Component Performance Studies

Air-Operated Valves

1987–2004

This report presents a performance evaluation of the air-operated valves (AOVs) at United States commercial reactors. The evaluation is based on the operating experience from 1987 through 2004, as reported in Licensee Event Reports (LERs), Nuclear Plant Reliability Data System (NPRDS), and Equipment Performance and Information Exchange (EPIX). This is the latest update to *NUREG-1715, Volume 3*, updating data, availability estimates, trends, and figures.

1   LATEST UNAVAILABILITY VALUES AND TRENDS

1.1   Overall Unavailability

The industry-wide unavailability of AOVs has been calculated from the operating experience for failure on demand, failure-to-open (FO), and failure-to-close (FC). The estimates are based on failures that occurred during unplanned demands, and cyclic and quarterly surveillance tests.

Table 1 shows overall results for the AOV. Two primary failure modes were identified. Failure probability estimates for the resulting failure modes are given in the table. Both ESF actuations and surveillance tests were treated as opportunities to observe possible failures.

Table 1.   Component performance data from 1987-2004.

Component	Estimated Number of Demands	Failure Mode	Number of Failures	Failure Probability		
				Lower Bound	MLE	Upper Bound
Air Operated Valve	56073	Fail-to-Close	29	2.03E-06	5.17E-04	1.99E-03
	56076	Fail-to-Open	31	2.17E-06	5.53E-04	2.12E-03
	56078	Fail on demand	76	5.33E-06	1.36E-03	5.21E-03

1.2   Unavailability Trend

A highly statistically significant[1] decreasing trend within the industry estimates of AOV failure on demand on a per fiscal year basis was identified. Figure 1 displays the trend by fiscal

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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

year of the AOV failure on demand calculated from the 1987–2004 experience. Table 2 shows the data points for Figure 1.
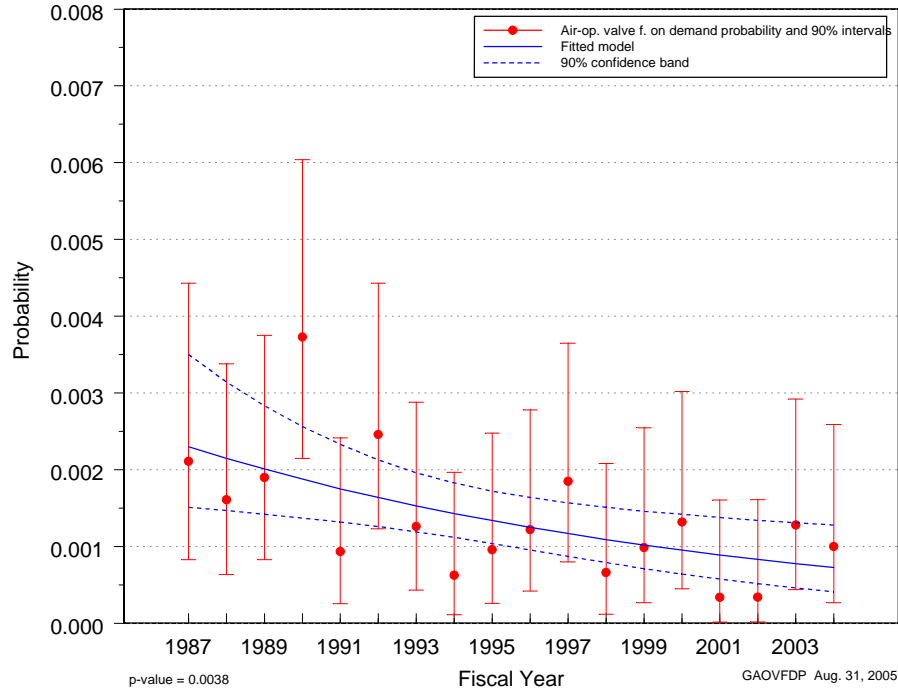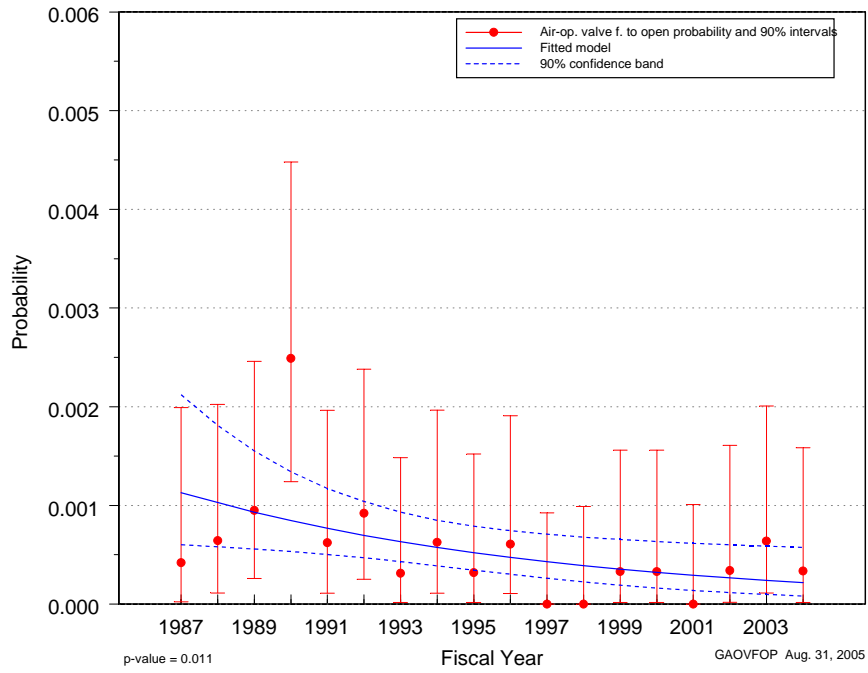

