	Proximate Cause	Discovery Method	Piece Part	Sub-Component	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
122	RHR-B	Operational/ Human Error	Test	Stem	Valve	Maintenance	1986	Failure to Close	Almost Complete	While testing the high pressure injection control valves, the motor operator overthrusted while going in the open direction. The valve operator overthrusted due to a design deficiency in the torque switch spring pack that allowed a buildup of grease between the Belleville washers which resulted in hydraulic lockup when the valve was operated. After discussion with component manufacturer, a plant modification was performed that machined notches in the ends of the motor operator torque limiting sleeve. These notches will provide a better grease relief path.
123	RHR-B	Other	Demand	Circuit	Actuator	Design	1987	Failure to Open	Partial	Failure of the auxiliary contact block assembly of valve motor close contactor (failed in open position) prevented energizing valve motor open contactor. Occurred on Unit 2/1 cross-connect isolation valve and on Unit 1 RHR isolation injection valve. The contacts failed in the open position, thereby preventing energization of the valve motor open contactor.
124	RHR-B	Other	Demand	Torque Switch	Actuator	Maintenance	1984	Failure to Close	Partial	Residual heat removal suction from suppression pool and shutdown cooling inboard isolation suction valve would trip thermal overload when attempting to open from closed position and failed to close completely. Torque switch setting was to high and limit switch settings were incorrect. Reset limit and torque switches.
125	RHR-B	Other	Demand	Torque Switch	Actuator	Maintenance	1984	Failure to Close	Partial	Both LCI loop's full flow test valves failed to go full closed due to a faulty torque switch.
126	RHR-B	Other	Demand	Torque Switch	Actuator	Maintenance	1984	Failure to Open	Partial	Residual heat removal suction from suppression pool and shutdown cooling inboard isolation suction valve would trip thermal overload when attempting to open from closed position and failed to close completely. Torque switch setting was to high and limit switch settings were incorrect. Reset limit and torque switches.
127	RHR-B	Other	Test	Breaker	Actuator	Maintenance	1986	Failure to Open	Partial	LCI test valve and LCI torus suction valve would not open upon demand and would trip the breaker upon movement. Found auxiliary contacts on breaker in open circuit not making up.
128	RHR-B	Other	Test	Limit Switch	Actuator	Maintenance	1984	Failure to Close	Partial	During a LCI operability test, full flow test valves were closed by position indication. However, the valves were not fully seated, and the LCI discharge piping drained. Valve position indication was out of adjustment.
129	RHR-B	Other	Test	Torque Switch	Actuator	Maintenance	1984	Failure to Close	Partial	LLRT failures on Torus Suction valves due to torque switch misadjustment.
130	RHR-P	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Circuit	Actuator	Design	1999	Failure to Open	Complete	Thermal overloads for two valves tripped due to design deficiency. Consequently, the normal closure of the valve will trip the thermal overload heater some percentage of the time.
131	RHR-P	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Limit Switch	Actuator	Design	1985	Failure to Close	Partial	Shutdown cooling system heat exchanger isolation valves were not fully closed. The condition resulted from premature actuation of valve motor operator position indication limit switches and control room indication of the valves being in the closed position. A change is being implemented for these valves to separate the torque switch bypass limit switch and the valve position indicating limit switch by rewiring the position indicating rotors.

