Component Performance Study

Motor-Operated Valves

1998–2006

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 2006 as reported in EPIX. The MOV failure modes considered are failure-to-open/close (failure to operate) (FTOC) 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. (see Figure 1)
- Frequency (events per reactor year) of MOV FTOC events. (see Figure 4)

Table 3 shows that 85% of the MOV FTOC failures occurred in 10 systems. Similarly, Table 4 shows that 85% of the MOV SO failures occurred in 10 systems.

[1] Statistically significant 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

The 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 reduced to include only those MOVs with ≤ 20 demands/year (to match the standby data collection criteria in NUREG/CR-6928) and includes MOVs in the systems listed in Table 1. Table 2 shows industry-wide failure probability and failure rate results for the MOV from Reference 1.

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	Valve Count
AFW	Auxiliary feedwater	484
CCW	Component cooling water	618
CHW	Chilled water system	46
CIS	Containment isolation system	389
CRD	Control rod drive	21
CSR	Containment spray recirculation	332
CTS	Condensate transfer system	6
CVC	Chemical and volume control	532
EPS	Emergency power supply	2
ESW	Emergency service water	899
FWS	Firewater	8
HCI	High pressure coolant injection	229
HCS	High pressure core spray	30
HPI	High pressure injection	953
HVC	Heating ventilation and air conditioning	24
IAS	Instrument air	14
ISO	Isolation condenser	20
LCI	Low pressure coolant injection	720
LCS	Low pressure core spray	190
LPI	Low pressure injection	1081
MFW	Main feedwater	316
MSS	Main steam	149
RCI	Reactor core isolation	284
RCS	Reactor coolant	157
RPS	Reactor protection	4
RRS	Reactor recirculation	68
RWC	Reactor water cleanup	13
SGT	Standby gas treatment	10
VSS	Vapor suppression	19
	Total	7618

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

3.2 MOV Failure Probability and Failure Rate Trends

Trends in failure probabilities and failure rates are shown in Figure 1 and Figure 2. The data for the trend plots are contained in Table 5 and Table 6 respectively.

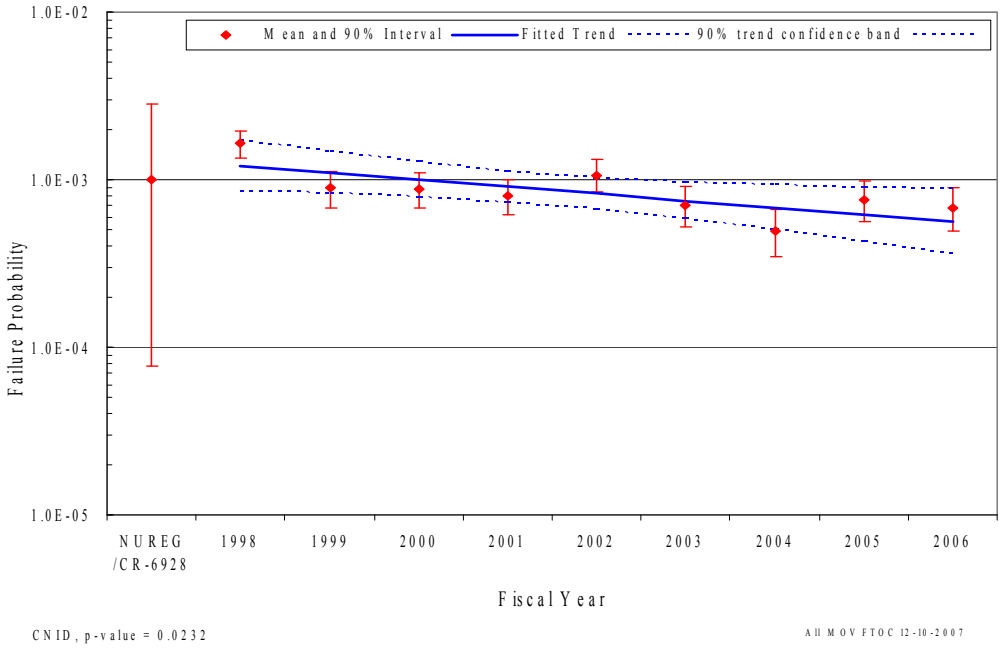

Figure 1. All systems, industry-wide MOV FTOC trend.