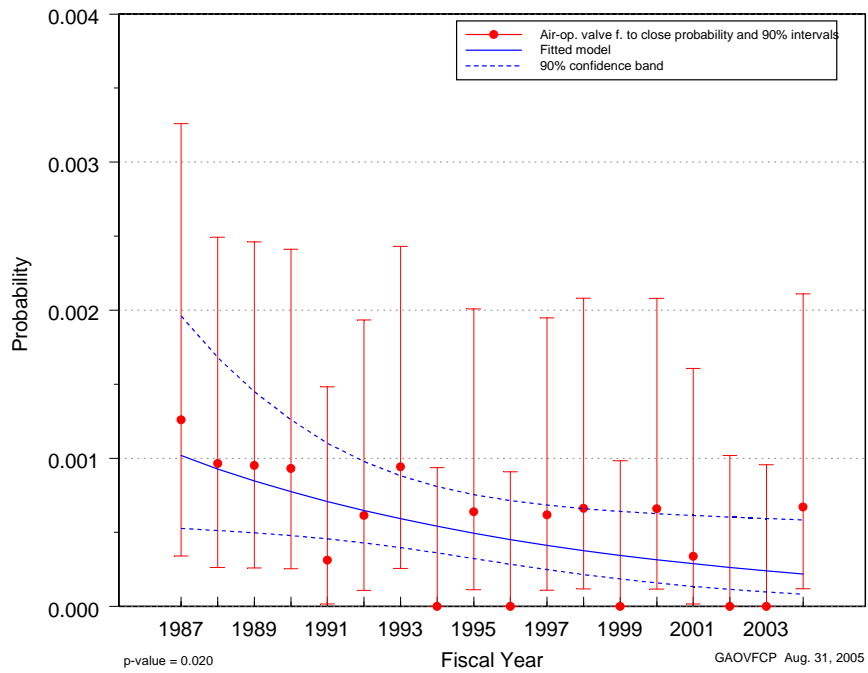**Figure 1. Air-operated valves failure on demand.**

A statistically significant decreasing trend within the industry estimates of AOV FO unavailability on a per fiscal year basis was identified. Figure 2 displays the trend by fiscal year of the AOV FO unavailability calculated from the 1987–2004 experience. Table 3 shows the data points for Figure 2.

