Component Performance Study

Motor-Operated Valves

1998–2010

1   INTRODUCTION

This report presents a performance evaluation of motor-operated valves (MOVs) at U.S. commercial nuclear power plants. This report does not estimate values for use in probabilistic risk assessments (PRAs), but does evaluate component performance over time. Reference 1 (NUREG/CR-6928) reports MOV unreliability estimates using Equipment Performance and Information Exchange (EPIX) data from 1998–2002 for use in PRAs.

The trend evaluations in this study are based on the operating experience failure reports from fiscal year (FY) 1998 through FY 2010 for the component reliability as reported in EPIX. The MOV failure modes considered are failure-to-open/close (failure to operate) (FTOC), (failure to operate or control) (FTOP) and spurious operation (SO).

Previously, the study relied on operating experience obtained from licensee event reports, Nuclear Plant Reliability Data System (NPRDS), and EPIX. The EPIX database (which includes as a subset the Mitigating Systems Performance Index (MSPI) designated devices) 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.

The objective of the effort for the updated component performance studies is to obtain annual performance trends of failure rates and probabilities. An overview of the trending methods, glossary of terms, and abbreviations can be found in the Overview and Reference document on the Reactor Operational Experience Results and Databases web page.

2   SUMMARY OF FINDINGS

The results of this study are summarized in this section. Of particular interest is the existence of any statistically significant[1] increasing trends. In this update, no statistically significant increasing trends were identified in the MOV results. Statistically significant decreasing trends were identified in the MOV results for the following:

- All systems, industry-wide MOV FTOC trend MOVs with ≤ 20 demands per year. (see Figure 1)

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[1] 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).

- All systems, industry-wide MOV FTOC trend MOVs with > 20 demands per year. (see Figure 2)
- Frequency (demands per reactor year) of MOV operation demands, ≤ 20 demands per year. (see Figure 7)
- Frequency (failures per reactor year) of MOV FTOC events ≤ 20 demands per year. (see Figure 9)
- Frequency (failures per reactor year) of MOV FTOC events > 20 demands per year. (see Figure 10)

Considering the low-demand MOVs; Table 3 shows that 71% of the MOV FTOC failures occurred in six systems. Table 4 shows that 79% of the MOV FTOP failures occurred in six systems. Similarly, Table 5 shows that 91% of the MOV SO failures occurred in seven systems. And considering the high-demand MOVs; Table 6 shows that 84% of the MOV FTOC failures occurred in five systems. Table 7 shows that 95% of the MOV FTOP failures occurred in six systems. Similarly, Table 8 shows that all of the MOV SO failures occurred in four systems.

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 and SO failure modes. The MOV data set obtained from EPIX was segregated to MOVs with ≤ 20 demands/year (d/yr) and MOVs with > 20 d/yr and includes MOVs in the systems listed in Table 1. NUREG/CR-6928 lists the industry failure data for MOVs with ≤ 20 d/yr. Table 2 shows industry-wide failure probability and failure rate results for the MOV with ≤ 20 d/yr from Reference 1. No results are shown for >20d/yr MOVs because Reference 1 does not present results for >20 d/yr.

The MOVs are assumed to operate both when the reactor is critical and during shutdown periods. The number of valves in operation is assumed to be constant throughout the study period. All demand types are considered—testing, non-testing, and, as applicable, emergency safeguard feature (ESF) demands.

Table 1. MOV systems.

System	Description	MOV Component Count			System	Description	MOV Component Count		
		Total	≤20 d/yr	>20 d/yr			Total	≤20 d/yr	>20 d/yr
AFW	Auxiliary feedwater	582	468	114	HVC	Heating ventilation and air conditioning	27	24	3
CCW	Component cooling water	834	690	144	ISO	Isolation condenser	20	19	1
CIS	Containment isolation system	23	19	4	LCS	Low pressure core spray	235	209	26
CRD	Control rod drive	25	15	10	MFW	Main feedwater	305	292	13
CSR	Containment spray recirculation	342	328	14	MSS	Main steam	171	163	8
					RCI	Reactor core isolation	334	304	30
CTS	Condensate transfer system	6	6		RCS	Reactor coolant	165	160	5
					RHR	Residual heat removal	2108	1827	281
CVC	Chemical and volume control	574	540	34	SWN	Emergency service water (Standby)	952	690	262
HCI	High pressure coolant injection	269	248	21	SWS	Standby service water	284	196	88
					VSS	Vapor suppression	14	14	
HCS	High pressure core spray	45	29	16		Total	8377	7215	1162
HPI	High pressure injection	1062	974	88					

Table 2. Industry-wide distributions of *p* (failure probability) and *λ* (hourly rate) for MOVs.

Failure Mode	5%	Median	Mean	95%	Distribution		
					Type	α	β
FTOC	8.0E-05	7.0E-04	1.0E-03	3.0E-03	Beta	1.20	1.20E+03
SO	1.5E-10	2.0E-08	4.0E-08	1.5E-07	Gamma	0.50	1.25E+07
FTOP	3.0E-10	7.0E-07	3.0E-06	1.5E-05	Gamma	0.30	1.00E+05

3.2 MOV Failure Probability and Failure Rate Trends

Trends in failure probabilities and failure rates are shown in Figure 1, Figure 2, Figure 3, Figure 4, Figure 5, and Figure 6. The data for the trend plots are contained in Table 9, Table 10, Table 11, Table 12, Table 13, and Table 14, respectively.

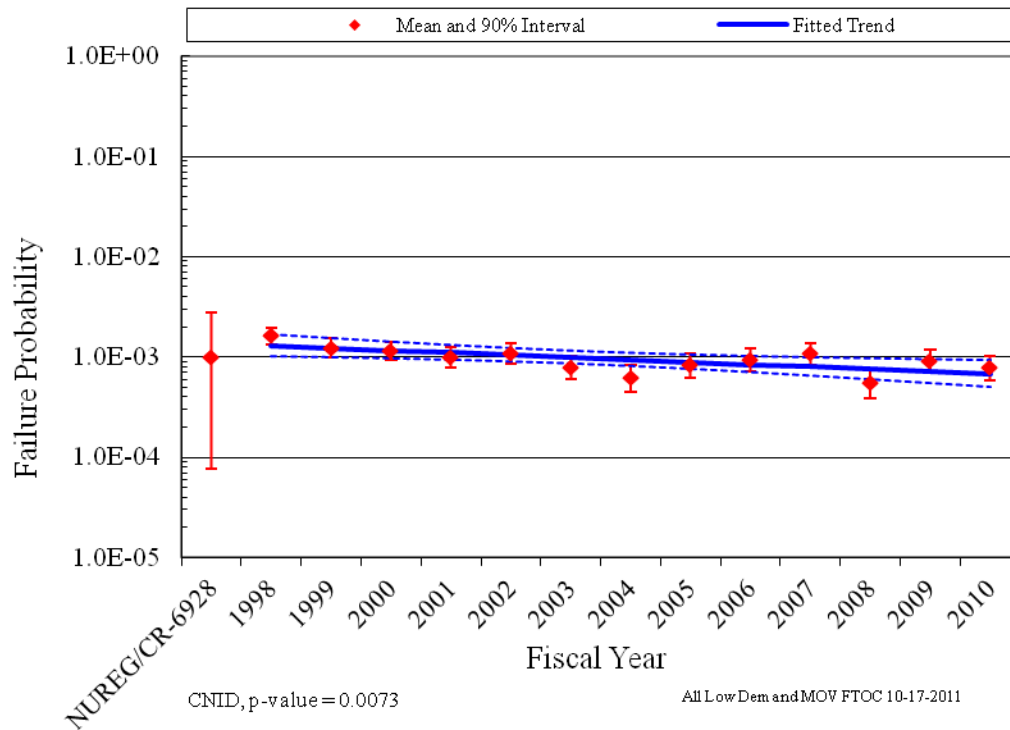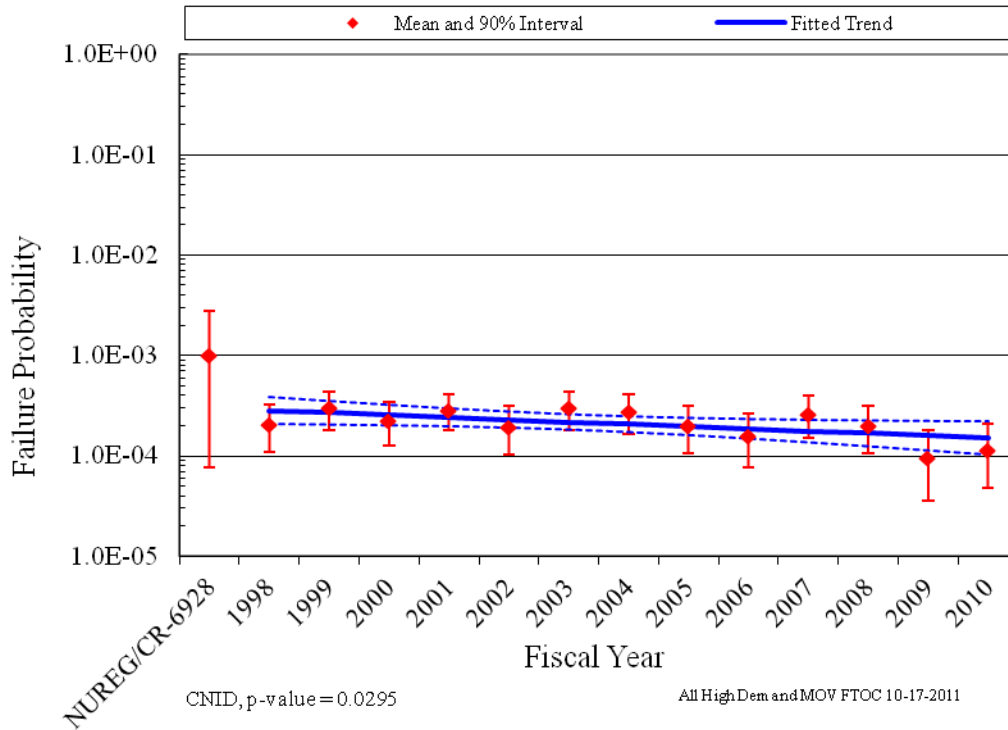Figure 1. All systems, industry-wide MOV FTOC trend MOVs with ≤ 20 demands per year.

