Component Performance Study

Air-Operated Valves

1998–2006

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 2006 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. (see Figure 1)
- Frequency (events per reactor year) of AOV FTOC events. (see Figure 4)

Table 3 shows that 85% of the AOV FTOC failures occurred in 7 systems. Similarly, Table 4 shows that 85% of the AOV SO failures occurred in 6 systems.

[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).

3 FAILURE PROBABILITIES AND FAILURE RATES

3.1 Overview

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

System	Description	Valve Count
AFW	Auxiliary feedwater	273
CCW	Component cooling water	349
CDS	Condensate system	13
CHW	Chilled water system	6
CIS	Containment isolation system	722
CRD	Control rod drive	93
CSR	Containment spray recirculation	28
CVC	Chemical and volume control	441
EPS	Emergency power supply	29
ESW	Emergency service water	285
FWS	Firewater	1
HPCI	High pressure coolant injection	8
HPSI	High pressure injection	82
HVAC	Heating ventilation and air conditioning	112
IAS	Instrument air	19
ICS	Ice condenser	12
ISO	Isolation condenser	4
LPCI	Low pressure coolant injection	36
LPCS	Low pressure core spray	9
LPI	Low pressure injection	210
MFW	Main feedwater	319
MSS	Main steam	101
NSW	Normal service water	99
RCIC	Reactor core isolation	5
RCS	Reactor coolant	24
RGW	Radioactive gaseous waste	2
RPS	Reactor protection	19
RRS	Reactor recirculation	18
VSS	Vapor suppression	36
	Total	3355

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 and Figure 2. The data for the trend plots are contained in Table 5 and Table 6 respectively.

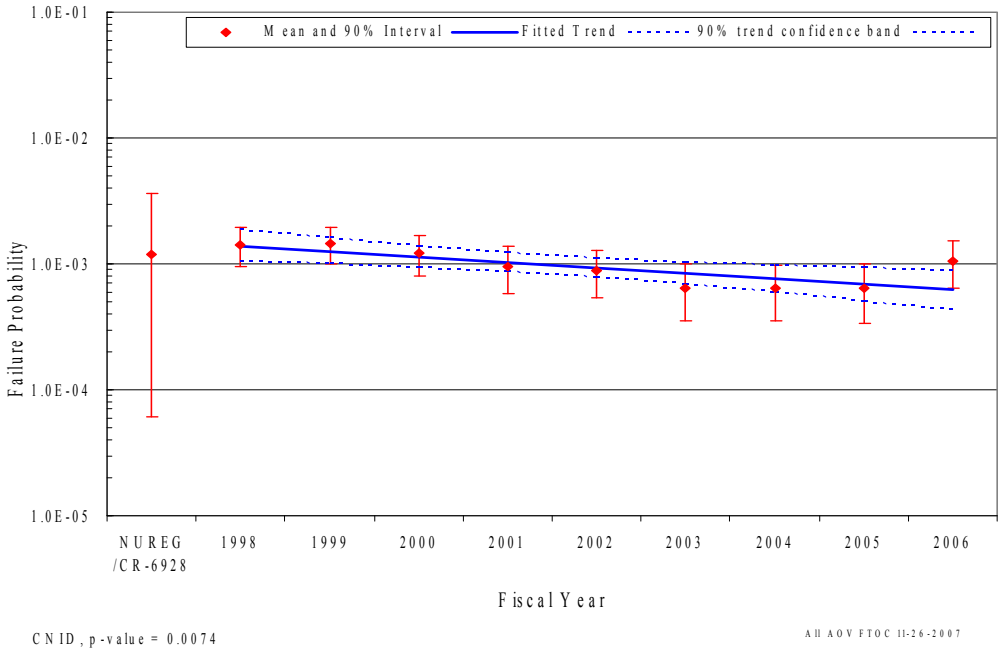

Figure 1. All systems, industry-wide AOV FTOC trend.

