1 MOTOR-OPERATED VALVE INSIGHTS

1.1 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 (NUREG/CR-6268, *Common-Cause Failure Database and Analysis System*.[1,2,3,4]) 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 1-1 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 1-1. 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

Failure Mode	Degree of Failure			Total
	Partial	Almost Complete	Complete	
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.

1.2 CCF Trends Overview

Figure 1-1 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[1] with a p-value[2] of 0.0001. Generic Letter (GL) 89-10, *Safety-Related Motor-Operated Valve Testing And Surveillance*[5] 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*[6] 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*[7] 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 1-2 through Figure 1-4 show trends for subsets of the MOV CCF events contained in Figure 1-1. Figure 1-2 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 1-3 and Figure 1-4 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 1-2, the bars at approximately 0.01 events per calendar-reactor year correspond to a single

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1. 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.

2. 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.

Complete MOV CCF event in the year and the bars at approximately 0.02 correspond to two Complete MOV CCF events in the year.

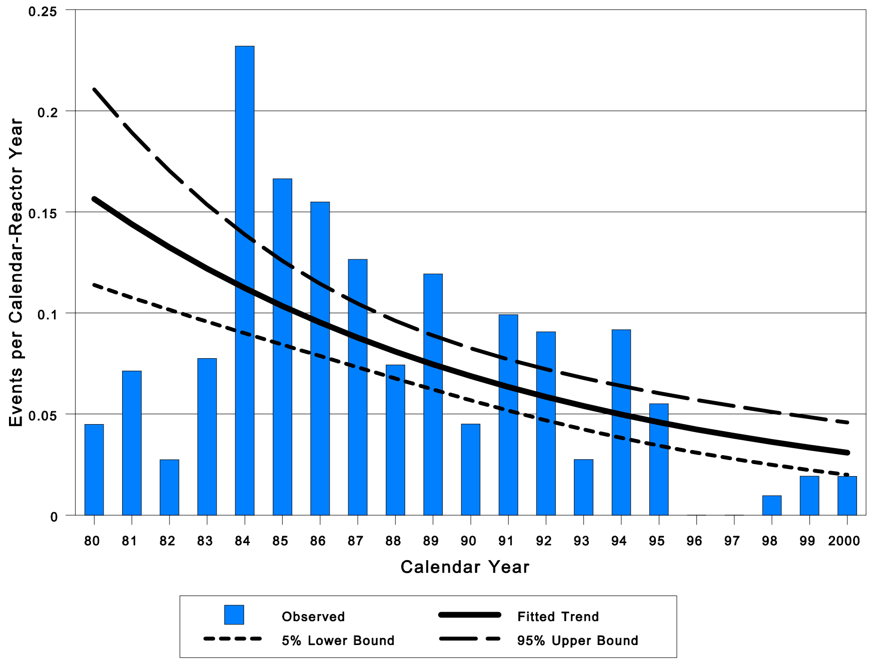

Figure 1-1. Trend for all MOV CCF events. The decreasing trend is statistically significant with a p-value = 0.0001.

