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Enhanced Component Performance Study: Motor-Operated Valves 1998–2016

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ABSTRACT

This report presents an enhanced performance evaluation of motor-operated valves (MOVs) at U.S. commercial nuclear power plants. The data used in this study are based on the operating experience failure reports from calendar year 1998 through 2016 as reported in the Institute of Nuclear Power Operations (INPO) Consolidated Events Database (ICES). The MOV failure modes considered are failure to open/close, failure to operate or control, and spurious operation. The component reliability estimates and the reliability data are trended for the most recent 10-year period while yearly estimates for reliability are provided for the entire study period. One highly significant increasing trend was observed for the frequency of fail-to-open or close demands per reactor year for low-demand (≤ 20 demands per year) valves. Two statistically significant decreasing trends were observed in the data: The failure probability estimate for valve fail-to-open/close for low-demand valves was found to be decreasing. The frequency of failures per reactor year for valves with fail-to-open/close failure modes, for valves low-demand valves, was found to be decreasing.

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TABLES

ACRONYMS

AFW	Auxiliary feed water
CCW	component cooling water
CNID	constrained non-informative prior distribution
CRD	control rod drive
CSR	containment spray recirculation
CVC	chemical and volume control
CY	calendar year
FTOC	failure-to-open/close (failure to operate)
FTOP	failure to operate or control
FY	fiscal year
HCI	high-pressure coolant injection
HCS	high-pressure core spray
HPI	high-pressure injection
ICES	INPO Consolidated Events Database
INPO	Institute of Nuclear Power Operations
ISO	isolation condenser
LCS	low-pressure core spray
MOV	motor-operated valve
MSPI	Mitigating Systems Performance Index
OLS	ordinary least squares
PRA	probabilistic risk assessment
RCI	reactor core isolation
RCS	reactor coolant
RHR	residual heat removal
SO	spurious operation
SWN	normally running service water
SWS	standby service water
UA	unavailability
VSS	vapor suppression

Enhanced Component Performance Study: Motor-Operated Valves 1998–2016

1. INTRODUCTION

This report presents a performance evaluation of motor-operated valves (MOVs) at U.S. commercial nuclear power plants from 1998 through 2016. The objective of the updated component performance studies is to obtain annual performance trends of failure rates and probabilities and to present an analysis of factors that could influence the component trends. This year's update has two changes from previous year's updates: 1) This year's results are based on calendar year (CY) instead of fiscal year (FY), and 2) The failure events included in this update are now all considered "hard" failures, which is to say the p-values indicating the likelihood the component would have failed during a 24-hour mission are now all 1.0. Previous updates include lesser p-values indicating a degraded condition that probably would have caused failure during a 24-hour mission.

The data used in this study are based on the operating experience failure reports from the Institute of Nuclear Power Operations' (INPO') Consolidated Events Database (ICES) [1], formerly the Equipment Performance and Information Exchange Database (EPIX). Maintenance unavailability (UA) performance data comes from Mitigating Systems Performance Index (MSPI) data from 2002 through 2016 [2]. Data for valves demanded more than 20 times per year (high-demand) are reported separately from the data for lesser-used (low-demand) valves. The MOV failure modes considered are failure-to-open/close (FTOC), failure to operate or control (FTOP), and spurious operation (SO) (see Section 5). Annual failure probabilities (failures per demand) are provided for FTOC events and annual failure rates (failures per valve hour) are provided for FTOP and SO events in Section 3. The estimates are trended for the most recent 10-year period while yearly estimates are provided for the entire study period.

This study is modeled on the web page updates associated with the NUREG-1715 series of reports [3], which were published around 2000. Those studies relied on operating experience obtained from licensee event reports, Nuclear Plant Reliability Data System, and ICES. The ICES database, which includes MSPI as a subset, has matured to the point where component availability and reliability can be estimated with a higher degree of assurance of accuracy. In addition, the population of data is much larger than the population used in the previous study.

While this report provides an overview of operational data and evaluate component performance over time, it makes no attempt to estimate values for use in probabilistic risk assessments (PRAs). The 2015 Component Reliability Update [4], which is an update to NUREG/CR-6928 [5], reports the MOV unreliability estimates for use in PRAs. Estimates from that report are included herein, for comparisons. These estimates are labelled "2015 Update" (or "Update 2015") in the associated tables and figures.

Engineering analyses were also performed with respect to time period and failure modes. In Section 4.1, the same failures used in Section 3 are used to estimate overall failure frequencies per plant reactor year. Frequencies of demands per plant reactor year for both groupings of MOVs are also provided for each year. As in Section 3, each of the estimates is trended for the most recent 10-year period. The frequencies show general industry performance and are not based on the number of valves at each plant.

Section 4.2 provides breakdowns of the failures for each failure mode for each valve grouping. The analyses are based on the following factors: sub-component, failure cause, detection method, and recovery.

An overview of the trending methods, glossary of terms, and abbreviations can be found in the Overview and Reference document [6] on the Reactor Operational Experience Results and Databases web page (http://nrcoe.inl.gov/resultsdb).

2. SUMMARY OF FINDINGS

The results of this study are summarized in this section. Of particular interest is the existence of any statistically significant[a] increasing trends.

2.1 Increasing Trends

2.1.1 Extremely Statistically Significant

- None.

2.1.2 Highly Statistically Significant

- The frequency of demands per reactor year for low-demand MOVs FTOC demands (see Figure 7).

2.1.3 Statistically Significant

- None.

2.2 Decreasing Trends

2.2.1 Extremely Statistically Significant

- None.

2.2.2 Highly Statistically Significant

- None.

2.2.3 Statistically Significant

- The failure probability estimate trend for all systems, industry-wide low-demand MOV FTOC (see Figure 1).
- The frequency (failures per reactor year) of low-demand MOV FTOC events (see Figure 9).

a. Statistical significance is defined in terms of the 'p-value.' A p-value is a probability indicating whether to accept or reject the null hypothesis that there is no trend in the data. P-values of less than or equal to 0.05 indicate that we are 95% confident that there is a trend in the data (reject the null hypothesis of no trend.) By convention, we use the "Michelin Guide" scale: p-value < 0.05 (statistically significant), p-value < 0.01 (highly statistically significant); p-value < 0.001 (extremely statistically significant).

3. FAILURE PROBABILITIES AND FAILURE RATES

3.1 Overview

Trends of industry-wide failure probabilities and failure rates of MOVs have been calculated from the operating experience for the FTOC, FTOP, and SO failure modes. The MOV data set obtained from ICES was partitioned to low-demand MOVs (those with less than or equal to 20 demands/year) and high-demand MOVs (those with greater than 20 demands/year). The data set includes MOVs in the systems listed in Table 1.

Table 2 shows industry-wide failure probability and failure rate results for low-demand MOV from Reference [4], or the 2015 Update. No 2015 Update results are shown for high-demand MOVs because Reference [4] does not provide them. The 2015 Update results are provided for comparison purposes and are important because they are intended for use in PRA. The results in this section demonstrate the extent to which the 2015 Update results remain suitable estimates for use in PRA.

The MOVs are assumed to operate both when the reactor is critical and during shutdown periods. The number of MOVs in operation is the number that have been in operation at some time during the study period. So new devices put in service during the period are included, as are devices that were in service at one time but have since been removed from service. All demand types are considered—testing, non-testing, and, as applicable, engineered safety feature demands.

Table 1. Summary of MOV counts in the systems in which they are found.

		MOV Count		
System	**Description**	**Total**	**Low Demand**	**High Demand**
AFW	Auxiliary feedwater	638	465	173
CCW	Component cooling water	859	626	233
CRD	Control rod drive	25	10	15
CSR	Containment spray recirculation	351	329	22
CVC	Chemical and volume control	13	13	
HCI	High pressure coolant injection	291	269	22
HCS	High pressure core spray	49	30	19
HPI	High pressure injection	1128	1008	120
ISO	Isolation condenser	20	14	6
LCS	Low pressure core spray	235	202	33
RCI	Reactor core isolation	354	319	35
RCS	Reactor coolant	111	104	7
RHR	Residual Heat Removal (LCI in BWRs; LPI in PWRs)	2189	1874	315
SWN	Normally operating service water	1011	728	283
SWS	Standby service water	316	216	100
VSS	Vapor suppression	14	14	
	Total	7604	6221	1383

Table 2. 2015 Update industry-wide distributions of p (failure probability) and λ (hourly rate) for low-demand MOVs.

Failure Mode	5%	Median	Mean	95%	Distribution		
					Type	α	β
FTOC	2.13E-4	7.28E-4	8.23E-4	1.75E-3	Beta	2.84	3.45E+03
FTOP	7.40E-9	4.76E-8	5.98E-8	1.54E-7	Gamma	1.55	2.59E+07
SO	2.90E-10	1.69E-8	3.24E-8	1.17E-7	Gamma	0.59	1.83E+07

3.2 MOV Failure Probability and Failure Rate Trends

Trends in failure probabilities and failure rates are shown in Figures 1–6. The data for the trend plots are contained in Tables 10–15, respectively.

The failure probability and failure rate estimates in the plots were obtained from a Bayesian update process. The means from the posterior distributions were plotted for each year. The 5th and 95th percentiles from the posterior distributions are also provided and give an indication of the relative uncertainty in the estimated parameters from year to year. When there are no failures, the uncertainty interval tends to be larger than the interval for years when there are one or more failures. The larger interval reflects the uncertainty that comes from having little information in that year's data. Such uncertainty intervals are sometimes strongly influenced by the prior distribution. In each plot, a relatively "weak" constrained non-informative prior distribution (CNID) is used, which has large bounds [7]. For failure probabilities, the posterior means for each year are calculated from

$$mean = \frac{failures + 0.5}{demands + 1} \quad (1)$$

For failure rates, the posterior means for each year are calculated from

$$mean = \frac{failures + 0.5}{operting\ hours} \quad (2)$$

The horizontal curves plotted around the regression lines in the graphs form 90 percent simultaneous confidence bands for the fitted lines. The bounds are larger than ordinary confidence bands for the trended values because they form a band that has a 90% probability of containing the entire line. In the lower left hand corner of the trend figures, the regression p-values are reported. They come from a statistical test on whether the slope of the regression line might be zero. Low p-values indicate that the slopes are not likely to be zero, and that trends therefore could exist. P-values of less than or equal to 0.05 indicate that we are 95% confident that there is a trend in the data (reject the null hypothesis of no trend.) By convention, this study uses the "Michelin Guide" scale: p-value < 0.05 (statistically significant), p-value < 0.01 (highly statistically significant); p-value < 0.001 (extremely statistically significant).

The regression methods are all based on "ordinary least squares" (OLS); which minimizes the square of the vertical distance between the annual data points and the regression line. The p-values assume normal distributions for the data in each year, with a constant variance across the years. In the case where the data involve failure counts, the method of iterative reweighing accounts for the fact that count data are not expected to have a constant variance (for example, the variance for Poisson-distributed counts is equal to the expected number of counts). Further information on the trending methods is provided in Section 2 of the Overview and Reference document [6].

A final feature of the trend graphs is that the 2015 Update baseline industry values from Table 2 are shown for comparison.

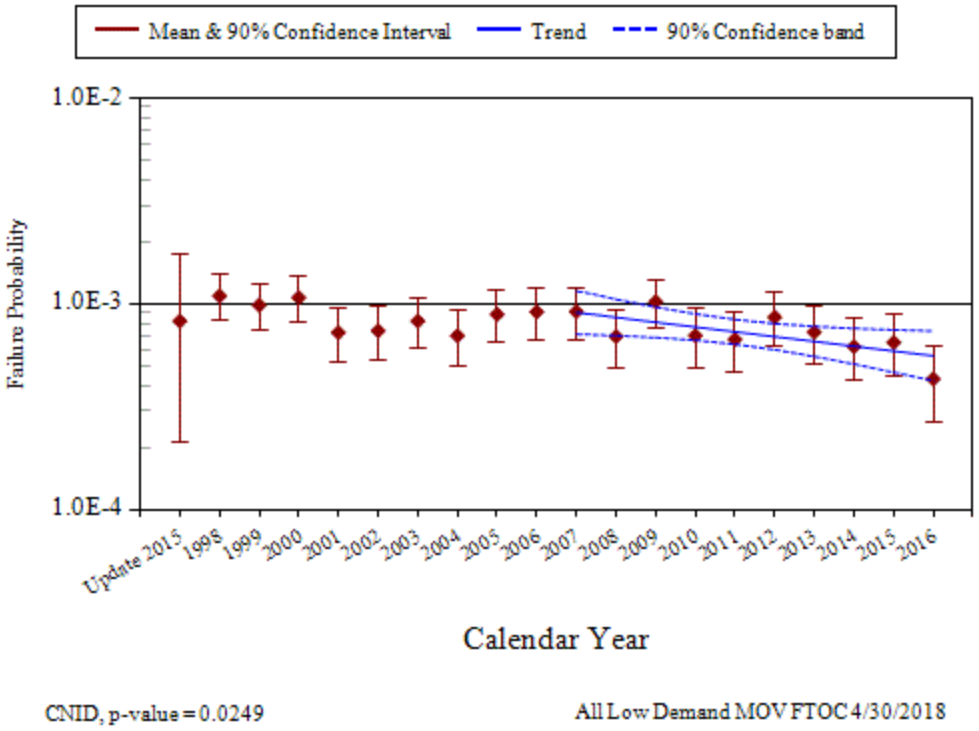

Figure 1. Failure probability estimate trend for all systems, industry-wide, low-demand MOV FTOC.