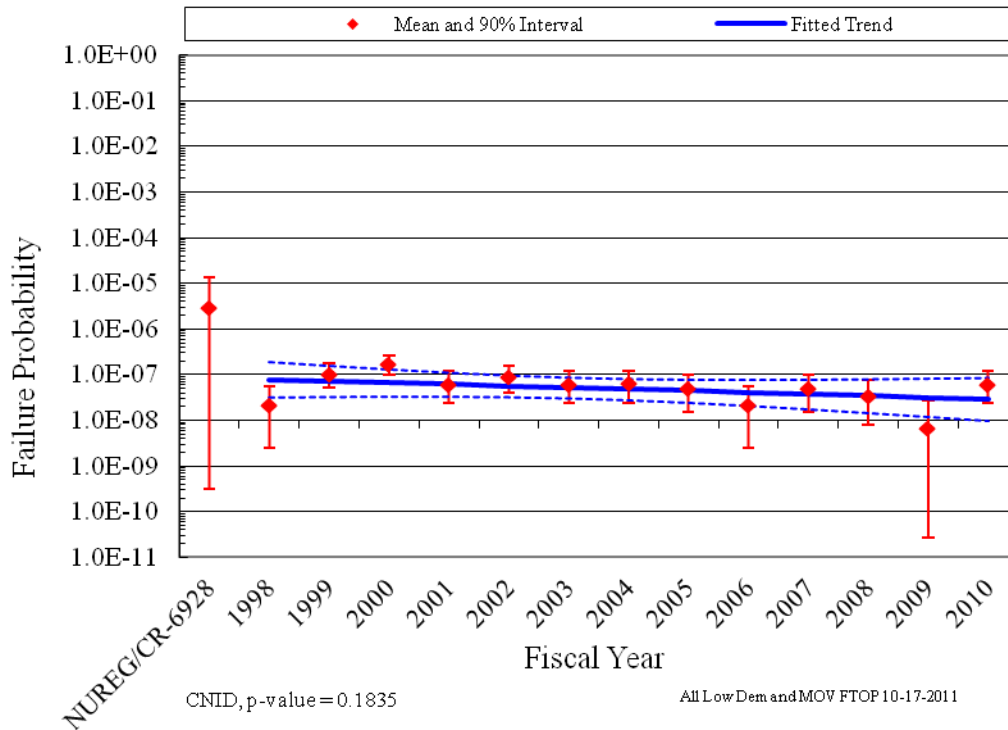Figure 2. All systems, industry-wide MOV FTOC trend MOVs with > 20 demands per year.

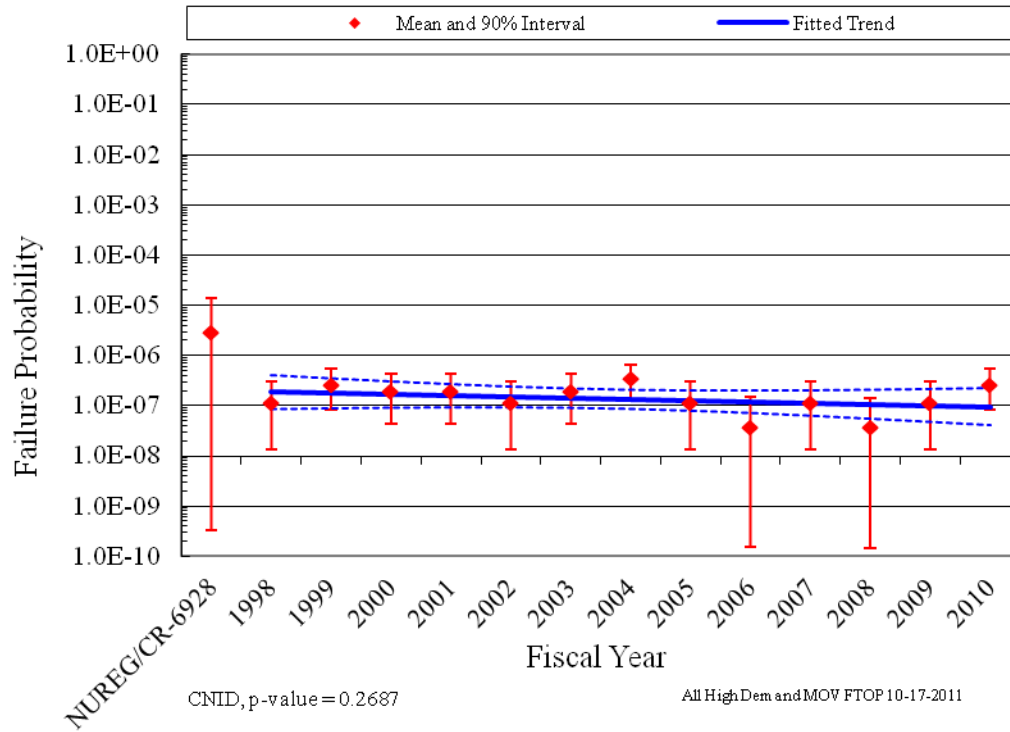Figure 3. All systems, industry-wide MOV FTOP trend MOVs with ≤ 20 demands per year.

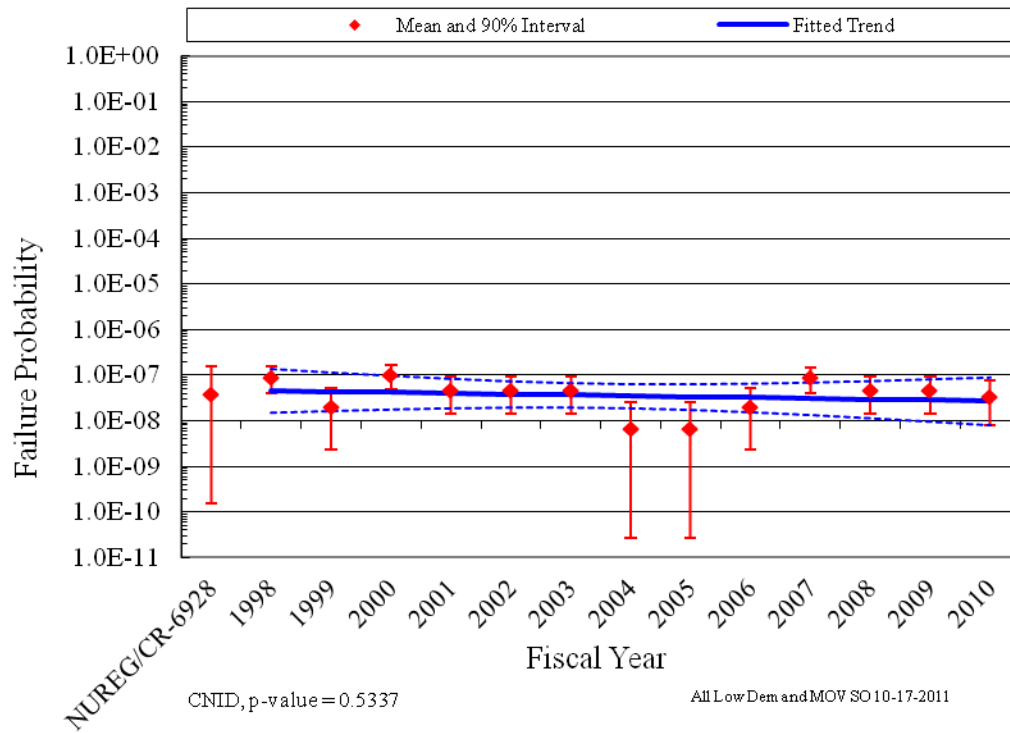Figure 4. All systems, industry-wide MOV FTOP trend MOVs with > 20 demands per year.