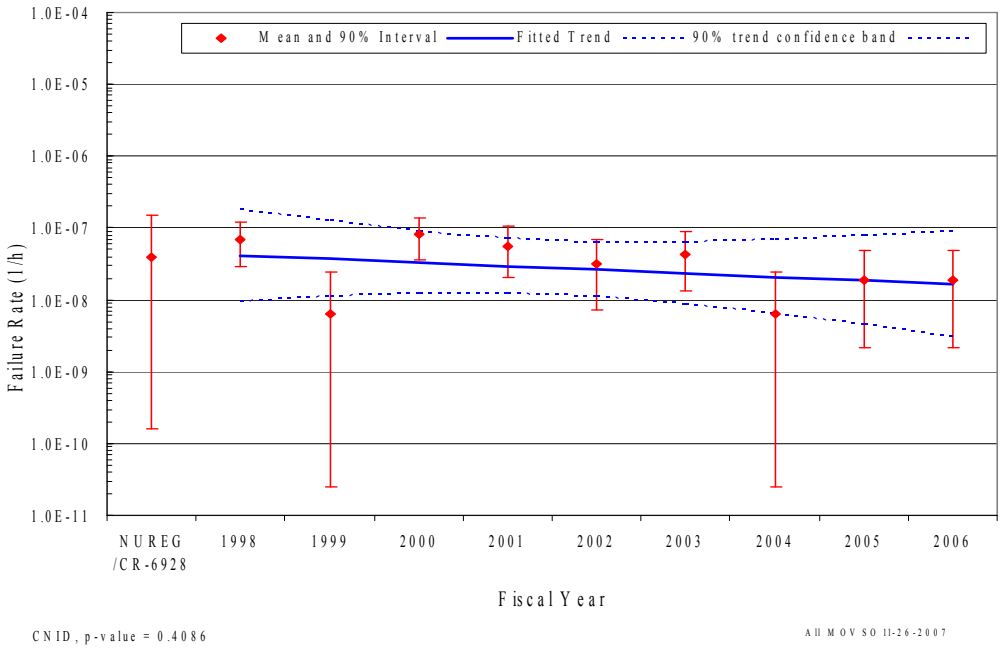

Figure 2. All systems, industry-wide MOV SO trend.

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 3 shows the trend for MOV demands. Figure 4 shows the trend in failure events for FTOC mode, and Figure 5 shows the trend for the SO failure events. Table 3 summarizes the failures by system, year, and the FTOC failure mode. The major contributing systems for the FTOC failure mode are ESW, LPI, LPCI, and HPSI. Table 4 summarizes the failures by system, year, and the SO failure mode. The major contributing systems for the SO failure mode are ESW, LPCI, RCIC, and CIS. Table 7, Table 8, and Table 9 provide the frequency (per reactor year) of MOV demands, FTOC events, and SO events, respectively. The rate methods described in Section 2 of the Overview and Reference document are used.