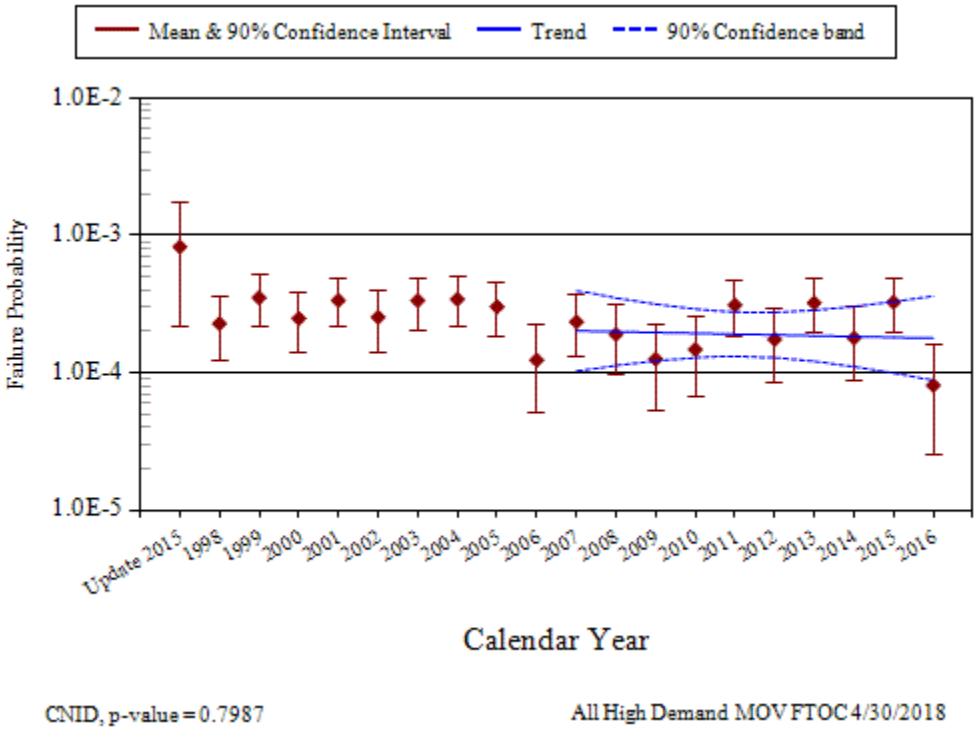

Figure 2. Failure probability estimate trend for all systems, industry-wide, high-demand MOV FTOC.

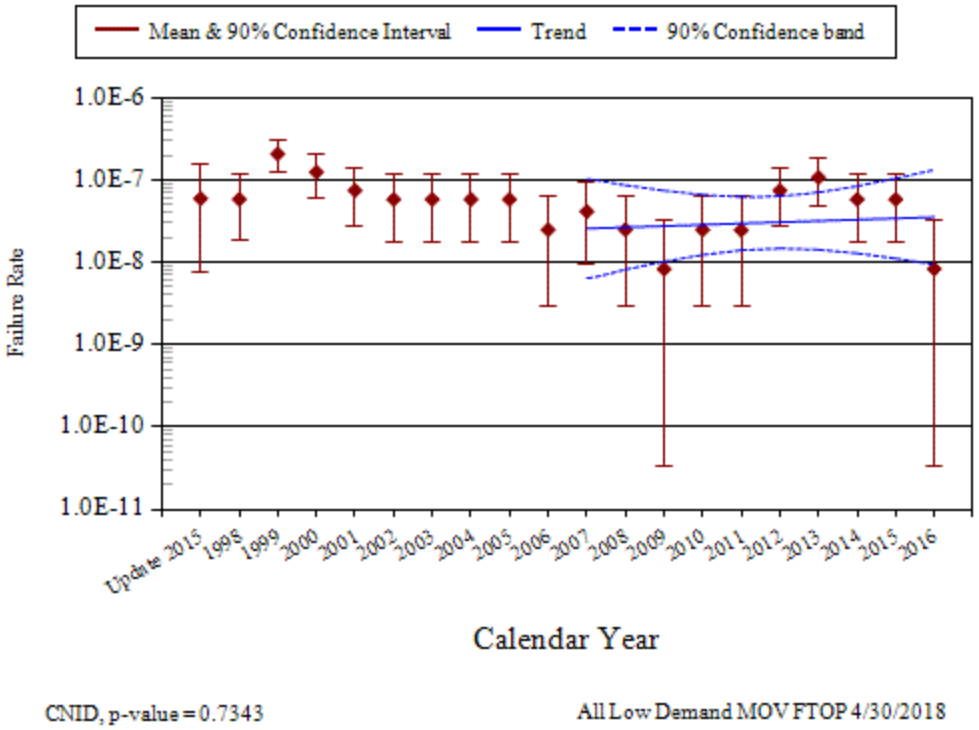

Figure 3. Failure rate estimate trend for all systems, industry-wide, low-demand MOV FTOP.

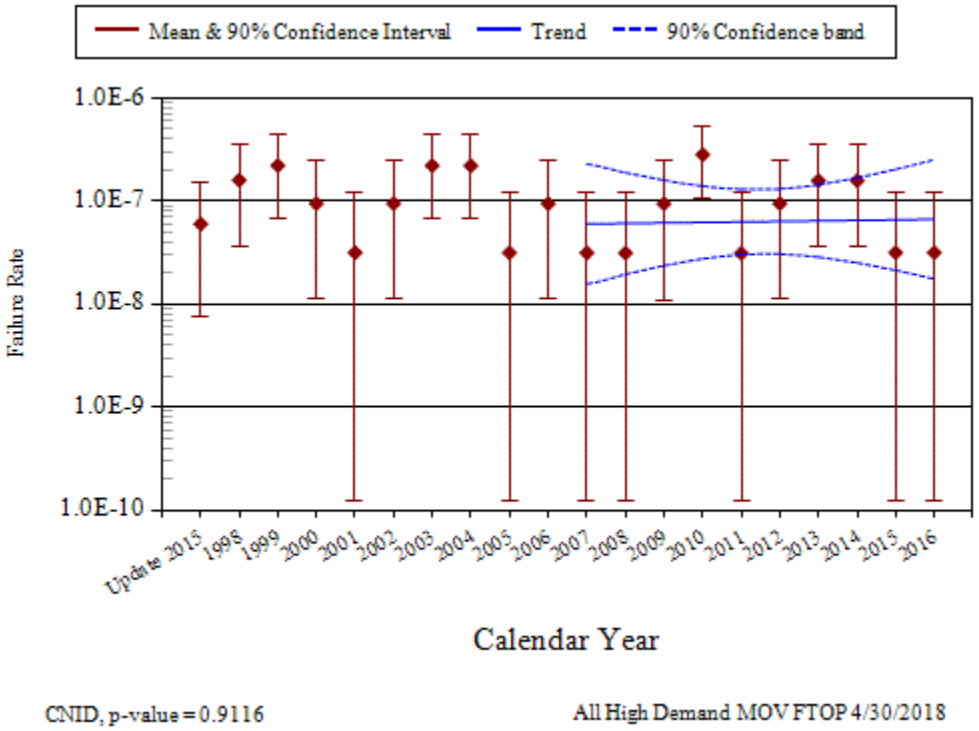

Figure 4. Failure rate estimate trend for all systems, industry-wide, high-demand MOV FTOP.

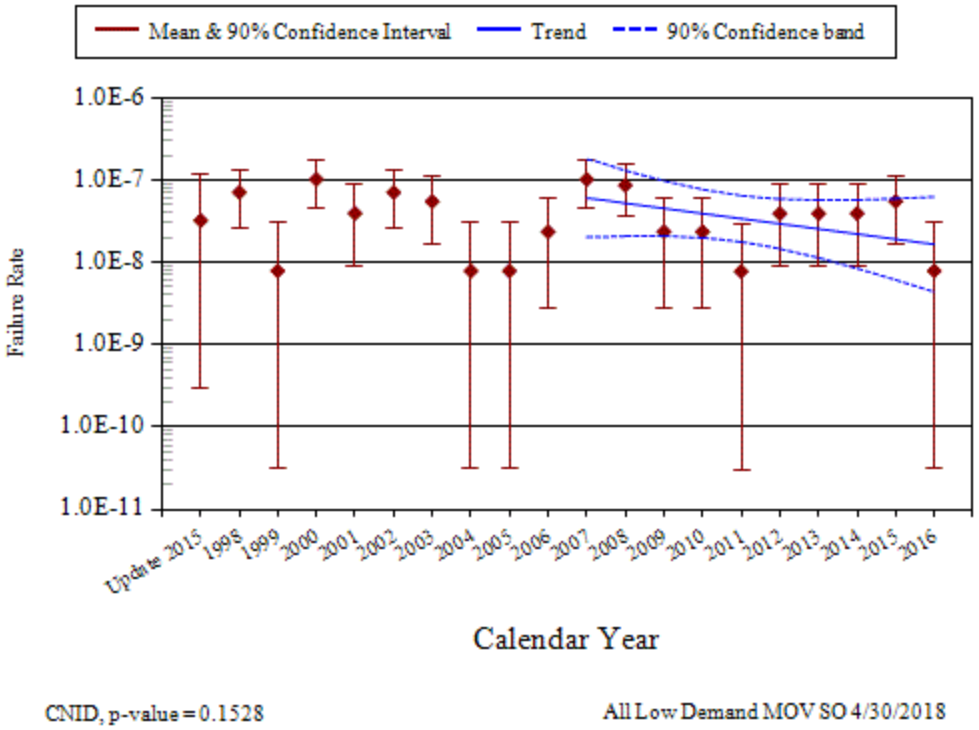

Figure 5. Failure rate estimate trend for all systems, industry-wide, low-demand MOV SO.

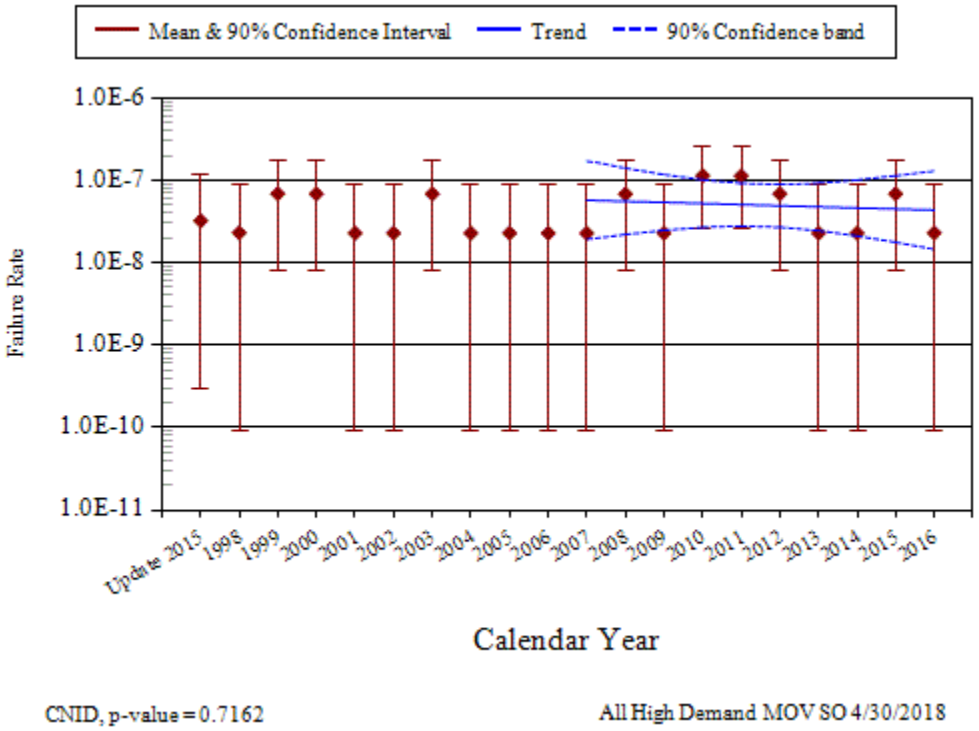

Figure 6. Failure rate estimate trend for all systems, industry-wide, high-demand MOV SO.

