Component Performance Studies

Air-Operated Valves

1987–2002

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 2002, 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*.

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 for the 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 combinations 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 1987-2002.

Component	Estimated Number of Demands	Failure Mode	Number of Failures	Failure Probability		
				Lower Bound	MLE	Upper Bound
Air-operated valve	49924	Failure on demand	72	1.18E-03	1.44E-03	1.74E-03
	49924	Failure to close	28	4.07E-04	5.61E-04	7.57E-04
	49924	Failure to open	28	4.07E-04	5.61E-04	7.57E-04

1.2 Unavailability Trend

A 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 year of the AOV failure on demand calculated from the 1987–2002 experience. Table 2 shows the data points for Figure 1. A statistically significant decreasing trend within the industry estimates of

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1.   The term "statistically significant" means that the data are too closely correlated to be attributed to chances and consequently have a systematic relationship. A p-value of less than 0.05 is generally considered to be statistically significant.

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 1987–2002 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[2].
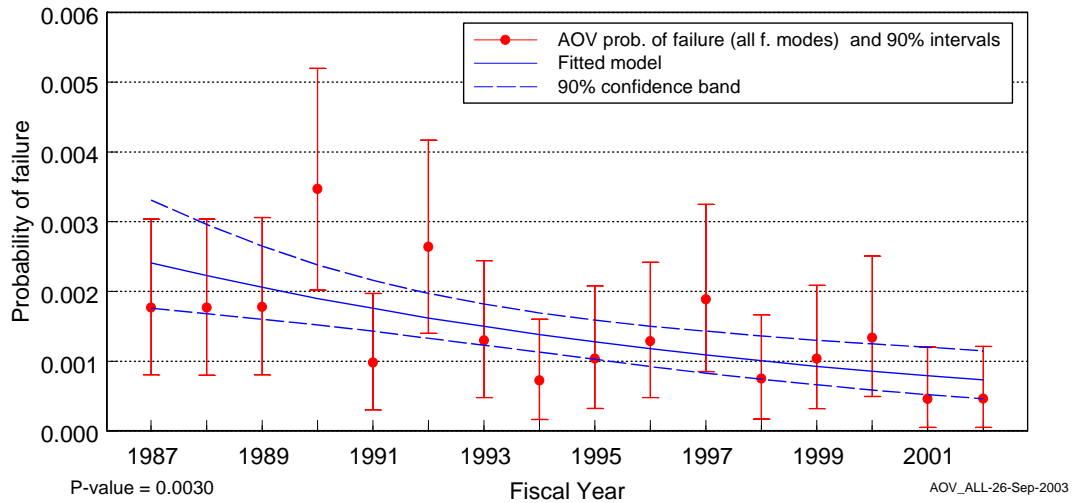

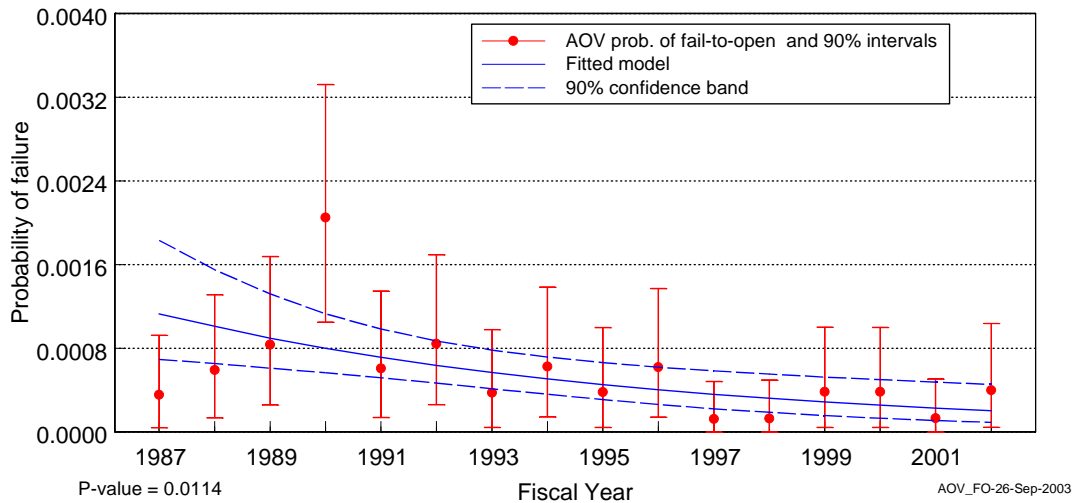**Figure 1. Air-operated valves failure on demand.**

Figure 2. Air-operated valves fail-to-open.

