Component Performance Study

Air-Operated Valves

1998–2009

1 INTRODUCTION

This report presents a performance evaluation of air-operated valves (AOVs) 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 AOV 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 2009 for the component reliability as reported in EPIX. The AOV 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 AOV results. Statistically significant decreasing trends were identified in the AOV results for the following:

- All systems, industry-wide AOV FTOC trend AOVs with ≤ 20 demands per year. (see Figure 1)
- Frequency (demands per reactor year) of AOV operation demands, ≤ 20 demands per year. (see Figure 5)

[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).

- Frequency (failures per reactor year) of AOV FTOC events ≤ 20 demands per year. (see Figure 7)

Considering the low-demand AOVs; Table 3 shows that 89% of the AOV FTOC failures occurred in seven systems. Similarly, Table 4 shows that 81% of the AOV SO failures occurred in five systems. And considering the high-demand AOVs; Table 5 shows that 85% of the AOV FTOC failures occurred in five systems. Similarly, Table 6 shows that 85% of the AOV SO failures occurred in two systems.

3 FAILURE PROBABILITIES AND FAILURE RATES

3.1 Overview

Trends of industry-wide failure probabilities and failure rates of AOVs have been calculated from the operating experience for the FTOC and SO failure modes. The AOV data set obtained from EPIX was segregated to AOVs with ≤ 20 demands/year (d/yr) and AOVs with > 20 d/yr and includes AOVs in the systems listed in Table 1. NUREG/CR-6928 lists the industry failure data for AOVs with ≤ 20 d/yr. Table 2 shows industry-wide failure probability and failure rate results for the AOV with ≤ 20 d/yr from Reference 1.

The AOVs 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. AOV systems.

		AOV Component Count		
System	Description	Total	≤20 d/yr	>20 d/yr
AFW	Auxiliary feedwater	343	200	143
CCW	Component cooling water	437	303	134
CDS	Condensate system	29	19	10
CRD	Control rod drive	115	81	34
CSR	Containment spray recirculation	28	26	2
CVC	Chemical and volume control	489	348	141
EPS	Emergency power supply	48	25	23
FWS	Firewater	1	1	
HCI	High pressure coolant injection	11	7	4
HPI	High pressure injection	93	73	20
ISO	Isolation condenser	10	6	4
LCS	Low pressure core spray	11	11	
MFW	Main feedwater	364	187	177
MSS	Main steam	120	105	15
RCI	Reactor core isolation	6	6	
RCS	Reactor coolant	109	55	54
RHR	Residual heat removal	247	154	93
SLC	Standby liquid control	1	1	
SWN	Emergency service water (Standby)	523	319	204
SWS	Standby service water	54	22	32
	Total	3039	1949	1090

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

Failure Mode	5%	Median	Mean	95%	Distribution		
					Type	α	β
FTOC	6.0E-05	8.0E-04	1.2E-03	4.0E-03	Beta	1.00	8.33E+02
SO	2.0E-11	5.0E-08	2.0E-07	9.0E-07	Gamma	0.30	1.50E+06

3.2 AOV Failure Probability and Failure Rate Trends

Trends in failure probabilities and failure rates are shown in Figure 1, Figure 2, Figure 3, and Figure 4. The data for the trend plots are contained in Table 7, Table 8, Table 9, and Table 10, respectively.

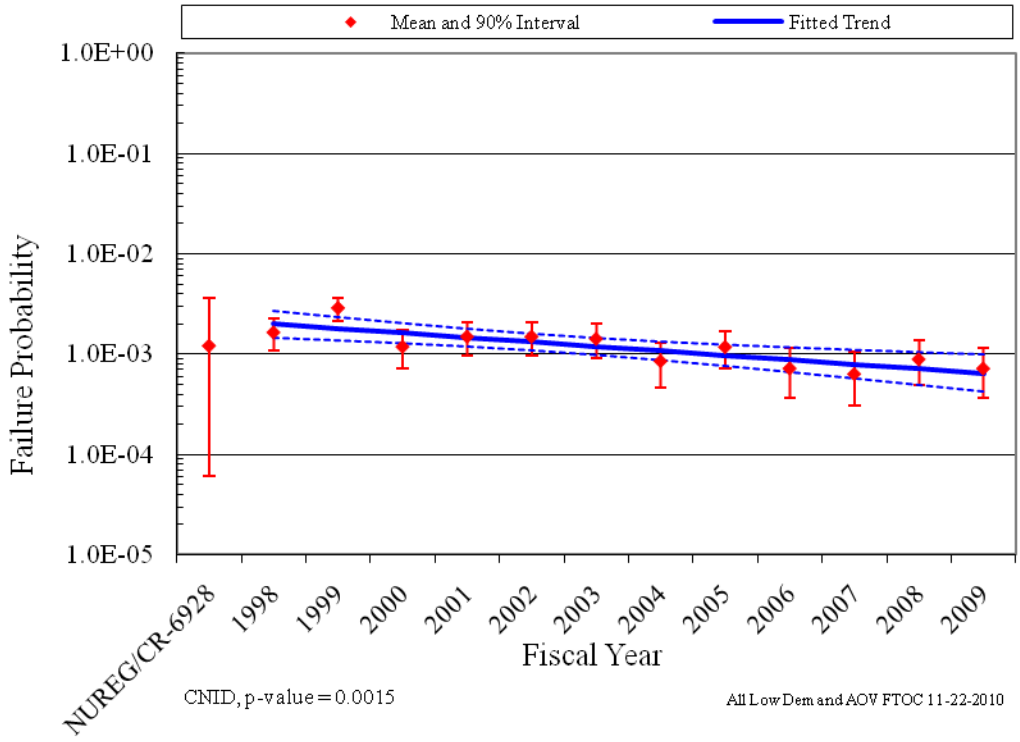

Figure 1. All systems, industry-wide AOV FTOC trend AOVs with ≤ 20 demands per year.