Figure 5. All systems, industry-wide MOV SO trend with ≤ 20 demands per year.
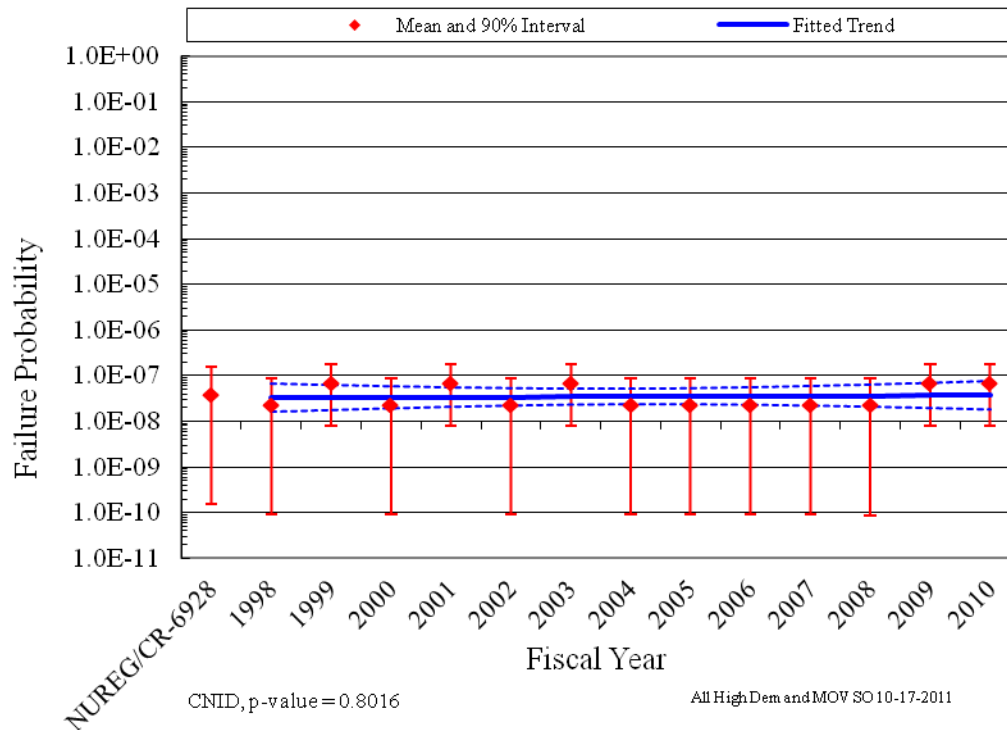
Figure 6. All systems, industry-wide MOV SO trend with > 20 demands per year.

In the plots, the means of the posterior distributions from the Bayesian update process were trended across the years. The posterior distributions were also used for the vertical bounds for each year. The 5th and 95th percentiles of these distributions give an indication of the relative variation from year to year in the data. When there are no failures, the interval is 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 determined by the prior distribution. In each plot, a relatively "flat" constrained noninformative prior distribution (CNID) is used, which has large bounds.

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 intervals 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 exist. Further information on the trending methods is provided in Section 2 of the Overview and Reference document. A final feature of the trend graphs is that the baseline industry values from Table 2 are shown for comparison.

4   ENGINEERING TRENDS

This section presents frequency trends for MOV failures and demands. The data are normalized by reactor year for plants that have the equipment being trended. Figure 7 and Figure 8 show the trend for MOV demands. Figure 9 and Figure 10 show the trend in failure events for FTOC mode, Figure 11 and Figure 12 show the trend in failure events for FTOP mode, and Figure 13 and Figure 14 show the trend for the SO failure events. Table 3 and Table 6 summarize the failures by system, year, and the FTOC failure mode. The top five (and ties) contributing systems for the FTOC failure mode are AFW, CCW, HPI, MFW, RHR, and SWN. Table 4 and Table 7 summarize the failures by system, year, and the FTOP

failure mode. The top five (and ties) contributing systems for the FTOC failure mode are CCW, HCI, LCS, RCI, RHR, and SWN. Table 5 and Table 8 summarize the failures by system, year, and the SO failure mode. The top five (and ties) contributing systems for the SO failure mode are AFW, CCW, RHR, SWN, and SWS. Table 15, Table 16, Table 17, Table 18, Table 19, Table 20, Table 21, and Table 22 provide the frequency (per reactor year) of MOV demands, 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 are used.
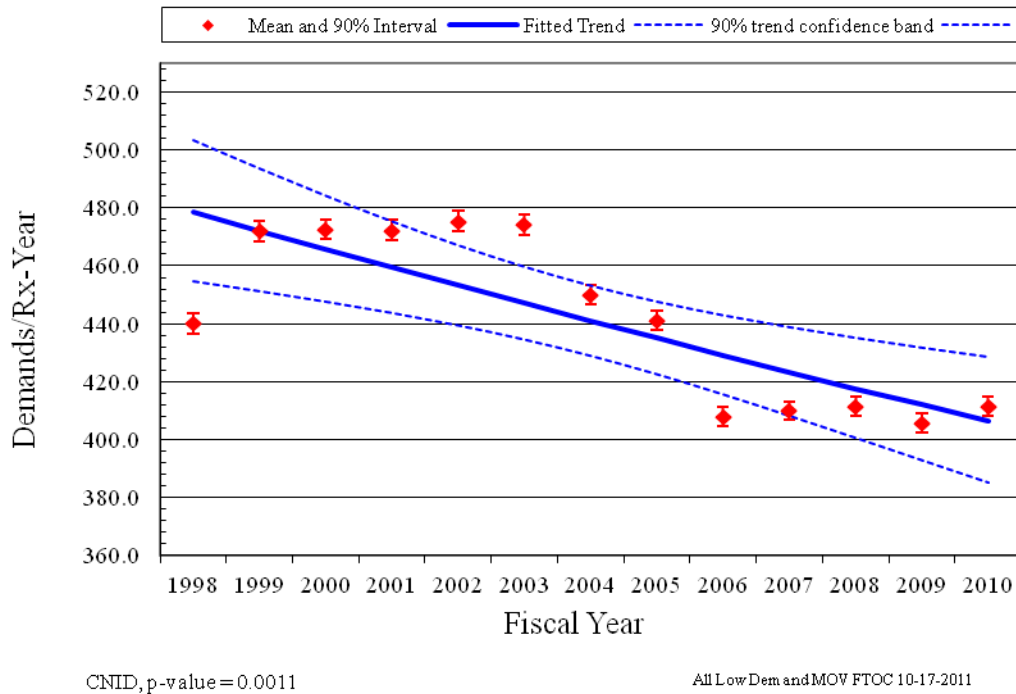
Figure 7. Frequency (demands per reactor year) of MOV operation demands, ≤ 20 demands per year.
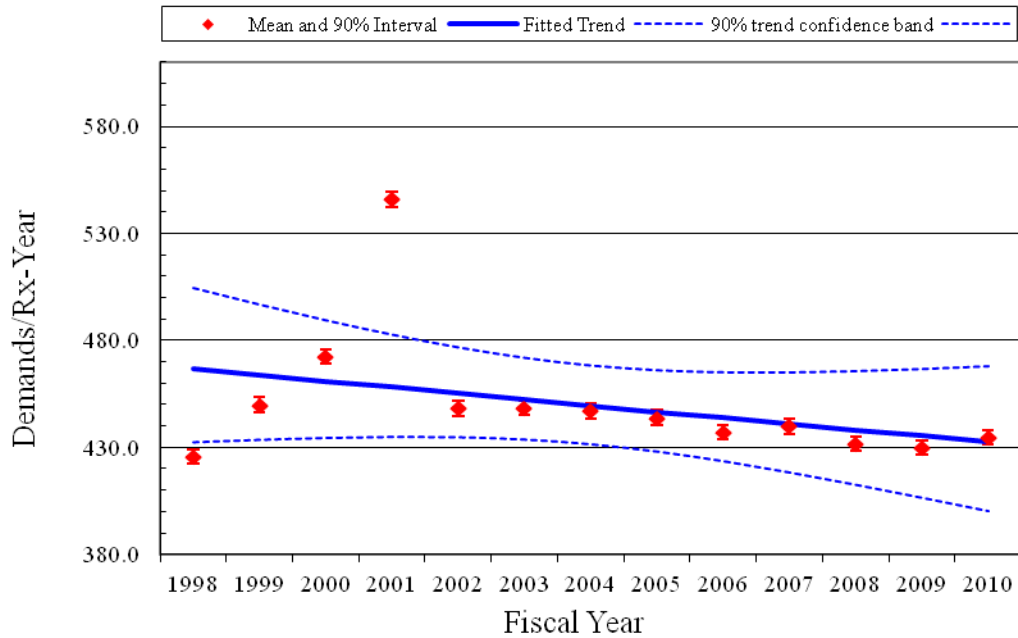
CNID, p-value = 0.1954   All High Dem and MOV FTOC 2-7-2012