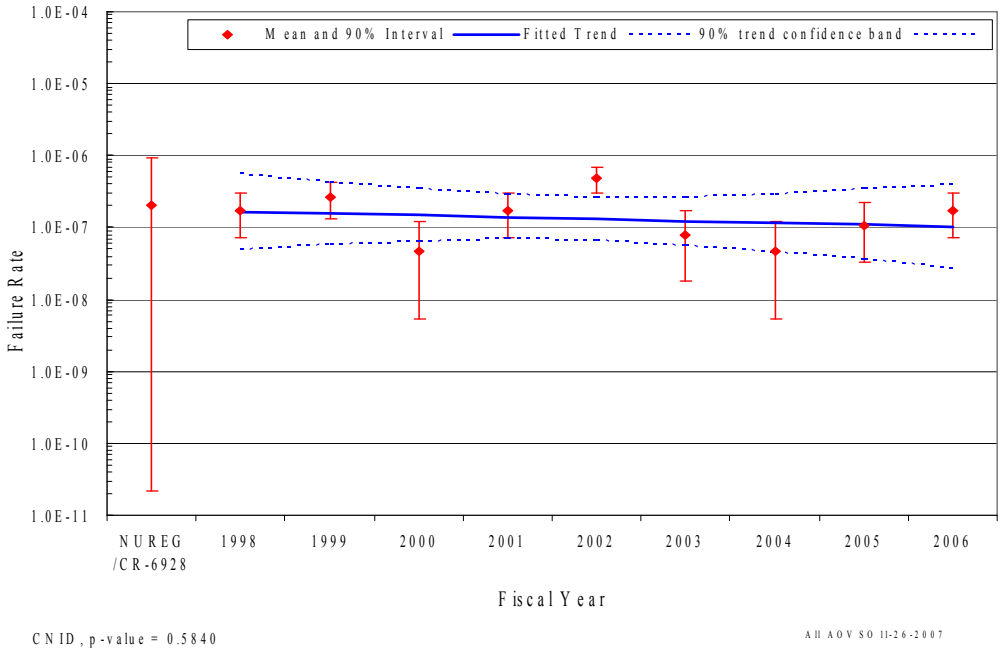

Figure 2. All systems, industry-wide AOV SO trend.

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 AOV failures and demands. The data are normalized by reactor year for plants that have the equipment being trended. Figure 3 shows the trend for AOV 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 AFW, CVC, ESW, and MFW. Table 4 summarizes the failures by system, year, and the SO failure mode. The major contributing systems for the SO failure mode are AFW, CCW, CVC, and MFW. Table 7, Table 8, and Table 9 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.

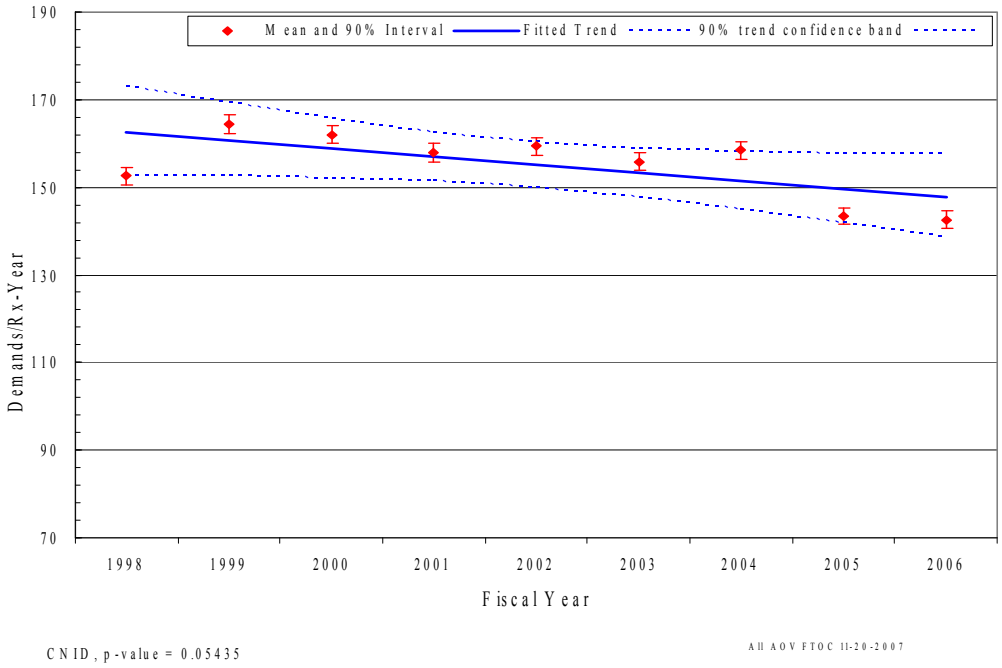

Figure 3. Frequency (events per reactor year) of AOV operation demands.