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2.   A p-value is a probability, with a value between zero and one, which is a measure of statistical significance. The smaller the p-value, the greater the significance. A p-value of less than 0.05 is generally considered statistically significant.
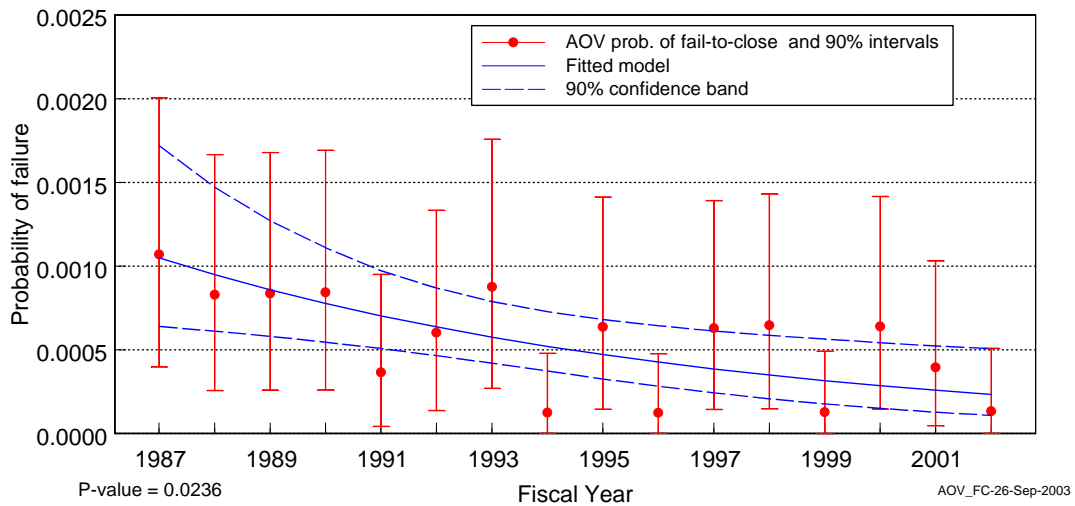
Figure 3. Air-operated valves fail-to-close.

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 a highly statistically significant decreasing trend. Table 5 shows the plot data.
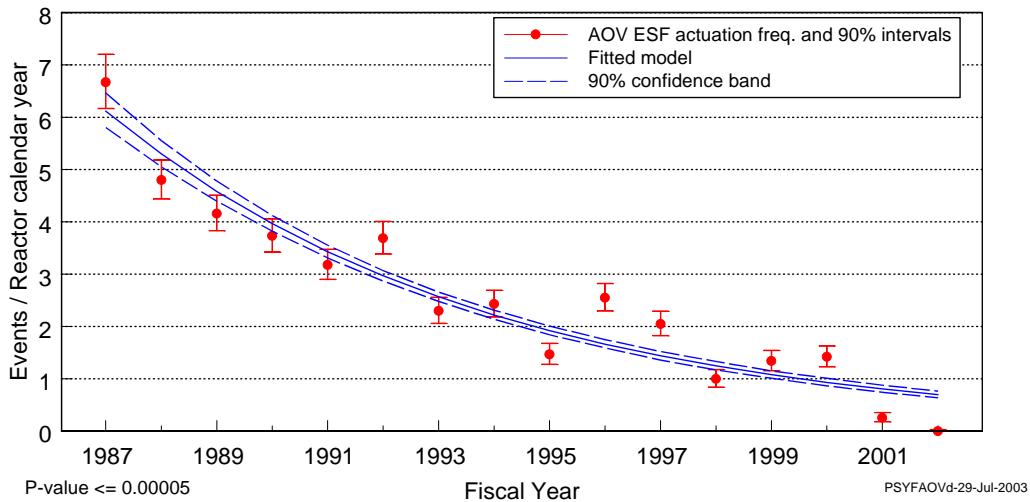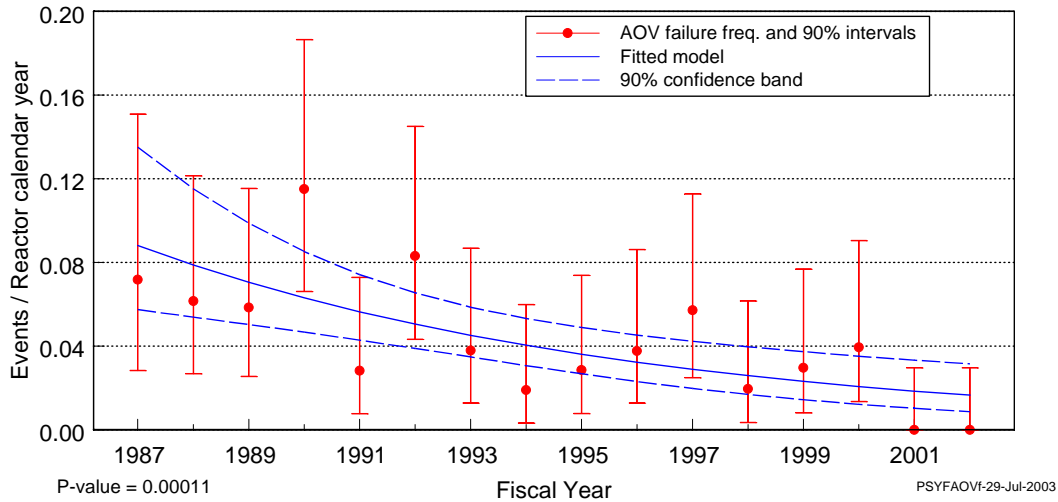