Figure 8. Frequency (demands per reactor year) of MOV operation demands, > 20 demands per year.
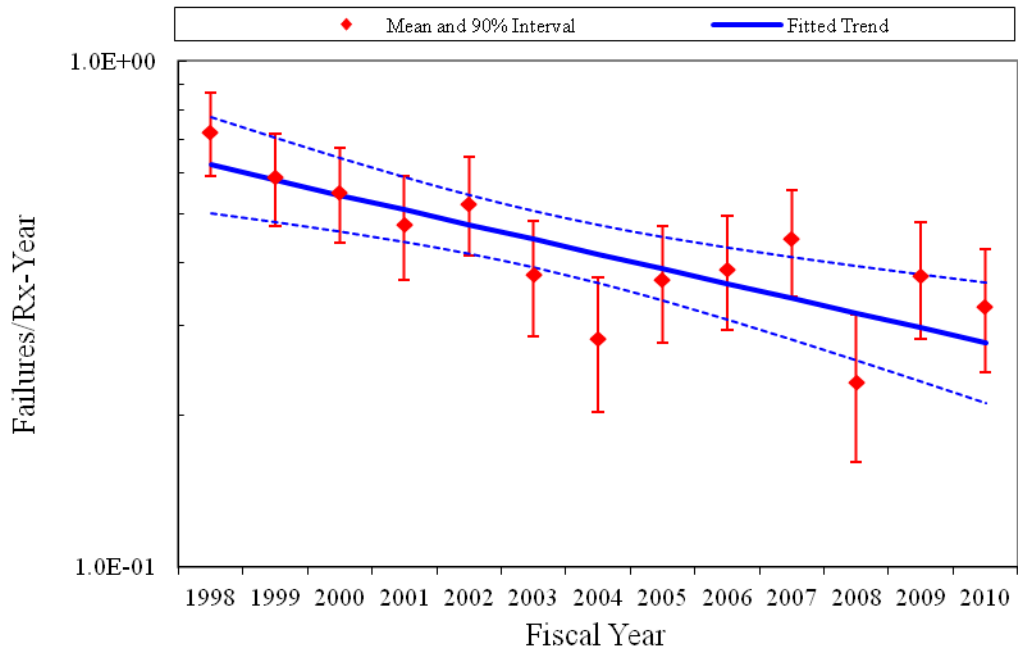
CNID, p-value = 0.0008   All Low Dem and MOV FTOC 10-17-2011

Figure 9. Frequency (failures per reactor year) of MOV FTOC events ≤ 20 demands per year.
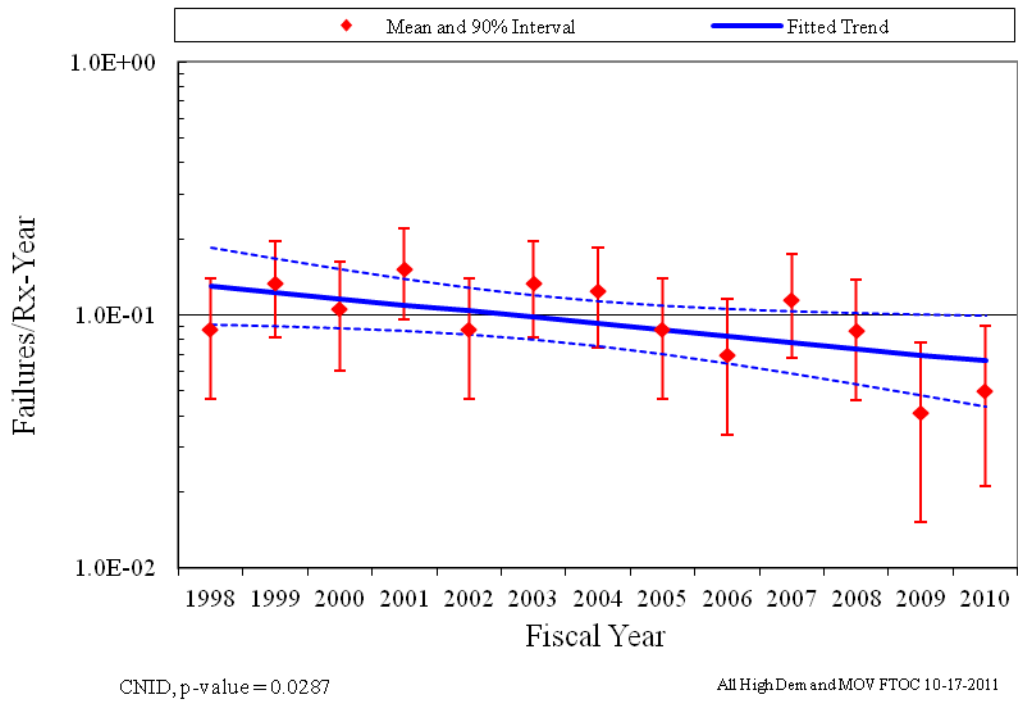
Figure 10. Frequency (failures per reactor year) of MOV FTOC events > 20 demands per year.
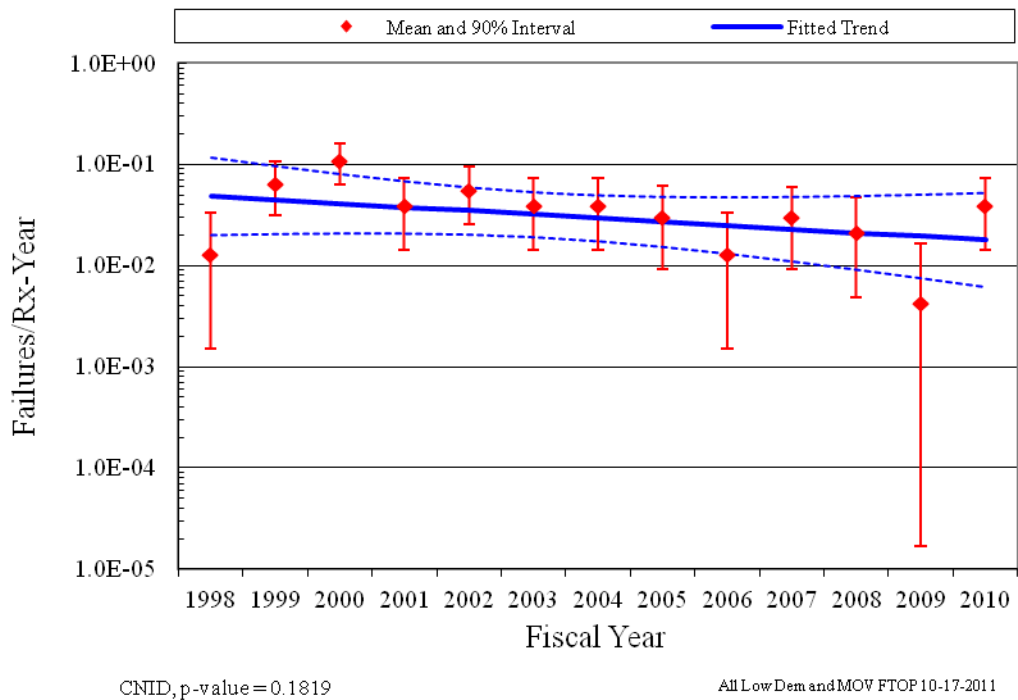
Figure 11. Frequency (failures per reactor year) of MOV FTOP events ≤ 20 demands per year.

CNID, p-value = 0.2759   All High Dem and MOV FTOP 10-17-2011
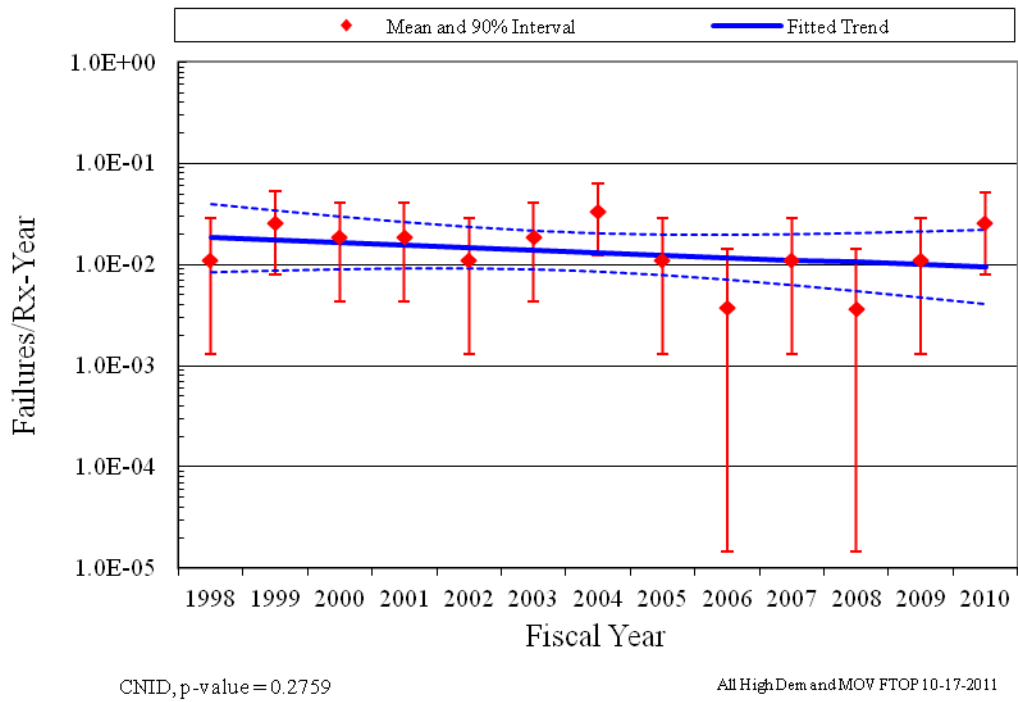
Figure 12. Frequency (failures per reactor year) of MOV FTOP events > 20 demands per year.