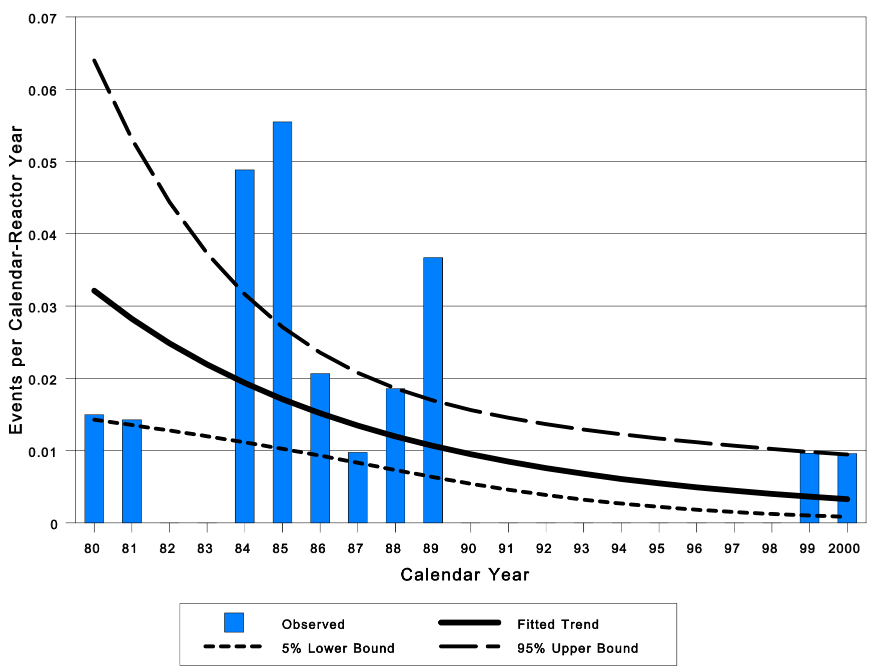

Figure 1-2. Trend for Complete MOV CCF events. The decreasing trend is statistically significant with a p-value = 0.0019.

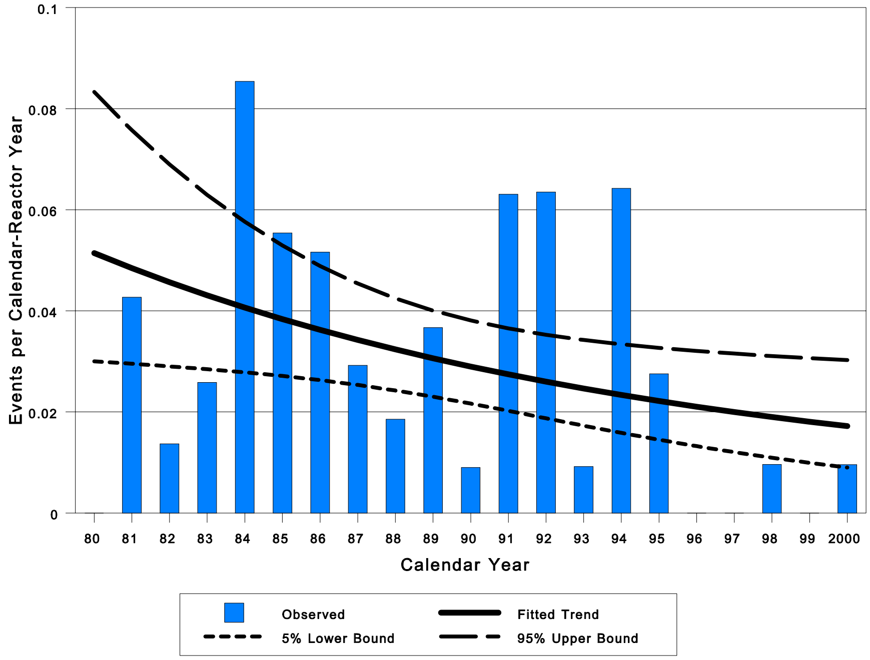

Figure 1-3. Trend for all MOV CCF events for the fail-to-close failure mode. The decreasing trend is statistically significant with a p-value = 0.0133