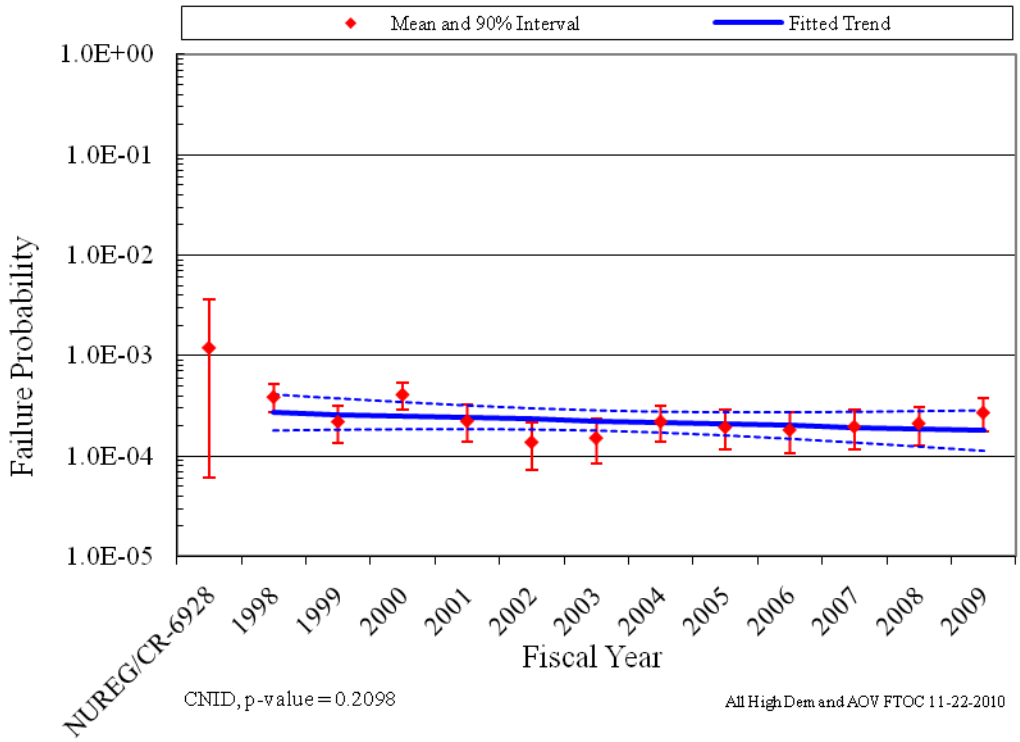

Figure 2. All systems, industry-wide AOV FTOC trend AOVs with > 20 demands per year.

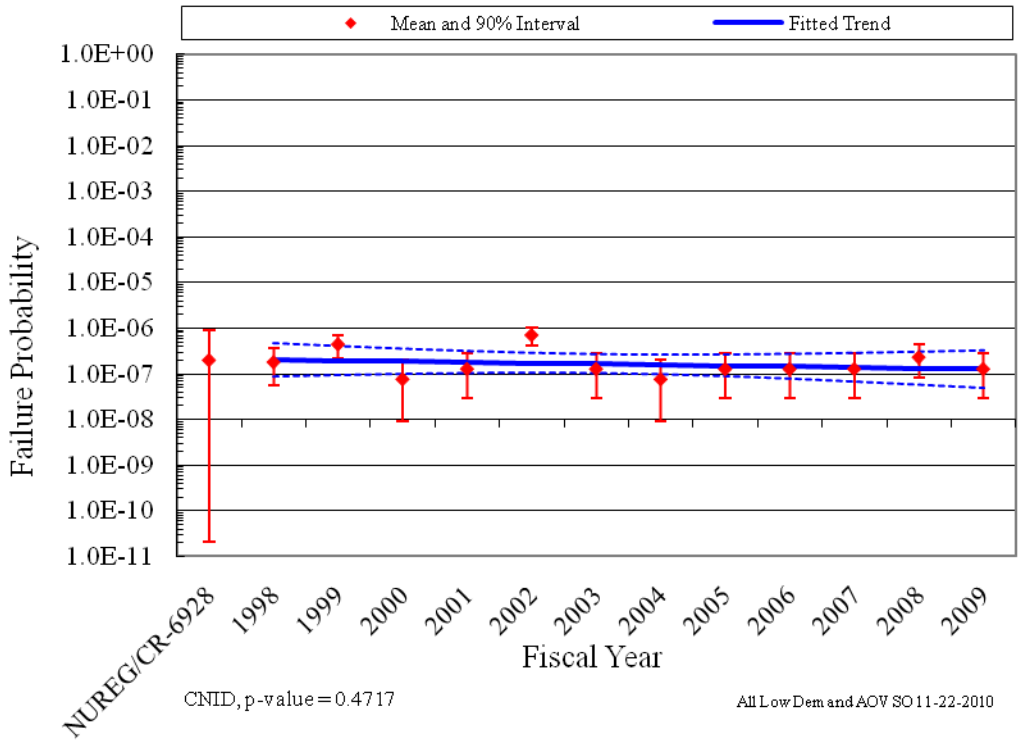

Figure 3. All systems, industry-wide AOV SO trend with ≤ 20 demands per year.