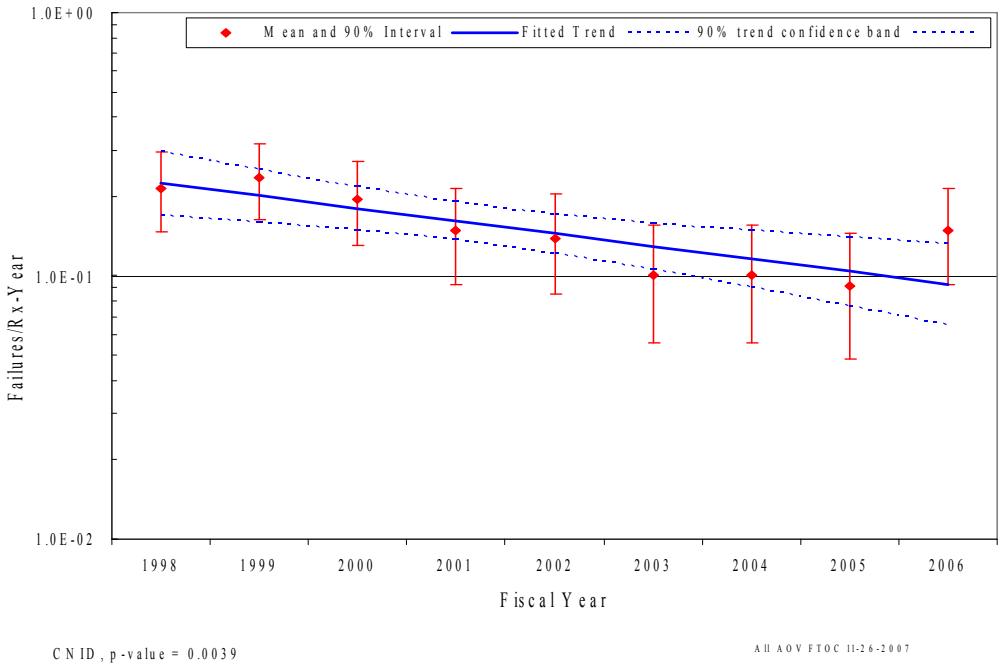

Figure 4. Frequency (events per reactor year) of AOV FTOC events.