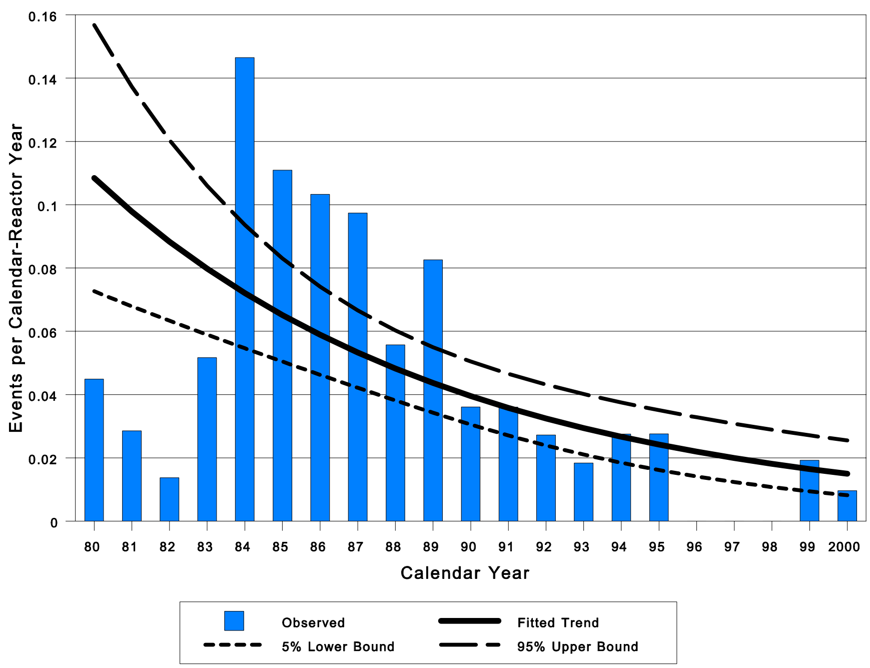

Figure 1-4. Trend for all MOV CCF events for the fail-to-open failure mode. The decreasing trend is statistically significant with a p-value = 0.0001.

1.3 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.

Figure 1-5 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.

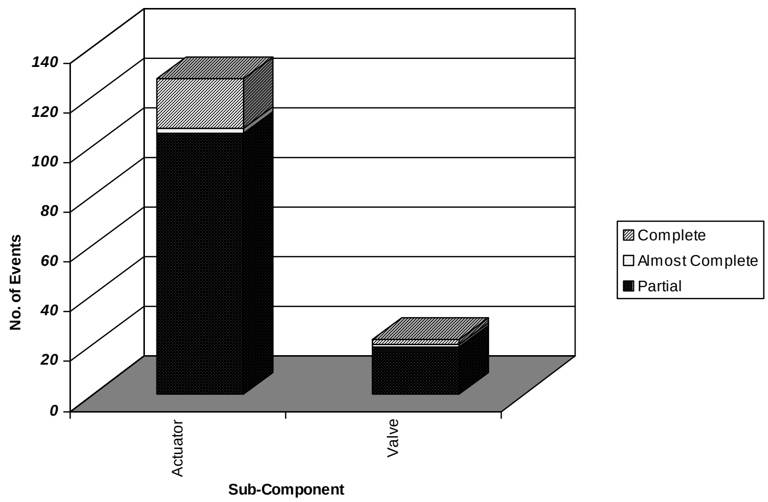

Figure 1-5. Sub-component distribution for all MOV CCF events.

1.4 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. Reference 3 contains additional details on the proximate cause categories, and how CCF event proximate causes are classified.

Figure 1-6 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.

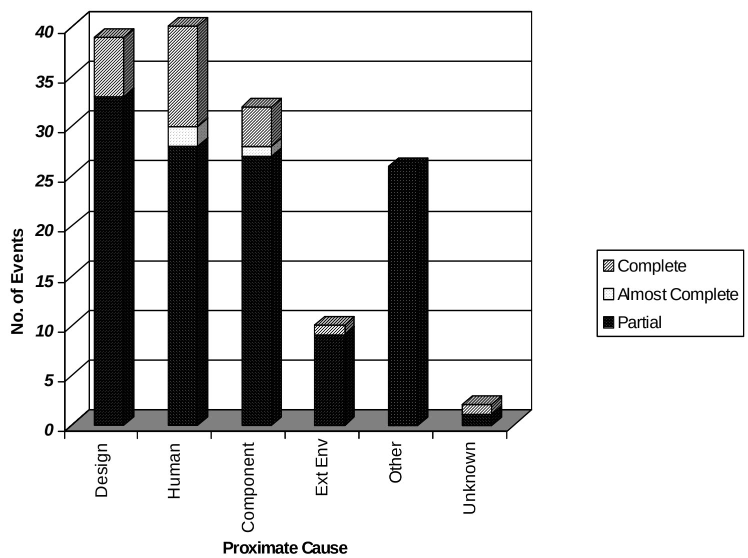

Figure 1-6. Proximate cause distribution for all MOV CCF events.