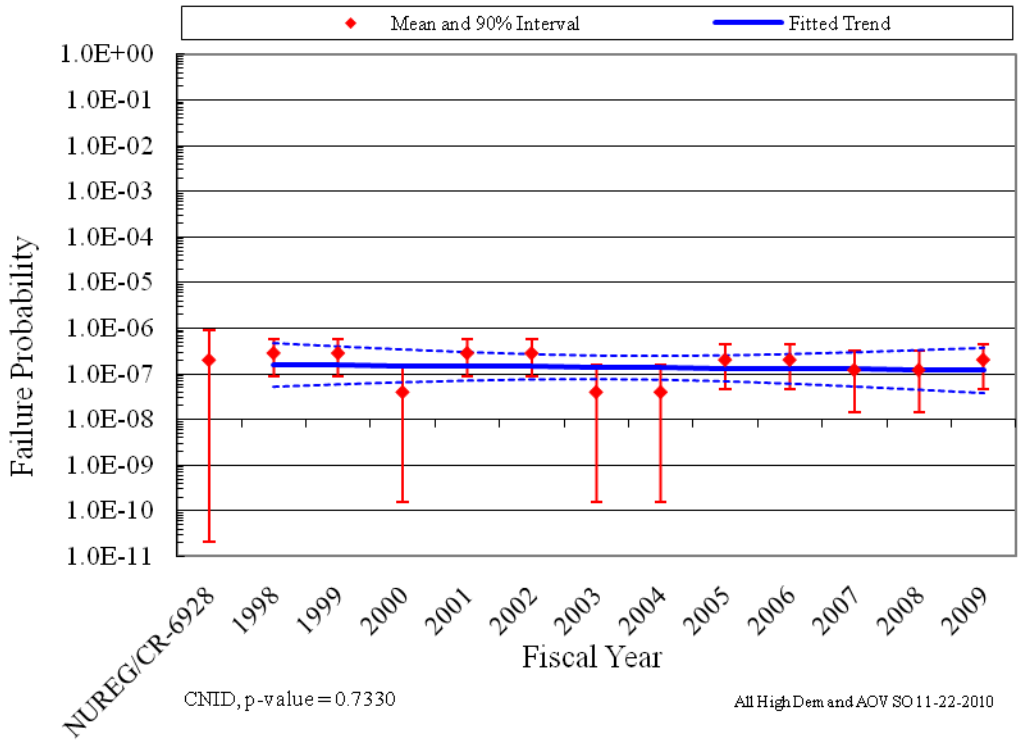

Figure 4. All systems, industry-wide AOV SO trend with > 20 demands per year.

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 AOV failures and demands. The data are normalized by reactor year for plants that have the equipment being trended. Figure 5 shows the trend for AOV demands. Figure 7 shows the trend in failure events for FTOC mode, and Figure 9 shows the trend for the SO failure events. Table 3 and Table 5 summarize the failures by system, year, and the FTOC failure mode. The top five contributing systems for the FTOC failure mode are AFW, CCW, CVC, MFW, and SWN. Table 4 and Table 6 summarize the failures by system, year, and the SO failure mode. The top five contributing systems for the SO failure mode are AFW, CCW, CRD, CVC, and MFW. Table 11,

Table 12, Table 13, Table 14, Table 15, and Table 16 provide the frequency (per reactor year) of AOV demands, FTOC 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.

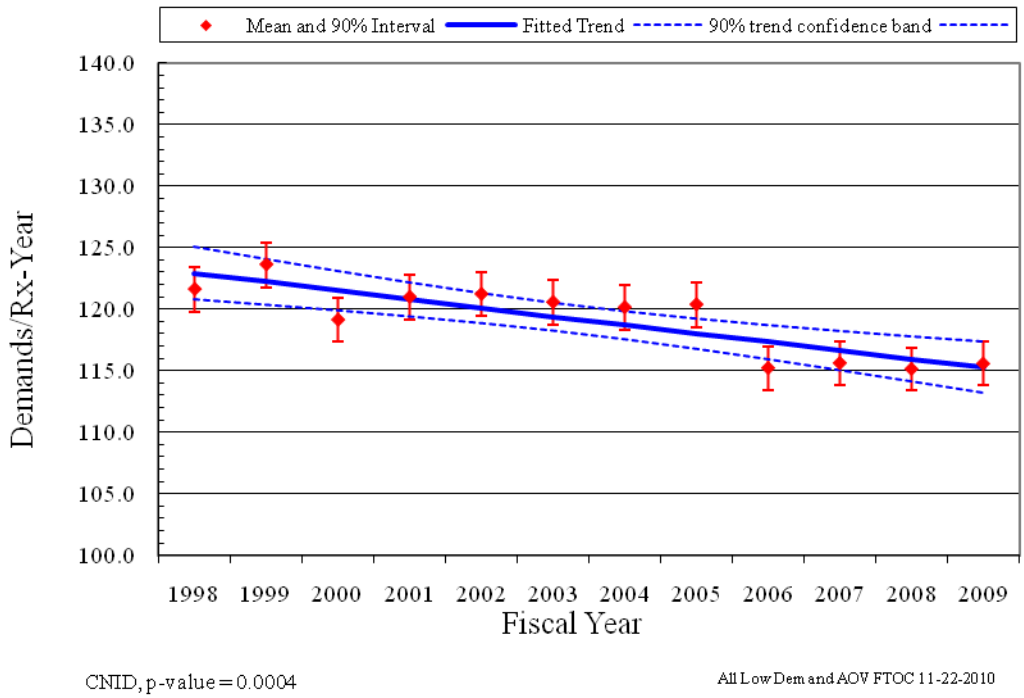

Figure 5. Frequency (demands per reactor year) of AOV operation demands, ≤ 20 demands per year.

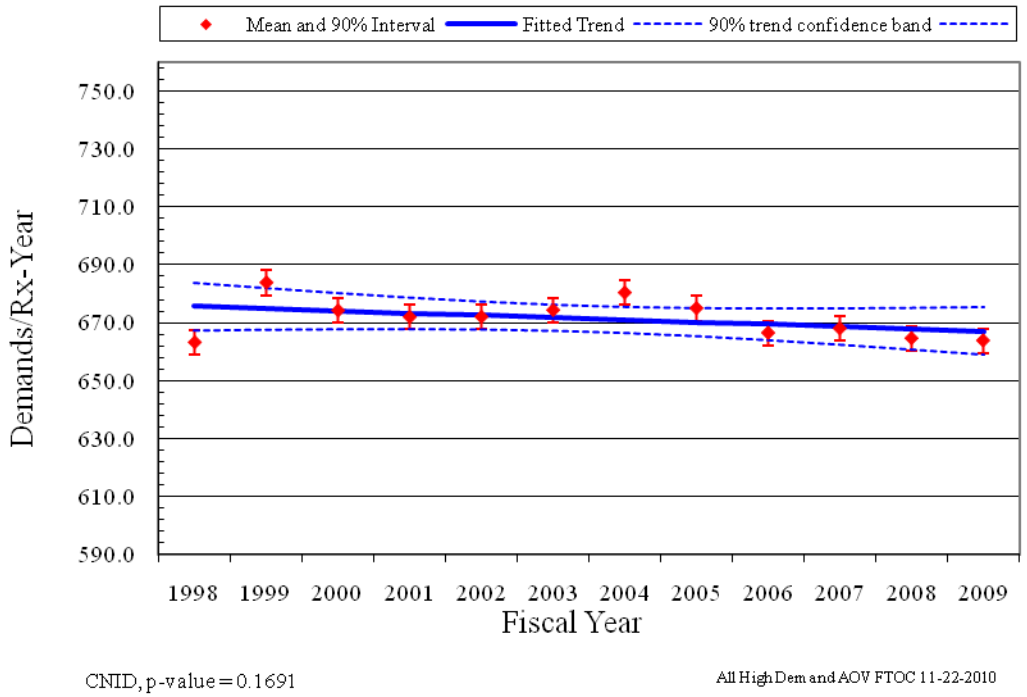

Figure 6. Frequency (demands per reactor year) of AOV operation demands, > 20 demands per year.