4. ENGINEERING ANALYSIS

4.1 Engineering Trends

This section presents frequency trends for MOV failures and demands. The data are normalized by reactor year for plants that report data for the equipment being trended. The trends provide an overview of the demand counts and failure counts associated with each failure mode across the years. Figure 7 shows the trend for total MOV FTOC demands among low-demand MOVs. Figure 9 shows the trend in failure events for the FTOC mode for low-demand MOVs, Figure 11 shows the trend in failure events for FTOP mode for these MOVs, and Figure 13 shows the trend for the SO failure events for these MOVs.

Figure 8 shows the trend for total MOV demands among high-demand MOVs. Figure 10 shows the trend in failure events for FTOC mode for high-demand MOVs, Figure 12 shows the trend in failure events for FTOP mode for these MOVs, and Figure 14 shows the trend for the SO failure events for these MOVs.

Table 3 summarizes the FTOC failure counts by system and year for low-demand MOVs. Table 4 summarizes the FTOP failure counts by system and year for low-demand MOVs. Table 5 summarizes the SO failure counts by system and year for low-demand MOVs.

Table 6 summarizes the FTOC failure counts by system and year for high-demand MOVs. Table 7 summarizes the FTOP failure counts by system and year for high-demand MOVs. Table 8 summarizes the SO failure counts by system and year for high-demand MOVs.

Tables 16–23 provide the plot data for frequency (per reactor year) of MOV demands, run hours, FTOC events, FTOP events, and SO events, respectively. The systems from Table 2 are trended together for each figure. The rate methods described in Section 2 of the Overview and Reference document [6] are used.

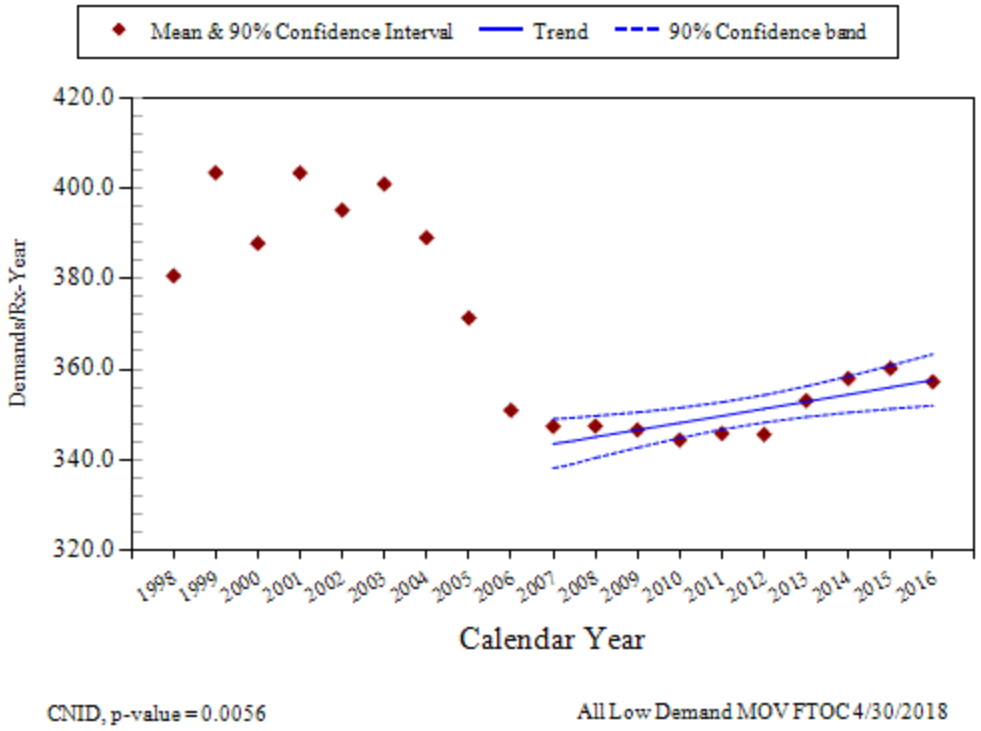

Figure 7. Frequency (demands per reactor year) of low-demand MOV FTOC demands.

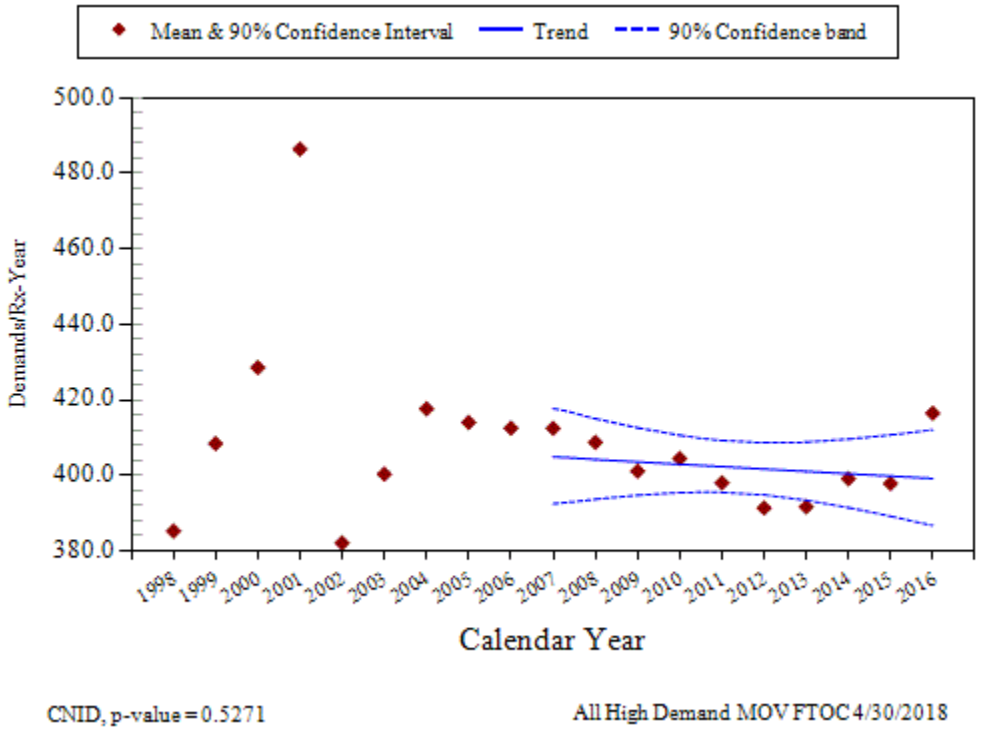

Figure 8. Frequency (demands per reactor year) of high-demand MOV FTOC demands.

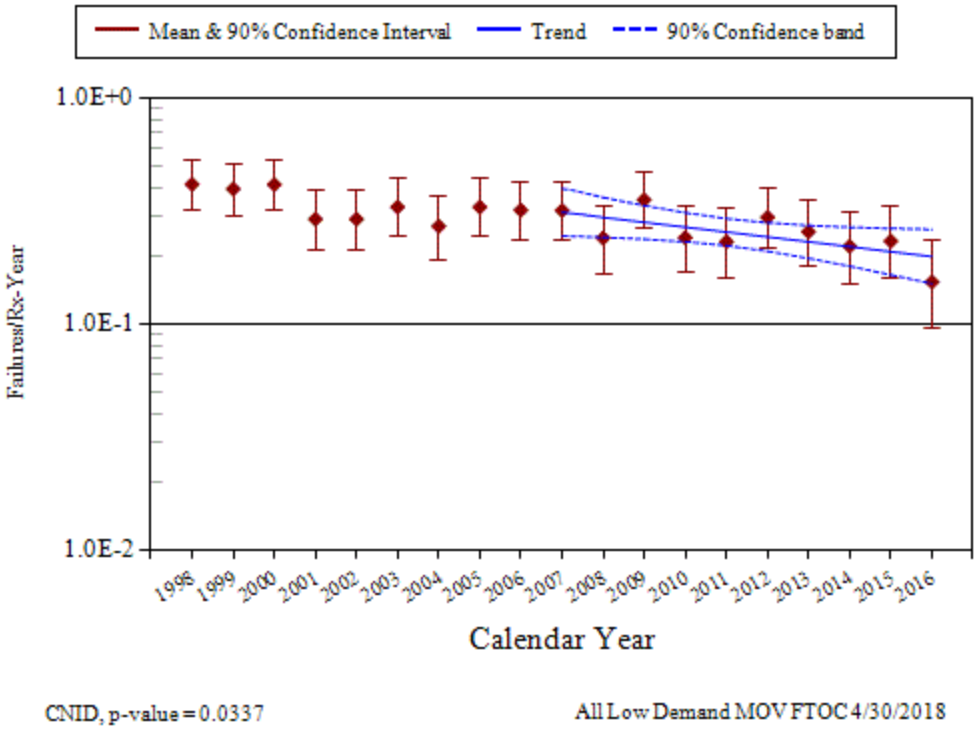

Figure 9. Frequency (failures per reactor year) of low-demand MOV FTOC events.

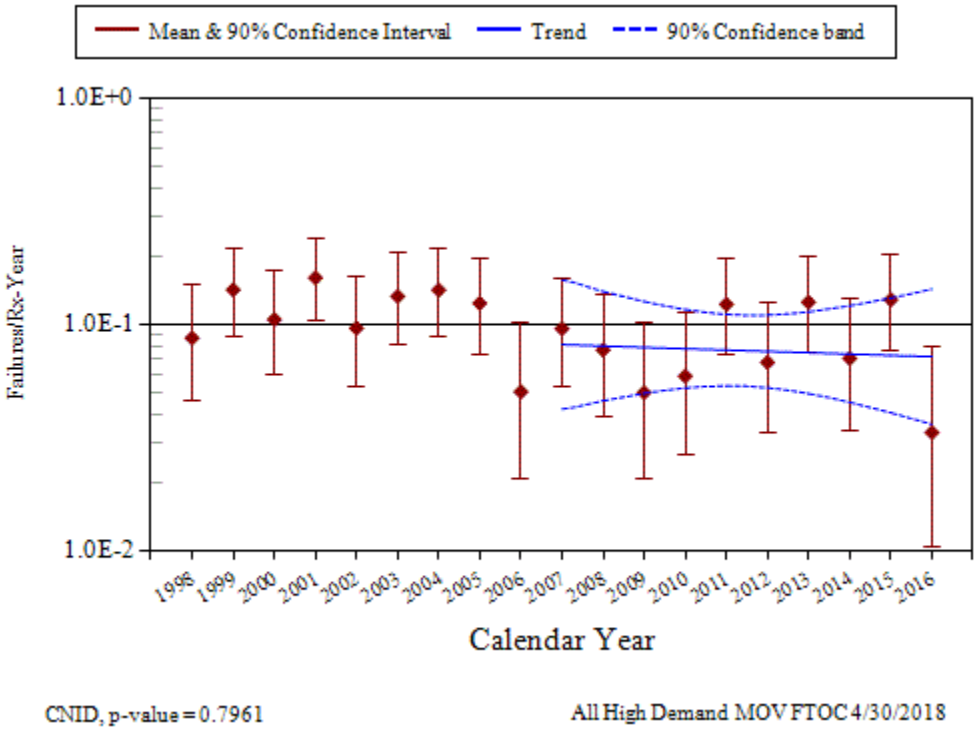

Figure 10. Frequency (failures per reactor year) of high-demand MOV FTOC events.

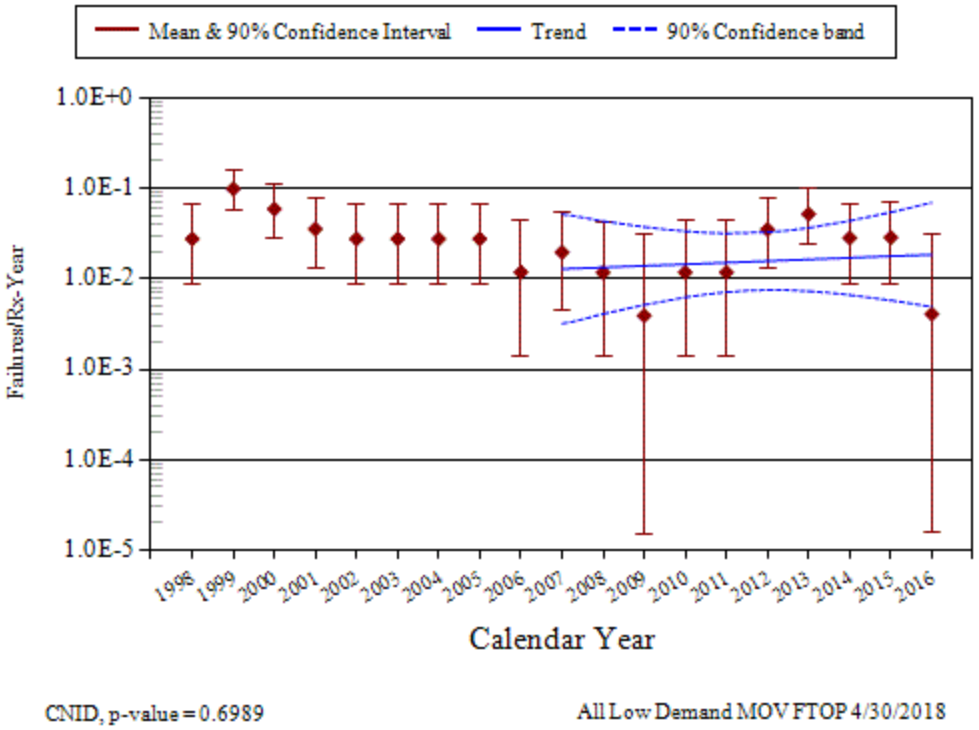

Figure 11. Frequency (failures per reactor year) of low-demand MOV FTOP events.