A statistically significant decreasing trend within the industry estimates of AOV FC unavailability on a per fiscal year basis was identified. Figure 3 shows the trend in the AOV FC unavailability. Table 4 shows the data points for Figure 3. Each figure is annotated with the p-value.

"Michelin Guide" scale: p-value < 0.05 (statistically significant), p-value < 0.01 (highly statistically significant); p-value < 0.001 (extremely statistically significant).
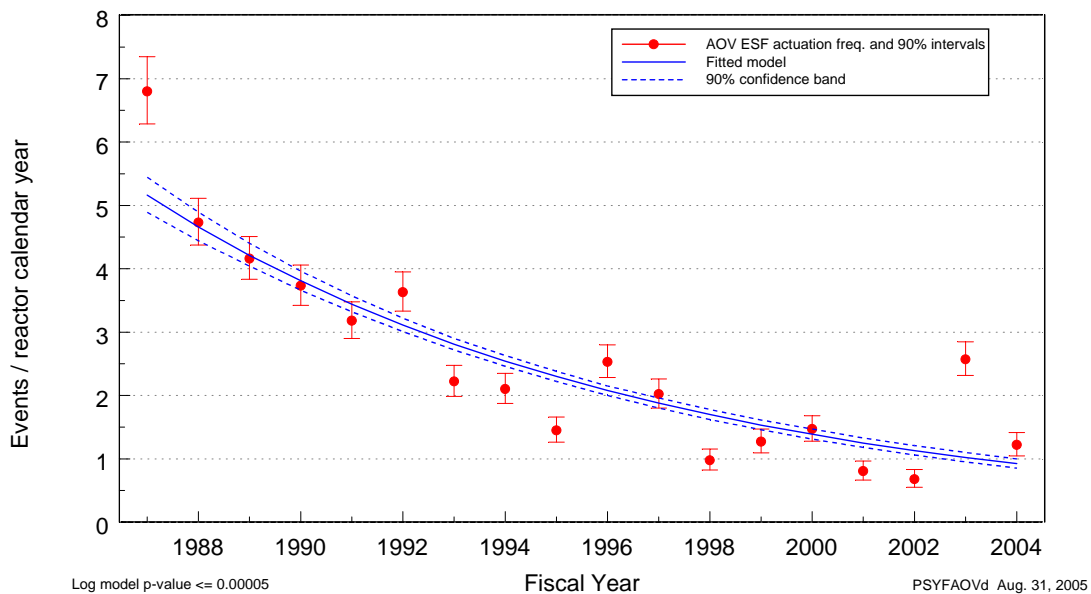
Figure 2. Air-operated valves fail-to-open.

Figure 3. Air-operated valves fail-to-close.

1.3 Unplanned Demand Trend

Trends were identified in the frequency of AOV unplanned demands Figure 4. When modeled as a function of fiscal year, the unplanned demand frequency exhibited an extremely statistically significant decreasing trend. Table 5 shows the plot data.

Figure 4. Frequency (events per operating year) of unplanned demands, as a function of fiscal year.