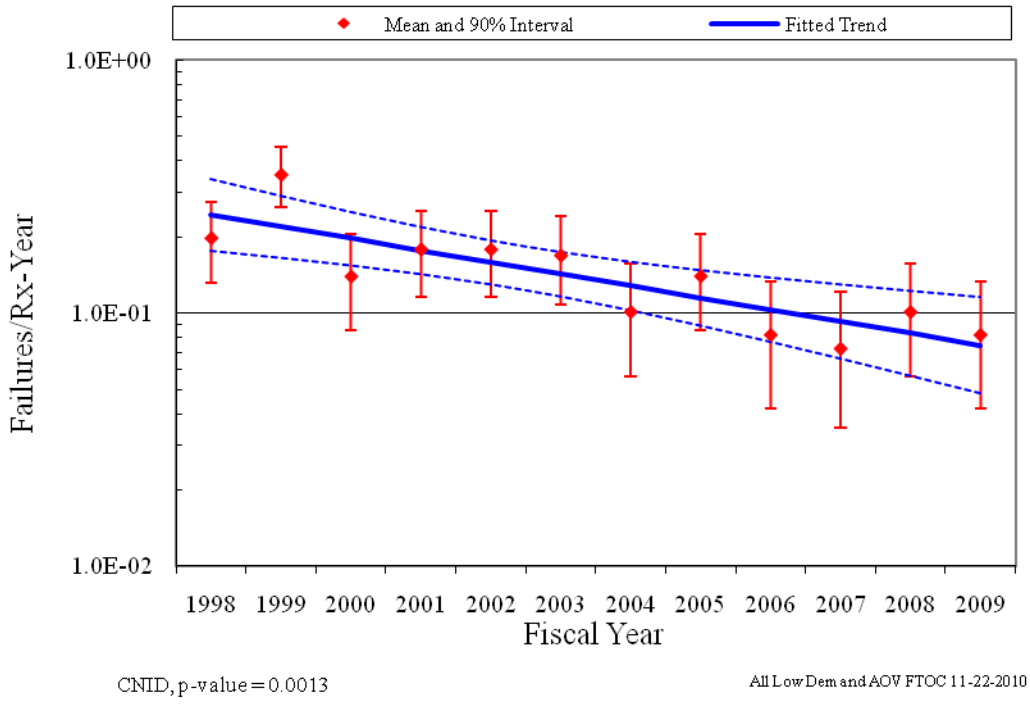

Figure 7. Frequency (failures per reactor year) of AOV FTOC events ≤ 20 demands per year.

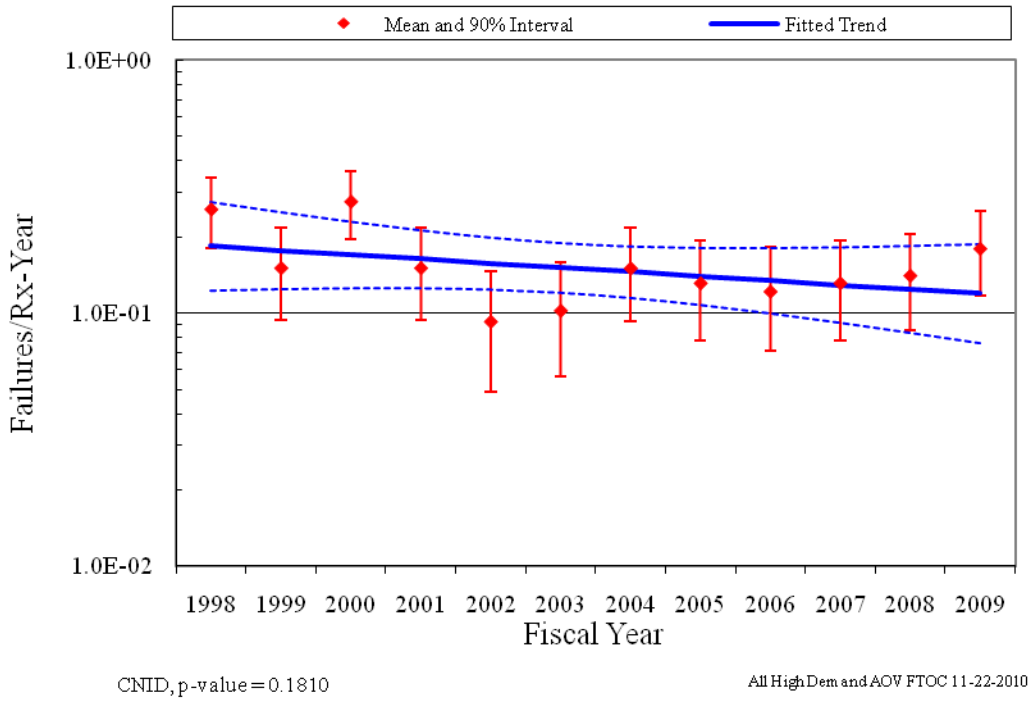

Figure 8. Frequency (failures per reactor year) of AOV FTOC events > 20 demands per year.