Figure 4. Frequency (events per operating year) of unplanned demands, as a function of fiscal year.

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, a 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.
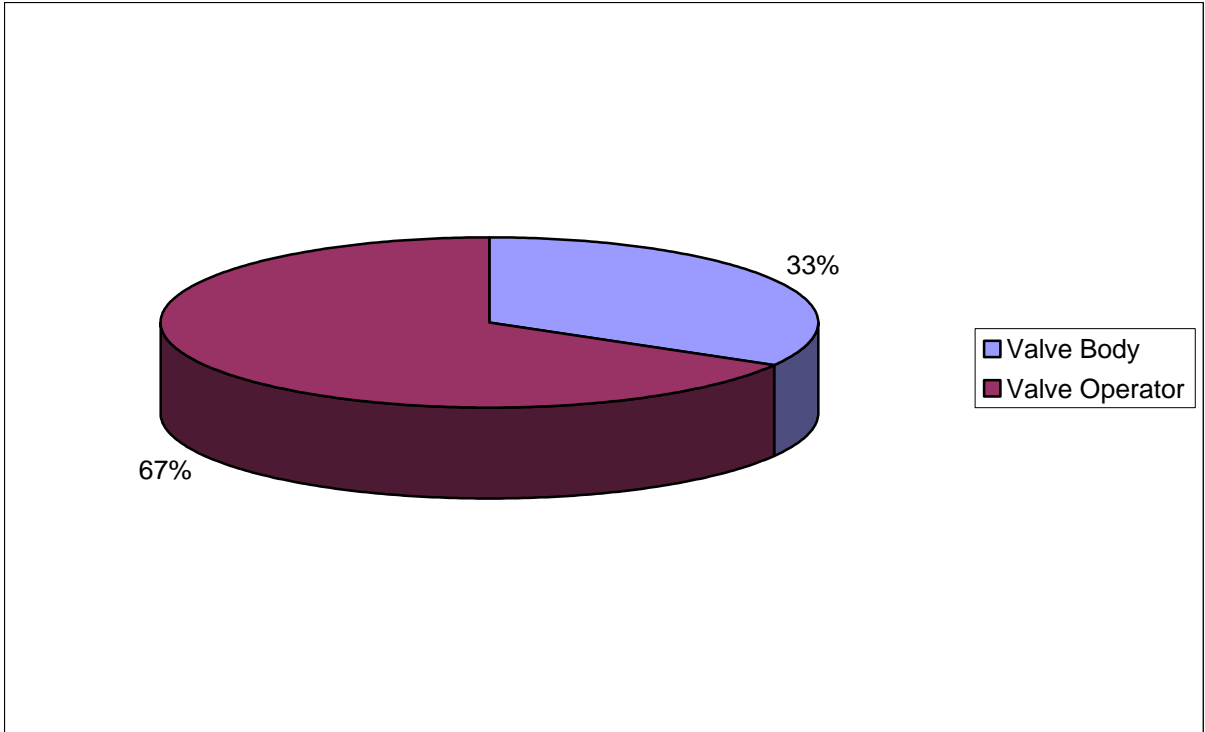
Figure 6. AOV sub-component distribution

1.5.2 Leading Systems.

Figure 7 shows the distribution of systems.