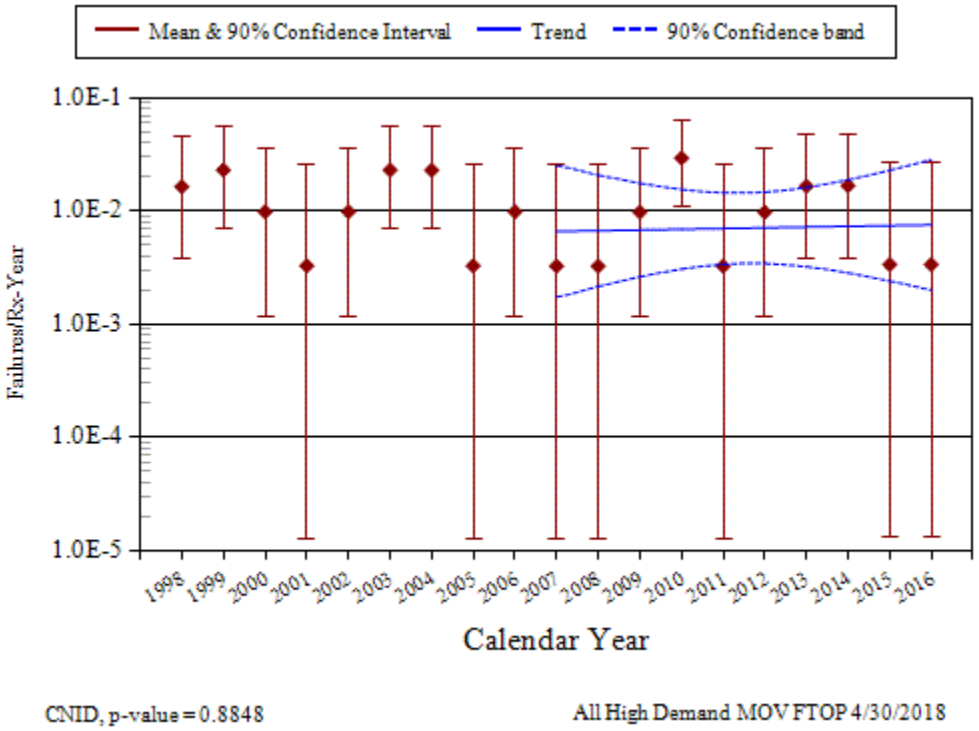

Figure 12. Frequency (failures per reactor year) of high-demand MOV FTOP events.

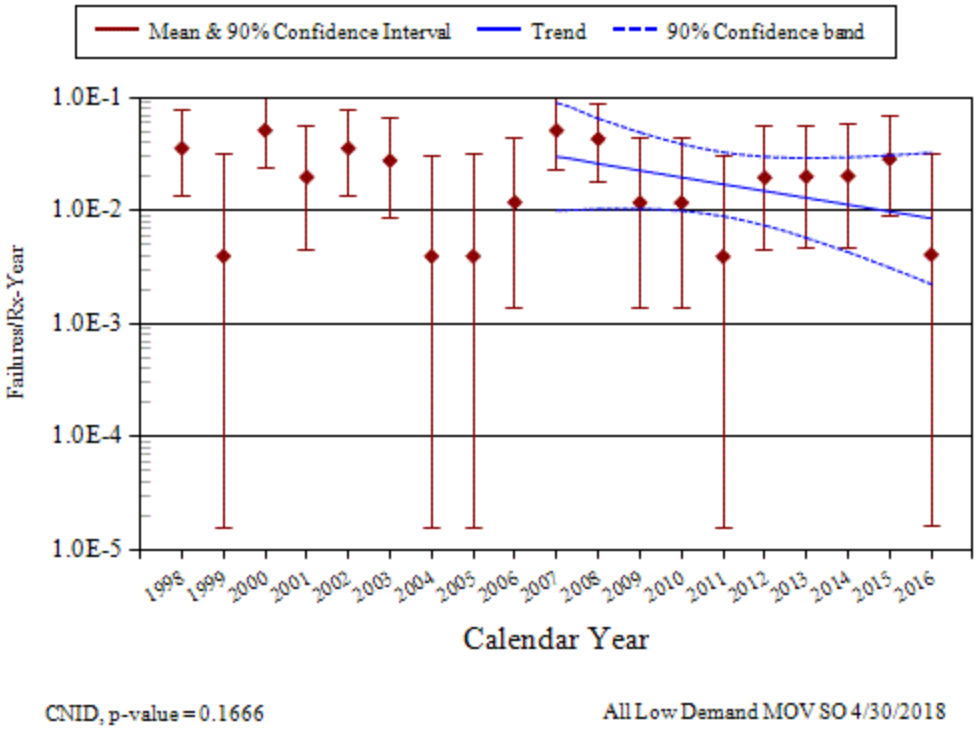

Figure 13. Frequency (failures per reactor year) of low-demand MOV SO events.

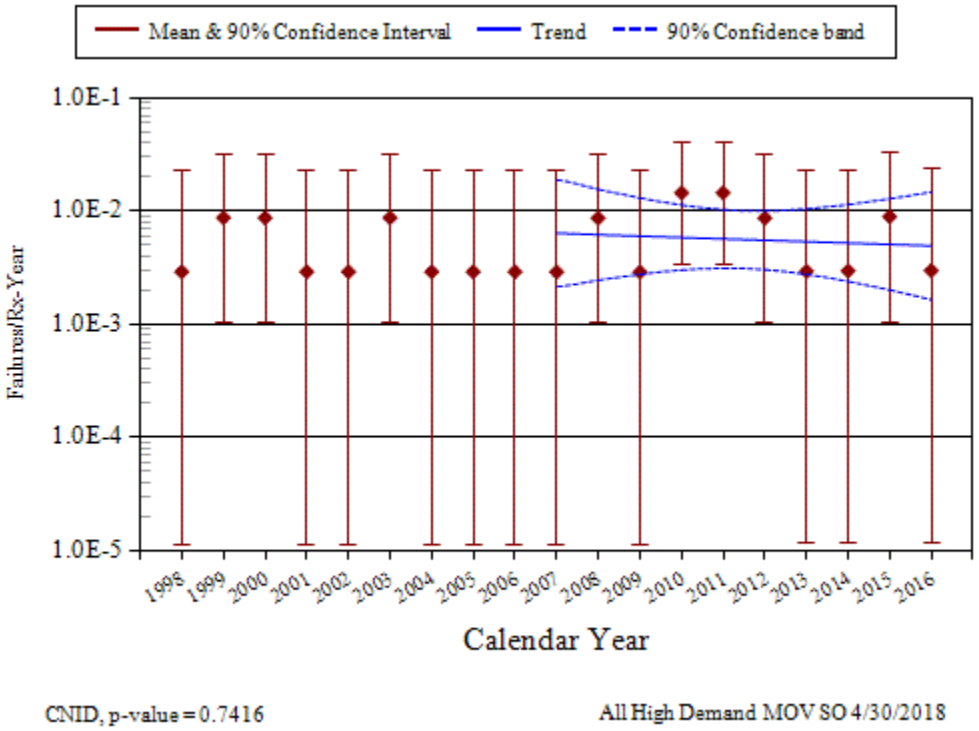

Figure 14. Frequency (failures per reactor year) of high-demand MOV SO events.

Table 3. Summary of low-demand MOV failure counts for the FTOC failure mode over time by system.

System Code	Valve Count	Valve Percent	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
AFW	465	7.5 %	2	1	5	5	4		3	4	4	2	30	11.5 %
CCW	626	10.1 %	1	2	2	2	2	1	3	1	3	2	19	7.3 %
CRD	10	0.2 %											0	0.0 %
CSR	329	5.3 %		1	1	1	2	1		2	3	1	12	4.6 %
CVC	13	0.2 %											0	0.0 %
HCI	269	4.3 %	8	4	4	1		3	1	1	1	1	24	9.2 %
HCS	30	0.5 %											0	0.0 %
HPI	1008	16.2 %	3		4	3	2	2	2	5	1		22	8.4 %
ISO	14	0.2 %					1						1	0.4 %
LCS	202	3.2 %	1				2	3	1				7	2.7 %
RCI	319	5.1 %	2	4		2	1	6	3		3		21	8.0 %
RCS	104	1.7 %			1			2	1			1	5	1.9 %
RHR	1874	30.1 %	14	8	15	10	5	9	5	7	5	6	84	32.2 %
SWN	728	11.7 %	1	5	4	1	3	4	6	2	3	1	30	11.5 %
SWS	216	3.5 %			1		2					1	4	1.5 %
VSS	14	0.2 %	1						1				2	0.8 %
Total	6221	100%	33	25	37	25	24	31	26	22	23	15	261	100%

Table 4. Summary of low-demand MOV failure counts for the FTOP failure mode over time by system.

System Code	Valve Count	Valve Percent	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
AFW	465	7.5 %		1		1		1	1				4	19.0 %
CCW	626	10.1 %									1		1	4.8 %
CRD	10	0.2 %											0	0.0 %
CSR	329	5.3 %											0	0.0 %
CVC	13	0.2 %											0	0.0 %
HCI	269	4.3 %	1						1		1		3	14.3 %
HCS	30	0.5 %											0	0.0 %
HPI	1008	16.2 %					1	1					2	9.5 %
ISO	14	0.2 %											0	0.0 %
LCS	202	3.2 %											0	0.0 %
RCI	319	5.1 %									1		1	4.8 %
RCS	104	1.7 %								1			1	4.8 %
RHR	1874	30.1 %	1					1	2				4	19.0 %
SWN	728	11.7 %						1	2	1			4	19.0 %
SWS	216	3.5 %											0	0.0 %
VSS	14	0.2 %								1			1	4.8 %
Total	6221	100%	2	1	0	1	1	4	6	3	3	0	21	100%

Table 5. Summary of low-demand MOV failure counts for the SO failure mode over time by system.

System Code	Valve Count	Valve Percent	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
AFW	465	7.5 %									1		1	4.5 %
CCW	626	10.1 %		4									4	18.2 %
CRD	10	0.2 %											0	0.0 %
CSR	329	5.3 %											0	0.0 %
CVC	13	0.2 %											0	0.0 %
HCI	269	4.3 %	1			1				1			3	13.6 %
HCS	30	0.5 %											0	0.0 %
HPI	1008	16.2 %											0	0.0 %
ISO	14	0.2 %											0	0.0 %
LCS	202	3.2 %	4										4	18.2 %
RCI	319	5.1 %		1	1			2	1				5	22.7 %
RCS	104	1.7 %											0	0.0 %
RHR	1874	30.1 %	1						1	1	2		5	22.7 %
SWN	728	11.7 %											0	0.0 %
SWS	216	3.5 %											0	0.0 %
VSS	14	0.2 %											0	0.0 %
Total	6221	100%	6	5	1	1	0	2	2	2	3	0	22	100%

Table 6. Summary of high-demand MOV failure counts for the FTOC failure mode over time by system.

System Code	Valve Count	Valve Percent	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
AFW	173	12.5 %	1	1	1	1	5		4	2	3		18	21.2 %
CCW	233	16.8 %		1			2				2	2	7	8.2 %
CRD	15	1.1 %											0	0.0 %
CSR	22	1.6 %								1	1		2	2.4 %
HCI	22	1.6 %		1		1	1			1			4	4.7 %
HCS	19	1.4 %		1									1	1.2 %
HPI	120	8.7 %					1		1				2	2.4 %
ISO	6	0.4 %											0	0.0 %
LCS	33	2.4 %		1		1		1					3	3.5 %
RCI	35	2.5 %					1	1	1				3	3.5 %
RCS	7	0.5 %											0	0.0 %
RHR	315	22.8 %	6	1	3	3	2	3	3	2	3		26	30.6 %
SWN	283	20.5 %	1	2	1			2	2		3		11	12.9 %
SWS	100	7.2 %	2				1		2	1	1	1	8	9.4 %
Total	1383	100%	10	8	5	6	13	7	13	7	13	3	85	100%

Table 7. Summary of high-demand MOV failure counts for the FTOP failure mode over time by system.