1.4 Failure Trend

The frequency of all failures (unplanned demands, surveillance tests, inspections, etc.) resulting in component unavailability identified in the experience was analyzed to determine trends. When modeled as a function of fiscal year, an extremely statistically significant decreasing trend was identified. The fitted frequency is plotted against fiscal year in Figure 5. Trends for AOV failures are plotted without regard to method of detection (the trend excludes maintenance out of service and support system failures). Table 6 shows the plot data.
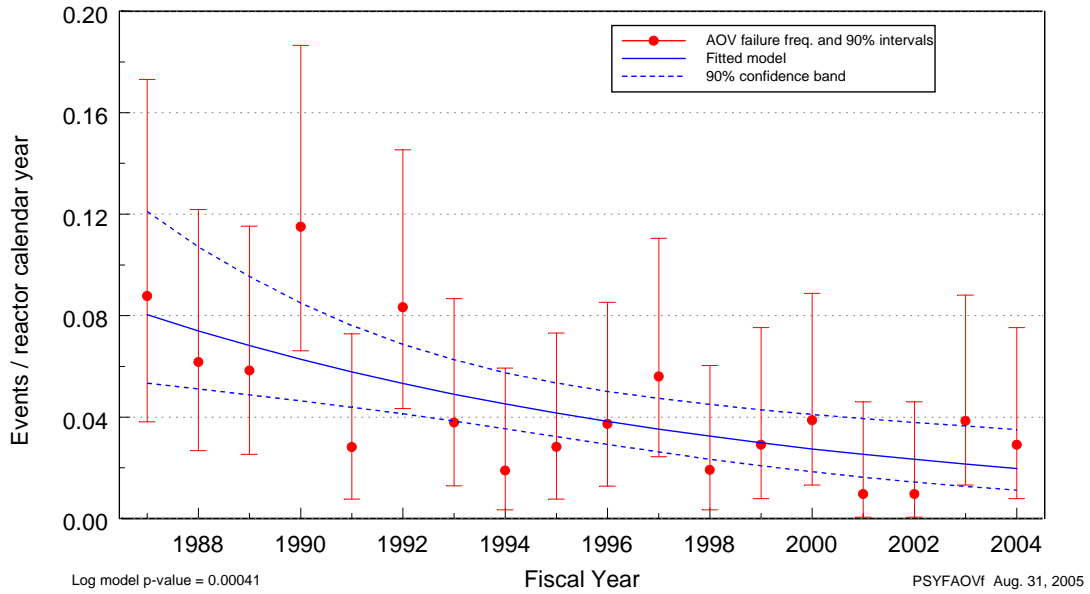
Figure 5. Frequency (events per operating year) of failures, as a function of fiscal year.

1.5 Major Contributors to Component Unreliability and Unavailability

1.5.1 Leading Component Failures.

The valve operator had the most failures in the air-operated valve data. Figure 6 shows the distribution of sub-component failures.

1.5.2 Leading Systems.

Figure 7 shows the distribution of systems.

Valve Body
32%

Valve Air
Operator
68%
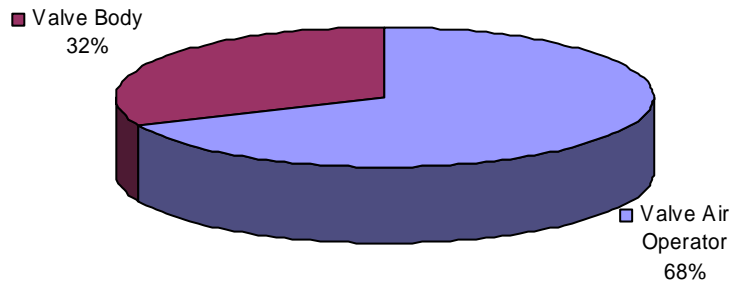
Figure 6. AOV sub-component failure distribution

Figure 7. AOV system failures distribution

2 DATA TABLES

This section contains the data tables that support the charts in the first sections.