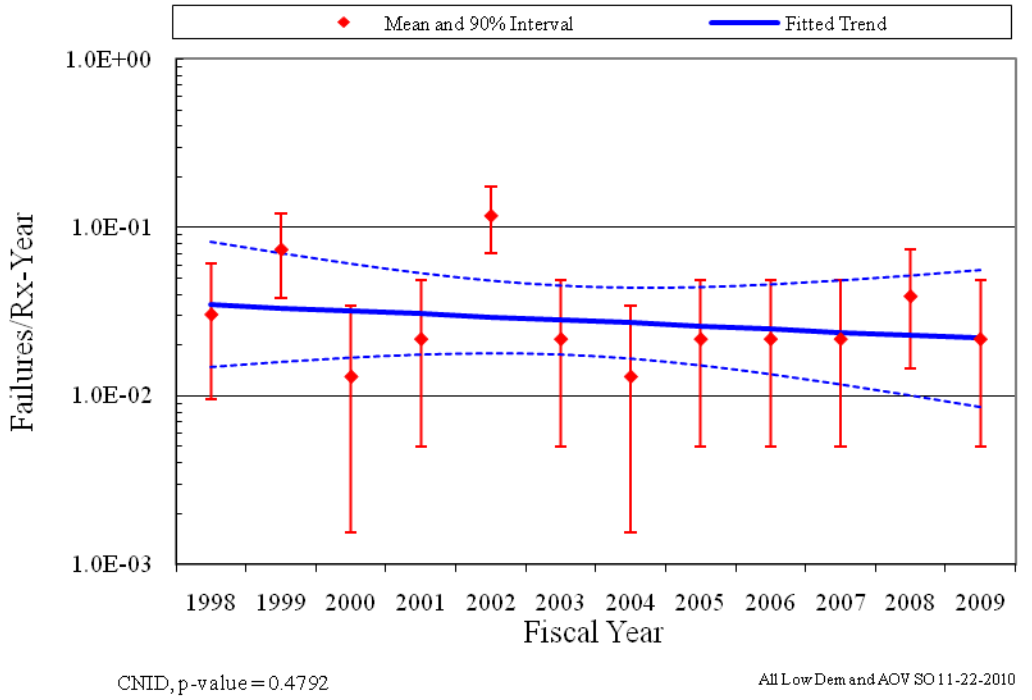

Figure 9. Frequency (failures per reactor year) of AOV SO events ≤ 20 demands per year.

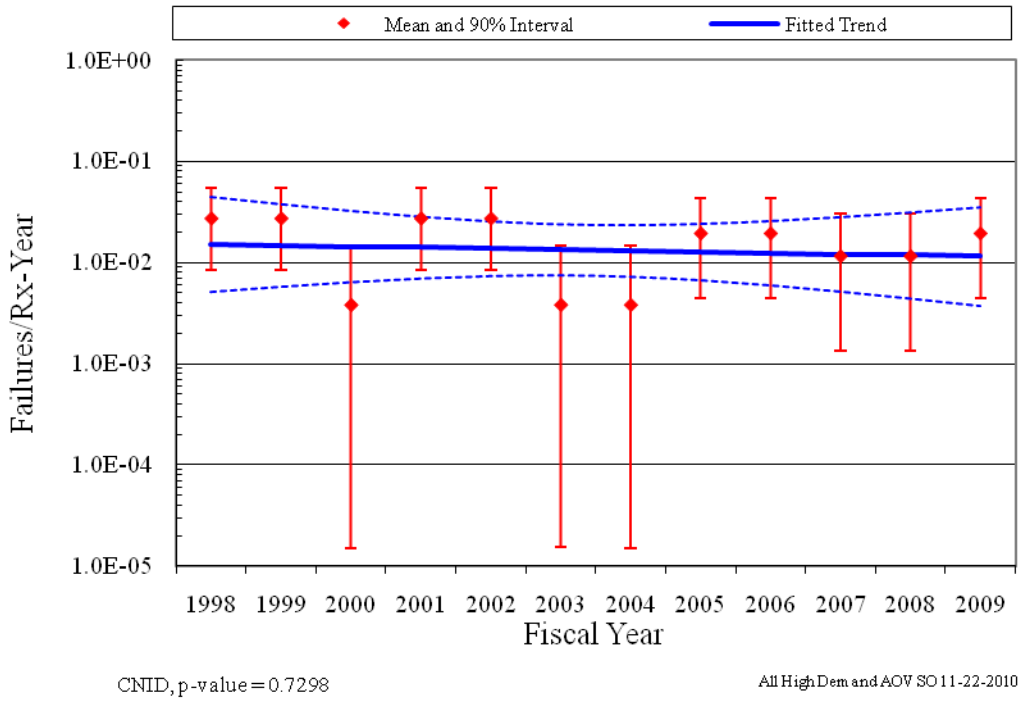

Figure 10. Frequency (failures per reactor year) of AOV SO events > 20 demands per year.

Table 3. Summary of AOV 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*	*Total*	*Percent of Failures*
AFW	200	10.5%	5		6	3	3			5	1	1		1	25	13.9%
CCW	303	16.0%	1	1		3	4	1	1	2	2	2	3	1	21	11.7%
CRD	81	4.3%		1											1	0.6%
CSR	26	1.4%	1							1					2	1.1%
CVC	348	18.4%	2	4	1	3	5	2	1		1	1		1	21	11.7%
HPI	73	3.9%				1		2			1		1		5	2.8%
ISO	6	0.3%					1								1	0.6%
LCS	11	0.6%		1											1	0.6%
MFW	187	9.9%	3	14	1	4	1	3	3	4		1		1	35	19.4%
MSS	105	5.5%	1	2	4		3	1					1		12	6.7%
RCI	6	0.3%											1		1	0.6%
RCS	55	2.9%		1				1	1					1	4	2.2%
RHR	154	8.1%	2	5			1	1			2	1		1	13	7.2%
SWN	319	16.8%	5	6	2	4		2	4	2	1	1	4	2	33	18.3%
SWS	22	1.2%		1				4							5	2.8%
Total	1896	100.0%	20	36	14	18	18	17	10	14	8	7	10	8	180	100.0%

Table 4. Summary of AOV 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*	*Total*	*Percent of Failures*
AFW	200	11.0%				2		1	1			1	1	1	7	16.7%
CCW	303	16.6%		1	1		7					1			10	23.8%
CRD	81	4.4%		4											4	9.5%
CVC	348	19.1%					5			1				1	7	16.7%
HPI	73	4.0%						1							1	2.4%
MFW	187	10.2%	1							1	2		2		6	14.3%
MSS	105	5.8%		2											2	4.8%
RCS	55	3.0%		1			1								2	4.8%
RHR	154	8.4%	1										1		2	4.8%
SWN	319	17.5%	1												1	2.4%
Total	1825	100.0%	3	8	1	2	13	2	1	2	2	2	4	2	42	100.0%