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."

1.5 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 3 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 1-7 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.

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.

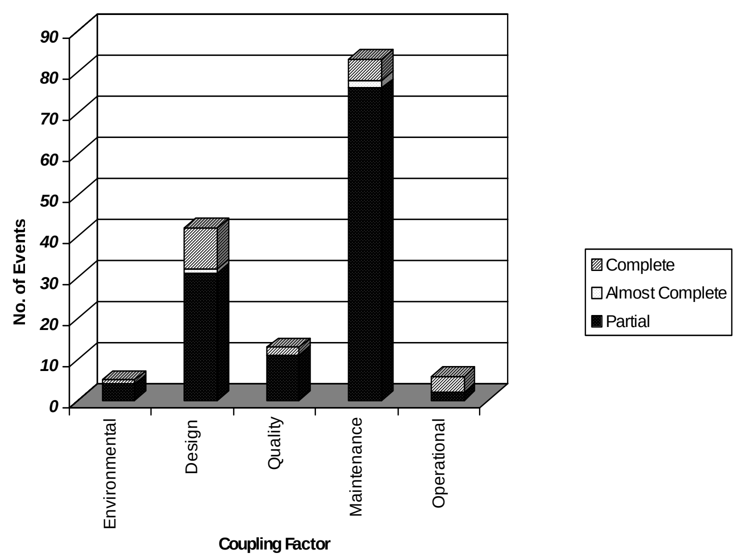

Figure 1-7. Coupling factor distribution for all MOV CCF events.

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.

1.6 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 1-8 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.

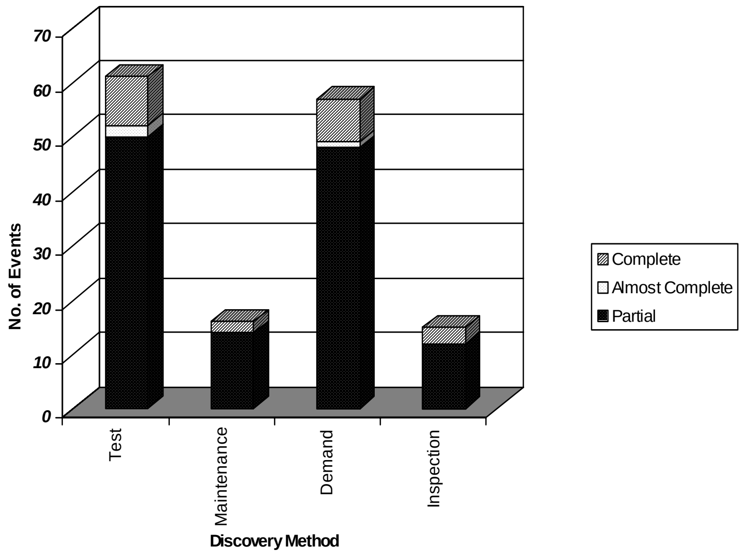

Figure 1-8. Discovery method distribution for all MOV CCF events.

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 1-9). 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 5) have increased the effectiveness of failure discovery via testing.