Table 2. Plot data table for AOV failure on demand. Figure 1

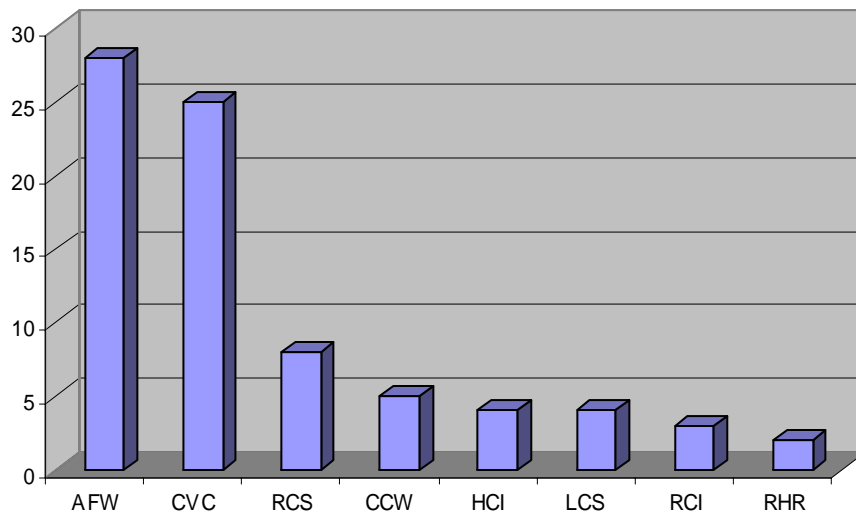| Fiscal Year	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	6.63E-04	1.68E-03	3.53E-03	1.44E-03	2.18E-03	3.31E-03
1988	6.33E-04	1.61E-03	3.38E-03	1.41E-03	2.05E-03	2.99E-03
1989	8.29E-04	1.90E-03	3.75E-03	1.37E-03	1.93E-03	2.71E-03
1990	2.15E-03	3.73E-03	6.03E-03	1.33E-03	1.81E-03	2.47E-03
1991	2.55E-04	9.35E-04	2.41E-03	1.28E-03	1.70E-03	2.25E-03
1992	1.22E-03	2.46E-03	4.43E-03	1.23E-03	1.60E-03	2.07E-03
1993	4.29E-04	1.26E-03	2.87E-03	1.17E-03	1.50E-03	1.92E-03
1994	1.11E-04	6.26E-04	1.97E-03	1.10E-03	1.41E-03	1.80E-03
1995	2.61E-04	9.59E-04	2.48E-03	1.03E-03	1.32E-03	1.70E-03
1996	4.15E-04	1.22E-03	2.78E-03	9.49E-04	1.24E-03	1.62E-03
1997	8.08E-04	1.85E-03	3.66E-03	8.70E-04	1.17E-03	1.56E-03
1998	1.18E-04	6.62E-04	2.08E-03	7.93E-04	1.10E-03	1.51E-03
1999	2.69E-04	9.86E-04	2.55E-03	7.20E-04	1.03E-03	1.47E-03
2000	4.51E-04	1.32E-03	3.02E-03	6.52E-04	9.66E-04	1.43E-03
2001	1.74E-05	3.38E-04	1.60E-03	5.88E-04	9.07E-04	1.40E-03
2002	1.74E-05	3.40E-04	1.61E-03	5.30E-04	8.52E-04	1.37E-03
2003	4.36E-04	1.28E-03	2.92E-03	4.77E-04	8.00E-04	1.34E-03
2004	2.74E-04	1.00E-03	2.59E-03	4.28E-04	7.51E-04	1.32E-03