CNID, p-value = 0.5288   All Low Dem and MOV SO 10-17-2011
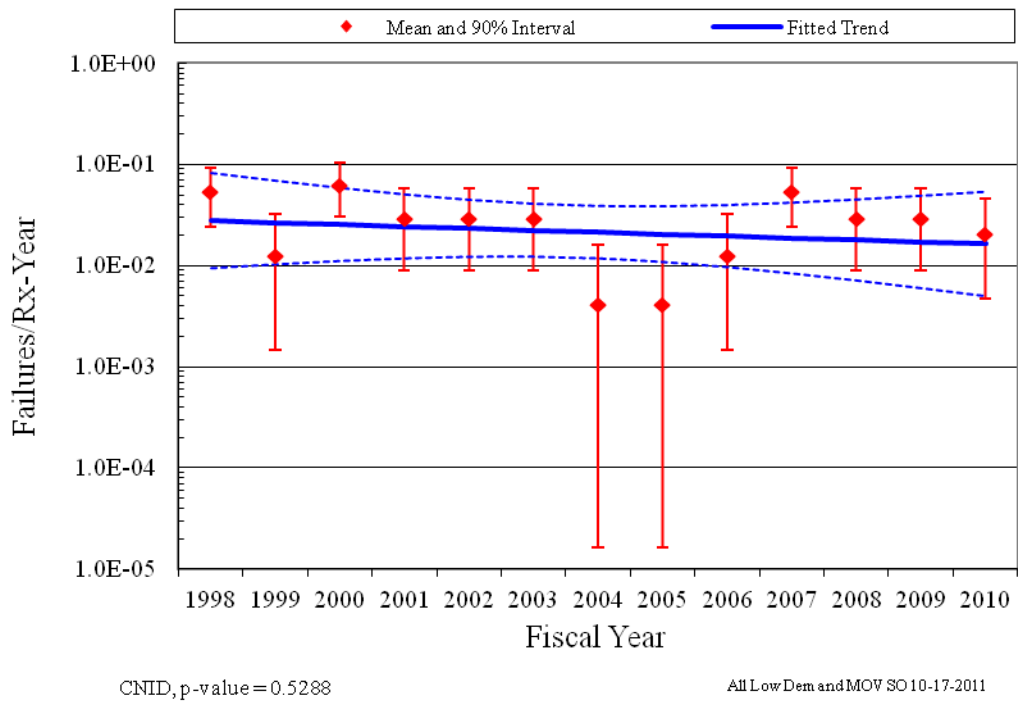
Figure 13. Frequency (failures per reactor year) of MOV SO events ≤ 20 demands per year.

Figure 14. Frequency (failures per reactor year) of MOV SO events > 20 demands per year.

Table 3. Summary of MOV failure counts for the FTOC failure mode over time by system ≤ 20 demands per year.

System Code	Valve Count	Valve Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	Total	Percent of Failures
AFW	468	6.5%	4	6	5	5	6		1	3	2	3	1	6	5	47	**8.0%**
CCW	690	9.6%	4	2	3	2	4	4	1		2	1		3	3	29	4.9%
CIS	19	0.3%											1			1	0.2%
CRD	15	0.2%		1												1	0.2%
CSR	328	4.5%	2	2	2		2	2	1		1		1	1		14	2.4%
CTS	6	0.1%		1												1	0.2%
CVC	540	7.5%	3	3	4		1	1			1	3	1	1		18	3.1%
HCI	248	3.4%	4	3	2	3	2	2	2	2	3	8		8	1	40	**6.8%**
HCS	29	0.4%		1	1											2	0.3%
HPI	974	13.5%	6	5	6	4	6	2	6	6	3	3	1	3	3	54	**9.2%**
HVC	24	0.3%	1	1												2	0.3%
ISO	19	0.3%		1	2	1			1	2						7	1.2%
LCS	209	2.9%	5	9	2	4	1	2			1	1				25	4.2%
MFW	292	4.0%	1					3	1	2	1	2	2	1	5	18	3.1%
MSS	163	2.3%		1	3	1	1	1	2	2		4	3	2	1	21	3.6%
RCI	304	4.2%	4	7	4	5	3	2	2	4	3	1	2	1	1	39	**6.6%**
RCS	160	2.2%				1			2		1					4	0.7%
RHR	1827	25.3%	20	13	16	10	26	12	9	15	16	17	8	8	13	183	**31.1%**
SWN	690	9.6%	8	4	6	11	3	7	1	1	6	1	4	4	2	58	**9.8%**
SWS	196	2.7%	14		1	2		1				1		1		20	3.4%
VSS	14	0.2%					1	2		1		1				5	0.8%
Total	7215	100.0%	76	60	57	49	56	41	29	38	40	46	24	39	34	589	100.0%

Table 4. Summary of MOV failure counts for the FTOP failure mode over time by system ≤ 20 demands per year.

System Code	Valve Count	Valve Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	*FY 10*	Total	Percent of Failures
AFW	468	6.6%			2		1	1	1				1		1	7	**13.2%**
CCW	690	9.7%			3	2				1						6	**11.3%**
CIS	19	0.3%											1			1	1.9%
CSR	328	4.6%							1							1	1.9%
CVC	540	7.6%						1								1	1.9%
HCI	248	3.5%										1				1	1.9%
HPI	974	13.7%					2								1	3	**5.7%**
HVC	24	0.3%					1									1	1.9%
LCS	209	2.9%		1												1	1.9%
MFW	292	4.1%				1			1			1				3	**5.7%**
MSS	163	2.3%					1									1	1.9%
RCI	304	4.3%		2												2	3.8%
RCS	160	2.2%								1						1	1.9%
RHR	1827	25.6%		5	6	1		2			1	1			2	18	**34.0%**
SWN	690	9.7%	1		2				1	1						5	**9.4%**
SWS	196	2.7%					1									1	1.9%
Total	7132	100.0%	1	8	13	4	6	4	4	3	1	3	2	0	4	53	100.0%

Table 5. Summary of MOV failure counts for the SO failure mode over time by system ≤ 20 demands per year.

System Code	Valve Count	Valve Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	Total	Percent of Failures
AFW	468	8.5%	1			1										2	**6.3%**
CCW	690	12.5%					1	1				2	2			6	**18.8%**
CSR	328	6.0%				1										1	3.1%
CVC	540	9.8%			1											1	3.1%
HCI	248	4.5%	1											1	1	3	**9.4%**
LCS	209	3.8%									1	4				5	**15.6%**
RCI	304	5.5%			3		1							1		5	**15.6%**
RHR	1827	33.2%	2		2			1						1		6	**18.8%**
SWN	690	12.5%					1									1	3.1%
SWS	196	3.6%	1					1								2	**6.3%**
Total	5500	100.0%	5	0	6	2	3	3	0	0	1	6	2	3	1	32	100.0%

Table 6. Summary of MOV failure counts for the FTOC failure mode over time by system > 20 demands per year.

System Code	Valve Count	Valve Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	Total	Percent of Failures
AFW	114	10.2%	1	1	3	2	1	7	2	1		3	1		1	23	**17.4%**
CCW	144	12.9%	1			1		2	2				1			7	**5.3%**
CVC	34	3.0%												3		3	2.3%
HCI	21	1.9%					1			1	1		1			4	3.0%
HCS	16	1.4%					1						1			2	1.5%
HPI	88	7.9%	1			1						1				3	2.3%
HVC	3	0.3%				1										1	0.8%
LCS	26	2.3%							1				1			2	1.5%
MSS	8	0.7%			1											1	0.8%
RCI	30	2.7%		1		1			1	2						5	3.8%
RHR	281	25.2%	4	7	6	4	2	2	2	4	2	6	2	3	1	45	**34.1%**
SWN	262	23.5%	2	5		5	2	1	5	1	3	1	1	1		27	**20.5%**
SWS	88	7.9%				2	2	2			1	1	1			9	**6.8%**
Total	1115	100.0%	9	14	11	16	9	14	13	9	7	12	9	4	5	132	100.0%

Table 7. Summary of MOV failure counts for the FTOP failure mode over time by system > 20 demands per year.