Table 5. Summary of AOV 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*	*Total*	*Percent of Failures*
AFW	143	13.9%	2	2	2	3		1	4	3	4	1	3		25	13.3%
CCW	134	13.0%	3		4						1				8	4.3%
CRD	34	3.3%	2		1										3	1.6%
CVC	141	13.7%	1	2			2					2	1		8	4.3%
MFW	177	17.2%	9	4	10	2	1	2	6	3	3	6	2	10	58	30.9%
MSS	15	1.5%			3						1		1		5	2.7%
RCS	54	5.3%				4		2	2	1		2			11	5.9%
RHR	93	9.1%	2	4	1		2	1			1	1	3	2	17	9.0%
SWN	204	19.9%	3	3	7	6	4	4	3	6	2	1	4	6	49	26.1%
SWS	32	3.1%	4												4	2.1%
Total	1027	100.0%	26	15	28	15	9	10	15	13	12	13	14	18	188	100.0%

Table 6. Summary of AOV 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*	*Total*	*Percent of Failures*
AFW	143	17.9%								1					1	5.0%
CCW	134	16.8%		1											1	5.0%
CVC	141	17.6%	1												1	5.0%
MFW	177	22.2%	2			1	2			1	1	1	1		9	45.0%
SWN	204	25.5%		2		2	1				1			2	8	40.0%
Total	799	100.0%	3	3	0	3	3	0	0	2	2	1	1	2	20	100.0%

5 AOV ASSEMBLY DESCRIPTION

An AOV assembly consists of a valve body and pneumatic operator sub-components (includes the circuit breaker). The valve body is generally a globe or butterfly type. The pneumatic operator is generally a piston or diaphragm type actuator. Main steam isolation valves and power operated relief valves are excluded from the AOV study even though pneumatically operated, as these are valves with different design and operating features.

The piece-parts of the valve body are the stem, packing, and internals. The pneumatic operator piece-parts may include piston internals/seals or diaphragm, positioner, mechanical linkage, volume booster, pilot valve, bolting, air regulator, airline, and wiring/contacts. Failures associated with instrument air systems that are not integral to the AOV assembly (e.g., contamination from the instrument air system that failed the AOV) are excluded in the AOV analysis.

6 DATA TABLES

Table 7. Plot data for industry-wide AOV 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						6.16E-05	3.59E-03	1.20E-03
1998	20	12161	2.00E-03	1.47E-03	2.74E-03	1.09E-03	2.26E-03	1.63E-03
1999	36	12361	1.81E-03	1.38E-03	2.37E-03	2.12E-03	3.67E-03	2.86E-03
2000	14	11944	1.63E-03	1.29E-03	2.06E-03	7.17E-04	1.72E-03	1.18E-03
2001	18	12097	1.47E-03	1.20E-03	1.81E-03	9.62E-04	2.09E-03	1.48E-03
2002	18	12121	1.33E-03	1.10E-03	1.61E-03	9.61E-04	2.08E-03	1.48E-03
2003	17	12055	1.20E-03	9.86E-04	1.46E-03	9.01E-04	2.00E-03	1.41E-03
2004	10	12046	1.08E-03	8.74E-04	1.34E-03	4.65E-04	1.31E-03	8.44E-04
2005	14	12036	9.75E-04	7.64E-04	1.24E-03	7.12E-04	1.71E-03	1.17E-03
2006	8	11520	8.80E-04	6.63E-04	1.17E-03	3.64E-04	1.16E-03	7.13E-04
2007	7	11560	7.94E-04	5.72E-04	1.10E-03	3.03E-04	1.04E-03	6.27E-04
2008	10	11543	7.16E-04	4.92E-04	1.04E-03	4.85E-04	1.37E-03	8.79E-04
2009	8	11555	6.46E-04	4.22E-04	9.90E-04	3.63E-04	1.15E-03	7.11E-04

Table 8. Plot data for industry-wide AOV 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						6.16E-05	3.59E-03	1.20E-03
1998	26	66309	2.71E-04	1.79E-04	4.09E-04	2.72E-04	5.18E-04	3.87E-04
1999	15	68374	2.61E-04	1.82E-04	3.74E-04	1.37E-04	3.19E-04	2.20E-04
2000	28	67594	2.52E-04	1.84E-04	3.43E-04	2.91E-04	5.42E-04	4.09E-04
2001	15	67184	2.43E-04	1.85E-04	3.18E-04	1.39E-04	3.24E-04	2.24E-04
2002	9	67191	2.34E-04	1.84E-04	2.98E-04	7.30E-05	2.17E-04	1.37E-04
2003	10	67423	2.25E-04	1.79E-04	2.83E-04	8.33E-05	2.35E-04	1.51E-04
2004	15	68214	2.17E-04	1.71E-04	2.75E-04	1.37E-04	3.20E-04	2.20E-04
2005	13	67489	2.09E-04	1.61E-04	2.72E-04	1.16E-04	2.88E-04	1.94E-04
2006	12	66637	2.02E-04	1.50E-04	2.72E-04	1.06E-04	2.74E-04	1.82E-04
2007	13	66792	1.94E-04	1.38E-04	2.74E-04	1.17E-04	2.91E-04	1.96E-04
2008	14	66630	1.87E-04	1.26E-04	2.79E-04	1.29E-04	3.09E-04	2.11E-04
2009	18	66372	1.80E-04	1.15E-04	2.84E-04	1.76E-04	3.81E-04	2.70E-04

Table 9. Plot data for industry-wide AOV SO trend with ≤ 20 demands per year. Figure 3