Table 3. Plot data table for AOV fail-to-open. Figure 2

Fiscal Year	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	1.73E-05	3.36E-04	1.60E-03	5.72E-04	1.07E-03	2.00E-03
1988	1.14E-04	6.43E-04	2.02E-03	5.55E-04	9.76E-04	1.71E-03
1989	2.59E-04	9.51E-04	2.46E-03	5.36E-04	8.91E-04	1.48E-03
1990	1.24E-03	2.49E-03	4.48E-03	5.14E-04	8.14E-04	1.29E-03
1991	1.11E-04	6.23E-04	1.96E-03	4.87E-04	7.43E-04	1.13E-03
1992	2.51E-04	9.21E-04	2.38E-03	4.57E-04	6.78E-04	1.01E-03
1993	1.61E-05	3.14E-04	1.49E-03	4.21E-04	6.19E-04	9.11E-04
1994	1.11E-04	6.26E-04	1.97E-03	3.82E-04	5.66E-04	8.37E-04
1995	1.64E-05	3.20E-04	1.52E-03	3.41E-04	5.16E-04	7.81E-04
1996	1.08E-04	6.08E-04	1.91E-03	3.01E-04	4.71E-04	7.39E-04
1997	0.00E+00	0.00E+00	9.25E-04	2.62E-04	4.30E-04	7.06E-04
1998	0.00E+00	0.00E+00	9.90E-04	2.27E-04	3.93E-04	6.80E-04
1999	1.69E-05	3.29E-04	1.56E-03	1.95E-04	3.59E-04	6.60E-04
2000	1.69E-05	3.30E-04	1.56E-03	1.67E-04	3.28E-04	6.42E-04
2001	0.00E+00	0.00E+00	1.01E-03	1.43E-04	2.99E-04	6.27E-04
2002	1.74E-05	3.40E-04	1.61E-03	1.22E-04	2.73E-04	6.14E-04
2003	1.13E-04	6.38E-04	2.01E-03	1.03E-04	2.49E-04	6.02E-04
2004	1.72E-05	3.35E-04	1.59E-03	8.77E-05	2.28E-04	5.91E-04

Table 4. Plot data table for AOV fail-to-close. Figure 3

Fiscal Year	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	2.75E-04	1.01E-03	2.61E-03	5.01E-04	9.62E-04	1.85E-03
1988	2.63E-04	9.64E-04	2.49E-03	4.90E-04	8.84E-04	1.59E-03
1989	2.59E-04	9.52E-04	2.46E-03	4.77E-04	8.12E-04	1.38E-03
1990	2.54E-04	9.32E-04	2.41E-03	4.61E-04	7.46E-04	1.21E-03
1991	1.60E-05	3.12E-04	1.48E-03	4.41E-04	6.85E-04	1.06E-03
1992	1.09E-04	6.14E-04	1.93E-03	4.17E-04	6.30E-04	9.51E-04
1993	2.57E-04	9.42E-04	2.43E-03	3.88E-04	5.79E-04	8.62E-04
1994	0.00E+00	0.00E+00	9.37E-04	3.55E-04	5.32E-04	7.95E-04
1995	1.14E-04	6.39E-04	2.01E-03	3.20E-04	4.89E-04	7.46E-04
1996	0.00E+00	0.00E+00	9.10E-04	2.84E-04	4.49E-04	7.09E-04
1997	1.10E-04	6.18E-04	1.94E-03	2.50E-04	4.12E-04	6.82E-04
1998	1.18E-04	6.62E-04	2.08E-03	2.17E-04	3.79E-04	6.61E-04
1999	0.00E+00	0.00E+00	9.84E-04	1.88E-04	3.48E-04	6.45E-04
2000	1.17E-04	6.60E-04	2.08E-03	1.62E-04	3.20E-04	6.33E-04
2001	1.74E-05	3.38E-04	1.60E-03	1.39E-04	2.94E-04	6.22E-04
2002	0.00E+00	0.00E+00	1.02E-03	1.19E-04	2.70E-04	6.14E-04
2003	0.00E+00	0.00E+00	9.56E-04	1.02E-04	2.48E-04	6.07E-04
2004	1.19E-04	6.70E-04	2.11E-03	8.66E-05	2.28E-04	6.01E-04