System Code	Valve Count	Valve Percent	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
AFW	173	12.5 %				1							1	10.0 %
CCW	233	16.8 %				1				2			3	30.0 %
CRD	15	1.1 %											0	0.0 %
CSR	22	1.6 %											0	0.0 %
HCI	22	1.6 %											0	0.0 %
HCS	19	1.4 %											0	0.0 %
HPI	120	8.7 %											0	0.0 %
ISO	6	0.4 %											0	0.0 %
LCS	33	2.4 %											0	0.0 %
RCI	35	2.5 %											0	0.0 %
RCS	7	0.5 %											0	0.0 %
RHR	315	22.8 %			1	1			1				3	30.0 %
SWN	283	20.5 %						1	1				2	20.0 %
SWS	100	7.2 %				1							1	10.0 %
Total	1383	100%	0	0	1	4	0	1	2	2	0	0	10	100%

Table 8. Summary of high-demand MOV failure counts for the SO failure mode over time by system.

System Code	Valve Count	Valve Percent	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
AFW	173	12.5 %											0	0.0 %
CCW	233	16.8 %											0	0.0 %
CRD	15	1.1 %											0	0.0 %
CSR	22	1.6 %											0	0.0 %
HCI	22	1.6 %											0	0.0 %
HCS	19	1.4 %									1		1	14.3 %
HPI	120	8.7 %											0	0.0 %
ISO	6	0.4 %											0	0.0 %
LCS	33	2.4 %											0	0.0 %
RCI	35	2.5 %				2		1					3	42.9 %
RCS	7	0.5 %											0	0.0 %
RHR	315	22.8 %		1			2						3	42.9 %
SWN	283	20.5 %											0	0.0 %
SWS	100	7.2 %											0	0.0 %
Total	1383	100%	0	1	0	2	2	1	0	0	1	0	7	100%

4.2 MOV Engineering Analysis by Failure Modes

The engineering analysis of MOV failure sub-components, causes, detection methods, and recovery are presented in this section. Each analysis first divides the events into two categories: low-demand MOVs (with less than or equal to 20 demands/year) and high-demand MOVs (with greater than 20 demands/year).

The second division of the events is by the failure mode determined after ICES data review by the staff. See Section 5 for more description of failure modes.

MOV sub-component contributions to the three failure modes are presented in Figure 15. The sub-component categories are similar to those used in the CCF database. For all three failure modes, the actuator is the largest contributor to the failure rates/probabilities.

MOV cause group contributions to the three failure modes are presented in Figure 16. The cause groups are similar to those used in the CCF database. Table 9 shows the breakdown of the cause groups with the specific causes that were coded during the data collection. The most likely cause for the FTOC, FTOP, and SO failure modes is grouped as Internal. Internal means that the cause was related to something within the MOV component such as a worn out part or the normal internal environment. Of particular interest is the Human cause group. The Human cause group is primarily influenced by maintenance and operating procedures and practices. In addition, the External Cause group is increasing in importance for the SO failure mode.

MOV detection methods for the three failure modes are presented in Figure 17. The most likely detection method for the FTOC failure mode is a testing demand. The FTOP and SO detection modes are heavily influenced by testing and non-test demands.

MOV recovery fractions for the three failure modes are presented in Figure 18. The overall non-recovery to recovery ratio is approximately 12:1.

Table 9. Component failure cause groups.

Group	Specific Cause	Description
Design	Construction/installation error or inadequacy	Used when a construction or installation error is made during the original or modification installation. This includes specification of incorrect component or material.
	Design error or inadequacy	Used when a design error is made.
	Manufacturing error or inadequacy	Used when a manufacturing error is made during component manufacture.
External	State of other component	Used when the cause of a failure is the result of a component state that is not associated with the component that failed. An example would be the diesel failed due to no fuel in the fuel storage tanks.
	Ambient environmental stress	Used when the cause of a failure is the result of an environmental condition from the location of the component.
Human	Accidental action (unintentional or undesired human errors)	Used when a human error (during the performance of an activity) results in an unintentional or undesired action.
	Human action procedure	Used when the correct procedure is not followed or the wrong procedure is followed. For example: when a missed step or incorrect step in a surveillance procedure results in a component failure.
	Inadequate maintenance	Used when a human error (during the performance of maintenance) results in an unintentional or undesired action.
Internal	Internal to component, piece-part	Used when the cause of a failure is a non-specific result of a failure internal to the component that failed other than aging or wear.
	Internal environment	The internal environment led to the failure. Debris/Foreign material as well as an operating medium chemistry issue.
	Set point drift	Used when the cause of a failure is the result of set point drift or adjustment.
	Age/Wear	Used when the cause of the failure is a non-specific aging or wear issue.
Other	Unknown	Used when the cause of the failure is not known.
	Other (stated cause does not fit other categories)	Used when the cause of a failure is provided but it does not meet any one of the descriptions.
Procedure	Inadequate procedure	Used when the cause of a failure is the result of an inadequate procedure operating or maintenance.

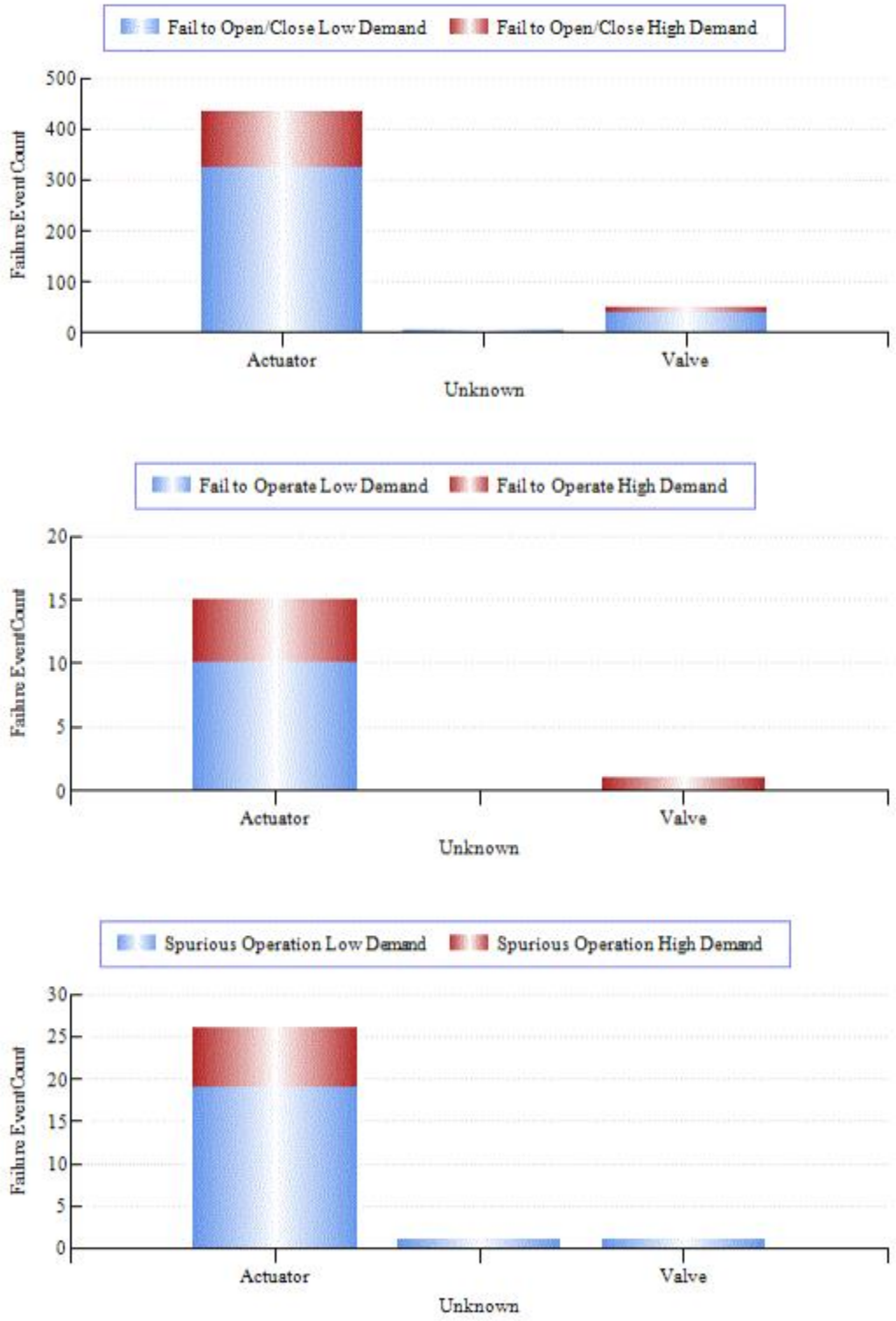

Figure 15. MOV failure event breakdown by subcomponent, failure mode, and demand rate.

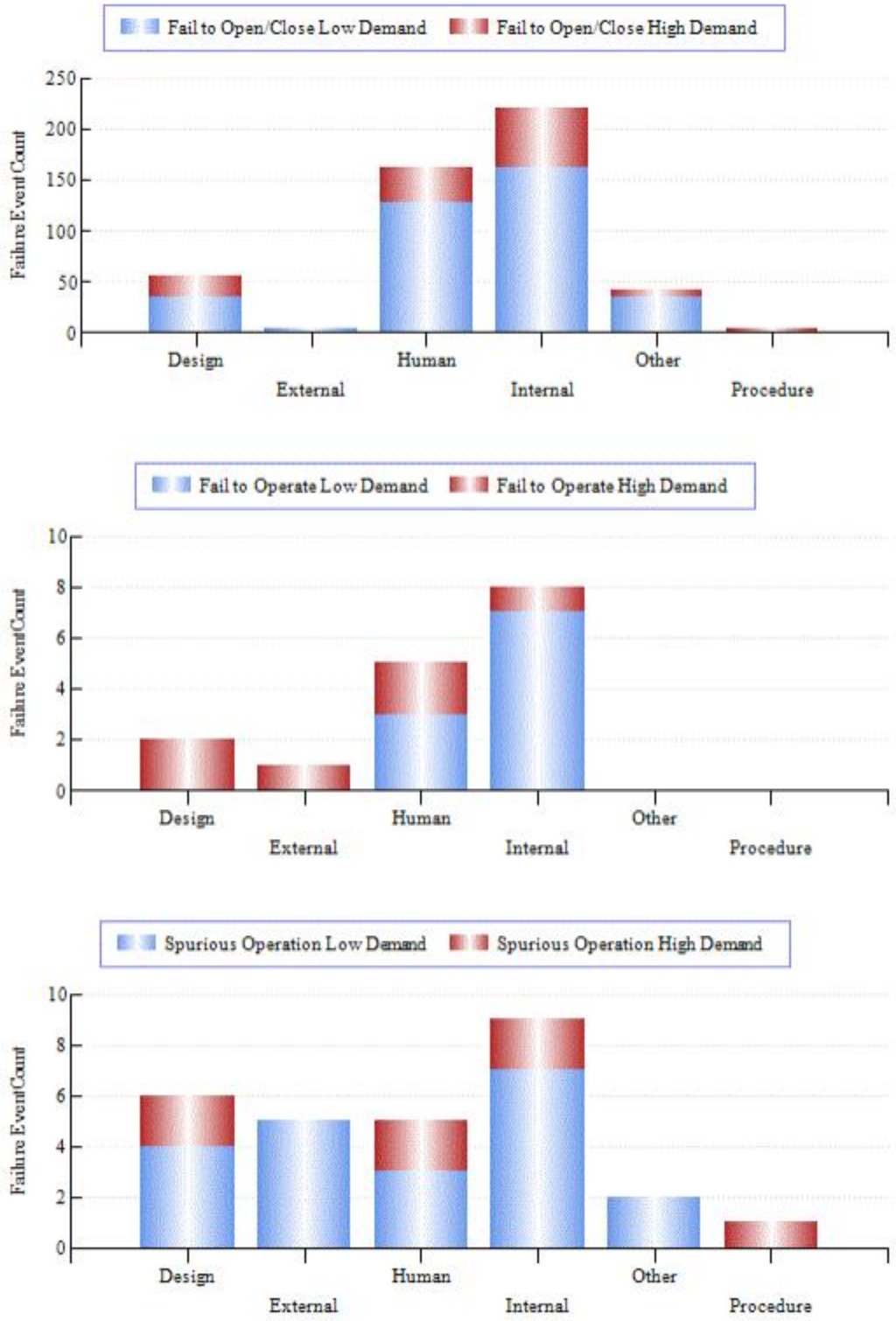

Figure 16. MOV failure event breakdown by cause group, failure mode, and demand rate.