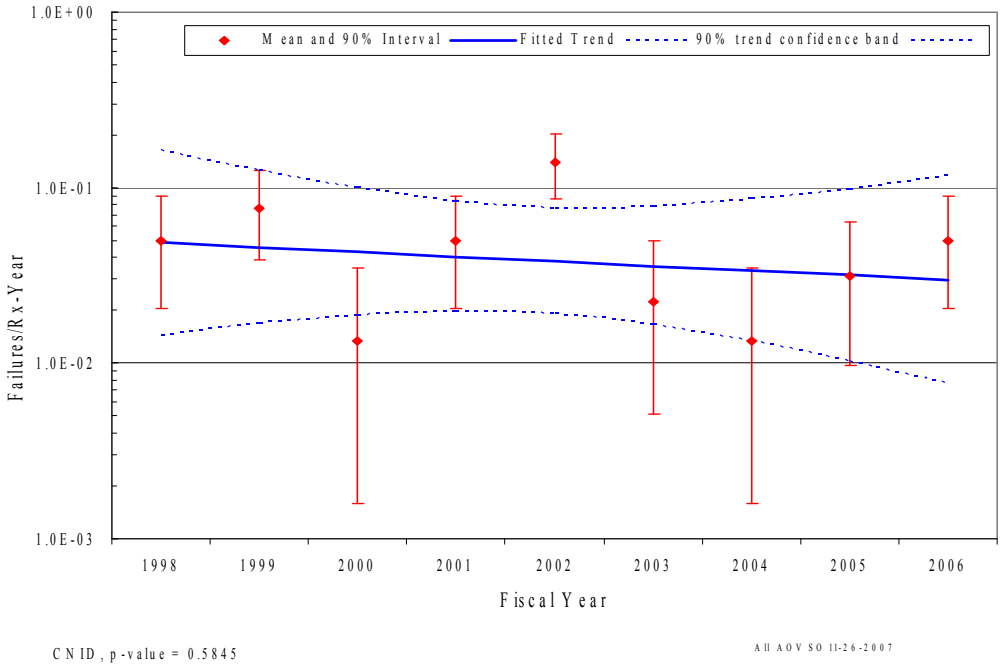

Figure 5. Frequency (events per reactor year) of AOV SO events.

Table 3. Summary of AOV 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	273	8.1%	4	0	1	3	0	0	0	4	2	14	10.1%
CCW	349	10.4%	2	0	2	1	3	1	0	0	2	11	7.9%
CDS	13	0.4%	0	0	0	0	0	0	0	0	0	0	0.0%
CHW	6	0.2%	0	1	1	0	0	0	0	0	0	2	1.4%
CIS	722	21.5%	1	4	2	2	3	1	1	0	0	14	10.1%
CRD	93	2.8%	0	1	1	0	0	0	0	0	0	2	1.4%
CSR	28	0.8%	1	0	0	0	0	0	0	1	0	2	1.4%
CVC	441	13.1%	2	3	1	1	5	2	0	0	1	15	10.8%
EPS	29	0.9%	0	0	0	0	0	0	0	0	0	0	0.0%
ESW	285	8.5%	5	5	2	3	0	1	3	1	3	23	16.5%
FWS	1	0.0%	0	0	0	0	0	0	0	0	0	0	0.0%
HPCI	8	0.2%	0	0	0	0	0	0	0	0	0	0	0.0%
HPSI	82	2.4%	0	0	0	0	0	2	0	0	1	3	2.2%
HVAC	112	3.3%	0	0	0	0	0	0	0	0	1	1	0.7%
IAS	19	0.6%	0	0	0	1	0	0	0	0	0	1	0.7%
ICS	12	0.4%	0	0	0	0	0	0	0	0	0	0	0.0%
ISO	4	0.1%	0	0	0	0	0	0	0	0	0	0	0.0%
LPCI	36	1.1%	0	0	0	0	0	0	0	0	1	1	0.7%
LPCS	9	0.3%	0	1	0	0	0	0	0	0	0	1	0.7%
LPI	210	6.3%	0	3	2	0	1	2	0	0	2	10	7.2%
MFW	319	9.5%	6	6	5	4	2	1	4	3	1	32	23.0%
MSS	101	3.0%	1	0	3	0	0	0	0	0	1	5	3.6%
NSW	99	3.0%	0	0	0	0	0	0	0	0	0	0	0.0%
RCIC	5	0.1%	0	0	0	0	0	0	0	0	0	0	0.0%
RCS	24	0.7%	0	0	0	0	0	0	0	0	0	0	0.0%
RGW	2	0.1%	0	0	0	0	0	0	0	0	0	0	0.0%
RPS	19	0.6%	0	0	0	0	0	0	1	0	0	1	0.7%
RRS	18	0.5%	0	0	0	0	0	0	0	0	0	0	0.0%
VSS	36	1.1%	0	0	0	0	0	0	1	0	0	1	0.7%
Total	3355	100.0%	22	24	20	15	14	10	10	9	15	139	100.0%