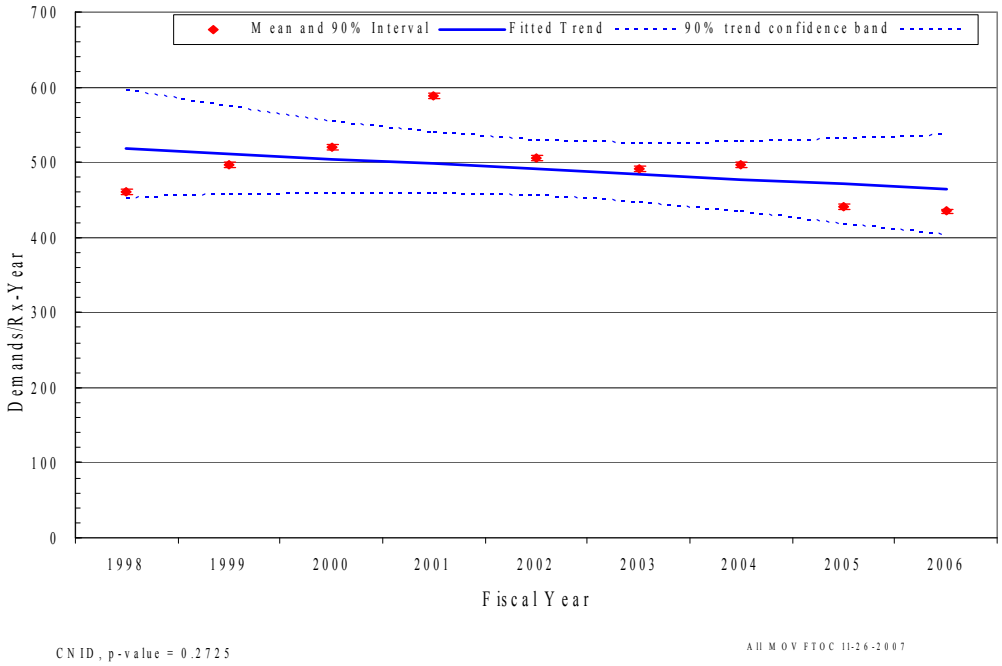

Figure 3. Frequency (events per reactor year) of MOV operation demands.

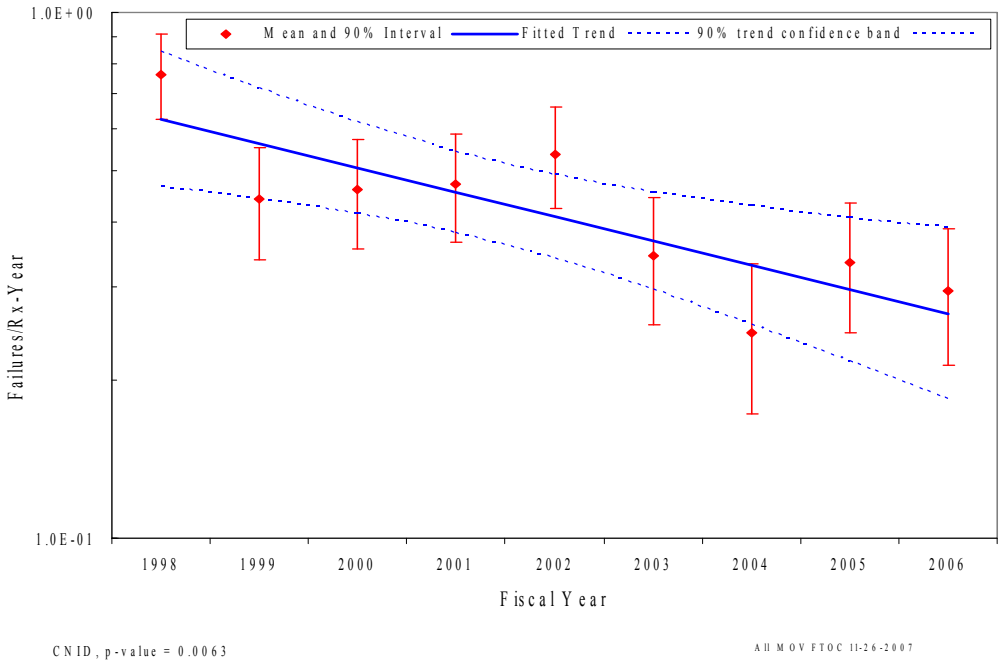

Figure 4. Frequency (events per reactor year) of MOV FTOC events.