System Code	Valve Count	Valve Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	Total	Percent of Failures
AFW	114	12.2%		1				1	2			1				5	**23.8%**
CCW	144	15.4%								1				1		2	**9.5%**
CVC	34	3.6%						1								1	4.8%
MFW	13	1.4%	1			2										3	**14.3%**
RHR	281	30.0%			1								1	1		3	**14.3%**
SWN	262	28.0%		2	1											3	**14.3%**
SWS	88	9.4%					1		2					1		4	**19.0%**
Total	936	100.0%	1	3	2	2	1	2	4	1	0	1	0	1	3	21	100.0%

Table 8. Summary of MOV failure counts for the SO failure mode over time by system > 20 demands per year.

System Code	Valve Count	Valve Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	Total	Percent of Failures
MFW	13	2.2%				1										1	**20.0%**
RCI	30	5.1%												1		1	**20.0%**
RHR	281	48.0%											1			1	**20.0%**
SWN	262	44.7%		1				1								2	**40.0%**
Total	586	100.0%	0	1	0	1	0	1	0	0	0	0	0	1	1	5	100.0%

5 MOV ASSEMBLY DESCRIPTION

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

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 Fail to Open/Close, which combines the Fail to Open and Fail to Close (FTOC) failure modes into a single category; Fail to Operate (FTOP), which is a rate-based failure mode that includes Fail to Control for a flow/temperature control device and any other rate-based failure modes not including spurious operation; and Spurious Operation (SO), which includes Spurious Opening and Spurious Closing.

6 DATA TABLES

Table 9. Plot data for industry-wide MOV FTOC trend with ≤ 20 demands per year. Figure 1

FY/ Source	Failures	Demands	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
NUREG /CR-6928						7.76E-05	2.81E-03	1.00E-03
1998	75	45329	1.30E-03	1.01E-03	1.66E-03	1.35E-03	1.97E-03	1.65E-03
1999	61	48613	1.23E-03	9.89E-04	1.53E-03	1.00E-03	1.52E-03	1.25E-03
2000	57	48811	1.16E-03	9.63E-04	1.41E-03	9.24E-04	1.43E-03	1.17E-03
2001	49	48648	1.10E-03	9.34E-04	1.30E-03	7.83E-04	1.25E-03	1.01E-03
2002	54	48972	1.05E-03	9.00E-04	1.22E-03	8.67E-04	1.36E-03	1.10E-03
2003	39	48841	9.91E-04	8.59E-04	1.14E-03	6.03E-04	1.02E-03	8.00E-04
2004	29	46488	9.39E-04	8.11E-04	1.09E-03	4.50E-04	8.29E-04	6.28E-04
2005	38	45440	8.90E-04	7.58E-04	1.04E-03	6.28E-04	1.07E-03	8.38E-04
2006	40	42005	8.43E-04	7.03E-04	1.01E-03	7.20E-04	1.21E-03	9.53E-04
2007	46	42369	7.99E-04	6.49E-04	9.83E-04	8.36E-04	1.36E-03	1.08E-03
2008	24	42925	7.57E-04	5.97E-04	9.60E-04	3.90E-04	7.63E-04	5.64E-04
2009	39	42185	7.17E-04	5.48E-04	9.40E-04	6.97E-04	1.18E-03	9.25E-04
2010	34	42810	6.80E-04	5.02E-04	9.21E-04	5.87E-04	1.03E-03	7.96E-04

Table 10. Plot data for industry-wide MOV FTOC trend with > 20 demands per year. Figure 2

FY/ Source	Failures	Demands	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
NUREG /CR-6928						7.76E-05	2.81E-03	1.00E-03
1998	9	43859	2.82E-04	2.06E-04	3.87E-04	1.10E-04	3.27E-04	2.06E-04
1999	14	46332	2.68E-04	2.03E-04	3.53E-04	1.82E-04	4.38E-04	2.98E-04
2000	11	48789	2.54E-04	2.00E-04	3.24E-04	1.28E-04	3.44E-04	2.25E-04
2001	16	56219	2.42E-04	1.95E-04	2.99E-04	1.78E-04	4.05E-04	2.82E-04
2002	9	46170	2.29E-04	1.90E-04	2.78E-04	1.04E-04	3.11E-04	1.96E-04
2003	14	46198	2.18E-04	1.82E-04	2.61E-04	1.83E-04	4.39E-04	2.99E-04
2004	13	46165	2.07E-04	1.72E-04	2.49E-04	1.67E-04	4.14E-04	2.79E-04
2005	9	45720	1.96E-04	1.60E-04	2.40E-04	1.05E-04	3.14E-04	1.98E-04
2006	7	45029	1.86E-04	1.48E-04	2.34E-04	7.67E-05	2.64E-04	1.59E-04
2007	12	45459	1.77E-04	1.36E-04	2.30E-04	1.53E-04	3.94E-04	2.62E-04
2008	9	44998	1.68E-04	1.25E-04	2.27E-04	1.07E-04	3.19E-04	2.01E-04
2009	4	44716	1.60E-04	1.14E-04	2.24E-04	3.54E-05	1.80E-04	9.57E-05
2010	5	45210	1.52E-04	1.03E-04	2.22E-04	4.82E-05	2.07E-04	1.16E-04

Table 11. Plot data for industry-wide MOV FTOP trend with ≤ 20 demands per year. Figure 3

FY/ Source	Failures	Demands	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
NUREG/ CR-6928						3.21E-10	1.37E-05	3.00E-06
1998	1	62923080	7.93E-08	3.26E-08	1.93E-07	2.48E-09	5.51E-08	2.12E-08
1999	7	63072000	7.30E-08	3.35E-08	1.59E-07	5.11E-08	1.76E-07	1.06E-07
2000	12	63107040	6.72E-08	3.40E-08	1.33E-07	1.03E-07	2.65E-07	1.76E-07
2001	4	63089520	6.18E-08	3.40E-08	1.13E-07	2.34E-08	1.19E-07	6.33E-08
2002	6	63054480	5.69E-08	3.31E-08	9.79E-08	4.15E-08	1.57E-07	9.15E-08
2003	4	63098280	5.24E-08	3.12E-08	8.79E-08	2.34E-08	1.19E-07	6.33E-08
2004	4	63054480	4.82E-08	2.84E-08	8.19E-08	2.34E-08	1.19E-07	6.34E-08
2005	3	63089520	4.44E-08	2.50E-08	7.90E-08	1.53E-08	9.90E-08	4.93E-08
2006	1	63133320	4.09E-08	2.13E-08	7.83E-08	2.47E-09	5.50E-08	2.11E-08
2007	3	63115800	3.76E-08	1.79E-08	7.91E-08	1.52E-08	9.90E-08	4.92E-08
2008	2	63168360	3.46E-08	1.48E-08	8.09E-08	8.05E-09	7.78E-08	3.51E-08
2009	0	63229680	3.19E-08	1.22E-08	8.35E-08	2.76E-11	2.70E-08	7.02E-09
2010	4	63203400	2.93E-08	9.92E-09	8.67E-08	2.34E-08	1.19E-07	6.32E-08

Table 12. Plot data for industry-wide MOV FTOP trend with > 20 demands per year. Figure 4

FY/ Source	Failures	Demands	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
NUREG/ CR-6928						3.21E-10	1.37E-05	3.00E-06
1998	1	9872520	1.89E-07	8.63E-08	4.14E-07	1.36E-08	3.02E-07	1.16E-07
1999	3	10038960	1.79E-07	8.96E-08	3.56E-07	8.28E-08	5.38E-07	2.67E-07
2000	2	10056480	1.69E-07	9.23E-08	3.09E-07	4.37E-08	4.22E-07	1.91E-07
2001	2	10038960	1.60E-07	9.39E-08	2.71E-07	4.38E-08	4.23E-07	1.91E-07
2002	1	10047720	1.51E-07	9.40E-08	2.42E-07	1.34E-08	2.98E-07	1.15E-07
2003	2	10056480	1.43E-07	9.19E-08	2.21E-07	4.37E-08	4.22E-07	1.91E-07
2004	4	10082760	1.35E-07	8.73E-08	2.08E-07	1.27E-07	6.44E-07	3.43E-07
2005	1	10091520	1.27E-07	8.04E-08	2.02E-07	1.34E-08	2.97E-07	1.14E-07
2006	0	10082760	1.20E-07	7.22E-08	2.01E-07	1.50E-10	1.46E-07	3.81E-08
2007	1	10082760	1.14E-07	6.37E-08	2.04E-07	1.34E-08	2.98E-07	1.14E-07
2008	0	10179120	1.08E-07	5.54E-08	2.09E-07	1.49E-10	1.45E-07	3.78E-08
2009	1	10135320	1.02E-07	4.78E-08	2.16E-07	1.33E-08	2.96E-07	1.14E-07
2010	3	10179120	9.61E-08	4.10E-08	2.26E-07	8.19E-08	5.32E-07	2.65E-07