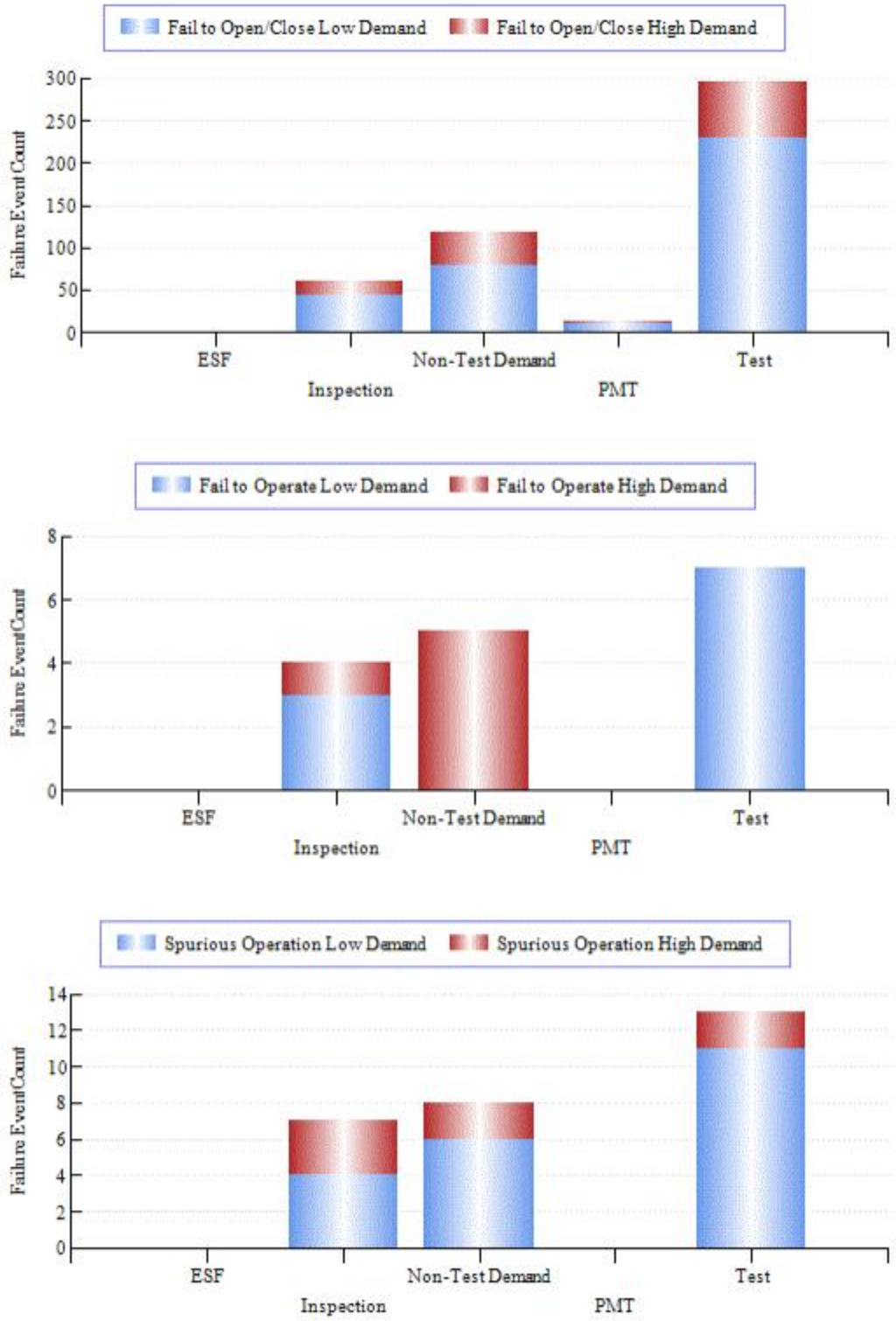

Figure 17. MOV failure event breakdown by method of detection, failure mode, and demand rate.

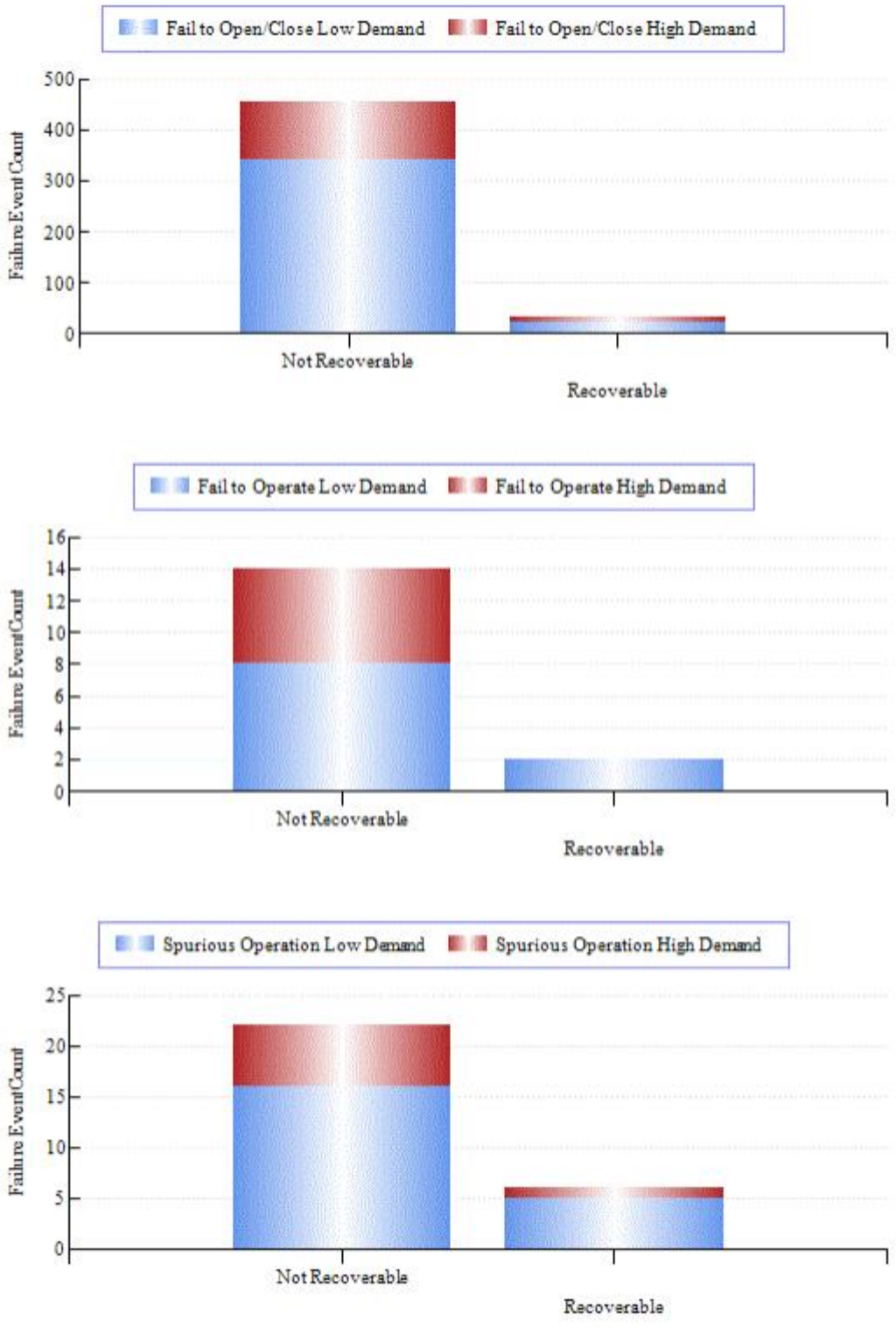

Figure 18. MOV failure event breakdown by recoverability, failure mode, and demand rate.

5. MOV ASSEMBLY DESCRIPTION

A MOV assembly consists of a valve body and motor-operated sub-components (including the circuit breaker). The valve body is generally a gate type. The motor-operator or ac/dc actuator is generally manufactured by Limitorque or Rotork.

The piece-parts of the valve body are the stem, packing, and internals. The motor-operator piece-parts include the torque switch, spring pack, limit switch, wiring/contacts, and motor internal and mechanical devices.

Failure modes for the MOV include

- FTOC, which combines the fail to open and fail to close failure modes into a single category;
- FTOP, which is a rate-based failure mode that includes FTC for a flow/temperature control device and any other rate-based failure modes except for SO, and
- SO, which includes spurious opening and spurious closing.

6. DATA TABLES

Table 10. Plot data for Figure 1, failure probability estimate trend for all systems, industry-wide, low-demand MOV FTOC.

Year/ Source	Failures	Demands	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						2.13E-04	1.75E-03	8.23E-04
1998	43	39,209				8.34E-04	1.40E-03	1.09E-03
1999	41	41,553				7.46E-04	1.27E-03	9.83E-04
2000	43	40,058				8.16E-04	1.37E-03	1.07E-03
2001	30	41,549				5.21E-04	9.77E-04	7.22E-04
2002	30	40,702				5.32E-04	9.97E-04	7.37E-04
2003	34	41,298				6.06E-04	1.09E-03	8.22E-04
2004	28	40,185				4.97E-04	9.53E-04	6.97E-04
2005	34	38,247				6.53E-04	1.18E-03	8.86E-04
2006	33	36,143				6.68E-04	1.21E-03	9.10E-04
2007	33	35,992	9.03E-04	7.10E-04	1.15E-03	6.70E-04	1.22E-03	9.13E-04
2008	25	36,233	8.56E-04	6.99E-04	1.05E-03	4.82E-04	9.61E-04	6.91E-04
2009	37	36,046	8.12E-04	6.84E-04	9.62E-04	7.63E-04	1.34E-03	1.02E-03
2010	25	35,812	7.69E-04	6.64E-04	8.91E-04	4.88E-04	9.72E-04	6.99E-04
2011	24	35,962	7.29E-04	6.35E-04	8.37E-04	4.63E-04	9.37E-04	6.69E-04
2012	31	36,039	6.91E-04	5.97E-04	8.00E-04	6.23E-04	1.15E-03	8.58E-04
2013	26	35,858	6.55E-04	5.53E-04	7.75E-04	5.10E-04	1.00E-03	7.25E-04
2014	22	35,794	6.21E-04	5.08E-04	7.58E-04	4.20E-04	8.77E-04	6.17E-04
2015	23	35,659	5.88E-04	4.64E-04	7.46E-04	4.44E-04	9.12E-04	6.47E-04
2016	15	35,371	5.57E-04	4.22E-04	7.36E-04	2.67E-04	6.57E-04	4.30E-04
Total	577	717,710						

Table 11. Plot data for Figure 2, failure probability estimate trend for all systems, industry-wide, high-demand MOV FTOC.

			Regression Curve Data Points			Plot Trend Error Bar Points		
Year/ Source	**Failures**	**Demands**	**Mean**	**Lower (5%)**	**Upper (95%)**	**Lower (5%)**	**Upper (95%)**	**Mean**
2015 Update						2.13E-04	1.75E-03	8.23E-04
1998	9	39,681				1.20E-04	3.88E-04	2.26E-04
1999	15	42,068				2.17E-04	5.33E-04	3.49E-04
2000	11	44,265				1.40E-04	4.03E-04	2.46E-04
2001	17	50,103				2.14E-04	4.97E-04	3.33E-04
2002	10	39,357				1.39E-04	4.21E-04	2.51E-04
2003	14	41,234				2.03E-04	5.15E-04	3.32E-04
2004	15	43,134				2.12E-04	5.20E-04	3.40E-04
2005	13	42,645				1.79E-04	4.72E-04	3.00E-04
2006	5	42,489				5.09E-05	2.49E-04	1.23E-04
2007	10	42,736	2.02E-04	1.03E-04	3.93E-04	1.28E-04	3.90E-04	2.33E-04
2008	8	42,627	1.99E-04	1.13E-04	3.50E-04	9.63E-05	3.35E-04	1.89E-04
2009	5	41,719	1.96E-04	1.22E-04	3.16E-04	5.18E-05	2.53E-04	1.25E-04
2010	6	42,066	1.94E-04	1.29E-04	2.91E-04	6.62E-05	2.81E-04	1.46E-04
2011	13	41,396	1.91E-04	1.32E-04	2.77E-04	1.84E-04	4.86E-04	3.08E-04
2012	7	40,818	1.88E-04	1.29E-04	2.75E-04	8.40E-05	3.19E-04	1.74E-04
2013	13	39,783	1.86E-04	1.21E-04	2.85E-04	1.91E-04	5.04E-04	3.20E-04
2014	7	39,912	1.83E-04	1.11E-04	3.04E-04	8.58E-05	3.26E-04	1.77E-04
2015	13	39,389	1.81E-04	9.93E-05	3.29E-04	1.93E-04	5.09E-04	3.23E-04
2016	3	41,241	1.78E-04	8.82E-05	3.61E-04	2.48E-05	1.94E-04	8.02E-05
Total	194	796,664						

Table 12. Plot data for Figure 3, failure rate estimate trend for all systems, industry-wide, low-demand MOV FTOP.