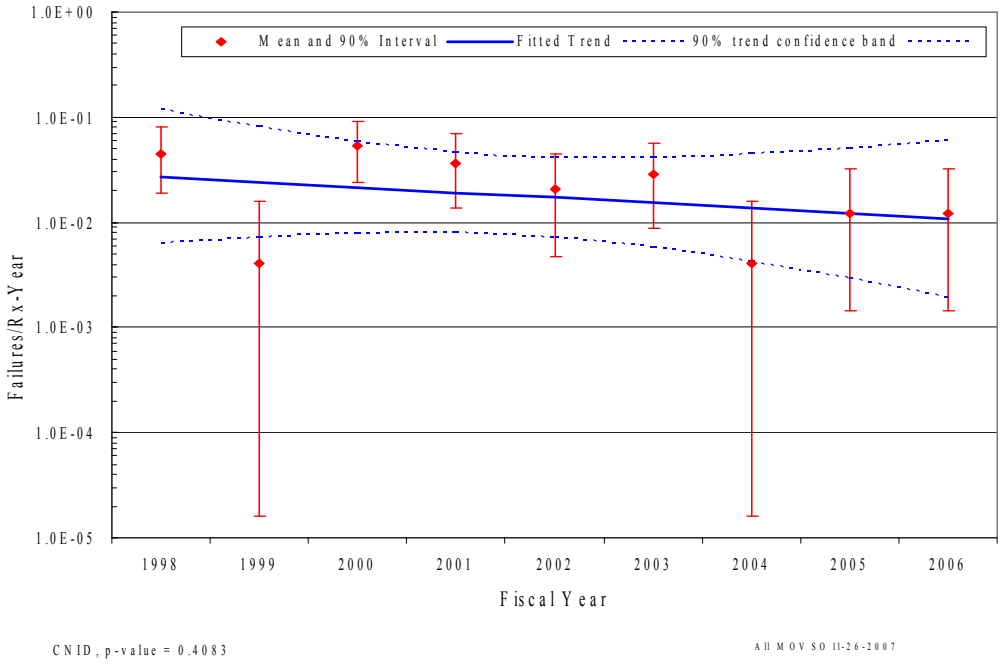

Figure 5. Frequency (events per reactor year) of MOV SO events.

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

System Code	Valve Count	Valve Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	Total	Percent of Failures
AFW	484	6.4%	4	5	5	5	4	0	2	2	2	29	7.3%
CCW	618	8.1%	5	1	2	2	4	3	0	0	1	18	4.5%
CHW	46	0.6%	0	1	0	0	0	0	1	0	0	2	0.5%
CIS	389	5.1%	5	2	2	3	4	3	0	2	2	23	5.8%
CRD	21	0.3%	0	1	0	0	0	0	0	0	0	1	0.3%
CSR	332	4.4%	1	2	1	0	2	1	1	1	1	10	2.5%
CTS	6	0.1%	0	1	0	0	0	0	0	0	0	1	0.3%
CVC	532	7.0%	3	3	4	0	1	1	0	0	1	13	3.3%
EPS	2	0.0%	0	0	0	1	0	0	0	0	0	1	0.3%
ESW	899	11.8%	22	2	7	18	5	8	1	1	7	71	17.9%
FWS	8	0.1%	0	1	0	0	0	0	0	0	0	1	0.3%
HPCI	229	3.0%	4	3	2	3	1	1	2	2	2	20	5.0%
HPCS	30	0.4%	0	0	0	0	1	0	0	0	0	1	0.3%
HPSI	953	12.5%	7	2	4	3	4	1	4	5	2	32	8.1%
HVAC	24	0.3%	1	1	0	1	0	0	0	0	0	3	0.8%
IAS	14	0.2%	0	0	0	0	0	0	0	0	0	0	0.0%
ISO	20	0.3%	0	1	2	1	0	0	0	0	0	4	1.0%
LPCI	720	9.5%	7	4	8	1	1	1	5	5	5	37	9.3%
LPCS	190	2.5%	4	7	1	1	1	1	0	0	1	16	4.0%
LPI	1081	14.2%	8	3	5	3	22	8	3	7	4	63	15.9%
MFW	316	4.1%	1	1	0	0	0	3	1	2	1	9	2.3%
MSS	149	2.0%	0	1	3	1	1	1	2	2	0	11	2.8%
RCIC	284	3.7%	3	3	0	3	3	1	1	4	0	18	4.5%
RCS	157	2.1%	0	0	0	1	0	0	2	0	1	4	1.0%
RPS	4	0.1%	0	0	0	0	0	0	0	0	0	0	0.0%
RRS	68	0.9%	0	0	1	1	0	0	0	0	0	2	0.5%
RWC	13	0.2%	3	0	0	0	0	0	0	0	0	3	0.8%
SGT	10	0.1%	0	0	0	0	0	0	0	0	0	0	0.0%
VSS	19	0.2%	0	0	0	0	1	2	0	1	0	4	1.0%
Total	7618	100.0%	78	45	47	48	55	35	25	34	30	397	100.0%

Table 4. Summary of MOV failure counts for the SO failure mode over time by system.