Table 13. Plot data for industry-wide MOV SO trend with ≤ 20 demands per year. Figure 5

FY/ Source	Failures	Hours	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
NUREG /CR-6928						1.57E-10	1.54E-07	4.00E-08
1998	6	62923080	4.55E-08	1.53E-08	1.35E-07	4.00E-08	1.52E-07	8.83E-08
1999	1	63072000	4.36E-08	1.67E-08	1.13E-07	2.39E-09	5.30E-08	2.03E-08
2000	7	63107040	4.17E-08	1.81E-08	9.64E-08	4.92E-08	1.69E-07	1.02E-07
2001	3	63089520	3.99E-08	1.92E-08	8.33E-08	1.47E-08	9.54E-08	4.75E-08
2002	3	63054480	3.83E-08	1.99E-08	7.37E-08	1.47E-08	9.54E-08	4.75E-08
2003	3	63098280	3.66E-08	1.99E-08	6.74E-08	1.47E-08	9.54E-08	4.75E-08
2004	0	63054480	3.51E-08	1.92E-08	6.42E-08	2.67E-11	2.61E-08	6.78E-09
2005	0	63089520	3.36E-08	1.77E-08	6.38E-08	2.67E-11	2.60E-08	6.78E-09
2006	1	63133320	3.22E-08	1.58E-08	6.56E-08	2.38E-09	5.30E-08	2.03E-08
2007	6	63115800	3.08E-08	1.37E-08	6.93E-08	3.99E-08	1.52E-07	8.81E-08
2008	3	63168360	2.95E-08	1.17E-08	7.45E-08	1.47E-08	9.53E-08	4.74E-08
2009	3	63229680	2.83E-08	9.85E-09	8.11E-08	1.47E-08	9.52E-08	4.74E-08
2010	2	63203400	2.71E-08	8.23E-09	8.90E-08	7.75E-09	7.49E-08	3.38E-08

Table 14. Plot data for industry-wide MOV SO trend, >20 demands per year. Figure 6

FY/ Source	Failures	Hours	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
NUREG /CR-6928						1.57E-10	1.54E-07	4.00E-08
1998	0	9872520	3.25E-08	1.58E-08	6.69E-08	9.03E-11	8.82E-08	2.30E-08
1999	1	10038960	3.29E-08	1.74E-08	6.22E-08	8.02E-09	1.78E-07	6.84E-08
2000	0	10056480	3.32E-08	1.90E-08	5.81E-08	8.95E-11	8.75E-08	2.28E-08
2001	1	10038960	3.36E-08	2.06E-08	5.48E-08	8.02E-09	1.78E-07	6.84E-08
2002	0	10047720	3.40E-08	2.20E-08	5.24E-08	8.96E-11	8.75E-08	2.28E-08
2003	1	10056480	3.43E-08	2.31E-08	5.10E-08	8.01E-09	1.78E-07	6.83E-08
2004	0	10082760	3.47E-08	2.37E-08	5.10E-08	8.94E-11	8.74E-08	2.27E-08
2005	0	10091520	3.51E-08	2.36E-08	5.23E-08	8.94E-11	8.73E-08	2.27E-08
2006	0	10082760	3.55E-08	2.29E-08	5.49E-08	8.94E-11	8.74E-08	2.27E-08
2007	0	10082760	3.59E-08	2.19E-08	5.88E-08	8.94E-11	8.74E-08	2.27E-08
2008	0	10179120	3.63E-08	2.06E-08	6.38E-08	8.90E-11	8.70E-08	2.26E-08
2009	1	10135320	3.67E-08	1.93E-08	6.98E-08	7.98E-09	1.77E-07	6.81E-08
2010	1	10179120	3.71E-08	1.79E-08	7.68E-08	7.97E-09	1.77E-07	6.79E-08

Table 15. Plot data for frequency (events per reactor year) of MOV operation demands with ≤ 20 demands per year. Figure 7

FY	Demands	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	45329	103.0	4.78E+02	4.55E+02	5.04E+02	4.37E+02	4.43E+02	4.40E+02
1999	48613	103.0	4.72E+02	4.51E+02	4.94E+02	4.68E+02	4.75E+02	4.72E+02
2000	48811	103.3	4.66E+02	4.48E+02	4.84E+02	4.69E+02	4.76E+02	4.73E+02
2001	48648	103.0	4.59E+02	4.44E+02	4.76E+02	4.69E+02	4.76E+02	4.72E+02
2002	48972	103.0	4.53E+02	4.39E+02	4.67E+02	4.72E+02	4.79E+02	4.75E+02
2003	48841	103.0	4.47E+02	4.35E+02	4.60E+02	4.71E+02	4.78E+02	4.74E+02
2004	46488	103.3	4.41E+02	4.29E+02	4.53E+02	4.47E+02	4.54E+02	4.50E+02
2005	45440	103.0	4.35E+02	4.23E+02	4.48E+02	4.38E+02	4.45E+02	4.41E+02
2006	42005	103.0	4.29E+02	4.16E+02	4.43E+02	4.05E+02	4.11E+02	4.08E+02
2007	42369	103.4	4.23E+02	4.08E+02	4.39E+02	4.07E+02	4.13E+02	4.10E+02
2008	42925	104.3	4.18E+02	4.01E+02	4.35E+02	4.08E+02	4.15E+02	4.12E+02
2009	42185	104.0	4.12E+02	3.93E+02	4.32E+02	4.02E+02	4.09E+02	4.06E+02
2010	42810	104.0	4.06E+02	3.85E+02	4.29E+02	4.08E+02	4.15E+02	4.12E+02

Table 16. Plot data for frequency (events per reactor year) of MOV operation demands with > 20 demands per year. Figure 8

FY	Demands	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	43859	103.0	4.67E+02	4.32E+02	5.04E+02	4.22E+02	4.29E+02	4.26E+02
1999	46332	103.0	4.64E+02	4.33E+02	4.97E+02	4.46E+02	4.53E+02	4.50E+02
2000	48789	103.3	4.61E+02	4.34E+02	4.89E+02	4.69E+02	4.76E+02	4.72E+02
2001	56219	103.0	4.58E+02	4.35E+02	4.83E+02	5.42E+02	5.50E+02	5.46E+02
2002	46170	103.0	4.55E+02	4.35E+02	4.77E+02	4.45E+02	4.52E+02	4.48E+02
2003	46198	103.0	4.52E+02	4.33E+02	4.72E+02	4.45E+02	4.52E+02	4.49E+02
2004	46165	103.3	4.49E+02	4.31E+02	4.68E+02	4.44E+02	4.50E+02	4.47E+02
2005	45720	103.0	4.47E+02	4.28E+02	4.66E+02	4.40E+02	4.47E+02	4.44E+02
2006	45029	103.0	4.44E+02	4.23E+02	4.65E+02	4.34E+02	4.41E+02	4.37E+02
2007	45459	103.4	4.41E+02	4.18E+02	4.65E+02	4.36E+02	4.43E+02	4.40E+02
2008	44998	104.3	4.38E+02	4.12E+02	4.66E+02	4.28E+02	4.35E+02	4.32E+02
2009	44716	104.0	4.35E+02	4.06E+02	4.67E+02	4.27E+02	4.33E+02	4.30E+02
2010	45210	104.0	4.33E+02	4.00E+02	4.68E+02	4.31E+02	4.38E+02	4.35E+02

Table 17. Plot data for frequency (events per reactor year) of MOV FTOC events with ≤ 20 demands per year. Figure 9

FY	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	75	103.0	6.23E-01	5.00E-01	7.77E-01	5.93E-01	8.67E-01	7.25E-01
1999	61	103.0	5.82E-01	4.80E-01	7.06E-01	4.72E-01	7.20E-01	5.91E-01
2000	57	103.3	5.45E-01	4.60E-01	6.44E-01	4.37E-01	6.75E-01	5.51E-01
2001	49	103.0	5.09E-01	4.39E-01	5.90E-01	3.70E-01	5.92E-01	4.75E-01
2002	54	103.0	4.76E-01	4.16E-01	5.44E-01	4.12E-01	6.45E-01	5.23E-01
2003	39	103.0	4.45E-01	3.91E-01	5.06E-01	2.86E-01	4.84E-01	3.79E-01
2004	29	103.3	4.16E-01	3.64E-01	4.75E-01	2.03E-01	3.73E-01	2.82E-01
2005	38	103.0	3.89E-01	3.36E-01	4.50E-01	2.77E-01	4.73E-01	3.70E-01
2006	40	103.0	3.64E-01	3.09E-01	4.28E-01	2.94E-01	4.95E-01	3.89E-01
2007	46	103.4	3.40E-01	2.82E-01	4.10E-01	3.43E-01	5.57E-01	4.45E-01
2008	24	104.3	3.18E-01	2.56E-01	3.94E-01	1.61E-01	3.15E-01	2.32E-01
2009	39	104.0	2.97E-01	2.33E-01	3.79E-01	2.83E-01	4.79E-01	3.76E-01
2010	34	104.0	2.78E-01	2.11E-01	3.65E-01	2.42E-01	4.25E-01	3.28E-01