			Regression Curve Data Points			Plot Trend Error Bar Points		
Year/ Source	Failures	Hours	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						7.40E-09	1.54E-07	5.98E-08
1998	3	51,736,560				1.70E-08	1.33E-07	5.48E-08
1999	12	51,867,960				1.14E-07	3.14E-07	1.95E-07
2000	7	51,929,280				5.67E-08	2.15E-07	1.17E-07
2001	4	51,894,240				2.60E-08	1.54E-07	7.03E-08
2002	3	51,876,720				1.69E-08	1.32E-07	5.47E-08
2003	3	51,885,480				1.69E-08	1.32E-07	5.47E-08
2004	3	51,841,680				1.69E-08	1.32E-07	5.47E-08
2005	3	51,885,480				1.69E-08	1.32E-07	5.47E-08
2006	1	51,981,840				2.75E-09	8.64E-08	2.34E-08
2007	2	52,043,160	2.58E-08	6.43E-09	1.03E-07	8.93E-09	1.10E-07	3.90E-08
2008	1	51,938,040	2.67E-08	8.21E-09	8.68E-08	2.75E-09	8.64E-08	2.34E-08
2009	0	51,920,520	2.77E-08	1.03E-08	7.46E-08	3.07E-11	6.10E-08	7.81E-09
2010	1	52,122,000	2.87E-08	1.24E-08	6.65E-08	2.74E-09	8.62E-08	2.34E-08
2011	1	52,595,040	2.97E-08	1.41E-08	6.27E-08	2.72E-09	8.56E-08	2.32E-08
2012	4	52,104,480	3.08E-08	1.48E-08	6.42E-08	2.59E-08	1.53E-07	7.01E-08
2013	6	52,034,400	3.19E-08	1.43E-08	7.14E-08	4.59E-08	1.95E-07	1.01E-07
2014	3	51,981,840	3.31E-08	1.29E-08	8.48E-08	1.69E-08	1.32E-07	5.46E-08
2015	3	52,008,120	3.43E-08	1.12E-08	1.05E-07	1.69E-08	1.32E-07	5.46E-08
2016	0	51,719,040	3.55E-08	9.47E-09	1.33E-07	3.08E-11	6.12E-08	7.83E-09
Total	60	987,365,880						

Table 13. Plot data for Figure 4, failure rate estimate trend for all systems, industry-wide, high-demand MOV FTOP.

			Regression Curve Data Points			Plot Trend Error Bar Points		
Year/ Source	Failures	Hours	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						7.40E-09	1.54E-07	5.98E-08
1998	2	11,256,600				3.42E-08	4.20E-07	1.49E-07
1999	3	11,423,040				6.41E-08	5.01E-07	2.07E-07
2000	1	11,449,320				1.04E-08	3.27E-07	8.86E-08
2001	0	11,431,800				1.16E-10	2.31E-07	2.96E-08
2002	1	11,449,320				1.04E-08	3.27E-07	8.86E-08
2003	3	11,440,560				6.41E-08	5.00E-07	2.07E-07
2004	3	11,475,600				6.39E-08	4.99E-07	2.06E-07
2005	0	11,484,360				1.16E-10	2.30E-07	2.95E-08
2006	1	11,493,120				1.04E-08	3.26E-07	8.84E-08
2007	0	11,501,880	5.99E-08	1.57E-08	2.28E-07	1.16E-10	2.30E-07	2.95E-08
2008	0	11,545,680	6.06E-08	1.95E-08	1.88E-07	1.16E-10	2.30E-07	2.94E-08
2009	1	11,519,400	6.13E-08	2.36E-08	1.59E-07	1.04E-08	3.26E-07	8.83E-08
2010	4	11,545,680	6.20E-08	2.75E-08	1.40E-07	9.77E-08	5.78E-07	2.64E-07
2011	0	11,668,320	6.27E-08	3.02E-08	1.30E-07	1.15E-10	2.28E-07	2.92E-08
2012	1	11,466,840	6.34E-08	3.06E-08	1.31E-07	1.04E-08	3.27E-07	8.85E-08
2013	2	11,431,800	6.42E-08	2.86E-08	1.44E-07	3.39E-08	4.16E-07	1.48E-07
2014	2	11,449,320	6.49E-08	2.51E-08	1.68E-07	3.38E-08	4.16E-07	1.48E-07
2015	0	11,440,560	6.56E-08	2.12E-08	2.03E-07	1.16E-10	2.31E-07	2.96E-08
2016	0	11,405,520	6.64E-08	1.75E-08	2.51E-07	1.16E-10	2.31E-07	2.96E-08
Total	24	217,878,720						

Table 14. Plot data for Figure 5, failure rate estimate trend for all systems, industry-wide, low-demand MOV SO.

			Regression Curve Data Points			Plot Trend Error Bar Points		
Year/ Source	Failures	Hours	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						2.90E-10	1.17E-07	3.24E-08
1998	4	51,736,560				2.63E-08	1.55E-07	7.11E-08
1999	0	51,867,960				3.10E-11	6.16E-08	7.88E-09
2000	6	51,929,280				4.64E-08	1.97E-07	1.02E-07
2001	2	51,894,240				9.03E-09	1.11E-07	3.94E-08
2002	4	51,876,720				2.62E-08	1.55E-07	7.09E-08
2003	3	51,885,480				1.71E-08	1.33E-07	5.52E-08
2004	0	51,841,680				3.10E-11	6.16E-08	7.89E-09
2005	0	51,885,480				3.10E-11	6.16E-08	7.88E-09
2006	1	51,981,840				2.77E-09	8.71E-08	2.36E-08
2007	6	52,043,160	6.03E-08	2.03E-08	1.79E-07	4.63E-08	1.96E-07	1.02E-07
2008	5	51,938,040	5.22E-08	2.08E-08	1.31E-07	3.60E-08	1.76E-07	8.66E-08
2009	1	51,920,520	4.52E-08	2.09E-08	9.81E-08	2.77E-09	8.72E-08	2.36E-08
2010	1	52,122,000	3.92E-08	1.99E-08	7.72E-08	2.76E-09	8.69E-08	2.36E-08
2011	0	52,595,040	3.40E-08	1.78E-08	6.50E-08	3.06E-11	6.09E-08	7.79E-09
2012	2	52,104,480	2.94E-08	1.47E-08	5.91E-08	9.00E-09	1.10E-07	3.93E-08
2013	2	52,034,400	2.55E-08	1.14E-08	5.72E-08	9.01E-09	1.11E-07	3.93E-08
2014	2	51,981,840	2.21E-08	8.46E-09	5.77E-08	9.01E-09	1.11E-07	3.93E-08
2015	3	52,008,120	1.91E-08	6.14E-09	5.97E-08	1.70E-08	1.33E-07	5.51E-08
2016	0	51,719,040	1.66E-08	4.39E-09	6.27E-08	3.11E-11	6.17E-08	7.90E-09
Total	42	987,365,880						

Table 15. Plot data for Figure 6, failure rate estimate trend for all systems, industry-wide, high-demand MOV SO.

			Regression Curve Data Points			Plot Trend Error Bar Points		
Year/ Source	Failures	Hours	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						2.90E-10	1.17E-07	3.24E-08
1998	0	11,256,600				1.04E-10	2.06E-07	2.64E-08
1999	1	11,423,040				9.22E-09	2.90E-07	7.86E-08
2000	1	11,449,320				9.20E-09	2.90E-07	7.85E-08
2001	0	11,431,800				1.03E-10	2.05E-07	2.62E-08
2002	0	11,449,320				1.03E-10	2.04E-07	2.62E-08
2003	1	11,440,560				9.21E-09	2.90E-07	7.85E-08
2004	0	11,475,600				1.03E-10	2.04E-07	2.61E-08
2005	0	11,484,360				1.03E-10	2.04E-07	2.61E-08
2006	0	11,493,120				1.03E-10	2.04E-07	2.61E-08
2007	0	11,501,880	5.75E-08	1.93E-08	1.71E-07	1.03E-10	2.04E-07	2.61E-08
2008	1	11,545,680	5.58E-08	2.21E-08	1.40E-07	9.16E-09	2.88E-07	7.81E-08
2009	0	11,519,400	5.41E-08	2.48E-08	1.18E-07	1.02E-10	2.04E-07	2.61E-08
2010	2	11,545,680	5.24E-08	2.70E-08	1.02E-07	2.98E-08	3.66E-07	1.30E-07
2011	2	11,668,320	5.08E-08	2.80E-08	9.23E-08	2.96E-08	3.64E-07	1.29E-07
2012	1	11,466,840	4.93E-08	2.71E-08	8.96E-08	9.20E-09	2.89E-07	7.84E-08
2013	0	11,431,800	4.78E-08	2.46E-08	9.29E-08	1.03E-10	2.05E-07	2.62E-08
2014	0	11,449,320	4.63E-08	2.12E-08	1.01E-07	1.03E-10	2.04E-07	2.62E-08
2015	1	11,440,560	4.49E-08	1.77E-08	1.14E-07	9.21E-09	2.90E-07	7.85E-08
2016	0	11,405,520	4.35E-08	1.45E-08	1.30E-07	1.03E-10	2.05E-07	2.62E-08
Total	10	217,878,720						

Table 16. Plot data for Figure 7, frequency (demands per reactor year) of low-demand MOV FTOC demands.

			Regression Curve Data Points			Plot Trend Error Bar Points		
Year	Demands	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	39,209	103.0				3.78E+02	3.84E+02	3.81E+02
1999	41,553	103.0				4.00E+02	4.07E+02	4.03E+02
2000	40,058	103.3				3.85E+02	3.91E+02	3.88E+02
2001	41,549	103.0				4.00E+02	4.07E+02	4.03E+02
2002	40,702	103.0				3.92E+02	3.98E+02	3.95E+02
2003	41,298	103.0				3.98E+02	4.04E+02	4.01E+02
2004	40,185	103.3				3.86E+02	3.92E+02	3.89E+02
2005	38,247	103.0				3.68E+02	3.74E+02	3.71E+02
2006	36,143	103.0				3.48E+02	3.54E+02	3.51E+02
2007	35,992	103.6	3.43E+02	3.38E+02	3.49E+02	3.44E+02	3.50E+02	3.47E+02
2008	36,233	104.3	3.45E+02	3.40E+02	3.50E+02	3.44E+02	3.50E+02	3.47E+02
2009	36,046	104.0	3.47E+02	3.43E+02	3.50E+02	3.44E+02	3.50E+02	3.47E+02
2010	35,812	104.0	3.48E+02	3.45E+02	3.51E+02	3.41E+02	3.47E+02	3.44E+02
2011	35,962	104.0	3.50E+02	3.47E+02	3.53E+02	3.43E+02	3.49E+02	3.46E+02
2012	36,039	104.3	3.51E+02	3.48E+02	3.54E+02	3.43E+02	3.49E+02	3.46E+02
2013	35,858	101.6	3.53E+02	3.49E+02	3.56E+02	3.50E+02	3.56E+02	3.53E+02
2014	35,794	100.0	3.54E+02	3.50E+02	3.58E+02	3.55E+02	3.61E+02	3.58E+02
2015	35,659	99.0	3.56E+02	3.51E+02	3.61E+02	3.57E+02	3.63E+02	3.60E+02
2016	35,371	99.0	3.58E+02	3.52E+02	3.63E+02	3.54E+02	3.60E+02	3.57E+02
Total	717,710	1,951.3						

Table 17. Plot data for Figure 8, frequency (demands per reactor year) of high-demand MOV FTOC demands.

			Regression Curve Data Points			Plot Trend Error Bar Points		
Year	Demands	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	39,681	103.0				3.82E+02	3.88E+02	3.85E+02
1999	42,068	103.0				4.05E+02	4.12E+02	4.08E+02
2000	44,265	103.3				4.25E+02	4.32E+02	4.29E+02
2001	50,103	103.0				4.83E+02	4.90E+02	4.86E+02
2002	39,357	103.0				3.79E+02	3.85E+02	3.82E+02
2003	41,234	103.0				3.97E+02	4.04E+02	4.00E+02
2004	43,134	103.3				4.14E+02	4.21E+02	4.18E+02
2005	42,645	103.0				4.11E+02	4.17E+02	4.14E+02
2006	42,489	103.0				4.09E+02	4.16E+02	4.13E+02
2007	42,736	103.6	4.05E+02	3.92E+02	4.18E+02	4.09E+02	4.16E+02	4.12E+02
2008	42,627	104.3	4.04E+02	3.94E+02	4.15E+02	4.06E+02	4.12E+02	4.09E+02
2009	41,719	104.0	4.04E+02	3.95E+02	4.13E+02	3.98E+02	4.04E+02	4.01E+02
2010	42,066	104.0	4.03E+02	3.95E+02	4.11E+02	4.01E+02	4.08E+02	4.04E+02
2011	41,396	104.0	4.02E+02	3.96E+02	4.09E+02	3.95E+02	4.01E+02	3.98E+02
2012	40,818	104.3	4.02E+02	3.95E+02	4.09E+02	3.88E+02	3.95E+02	3.91E+02
2013	39,783	101.6	4.01E+02	3.93E+02	4.09E+02	3.88E+02	3.95E+02	3.92E+02
2014	39,912	100.0	4.00E+02	3.91E+02	4.10E+02	3.96E+02	4.02E+02	3.99E+02
2015	39,389	99.0	4.00E+02	3.89E+02	4.11E+02	3.95E+02	4.01E+02	3.98E+02
2016	41,241	99.0	3.99E+02	3.87E+02	4.12E+02	4.13E+02	4.20E+02	4.16E+02
Total	796,664	1,951.3						

Table 18. Plot data for Figure 9, frequency (failures per reactor year) of low-demand MOV FTOC events.