System Code	Valve Count	Valve Percent	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	Total	Percent of Failures
AFW	484	6.4%	1	0	0	1	0	0	0	0	0	2	9.1%
CCW	618	8.1%	0	0	0	0	1	1	0	0	0	2	9.1%
CHW	46	0.6%	0	0	0	0	0	0	0	0	0	0	0.0%
CIS	389	5.1%	0	0	0	1	0	0	0	0	0	1	4.5%
CRD	21	0.3%	0	0	0	0	0	0	0	0	0	0	0.0%
CSR	332	4.4%	0	0	0	1	0	0	0	0	0	1	4.5%
CTS	6	0.1%	0	0	0	0	0	0	0	0	0	0	0.0%
CVC	532	7.0%	0	0	1	0	0	0	0	0	0	1	4.5%
EPS	2	0.0%	0	0	0	0	0	0	0	0	0	0	0.0%
ESW	899	11.8%	1	0	0	0	0	1	0	0	0	2	9.1%
FWS	8	0.1%	0	0	0	0	0	0	0	0	0	0	0.0%
HPCI	229	3.0%	1	0	0	0	0	1	0	0	0	2	9.1%
HPCS	30	0.4%	0	0	0	0	0	0	0	0	0	0	0.0%
HPSI	953	12.5%	0	0	0	0	0	0	0	0	0	0	0.0%
HVAC	24	0.3%	0	0	0	0	0	0	0	0	0	0	0.0%
IAS	14	0.2%	0	0	0	0	0	0	0	0	0	0	0.0%
ISO	20	0.3%	0	0	0	0	0	0	0	0	0	0	0.0%
LPCI	720	9.5%	2	0	2	0	0	0	0	0	0	4	18.2%
LPCS	190	2.5%	0	0	0	0	0	0	0	0	1	1	4.5%
LPI	1081	14.2%	0	0	0	0	0	0	0	0	0	0	0.0%
MFW	316	4.1%	0	0	0	1	0	0	0	0	0	1	4.5%
MSS	149	2.0%	0	0	0	0	0	0	0	0	0	0	0.0%
RCIC	284	3.7%	0	0	2	0	1	0	0	0	0	3	13.6%
RCS	157	2.1%	0	0	0	0	0	0	0	0	0	0	0.0%
RPS	4	0.1%	0	0	0	0	0	0	0	0	0	0	0.0%
RRS	68	0.9%	0	0	0	0	0	0	0	0	0	0	0.0%
RWC	13	0.2%	0	0	1	0	0	0	0	1	0	2	9.1%
SGT	10	0.1%	0	0	0	0	0	0	0	0	0	0	0.0%
VSS	19	0.2%	0	0	0	0	0	0	0	0	0	0	0.0%
Total	7618	100.0%	5	0	6	4	2	3	0	1	1	22	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.

6 DATA TABLES

Table 5. Plot data for industry-wide MOV FTOC trend. 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	78	47010.8	1.21E-03	8.50E-04	1.73E-03	1.35E-03	1.96E-03	1.65E-03
1999	45	50726.4	1.10E-03	8.24E-04	1.47E-03	6.82E-04	1.11E-03	8.87E-04
2000	47	53179.3	1.00E-03	7.87E-04	1.27E-03	6.83E-04	1.10E-03	8.84E-04
2001	48	60038.8	9.08E-04	7.35E-04	1.12E-03	6.21E-04	9.97E-04	8.00E-04
2002	55	51533.9	8.25E-04	6.65E-04	1.02E-03	8.41E-04	1.31E-03	1.07E-03
2003	35	50144.5	7.49E-04	5.83E-04	9.62E-04	5.18E-04	9.03E-04	7.00E-04
2004	25	50754.2	6.80E-04	5.01E-04	9.24E-04	3.47E-04	6.69E-04	4.97E-04
2005	34	44917.8	6.18E-04	4.26E-04	8.97E-04	5.59E-04	9.82E-04	7.58E-04
2006	30	44342.7	5.61E-04	3.59E-04	8.76E-04	4.90E-04	8.93E-04	6.79E-04

Table 6. Plot data for industry-wide MOV SO trend. Figure 2

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	5	66733680	4.15E-08	9.55E-09	1.80E-07	2.86E-08	1.23E-07	6.87E-08
1999	0	66733680	3.70E-08	1.10E-08	1.24E-07	2.46E-11	2.40E-08	6.24E-09
2000	6	66733680	3.30E-08	1.21E-08	9.02E-08	3.68E-08	1.40E-07	8.12E-08
2001	4	66733680	2.94E-08	1.22E-08	7.08E-08	2.08E-08	1.06E-07	5.62E-08
2002	2	66733680	2.62E-08	1.10E-08	6.25E-08	7.15E-09	6.91E-08	3.12E-08
2003	3	66733680	2.34E-08	8.77E-09	6.23E-08	1.35E-08	8.78E-08	4.37E-08
2004	0	66733680	2.08E-08	6.42E-09	6.77E-08	2.46E-11	2.40E-08	6.24E-09
2005	1	66733680	1.86E-08	4.46E-09	7.74E-08	2.20E-09	4.88E-08	1.87E-08
2006	1	66733680	1.66E-08	3.01E-09	9.12E-08	2.20E-09	4.88E-08	1.87E-08