Table 18. Plot data for frequency (events per reactor year) of MOV FTOC events with > 20 demands per year. Figure 10

FY	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	9	103.0	1.30E-01	9.18E-02	1.85E-01	4.68E-02	1.39E-01	8.79E-02
1999	14	103.0	1.23E-01	9.05E-02	1.67E-01	8.19E-02	1.97E-01	1.34E-01
2000	11	103.3	1.16E-01	8.89E-02	1.52E-01	6.04E-02	1.62E-01	1.06E-01
2001	16	103.0	1.10E-01	8.68E-02	1.39E-01	9.65E-02	2.19E-01	1.53E-01
2002	9	103.0	1.04E-01	8.39E-02	1.28E-01	4.68E-02	1.39E-01	8.79E-02
2003	14	103.0	9.80E-02	8.02E-02	1.20E-01	8.19E-02	1.97E-01	1.34E-01
2004	13	103.3	9.26E-02	7.55E-02	1.14E-01	7.45E-02	1.85E-01	1.25E-01
2005	9	103.0	8.75E-02	7.01E-02	1.09E-01	4.68E-02	1.39E-01	8.79E-02
2006	7	103.0	8.26E-02	6.45E-02	1.06E-01	3.36E-02	1.16E-01	6.94E-02
2007	12	103.4	7.81E-02	5.88E-02	1.04E-01	6.74E-02	1.74E-01	1.15E-01
2008	9	104.3	7.37E-02	5.33E-02	1.02E-01	4.63E-02	1.38E-01	8.69E-02
2009	4	104.0	6.96E-02	4.82E-02	1.01E-01	1.52E-02	7.76E-02	4.13E-02
2010	5	104.0	6.58E-02	4.35E-02	9.96E-02	2.10E-02	9.02E-02	5.04E-02

Table 19. Plot data for frequency (events per reactor year) of MOV FTOP events with ≤ 20 demands per year. Figure 11

FY	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	1	103.0	4.85E-02	1.99E-02	1.18E-01	1.52E-03	3.37E-02	1.29E-02
1999	7	103.0	4.47E-02	2.05E-02	9.74E-02	3.13E-02	1.08E-01	6.46E-02
2000	12	103.3	4.11E-02	2.08E-02	8.12E-02	6.28E-02	1.62E-01	1.07E-01
2001	4	103.0	3.78E-02	2.07E-02	6.89E-02	1.43E-02	7.29E-02	3.88E-02
2002	6	103.0	3.48E-02	2.02E-02	5.99E-02	2.54E-02	9.64E-02	5.60E-02
2003	4	103.0	3.20E-02	1.91E-02	5.37E-02	1.43E-02	7.29E-02	3.88E-02
2004	4	103.3	2.95E-02	1.73E-02	5.00E-02	1.43E-02	7.27E-02	3.87E-02
2005	3	103.0	2.71E-02	1.52E-02	4.82E-02	9.34E-03	6.06E-02	3.02E-02
2006	1	103.0	2.49E-02	1.30E-02	4.78E-02	1.52E-03	3.37E-02	1.29E-02
2007	3	103.4	2.29E-02	1.09E-02	4.83E-02	9.31E-03	6.04E-02	3.01E-02
2008	2	104.3	2.11E-02	9.03E-03	4.94E-02	4.88E-03	4.72E-02	2.13E-02
2009	0	104.0	1.94E-02	7.41E-03	5.09E-02	1.68E-05	1.64E-02	4.27E-03
2010	4	104.0	1.79E-02	6.04E-03	5.29E-02	1.42E-02	7.23E-02	3.84E-02

Table 20. Plot data for frequency (events per reactor year) of MOV FTOP events with > 20 demands per year. Figure 12

FY	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	1	103.0	1.83E-02	8.37E-03	4.01E-02	1.31E-03	2.91E-02	1.12E-02
1999	3	103.0	1.73E-02	8.69E-03	3.46E-02	8.07E-03	5.24E-02	2.61E-02
2000	2	103.3	1.64E-02	8.96E-03	3.00E-02	4.26E-03	4.11E-02	1.86E-02
2001	2	103.0	1.55E-02	9.13E-03	2.64E-02	4.27E-03	4.12E-02	1.86E-02
2002	1	103.0	1.47E-02	9.14E-03	2.36E-02	1.31E-03	2.91E-02	1.12E-02
2003	2	103.0	1.39E-02	8.94E-03	2.16E-02	4.27E-03	4.12E-02	1.86E-02
2004	4	103.3	1.31E-02	8.50E-03	2.03E-02	1.24E-02	6.29E-02	3.35E-02
2005	1	103.0	1.24E-02	7.84E-03	1.97E-02	1.31E-03	2.91E-02	1.12E-02
2006	0	103.0	1.18E-02	7.05E-03	1.96E-02	1.46E-05	1.43E-02	3.72E-03
2007	1	103.4	1.11E-02	6.22E-03	1.99E-02	1.31E-03	2.90E-02	1.11E-02
2008	0	104.3	1.05E-02	5.41E-03	2.05E-02	1.45E-05	1.42E-02	3.69E-03
2009	1	104.0	9.95E-03	4.67E-03	2.12E-02	1.30E-03	2.89E-02	1.11E-02
2010	3	104.0	9.42E-03	4.01E-03	2.21E-02	8.01E-03	5.20E-02	2.59E-02

Table 21. Plot data for frequency (events per reactor year) of MOV SO events ≤ 20 demands per year. Figure 13

FY	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	6	103.0	2.79E-02	9.42E-03	8.24E-02	2.45E-02	9.28E-02	5.40E-02
1999	1	103.0	2.67E-02	1.03E-02	6.93E-02	1.46E-03	3.24E-02	1.25E-02
2000	7	103.3	2.55E-02	1.11E-02	5.89E-02	3.01E-02	1.04E-01	6.21E-02
2001	3	103.0	2.44E-02	1.17E-02	5.09E-02	9.00E-03	5.84E-02	2.91E-02
2002	3	103.0	2.34E-02	1.22E-02	4.50E-02	9.00E-03	5.84E-02	2.91E-02
2003	3	103.0	2.24E-02	1.22E-02	4.12E-02	9.00E-03	5.84E-02	2.91E-02
2004	0	103.3	2.14E-02	1.17E-02	3.92E-02	1.63E-05	1.59E-02	4.14E-03
2005	0	103.0	2.05E-02	1.08E-02	3.89E-02	1.63E-05	1.59E-02	4.15E-03
2006	1	103.0	1.96E-02	9.64E-03	4.00E-02	1.46E-03	3.24E-02	1.25E-02
2007	6	103.4	1.88E-02	8.37E-03	4.23E-02	2.44E-02	9.26E-02	5.38E-02
2008	3	104.3	1.80E-02	7.14E-03	4.54E-02	8.90E-03	5.78E-02	2.88E-02
2009	3	104.0	1.72E-02	6.01E-03	4.94E-02	8.92E-03	5.79E-02	2.88E-02
2010	2	104.0	1.65E-02	5.03E-03	5.41E-02	4.72E-03	4.56E-02	2.06E-02

Table 22. Plot data for frequency (events per reactor year) of MOV SO events > 20 demands per year. Figure 14

FY	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	0	103.0	3.16E-03	1.53E-03	6.51E-03	8.73E-06	8.53E-03	2.22E-03
1999	1	103.0	3.20E-03	1.69E-03	6.05E-03	7.81E-04	1.74E-02	6.66E-03
2000	0	103.3	3.23E-03	1.85E-03	5.66E-03	8.72E-06	8.52E-03	2.22E-03
2001	1	103.0	3.27E-03	2.00E-03	5.34E-03	7.81E-04	1.74E-02	6.66E-03
2002	0	103.0	3.31E-03	2.14E-03	5.11E-03	8.73E-06	8.53E-03	2.22E-03
2003	1	103.0	3.35E-03	2.25E-03	4.98E-03	7.81E-04	1.74E-02	6.66E-03
2004	0	103.3	3.38E-03	2.31E-03	4.97E-03	8.72E-06	8.52E-03	2.22E-03
2005	0	103.0	3.42E-03	2.30E-03	5.10E-03	8.73E-06	8.53E-03	2.22E-03
2006	0	103.0	3.46E-03	2.24E-03	5.36E-03	8.73E-06	8.53E-03	2.22E-03
2007	0	103.4	3.50E-03	2.14E-03	5.74E-03	8.72E-06	8.52E-03	2.22E-03
2008	0	104.3	3.54E-03	2.01E-03	6.23E-03	8.68E-06	8.48E-03	2.21E-03
2009	1	104.0	3.58E-03	1.88E-03	6.82E-03	7.78E-04	1.73E-02	6.63E-03
2010	1	104.0	3.62E-03	1.75E-03	7.50E-03	7.78E-04	1.73E-02	6.63E-03

7   REFERENCE

1.   S.A. Eide, et al, *Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, NUREG/CR-6928, February 2007.