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 fail on demand. Figure 1

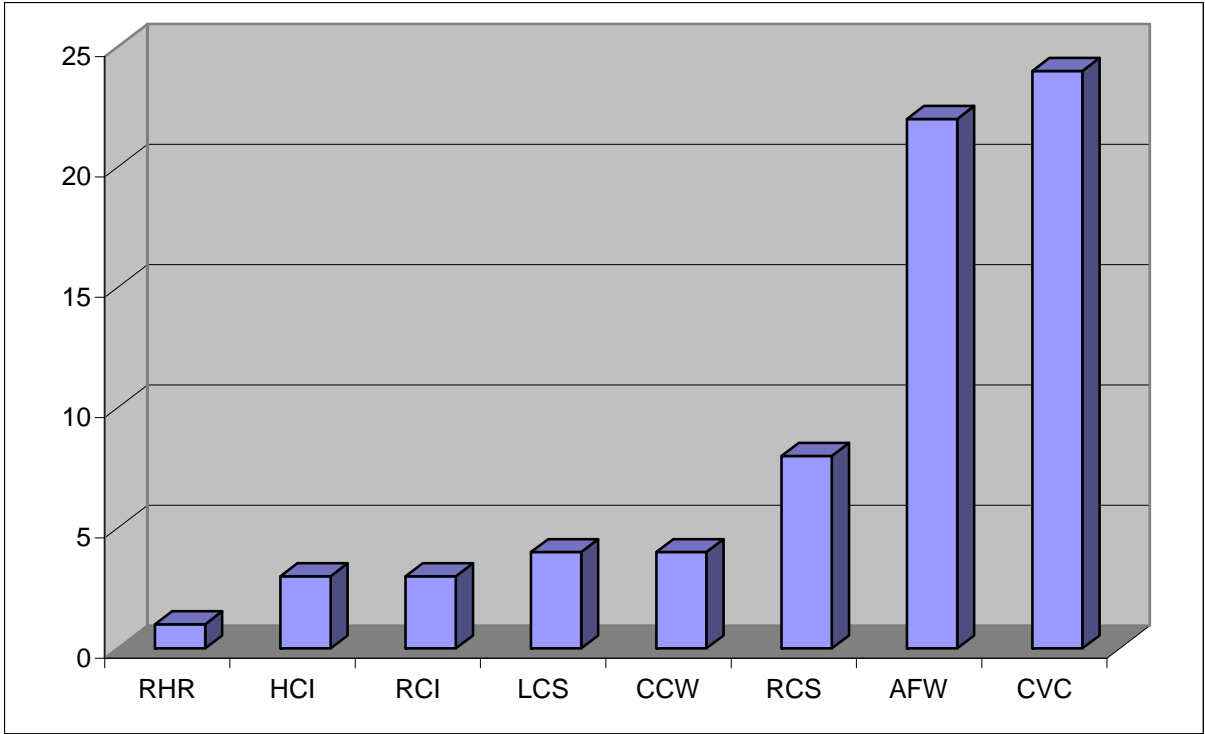| Fiscal Year	Plot Trend Error Bar Points			Regression Curve Data Points		
	Lower (5%)	Mean	Upper (95%)	Lower (5%)	Mean	Upper (95%)
1987	8.00E-04	1.77E-03	3.03E-03	1.76E-03	2.41E-03	3.31E-03
1988	8.01E-04	1.77E-03	3.04E-03	1.68E-03	2.23E-03	2.96E-03
1989	8.08E-04	1.78E-03	3.06E-03	1.60E-03	2.06E-03	2.65E-03
1990	2.02E-03	3.47E-03	5.20E-03	1.52E-03	1.90E-03	2.38E-03
1991	3.04E-04	9.83E-04	1.97E-03	1.43E-03	1.76E-03	2.16E-03
1992	1.40E-03	2.64E-03	4.17E-03	1.33E-03	1.62E-03	1.97E-03
1993	4.81E-04	1.30E-03	2.45E-03	1.23E-03	1.50E-03	1.82E-03
1994	1.66E-04	7.24E-04	1.60E-03	1.13E-03	1.38E-03	1.69E-03
1995	3.21E-04	1.04E-03	2.08E-03	1.03E-03	1.28E-03	1.59E-03
1996	4.76E-04	1.29E-03	2.42E-03	9.24E-04	1.18E-03	1.50E-03
1997	8.57E-04	1.89E-03	3.25E-03	8.29E-04	1.09E-03	1.43E-03
1998	1.72E-04	7.52E-04	1.66E-03	7.41E-04	1.01E-03	1.36E-03
1999	3.23E-04	1.04E-03	2.10E-03	6.61E-04	9.28E-04	1.30E-03
2000	4.94E-04	1.34E-03	2.51E-03	5.88E-04	8.57E-04	1.25E-03
2001	5.40E-05	4.62E-04	1.20E-03	5.22E-04	7.92E-04	1.20E-03
2002	5.44E-05	4.65E-04	1.21E-03	4.63E-04	7.31E-04	1.15E-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	4.16E-05	3.55E-04	9.25E-04	6.94E-04	1.13E-03	1.83E-03
1988	1.36E-04	5.93E-04	1.31E-03	6.54E-04	1.01E-03	1.55E-03
1989	2.59E-04	8.36E-04	1.68E-03	6.12E-04	8.97E-04	1.32E-03
1990	1.04E-03	2.05E-03	3.32E-03	5.67E-04	8.01E-04	1.13E-03
1991	1.39E-04	6.09E-04	1.35E-03	5.19E-04	7.15E-04	9.84E-04
1992	2.61E-04	8.44E-04	1.69E-03	4.68E-04	6.38E-04	8.70E-04
1993	4.40E-05	3.75E-04	9.77E-04	4.14E-04	5.69E-04	7.83E-04
1994	1.43E-04	6.26E-04	1.38E-03	3.61E-04	5.08E-04	7.16E-04
1995	4.48E-05	3.83E-04	9.97E-04	3.10E-04	4.53E-04	6.63E-04
1996	1.42E-04	6.20E-04	1.37E-03	2.64E-04	4.05E-04	6.20E-04
1997	4.89E-07	1.26E-04	4.83E-04	2.23E-04	3.61E-04	5.84E-04
1998	5.03E-07	1.29E-04	4.96E-04	1.88E-04	3.22E-04	5.53E-04
1999	4.51E-05	3.85E-04	1.00E-03	1.58E-04	2.88E-04	5.25E-04
2000	4.50E-05	3.84E-04	9.99E-04	1.32E-04	2.57E-04	5.00E-04