Item	System	Proximate Cause	Discovery Method	Piece Part	Sub-Component	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
132	RHR-P	Design/ Construction/ Manufacture/ Installation Inadequacy	Demand	Transmission	Actuator	Design	1991	Failure to Open	Partial	The motor operator for cold leg isolation valve electrically engaged while the valve was being manually stroked open during post-modification testing. The motor operator electrically engaged and closed the valve (short stroking). Investigation determined that this electrical short stroking of the valve caused the motor pinion key to shear. Other safety-related motor operators were inspected. The motor operators were identified as having failed keys similar to the failed key identified earlier. Further investigation revealed small cracks emanating from both corners of the keyway on the motor shaft. The root cause of the sheared motor pinion gear was that the key material was inadequate.
133	RHR-P	Design/ Construction/ Manufacture/ Installation Inadequacy	Test	Torque Switch	Actuator	Design	1985	Failure to Open	Partial	During maintenance testing it was determined several residual heat removal MOVs wouldn't develop the required thrust as specified by the motor operated valve testing program. The failure was attributed to an improper torque switch installation due to incorrect engineering calculations of original design values. The appropriate torque switch was installed, adjusted per the revised engineering values, tested, and returned to service.
134	RHR-P	External Environment	Demand	Body	Valve	Maintenance	1985	Failure to Open	Partial	Shutdown cooling isolation valves wouldn't fully open. One was attributed to boric acid buildup and the other cause is unknown.
135	RHR-P	External Environment	Demand	Torque Switch	Actuator	Design	1983	Failure to Close	Partial	Two RHR MOVs were not giving remote indication in the full close position of valve. Torque switch inoperative, not rotating on closing stroke. The torque switch setting screw was found loose most likely due to valve vibration.
136	RHR-P	Internal to Component	Test	Torque Switch	Actuator	Maintenance	1986	Failure to Open	Partial	While the unit was in shutdown for refueling, the BWST outlet valve operator failed to open during motor operated valve actuation testing. The torque switch was out of balance.
137	RHR-P	Operational/ Human Error	Demand	Disk	Valve	Quality	1987	Failure to Close	Partial	The residual heat removal system safety injection to reactor coolant loop isolation MOVs were leaking through while closed and could not be isolated. Valve split disks were reversed during initial installation and were 180 degrees out from the proper orientation. This caused seat leakage due to lack of seating contact.
138	RHR-P	Operational/ Human Error	Demand	Torque Switch	Actuator	Maintenance	1983	Failure to Open	Almost Complete	Shutdown cooling system heat exchanger isolation valves could not be remotely opened from the control room. The inability of the valves to remotely open was attributed to incorrect open sequence torque and limit switch settings. The incorrect settings caused the motor on the valves to stop before the valves had come off their seats.
139	RHR-P	Operational/ Human Error	Demand	Transmission	Actuator	Operational	1995	Failure to Close	Partial	Low Pressure Injection valves were overtorqued open in error during manual backseating after past packing leaks. Excessive force was applied when disengaged from electric operation, causing clutch ring to bind-up when electric operation was re-initiated.
140	RHR-P	Operational/ Human Error	Maintenance	Limit Switch	Actuator	Maintenance	1986	Failure to Close	Partial	Low pressure safety injection flow control containment isolation valves' stroke travel was greater than allowable. The cause was open limit switches out of adjustment.
141	RHR-P	Operational/ Human Error	Test	Limit Switch	Actuator	Maintenance	1991	Failure to Close	Partial	LPI MOVs failed to open. Incorrect setpoints of the valve operator limit switches. Root cause was insufficient control of setpoints.
142	RHR-P	Other	Demand	Limit Switch	Actuator	Maintenance	1983	Failure to Open	Partial	MOV motor torqued out on start of open/close cycle. Limit switches out of adjustment.
143	RHR-P	Other	Demand	Limit Switch	Actuator	Maintenance	1987	Failure to Open	Partial	Residual heat removal pump suctions from feedwater storage tank valve and containment sump would not operate from control room. Cause of valve's failure to operate was limit switches out of adjustment.
144	RHR-P	Other	Demand	Torque Switch	Actuator	Maintenance	1987	Failure to Open	Partial	RHR pump suction MOV isolation valves would not fully open on demand. The cause of this failure was due to both torque switches were out of adjustment. Both valves could be closed on repeated attempts but not reopened completely.

Item	System	Proximate Cause	Discovery Method	Piece Part	Sub-Component	Coupling Factor	Year	Failure Mode	Degree of Failure	Description
145	RHR-P	Other	Test	Limit Switch	Actuator	Design	1995	Failure to Open	Partial	LPI throttle valves failed to stroke fully open. As a result, minimum flow for LPSI injection legs were below the minimum design basis flow.
146	RHR-P	Other	Test	Limit Switch	Actuator	Design	1995	Failure to Open	Partial	LPI throttle valves over traveled in the open direction by approximately 1/2 inch. This resulted in LPI flow exceeding Tech spec limits..
147	RHR-P	Other	Test	Limit Switch	Actuator	Maintenance	1990	Failure to Open	Partial	Stem travel was excessive on low pressure safety injection flow control containment isolation valves. The opening travel was excessive, due to limit switch out of adjustment.
148	RHR-P	Other	Test	Torque Switch	Actuator	Maintenance	1984	Failure to Open	Partial	While performing sump valve stroke test two MOVs failed to re-open after being stroked closed. The cause of the failures has been determined to be that the bypass circuit time was too short. This prevented the valves from opening until the control switch had been operated several times.
149	RHR-P	Unknown	Demand	Transmission	Actuator	Maintenance	1985	Failure to Close	Partial	Low pressure injection supply from the borated water storage tank isolation valves would not close due to broken worm shaft clutch gear on valve operator.

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10. SUPPLEMENTARY NOTES
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11. ABSTRACT (200 words or less)
This report documents a study performed on the set of common-cause failures (CCF) of motor-operated valves (MOV) from 1980 to 2000. The data studied here were derived from the NRC CCF database, which is based on US commercial nuclear power plant event data. This report is the result of an in-depth review of the MOV CCF data and presents several insights about the MOV CCF data. The objective of this document is to look beyond the CCF parameter estimates that can be obtained from the CCF data, to gain further understanding of why CCF events occur and what measures may be taken to prevent, or at least mitigate the effect of, MOV CCF events. This report presents quantitative presentation of the MOV CCF data and discussion of some engineering aspects of the MOV events.

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