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						2.14E-11	9.15E-07	2.00E-07
1998	3	16898040	2.06E-07	8.76E-08	4.85E-07	5.62E-08	3.65E-07	1.81E-07
1999	8	16871760	1.98E-07	9.37E-08	4.16E-07	2.25E-07	7.16E-07	4.41E-07
2000	1	16959360	1.89E-07	9.93E-08	3.61E-07	9.09E-09	2.02E-07	7.75E-08
2001	2	16950600	1.81E-07	1.03E-07	3.18E-07	2.96E-08	2.86E-07	1.29E-07
2002	13	16950600	1.74E-07	1.05E-07	2.87E-07	4.17E-07	1.04E-06	6.98E-07
2003	2	16968120	1.67E-07	1.03E-07	2.68E-07	2.96E-08	2.86E-07	1.29E-07
2004	1	17011920	1.60E-07	9.78E-08	2.60E-07	9.06E-09	2.01E-07	7.73E-08
2005	2	17011920	1.53E-07	8.91E-08	2.62E-07	2.95E-08	2.85E-07	1.29E-07
2006	2	17073240	1.46E-07	7.90E-08	2.71E-07	2.94E-08	2.84E-07	1.28E-07
2007	2	17020680	1.40E-07	6.88E-08	2.86E-07	2.95E-08	2.85E-07	1.29E-07
2008	4	17055720	1.34E-07	5.92E-08	3.06E-07	8.55E-08	4.35E-07	2.31E-07
2009	2	17029440	1.29E-07	5.05E-08	3.29E-07	2.95E-08	2.85E-07	1.29E-07

Table 10. Plot data for industry-wide AOV SO trend, >20 demands per year. Figure 4

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						2.14E-11	9.15E-07	2.00E-07
1998	3	9557160	1.59E-07	5.37E-08	4.72E-07	8.77E-08	5.69E-07	2.83E-07
1999	3	9583440	1.55E-07	6.02E-08	4.01E-07	8.75E-08	5.68E-07	2.83E-07
2000	0	9574680	1.52E-07	6.67E-08	3.44E-07	1.59E-10	1.55E-07	4.04E-08
2001	3	9539640	1.48E-07	7.25E-08	3.01E-07	8.78E-08	5.70E-07	2.84E-07
2002	3	9627240	1.44E-07	7.66E-08	2.71E-07	8.72E-08	5.66E-07	2.82E-07
2003	0	9592200	1.41E-07	7.79E-08	2.54E-07	1.59E-10	1.55E-07	4.04E-08
2004	0	9557160	1.37E-07	7.55E-08	2.50E-07	1.59E-10	1.55E-07	4.05E-08
2005	2	9565920	1.34E-07	6.99E-08	2.57E-07	4.63E-08	4.48E-07	2.02E-07
2006	2	9530880	1.31E-07	6.23E-08	2.74E-07	4.65E-08	4.49E-07	2.03E-07
2007	1	9539640	1.27E-07	5.43E-08	2.99E-07	1.43E-08	3.17E-07	1.22E-07
2008	1	9548400	1.24E-07	4.65E-08	3.33E-07	1.42E-08	3.16E-07	1.21E-07
2009	2	9522120	1.21E-07	3.94E-08	3.74E-07	4.65E-08	4.49E-07	2.03E-07

Table 11. Plot data for frequency (events per reactor year) of AOV operation demands with ≤ 20 demands per year. Figure 5

FY	Demands	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	12161	100.0	1.23E+02	1.21E+02	1.25E+02	1.20E+02	1.23E+02	1.22E+02
1999	12361	100.0	1.22E+02	1.20E+02	1.24E+02	1.22E+02	1.25E+02	1.24E+02
2000	11944	100.3	1.22E+02	1.20E+02	1.23E+02	1.17E+02	1.21E+02	1.19E+02
2001	12097	100.0	1.21E+02	1.19E+02	1.22E+02	1.19E+02	1.23E+02	1.21E+02
2002	12121	100.0	1.20E+02	1.19E+02	1.21E+02	1.19E+02	1.23E+02	1.21E+02
2003	12055	100.0	1.19E+02	1.18E+02	1.21E+02	1.19E+02	1.22E+02	1.21E+02
2004	12046	100.3	1.19E+02	1.18E+02	1.20E+02	1.18E+02	1.22E+02	1.20E+02
2005	12036	100.0	1.18E+02	1.17E+02	1.19E+02	1.19E+02	1.22E+02	1.20E+02
2006	11520	100.0	1.17E+02	1.16E+02	1.19E+02	1.13E+02	1.17E+02	1.15E+02
2007	11560	100.0	1.17E+02	1.15E+02	1.18E+02	1.14E+02	1.17E+02	1.16E+02
2008	11543	100.3	1.16E+02	1.14E+02	1.18E+02	1.13E+02	1.17E+02	1.15E+02
2009	11555	100.0	1.15E+02	1.13E+02	1.17E+02	1.14E+02	1.17E+02	1.16E+02

Table 12. Plot data for frequency (events per reactor year) of AOV operation demands with > 20 demands per year. Figure 6

FY	Demands	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	66309	100.0	6.76E+02	6.67E+02	6.84E+02	6.59E+02	6.67E+02	6.63E+02
1999	68374	100.0	6.75E+02	6.68E+02	6.82E+02	6.79E+02	6.88E+02	6.84E+02
2000	67594	100.3	6.74E+02	6.68E+02	6.80E+02	6.70E+02	6.78E+02	6.74E+02
2001	67184	100.0	6.73E+02	6.68E+02	6.79E+02	6.68E+02	6.76E+02	6.72E+02
2002	67191	100.0	6.73E+02	6.68E+02	6.77E+02	6.68E+02	6.76E+02	6.72E+02
2003	67423	100.0	6.72E+02	6.67E+02	6.76E+02	6.70E+02	6.79E+02	6.74E+02
2004	68214	100.3	6.71E+02	6.67E+02	6.75E+02	6.76E+02	6.85E+02	6.80E+02
2005	67489	100.0	6.70E+02	6.65E+02	6.75E+02	6.71E+02	6.79E+02	6.75E+02
2006	66637	100.0	6.69E+02	6.64E+02	6.75E+02	6.62E+02	6.71E+02	6.66E+02
2007	66792	100.0	6.69E+02	6.63E+02	6.75E+02	6.64E+02	6.72E+02	6.68E+02
2008	66630	100.3	6.68E+02	6.61E+02	6.75E+02	6.60E+02	6.69E+02	6.64E+02
2009	66372	100.0	6.67E+02	6.59E+02	6.75E+02	6.59E+02	6.68E+02	6.64E+02

Table 13. Plot data for frequency (events per reactor year) of AOV FTOC events with ≤ 20 demands per year. Figure 7