Table 4. Summary of AOV 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	273	8.1%	0	0	0	2	1	1	1	0	0	5	11.1%
CCW	349	10.4%	0	2	1	0	7	0	0	0	0	10	22.2%
CDS	13	0.4%	0	0	0	0	0	0	0	0	0	0	0.0%
CHW	6	0.2%	0	0	0	0	0	0	0	0	0	0	0.0%
CIS	722	21.5%	0	0	0	0	0	0	0	0	0	0	0.0%
CRD	93	2.8%	0	4	0	0	0	0	0	0	0	4	8.9%
CSR	28	0.8%	0	0	0	0	0	0	0	0	0	0	0.0%
CVC	441	13.1%	0	0	0	0	5	0	0	1	0	6	13.3%
EPS	29	0.9%	0	0	0	0	0	0	0	0	0	0	0.0%
ESW	285	8.5%	0	0	0	2	0	0	0	0	1	3	6.7%
FWS	1	0.0%	0	0	0	0	0	0	0	0	0	0	0.0%
HPCI	8	0.2%	0	0	0	0	0	0	0	0	0	0	0.0%
HPSI	82	2.4%	0	0	0	0	0	1	0	0	0	1	2.2%
HVAC	112	3.3%	0	0	0	0	0	0	0	0	0	0	0.0%
IAS	19	0.6%	0	0	0	0	0	0	0	0	0	0	0.0%
ICS	12	0.4%	0	0	0	0	0	0	0	0	0	0	0.0%
ISO	4	0.1%	0	0	0	0	0	0	0	0	0	0	0.0%
LPCI	36	1.1%	0	0	0	0	0	0	0	0	0	0	0.0%
LPCS	9	0.3%	0	0	0	0	0	0	0	0	0	0	0.0%
LPI	210	6.3%	2	0	0	0	0	0	0	0	0	2	4.4%
MFW	319	9.5%	3	0	0	1	2	0	0	2	3	11	24.4%
MSS	101	3.0%	0	2	0	0	0	0	0	0	0	2	4.4%
NSW	99	3.0%	0	0	0	0	0	0	0	0	0	0	0.0%
RCIC	5	0.1%	0	0	0	0	0	0	0	0	0	0	0.0%
RCS	24	0.7%	0	0	0	0	0	0	0	0	0	0	0.0%
RGW	2	0.1%	0	0	0	0	0	0	0	0	0	0	0.0%
RPS	19	0.6%	0	0	0	0	0	0	0	0	0	0	0.0%
RRS	18	0.5%	0	0	0	0	0	0	0	0	0	0	0.0%
VSS	36	1.1%	0	0	0	0	0	0	0	0	1	1	2.2%
Total	3355	100.0%	5	8	1	5	15	2	1	3	5	45	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 5. Plot data for industry-wide AOV 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						6.16E-05	3.59E-03	1.20E-03
1998	22	15406.1	1.40E-03	1.04E-03	1.87E-03	9.61E-04	1.93E-03	1.41E-03
1999	24	16601.9	1.26E-03	9.91E-04	1.60E-03	9.91E-04	1.94E-03	1.43E-03
2000	20	16414.8	1.14E-03	9.33E-04	1.39E-03	8.07E-04	1.68E-03	1.21E-03
2001	15	15948.9	1.03E-03	8.62E-04	1.23E-03	5.85E-04	1.37E-03	9.42E-04
2002	14	16092.5	9.29E-04	7.76E-04	1.11E-03	5.33E-04	1.28E-03	8.74E-04
2003	10	15745.4	8.39E-04	6.82E-04	1.03E-03	3.56E-04	1.00E-03	6.46E-04
2004	10	16045.8	7.58E-04	5.89E-04	9.77E-04	3.50E-04	9.86E-04	6.34E-04
2005	9	14487.9	6.85E-04	5.04E-04	9.31E-04	3.37E-04	1.00E-03	6.34E-04
2006	15	14402.6	6.19E-04	4.29E-04	8.93E-04	6.46E-04	1.51E-03	1.04E-03

Table 6. Plot data for industry-wide AOV 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						2.14E-11	9.15E-07	2.00E-07
1998	5	29389800	1.67E-07	4.96E-08	5.61E-07	7.08E-08	3.05E-07	1.70E-07
1999	8	29389800	1.57E-07	5.76E-08	4.28E-07	1.34E-07	4.27E-07	2.63E-07
2000	1	29389800	1.48E-07	6.44E-08	3.39E-07	5.45E-09	1.21E-07	4.64E-08
2001	5	29389800	1.39E-07	6.78E-08	2.85E-07	7.08E-08	3.05E-07	1.70E-07
2002	15	29389800	1.31E-07	6.51E-08	2.63E-07	2.98E-07	6.96E-07	4.80E-07
2003	2	29389800	1.23E-07	5.66E-08	2.68E-07	1.77E-08	1.71E-07	7.74E-08
2004	1	29389800	1.16E-07	4.57E-08	2.94E-07	5.45E-09	1.21E-07	4.64E-08
2005	3	29389800	1.09E-07	3.52E-08	3.38E-07	3.36E-08	2.18E-07	1.08E-07
2006	5	29389800	1.03E-07	2.65E-08	3.97E-07	7.08E-08	3.05E-07	1.70E-07