2001	5.13E-07	1.32E-04	5.06E-04	1.10E-04	2.29E-04	4.76E-04
2002	4.67E-05	3.99E-04	1.04E-03	9.18E-05	2.04E-04	4.55E-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	3.94E-04	1.07E-03	2.00E-03	6.40E-04	1.05E-03	1.72E-03
1988	2.57E-04	8.30E-04	1.67E-03	6.11E-04	9.49E-04	1.47E-03
1989	2.59E-04	8.36E-04	1.68E-03	5.81E-04	8.59E-04	1.27E-03
1990	2.61E-04	8.43E-04	1.69E-03	5.46E-04	7.77E-04	1.11E-03
1991	4.28E-05	3.65E-04	9.51E-04	5.08E-04	7.03E-04	9.73E-04
1992	1.38E-04	6.03E-04	1.33E-03	4.66E-04	6.37E-04	8.69E-04
1993	2.71E-04	8.76E-04	1.76E-03	4.20E-04	5.76E-04	7.89E-04
1994	4.86E-07	1.25E-04	4.80E-04	3.73E-04	5.21E-04	7.28E-04
1995	1.46E-04	6.38E-04	1.41E-03	3.26E-04	4.72E-04	6.81E-04
1996	4.82E-07	1.24E-04	4.76E-04	2.83E-04	4.27E-04	6.44E-04
1997	1.44E-04	6.29E-04	1.39E-03	2.43E-04	3.86E-04	6.13E-04
1998	1.48E-04	6.47E-04	1.43E-03	2.08E-04	3.50E-04	5.87E-04
1999	4.99E-07	1.28E-04	4.93E-04	1.77E-04	3.16E-04	5.64E-04
2000	1.46E-04	6.40E-04	1.42E-03	1.51E-04	2.86E-04	5.43E-04
2001	4.64E-05	3.96E-04	1.03E-03	1.28E-04	2.59E-04	5.24E-04
2002	5.16E-07	1.33E-04	5.10E-04	1.08E-04	2.34E-04	5.07E-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	6.17E+00	6.67E+00	7.21E+00	5.80E+00	6.12E+00	6.46E+00
1988	4.44E+00	4.80E+00	5.18E+00	5.05E+00	5.30E+00	5.55E+00
1989	3.84E+00	4.16E+00	4.51E+00	4.39E+00	4.58E+00	4.78E+00
1990	3.42E+00	3.73E+00	4.06E+00	3.82E+00	3.97E+00	4.12E+00
1991	2.90E+00	3.18E+00	3.48E+00	3.31E+00	3.43E+00	3.55E+00
1992	3.39E+00	3.69E+00	4.01E+00	2.87E+00	2.97E+00	3.07E+00
1993	2.06E+00	2.30E+00	2.55E+00	2.48E+00	2.57E+00	2.66E+00
1994	2.18E+00	2.43E+00	2.69E+00	2.14E+00	2.22E+00	2.31E+00
1995	1.28E+00	1.47E+00	1.68E+00	1.84E+00	1.92E+00	2.01E+00
1996	2.30E+00	2.55E+00	2.82E+00	1.59E+00	1.66E+00	1.75E+00
1997	1.83E+00	2.05E+00	2.30E+00	1.36E+00	1.44E+00	1.52E+00
1998	8.41E-01	9.98E-01	1.18E+00	1.17E+00	1.25E+00	1.33E+00
1999	1.15E+00	1.34E+00	1.54E+00	1.01E+00	1.08E+00	1.15E+00
2000	1.23E+00	1.42E+00	1.63E+00	8.65E-01	9.33E-01	1.01E+00
2001	1.80E-01	2.57E-01	3.57E-01	7.42E-01	8.07E-01	8.78E-01
2002	0.00E+00	0.00E+00	2.97E-02	6.37E-01	6.99E-01	7.66E-01