FY	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	20	100.0	2.45E-01	1.77E-01	3.38E-01	1.32E-01	2.76E-01	1.98E-01
1999	36	100.0	2.20E-01	1.66E-01	2.90E-01	2.63E-01	4.55E-01	3.53E-01
2000	14	100.3	1.97E-01	1.55E-01	2.51E-01	8.55E-02	2.05E-01	1.40E-01
2001	18	100.0	1.77E-01	1.43E-01	2.19E-01	1.17E-01	2.53E-01	1.79E-01
2002	18	100.0	1.59E-01	1.30E-01	1.94E-01	1.17E-01	2.53E-01	1.79E-01
2003	17	100.0	1.43E-01	1.17E-01	1.75E-01	1.09E-01	2.41E-01	1.69E-01
2004	10	100.3	1.28E-01	1.03E-01	1.60E-01	5.59E-02	1.58E-01	1.01E-01
2005	14	100.0	1.15E-01	8.94E-02	1.48E-01	8.57E-02	2.06E-01	1.40E-01
2006	8	100.0	1.03E-01	7.71E-02	1.38E-01	4.20E-02	1.33E-01	8.23E-02
2007	7	100.0	9.28E-02	6.61E-02	1.30E-01	3.51E-02	1.21E-01	7.26E-02
2008	10	100.3	8.33E-02	5.65E-02	1.23E-01	5.59E-02	1.58E-01	1.01E-01
2009	8	100.0	7.48E-02	4.82E-02	1.16E-01	4.20E-02	1.33E-01	8.23E-02

Table 14. Plot data for frequency (events per reactor year) of AOV FTOC events with > 20 demands per year. Figure 8

FY	Failures	Reactor Years	Regression Curve Data Points			Plot Trend Error Bar Points		
			Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	26	100.0	1.84E-01	1.23E-01	2.76E-01	1.81E-01	3.44E-01	2.57E-01
1999	15	100.0	1.77E-01	1.25E-01	2.52E-01	9.34E-02	2.18E-01	1.50E-01
2000	28	100.3	1.70E-01	1.26E-01	2.31E-01	1.96E-01	3.65E-01	2.75E-01
2001	15	100.0	1.64E-01	1.26E-01	2.13E-01	9.34E-02	2.18E-01	1.50E-01
2002	9	100.0	1.58E-01	1.24E-01	2.00E-01	4.90E-02	1.46E-01	9.21E-02
2003	10	100.0	1.51E-01	1.21E-01	1.90E-01	5.62E-02	1.58E-01	1.02E-01
2004	15	100.3	1.46E-01	1.15E-01	1.84E-01	9.32E-02	2.17E-01	1.50E-01
2005	13	100.0	1.40E-01	1.08E-01	1.82E-01	7.83E-02	1.94E-01	1.31E-01
2006	12	100.0	1.35E-01	9.99E-02	1.81E-01	7.08E-02	1.82E-01	1.21E-01
2007	13	100.0	1.29E-01	9.17E-02	1.83E-01	7.83E-02	1.94E-01	1.31E-01
2008	14	100.3	1.24E-01	8.37E-02	1.85E-01	8.56E-02	2.06E-01	1.40E-01
2009	18	100.0	1.20E-01	7.61E-02	1.88E-01	1.17E-01	2.53E-01	1.79E-01

Table 15. Plot data for frequency (events per reactor year) of AOV SO events ≤ 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	3	100.0	3.48E-02	1.48E-02	8.20E-02	9.50E-03	6.16E-02	3.07E-02
1999	8	100.0	3.34E-02	1.59E-02	7.04E-02	3.80E-02	1.21E-01	7.45E-02
2000	1	100.3	3.20E-02	1.68E-02	6.11E-02	1.54E-03	3.42E-02	1.31E-02
2001	2	100.0	3.07E-02	1.75E-02	5.38E-02	5.02E-03	4.85E-02	2.19E-02
2002	13	100.0	2.95E-02	1.78E-02	4.87E-02	7.08E-02	1.76E-01	1.18E-01
2003	2	100.0	2.83E-02	1.76E-02	4.55E-02	5.02E-03	4.85E-02	2.19E-02
2004	1	100.3	2.71E-02	1.66E-02	4.42E-02	1.54E-03	3.42E-02	1.31E-02
2005	2	100.0	2.60E-02	1.51E-02	4.46E-02	5.02E-03	4.85E-02	2.19E-02
2006	2	100.0	2.49E-02	1.34E-02	4.62E-02	5.02E-03	4.85E-02	2.19E-02
2007	2	100.0	2.39E-02	1.17E-02	4.87E-02	5.02E-03	4.85E-02	2.19E-02
2008	4	100.3	2.29E-02	1.01E-02	5.21E-02	1.45E-02	7.39E-02	3.93E-02
2009	2	100.0	2.20E-02	8.61E-03	5.61E-02	5.02E-03	4.85E-02	2.19E-02

Table 16. Plot data for frequency (events per reactor year) of AOV SO events > 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	3	100.0	1.52E-02	5.14E-03	4.52E-02	8.38E-03	5.44E-02	2.71E-02
1999	3	100.0	1.49E-02	5.76E-03	3.84E-02	8.38E-03	5.44E-02	2.71E-02
2000	0	100.3	1.45E-02	6.37E-03	3.29E-02	1.52E-05	1.48E-02	3.86E-03
2001	3	100.0	1.41E-02	6.93E-03	2.88E-02	8.38E-03	5.44E-02	2.71E-02
2002	3	100.0	1.38E-02	7.32E-03	2.59E-02	8.38E-03	5.44E-02	2.71E-02
2003	0	100.0	1.34E-02	7.44E-03	2.43E-02	1.52E-05	1.49E-02	3.87E-03
2004	0	100.3	1.31E-02	7.21E-03	2.38E-02	1.52E-05	1.48E-02	3.86E-03
2005	2	100.0	1.28E-02	6.67E-03	2.45E-02	4.43E-03	4.28E-02	1.93E-02
2006	2	100.0	1.25E-02	5.95E-03	2.61E-02	4.43E-03	4.28E-02	1.93E-02
2007	1	100.0	1.22E-02	5.18E-03	2.86E-02	1.36E-03	3.02E-02	1.16E-02
2008	1	100.3	1.19E-02	4.43E-03	3.18E-02	1.36E-03	3.02E-02	1.16E-02
2009	2	100.0	1.16E-02	3.75E-03	3.57E-02	4.43E-03	4.28E-02	1.93E-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.