Table 7. Plot data for frequency (events per reactor year) of MOV operation demands. Figure 3

FY	Demands	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	47011	102.0	5.19E+02	4.52E+02	5.95E+02	4.57E+02	4.64E+02	4.61E+02
1999	50726	102.0	5.12E+02	4.56E+02	5.74E+02	4.94E+02	5.01E+02	4.97E+02
2000	53179	102.3	5.05E+02	4.59E+02	5.55E+02	5.16E+02	5.24E+02	5.20E+02
2001	60039	102.0	4.98E+02	4.59E+02	5.40E+02	5.85E+02	5.93E+02	5.89E+02
2002	51534	102.0	4.91E+02	4.55E+02	5.30E+02	5.02E+02	5.09E+02	5.05E+02
2003	50145	102.0	4.84E+02	4.46E+02	5.26E+02	4.88E+02	4.95E+02	4.92E+02
2004	50754	102.3	4.78E+02	4.33E+02	5.27E+02	4.93E+02	5.00E+02	4.96E+02
2005	44918	102.0	4.71E+02	4.18E+02	5.30E+02	4.37E+02	4.44E+02	4.40E+02
2006	44343	102.0	4.65E+02	4.03E+02	5.36E+02	4.31E+02	4.38E+02	4.35E+02

Table 8. Plot data for frequency (events per reactor year) of MOV FTOC events. Figure 4

FY	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	78	102.0	6.26E-01	4.67E-01	8.40E-01	6.25E-01	9.08E-01	7.61E-01
1999	45	102.0	5.63E-01	4.42E-01	7.17E-01	3.39E-01	5.54E-01	4.41E-01
2000	47	102.3	5.06E-01	4.14E-01	6.19E-01	3.55E-01	5.74E-01	4.59E-01
2001	48	102.0	4.55E-01	3.81E-01	5.45E-01	3.65E-01	5.86E-01	4.70E-01
2002	55	102.0	4.09E-01	3.40E-01	4.92E-01	4.25E-01	6.62E-01	5.38E-01
2003	35	102.0	3.68E-01	2.97E-01	4.56E-01	2.55E-01	4.44E-01	3.44E-01
2004	25	102.3	3.31E-01	2.55E-01	4.29E-01	1.72E-01	3.32E-01	2.47E-01
2005	34	102.0	2.98E-01	2.17E-01	4.08E-01	2.47E-01	4.33E-01	3.34E-01
2006	30	102.0	2.68E-01	1.84E-01	3.89E-01	2.13E-01	3.89E-01	2.96E-01

Table 9. Plot data for frequency (events per reactor year) of MOV SO events. Figure 5

FY	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	5	102.0	2.71E-02	6.25E-03	1.18E-01	1.87E-02	8.04E-02	4.49E-02
1999	0	102.0	2.42E-02	7.19E-03	8.14E-02	1.61E-05	1.57E-02	4.08E-03
2000	6	102.3	2.16E-02	7.89E-03	5.90E-02	2.40E-02	9.11E-02	5.30E-02
2001	4	102.0	1.92E-02	7.98E-03	4.63E-02	1.36E-02	6.91E-02	3.68E-02
2002	2	102.0	1.71E-02	7.18E-03	4.09E-02	4.68E-03	4.52E-02	2.04E-02
2003	3	102.0	1.53E-02	5.73E-03	4.07E-02	8.85E-03	5.75E-02	2.86E-02
2004	0	102.3	1.36E-02	4.19E-03	4.43E-02	1.60E-05	1.57E-02	4.08E-03
2005	1	102.0	1.21E-02	2.91E-03	5.06E-02	1.44E-03	3.19E-02	1.23E-02
2006	1	102.0	1.08E-02	1.97E-03	5.96E-02	1.44E-03	3.19E-02	1.23E-02

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.