Table 7. Plot data for frequency (events per reactor year) of AOV 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	15406	101.0	1.63E+02	1.53E+02	1.73E+02	1.51E+02	1.55E+02	1.53E+02
1999	16602	101.0	1.61E+02	1.53E+02	1.69E+02	1.62E+02	1.66E+02	1.64E+02
2000	16415	101.3	1.59E+02	1.52E+02	1.66E+02	1.60E+02	1.64E+02	1.62E+02
2001	15949	101.0	1.57E+02	1.51E+02	1.63E+02	1.56E+02	1.60E+02	1.58E+02
2002	16093	101.0	1.55E+02	1.50E+02	1.60E+02	1.57E+02	1.61E+02	1.59E+02
2003	15745	101.0	1.53E+02	1.48E+02	1.59E+02	1.54E+02	1.58E+02	1.56E+02
2004	16046	101.3	1.51E+02	1.45E+02	1.58E+02	1.56E+02	1.61E+02	1.58E+02
2005	14488	101.0	1.50E+02	1.42E+02	1.58E+02	1.41E+02	1.45E+02	1.43E+02
2006	14403	101.0	1.48E+02	1.39E+02	1.58E+02	1.41E+02	1.45E+02	1.43E+02

Table 8. Plot data for frequency (events per reactor year) of AOV 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	22	101.0	2.25E-01	1.70E-01	2.97E-01	1.47E-01	2.96E-01	2.16E-01
1999	24	101.0	2.01E-01	1.60E-01	2.53E-01	1.63E-01	3.18E-01	2.35E-01
2000	20	101.3	1.80E-01	1.49E-01	2.18E-01	1.31E-01	2.72E-01	1.96E-01
2001	15	101.0	1.61E-01	1.36E-01	1.91E-01	9.25E-02	2.16E-01	1.49E-01
2002	14	101.0	1.45E-01	1.21E-01	1.72E-01	8.49E-02	2.04E-01	1.39E-01
2003	10	101.0	1.29E-01	1.06E-01	1.58E-01	5.56E-02	1.57E-01	1.01E-01
2004	10	101.3	1.16E-01	9.06E-02	1.48E-01	5.54E-02	1.56E-01	1.00E-01
2005	9	101.0	1.04E-01	7.70E-02	1.40E-01	4.85E-02	1.45E-01	9.11E-02
2006	15	101.0	9.29E-02	6.52E-02	1.32E-01	9.25E-02	2.16E-01	1.49E-01

Table 9. Plot data for frequency (events per reactor year) of AOV 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	101.0	4.85E-02	1.44E-02	1.63E-01	2.06E-02	8.86E-02	4.96E-02
1999	8	101.0	4.56E-02	1.67E-02	1.25E-01	3.91E-02	1.24E-01	7.66E-02
2000	1	101.3	4.29E-02	1.87E-02	9.86E-02	1.58E-03	3.51E-02	1.35E-02
2001	5	101.0	4.04E-02	1.97E-02	8.29E-02	2.06E-02	8.86E-02	4.96E-02
2002	15	101.0	3.80E-02	1.89E-02	7.66E-02	8.69E-02	2.03E-01	1.40E-01
2003	2	101.0	3.58E-02	1.64E-02	7.80E-02	5.16E-03	4.99E-02	2.25E-02
2004	1	101.3	3.37E-02	1.33E-02	8.57E-02	1.58E-03	3.51E-02	1.35E-02
2005	3	101.0	3.17E-02	1.02E-02	9.83E-02	9.76E-03	6.34E-02	3.15E-02
2006	5	101.0	2.99E-02	7.70E-03	1.16E-01	2.06E-02	8.86E-02	4.96E-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.