			Regression Curve Data Points			Plot Trend Error Bar Points		
Year	Failures	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	43	103.0				3.17E-01	5.34E-01	4.14E-01
1999	41	103.0				3.00E-01	5.12E-01	3.95E-01
2000	43	103.3				3.16E-01	5.32E-01	4.13E-01
2001	30	103.0				2.10E-01	3.93E-01	2.91E-01
2002	30	103.0				2.10E-01	3.93E-01	2.91E-01
2003	34	103.0				2.42E-01	4.37E-01	3.29E-01
2004	28	103.3				1.93E-01	3.70E-01	2.71E-01
2005	34	103.0				2.42E-01	4.37E-01	3.29E-01
2006	33	103.0				2.34E-01	4.26E-01	3.19E-01
2007	33	103.6	3.11E-01	2.45E-01	3.96E-01	2.33E-01	4.23E-01	3.17E-01
2008	25	104.3	2.96E-01	2.42E-01	3.63E-01	1.68E-01	3.34E-01	2.40E-01
2009	37	104.0	2.82E-01	2.38E-01	3.34E-01	2.65E-01	4.65E-01	3.54E-01
2010	25	104.0	2.68E-01	2.31E-01	3.10E-01	1.68E-01	3.35E-01	2.41E-01
2011	24	104.0	2.55E-01	2.22E-01	2.93E-01	1.60E-01	3.24E-01	2.31E-01
2012	31	104.3	2.43E-01	2.10E-01	2.81E-01	2.15E-01	3.99E-01	2.96E-01
2013	26	101.6	2.31E-01	1.95E-01	2.73E-01	1.80E-01	3.54E-01	2.56E-01
2014	22	100.0	2.20E-01	1.80E-01	2.68E-01	1.50E-01	3.14E-01	2.21E-01
2015	23	99.0	2.09E-01	1.65E-01	2.65E-01	1.60E-01	3.29E-01	2.33E-01
2016	15	99.0	1.99E-01	1.51E-01	2.62E-01	9.55E-02	2.35E-01	1.54E-01
Total	577	1,951.3						

Table 19. Plot data for Figure 10, frequency (failures per reactor year) of high-demand MOV FTOC events.

			Regression Curve Data Points			Plot Trend Error Bar Points		
Year	Failures	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	9	103.0				4.64E-02	1.50E-01	8.72E-02
1999	15	103.0				8.85E-02	2.17E-01	1.42E-01
2000	11	103.3				5.99E-02	1.72E-01	1.05E-01
2001	17	103.0				1.03E-01	2.39E-01	1.61E-01
2002	10	103.0				5.32E-02	1.61E-01	9.63E-02
2003	14	103.0				8.12E-02	2.06E-01	1.33E-01
2004	15	103.3				8.82E-02	2.17E-01	1.42E-01
2005	13	103.0				7.41E-02	1.95E-01	1.24E-01
2006	5	103.0				2.10E-02	1.03E-01	5.05E-02
2007	10	103.6	8.14E-02	4.22E-02	1.57E-01	5.29E-02	1.60E-01	9.58E-02
2008	8	104.3	8.03E-02	4.61E-02	1.40E-01	3.93E-02	1.37E-01	7.71E-02
2009	5	104.0	7.92E-02	4.96E-02	1.26E-01	2.08E-02	1.02E-01	5.00E-02
2010	6	104.0	7.81E-02	5.24E-02	1.16E-01	2.68E-02	1.14E-01	5.91E-02
2011	13	104.0	7.71E-02	5.36E-02	1.11E-01	7.34E-02	1.93E-01	1.23E-01
2012	7	104.3	7.61E-02	5.26E-02	1.10E-01	3.29E-02	1.25E-01	6.80E-02
2013	13	101.6	7.50E-02	4.95E-02	1.14E-01	7.51E-02	1.98E-01	1.26E-01
2014	7	100.0	7.40E-02	4.53E-02	1.21E-01	3.43E-02	1.30E-01	7.08E-02
2015	13	99.0	7.30E-02	4.08E-02	1.31E-01	7.69E-02	2.03E-01	1.29E-01
2016	3	99.0	7.21E-02	3.63E-02	1.43E-01	1.03E-02	8.06E-02	3.33E-02
Total	194	1,951.3						

Table 20. Plot data for Figure 11, frequency (failures per reactor year) of low-demand MOV FTOP events.

			Regression Curve Data Points			Plot Trend Error Bar Points		
Year	Failures	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	3	103.0				8.55E-03	6.67E-02	2.76E-02
1999	12	103.0				5.76E-02	1.58E-01	9.86E-02
2000	7	103.3				2.86E-02	1.09E-01	5.90E-02
2001	4	103.0				1.31E-02	7.76E-02	3.55E-02
2002	3	103.0				8.55E-03	6.67E-02	2.76E-02
2003	3	103.0				8.55E-03	6.67E-02	2.76E-02
2004	3	103.3				8.53E-03	6.66E-02	2.75E-02
2005	3	103.0				8.55E-03	6.67E-02	2.76E-02
2006	1	103.0				1.39E-03	4.37E-02	1.18E-02
2007	2	103.6	1.28E-02	3.19E-03	5.13E-02	4.50E-03	5.52E-02	1.96E-02
2008	1	104.3	1.33E-02	4.10E-03	4.34E-02	1.37E-03	4.32E-02	1.17E-02
2009	0	104.0	1.39E-02	5.15E-03	3.75E-02	1.54E-05	3.06E-02	3.91E-03
2010	1	104.0	1.45E-02	6.24E-03	3.35E-02	1.38E-03	4.33E-02	1.17E-02
2011	1	104.0	1.51E-02	7.14E-03	3.18E-02	1.38E-03	4.33E-02	1.17E-02
2012	4	104.3	1.57E-02	7.53E-03	3.27E-02	1.30E-02	7.68E-02	3.51E-02
2013	6	101.6	1.64E-02	7.30E-03	3.66E-02	2.35E-02	9.97E-02	5.18E-02
2014	3	100.0	1.70E-02	6.63E-03	4.38E-02	8.75E-03	6.83E-02	2.83E-02
2015	3	99.0	1.77E-02	5.78E-03	5.45E-02	8.82E-03	6.89E-02	2.85E-02
2016	0	99.0	1.85E-02	4.91E-03	6.96E-02	1.60E-05	3.18E-02	4.07E-03
Total	60	1,951.3						

Table 21. Plot data for Figure 12, frequency (failures per reactor year) of high-demand MOV FTOP events.

			Regression Curve Data Points			Plot Trend Error Bar Points		
Year	Failures	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	2	103.0				3.77E-03	4.63E-02	1.65E-02
1999	3	103.0				7.14E-03	5.57E-02	2.31E-02
2000	1	103.3				1.16E-03	3.64E-02	9.87E-03
2001	0	103.0				1.30E-05	2.57E-02	3.29E-03
2002	1	103.0				1.16E-03	3.65E-02	9.88E-03
2003	3	103.0				7.14E-03	5.57E-02	2.31E-02
2004	3	103.3				7.13E-03	5.56E-02	2.30E-02
2005	0	103.0				1.30E-05	2.57E-02	3.29E-03
2006	1	103.0				1.16E-03	3.65E-02	9.88E-03
2007	0	103.6	6.63E-03	1.75E-03	2.51E-02	1.29E-05	2.56E-02	3.28E-03
2008	0	104.3	6.73E-03	2.17E-03	2.08E-02	1.28E-05	2.55E-02	3.27E-03
2009	1	104.0	6.83E-03	2.64E-03	1.77E-02	1.15E-03	3.62E-02	9.82E-03
2010	4	104.0	6.93E-03	3.09E-03	1.56E-02	1.09E-02	6.44E-02	2.95E-02
2011	0	104.0	7.03E-03	3.40E-03	1.46E-02	1.29E-05	2.56E-02	3.27E-03
2012	1	104.3	7.14E-03	3.46E-03	1.48E-02	1.15E-03	3.62E-02	9.80E-03
2013	2	101.6	7.25E-03	3.24E-03	1.62E-02	3.81E-03	4.68E-02	1.66E-02
2014	2	100.0	7.36E-03	2.86E-03	1.90E-02	3.85E-03	4.73E-02	1.68E-02
2015	0	99.0	7.47E-03	2.42E-03	2.30E-02	1.33E-05	2.64E-02	3.38E-03
2016	0	99.0	7.58E-03	2.01E-03	2.86E-02	1.33E-05	2.64E-02	3.38E-03
Total	24	1,951.3						

Table 22. Plot data for Figure 13, frequency (failures per reactor year) of low-demand MOV SO events.

			Regression Curve Data Points			Plot Trend Error Bar Points		
Year	Failures	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	4	103.0				1.32E-02	7.82E-02	3.58E-02
1999	0	103.0				1.56E-05	3.11E-02	3.98E-03
2000	6	103.3				2.34E-02	9.92E-02	5.16E-02
2001	2	103.0				4.55E-03	5.59E-02	1.99E-02
2002	4	103.0				1.32E-02	7.82E-02	3.58E-02
2003	3	103.0				8.62E-03	6.73E-02	2.78E-02
2004	0	103.3				1.56E-05	3.10E-02	3.97E-03
2005	0	103.0				1.56E-05	3.11E-02	3.98E-03
2006	1	103.0				1.40E-03	4.40E-02	1.19E-02
2007	6	103.6	3.00E-02	1.00E-02	8.96E-02	2.33E-02	9.89E-02	5.14E-02
2008	5	104.3	2.61E-02	1.04E-02	6.56E-02	1.80E-02	8.80E-02	4.33E-02
2009	1	104.0	2.27E-02	1.04E-02	4.94E-02	1.39E-03	4.37E-02	1.18E-02
2010	1	104.0	1.98E-02	1.00E-02	3.90E-02	1.39E-03	4.37E-02	1.18E-02
2011	0	104.0	1.72E-02	8.97E-03	3.30E-02	1.55E-05	3.08E-02	3.94E-03
2012	2	104.3	1.50E-02	7.44E-03	3.01E-02	4.51E-03	5.54E-02	1.97E-02
2013	2	101.6	1.30E-02	5.79E-03	2.93E-02	4.61E-03	5.66E-02	2.01E-02
2014	2	100.0	1.13E-02	4.32E-03	2.98E-02	4.67E-03	5.73E-02	2.04E-02
2015	3	99.0	9.87E-03	3.15E-03	3.10E-02	8.90E-03	6.95E-02	2.87E-02
2016	0	99.0	8.59E-03	2.26E-03	3.27E-02	1.61E-05	3.21E-02	4.11E-03
Total	42	1,951.3						

Table 23. Plot data for Figure 14, frequency (failures per reactor year) of high-demand MOV SO events.

			Regression Curve Data Points			Plot Trend Error Bar Points		
Year	Failures	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	0	103.0				1.15E-05	2.28E-02	2.92E-03
1999	1	103.0				1.03E-03	3.23E-02	8.76E-03
2000	1	103.3				1.03E-03	3.23E-02	8.74E-03
2001	0	103.0				1.15E-05	2.28E-02	2.92E-03
2002	0	103.0				1.15E-05	2.28E-02	2.92E-03
2003	1	103.0				1.03E-03	3.23E-02	8.76E-03
2004	0	103.3				1.15E-05	2.28E-02	2.91E-03
2005	0	103.0				1.15E-05	2.28E-02	2.92E-03
2006	0	103.0				1.15E-05	2.28E-02	2.92E-03
2007	0	103.6	6.37E-03	2.15E-03	1.89E-02	1.14E-05	2.27E-02	2.91E-03
2008	1	104.3	6.20E-03	2.46E-03	1.56E-02	1.02E-03	3.21E-02	8.69E-03
2009	0	104.0	6.03E-03	2.77E-03	1.31E-02	1.14E-05	2.27E-02	2.90E-03
2010	2	104.0	5.86E-03	3.03E-03	1.13E-02	3.33E-03	4.08E-02	1.45E-02
2011	2	104.0	5.70E-03	3.14E-03	1.03E-02	3.33E-03	4.08E-02	1.45E-02
2012	1	104.3	5.54E-03	3.05E-03	1.01E-02	1.02E-03	3.21E-02	8.69E-03
2013	0	101.6	5.39E-03	2.77E-03	1.05E-02	1.16E-05	2.30E-02	2.94E-03
2014	0	100.0	5.24E-03	2.40E-03	1.14E-02	1.17E-05	2.32E-02	2.97E-03
2015	1	99.0	5.10E-03	2.01E-03	1.29E-02	1.05E-03	3.31E-02	8.97E-03
2016	0	99.0	4.96E-03	1.66E-03	1.48E-02	1.18E-05	2.34E-02	2.99E-03
Total	10	1,951.3						

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