Table 5. Plot data for demand trend. Figure 4

Fiscal Year	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	4.72E+00	5.10E+00	5.51E+00	4.57E+00	4.82E+00	5.08E+00
1988	4.38E+00	4.73E+00	5.11E+00	4.18E+00	4.39E+00	4.60E+00
1989	3.83E+00	4.16E+00	4.51E+00	3.83E+00	3.99E+00	4.17E+00
1990	3.42E+00	3.73E+00	4.06E+00	3.50E+00	3.63E+00	3.78E+00
1991	2.90E+00	3.18E+00	3.48E+00	3.19E+00	3.31E+00	3.43E+00
1992	3.33E+00	3.63E+00	3.94E+00	2.91E+00	3.01E+00	3.11E+00
1993	1.98E+00	2.22E+00	2.47E+00	2.65E+00	2.74E+00	2.83E+00
1994	1.88E+00	2.10E+00	2.35E+00	2.41E+00	2.49E+00	2.57E+00
1995	1.27E+00	1.45E+00	1.66E+00	2.19E+00	2.27E+00	2.35E+00
1996	2.28E+00	2.53E+00	2.79E+00	1.99E+00	2.06E+00	2.14E+00
1997	1.80E+00	2.02E+00	2.26E+00	1.80E+00	1.88E+00	1.96E+00
1998	8.25E-01	9.78E-01	1.15E+00	1.63E+00	1.71E+00	1.79E+00
1999	1.09E+00	1.27E+00	1.47E+00	1.48E+00	1.56E+00	1.64E+00
2000	1.28E+00	1.47E+00	1.68E+00	1.34E+00	1.42E+00	1.50E+00
2001	6.66E-01	8.06E-01	9.67E-01	1.21E+00	1.29E+00	1.37E+00
2002	5.52E-01	6.80E-01	8.29E-01	1.10E+00	1.17E+00	1.25E+00
2003	2.32E+00	2.57E+00	2.85E+00	9.92E-01	1.07E+00	1.15E+00
2004	1.05E+00	1.22E+00	1.42E+00	8.97E-01	9.71E-01	1.05E+00

Table 6. Plot data for failure trend. Figure 5

Fiscal Year	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	2.87E-02	6.58E-02	1.30E-01	5.03E-02	7.54E-02	1.13E-01
1988	2.69E-02	6.17E-02	1.22E-01	4.84E-02	6.99E-02	1.01E-01
1989	2.54E-02	5.84E-02	1.15E-01	4.65E-02	6.48E-02	9.03E-02
1990	6.65E-02	1.15E-01	1.87E-01	4.45E-02	6.00E-02	8.10E-02
1991	7.68E-03	2.82E-02	7.29E-02	4.23E-02	5.56E-02	7.31E-02
1992	4.35E-02	8.33E-02	1.45E-01	4.00E-02	5.15E-02	6.65E-02
1993	1.29E-02	3.79E-02	8.67E-02	3.74E-02	4.78E-02	6.09E-02
1994	3.35E-03	1.89E-02	5.94E-02	3.47E-02	4.43E-02	5.64E-02
1995	7.71E-03	2.83E-02	7.31E-02	3.19E-02	4.10E-02	5.27E-02
1996	1.27E-02	3.73E-02	8.53E-02	2.91E-02	3.80E-02	4.97E-02
1997	2.44E-02	5.60E-02	1.11E-01	2.63E-02	3.52E-02	4.72E-02
1998	3.41E-03	1.92E-02	6.04E-02	2.36E-02	3.26E-02	4.51E-02
1999	7.94E-03	2.91E-02	7.53E-02	2.11E-02	3.02E-02	4.33E-02
2000	1.33E-02	3.88E-02	8.89E-02	1.89E-02	2.80E-02	4.17E-02
2001	4.98E-04	9.71E-03	4.61E-02	1.68E-02	2.60E-02	4.02E-02
2002	4.98E-04	9.71E-03	4.61E-02	1.49E-02	2.41E-02	3.88E-02
2003	1.31E-02	3.85E-02	8.80E-02	1.32E-02	2.23E-02	3.76E-02
2004	7.94E-03	2.91E-02	7.53E-02	1.17E-02	2.07E-02	3.64E-02

3   COMPONENT DESCRIPTIONS AND BOUNDARIES

3.1   AOV Assembly Description and Boundaries

An AOV assembly consists of a valve body and pneumatic operator sub-components (excludes 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 AOV component boundaries are the AOV assembly, its sub-components described above, and the piece-parts of the sub-components. 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.