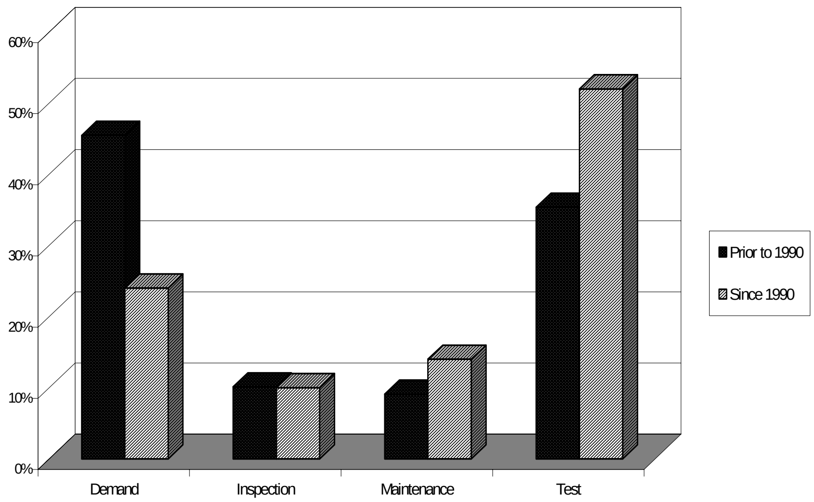

Figure 1-9. Method of discovery before and after 1990.

1.7 MOV CCF System Observations

Figure 1-10 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.

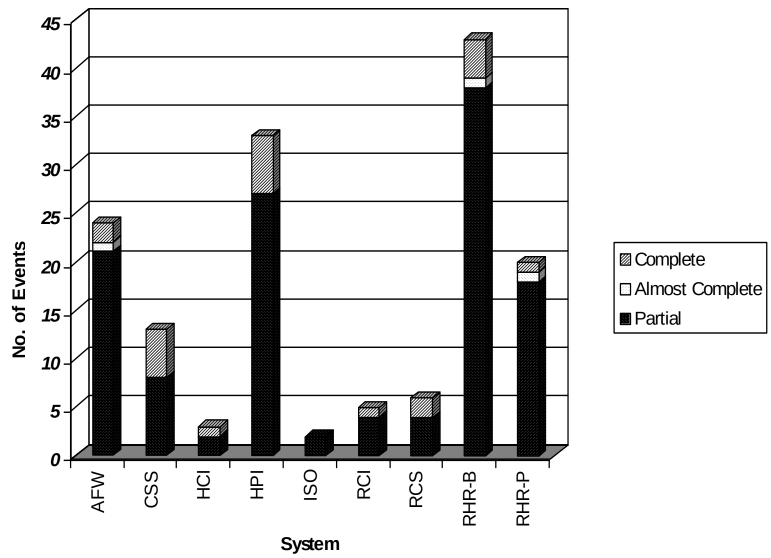

Figure 1-10. Distribution of MOV CCF events by system.

1.8 Other MOV CCF Observations

Figure 1-11 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.

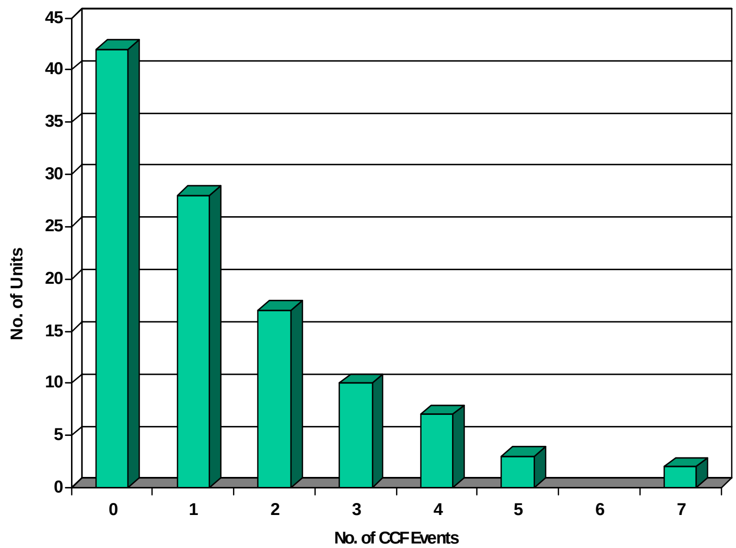

Figure 1-11. Distribution of NPP units experiencing a multiplicity of CCFs for all MOV CCF events.

2 REFERENCES

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