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	2.83E-02	7.18E-02	1.51E-01	5.75E-02	8.81E-02	1.35E-01
1988	2.68E-02	6.15E-02	1.21E-01	5.39E-02	7.88E-02	1.15E-01
1989	2.55E-02	5.85E-02	1.15E-01	5.03E-02	7.05E-02	9.87E-02
1990	6.65E-02	1.15E-01	1.87E-01	4.67E-02	6.31E-02	8.52E-02
1991	7.68E-03	2.82E-02	7.29E-02	4.29E-02	5.64E-02	7.42E-02
1992	4.34E-02	8.31E-02	1.45E-01	3.89E-02	5.05E-02	6.55E-02
1993	1.30E-02	3.79E-02	8.68E-02	3.48E-02	4.52E-02	5.86E-02
1994	3.38E-03	1.90E-02	6.00E-02	3.07E-02	4.04E-02	5.32E-02
1995	7.79E-03	2.86E-02	7.38E-02	2.68E-02	3.62E-02	4.89E-02
1996	1.29E-02	3.77E-02	8.62E-02	2.31E-02	3.23E-02	4.53E-02
1997	2.48E-02	5.71E-02	1.13E-01	1.98E-02	2.89E-02	4.23E-02
1998	3.48E-03	1.96E-02	6.16E-02	1.69E-02	2.59E-02	3.97E-02
1999	8.10E-03	2.97E-02	7.68E-02	1.44E-02	2.32E-02	3.74E-02
2000	1.35E-02	3.95E-02	9.04E-02	1.22E-02	2.07E-02	3.52E-02
2001	0.00E+00	0.00E+00	2.97E-02	1.03E-02	1.85E-02	3.33E-02
2002	0.00E+00	0.00E+00	2.97E-02	8.73E-03	1.66E-02	3.15E-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.