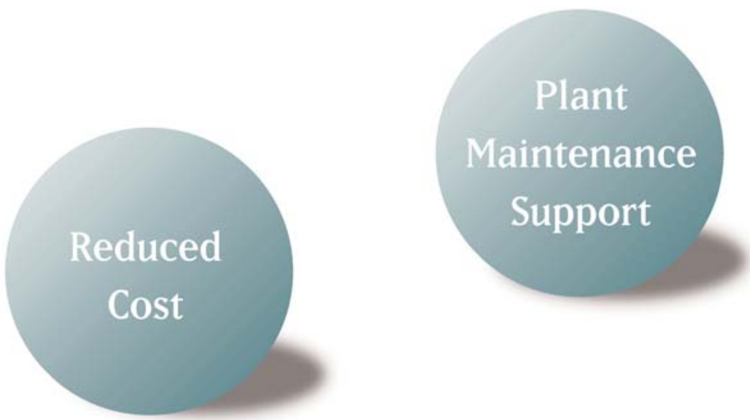
Severe Duty Valve Maintenance Guide

Technical Report



Severe Duty Valve Maintenance Guide

1011828

Final Report, December 2005

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CITATIONS

This report was prepared by

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This report describes research sponsored by EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

Severe Duty Valve Maintenance Guide. EPRI, Palo Alto, CA: 2005. 1011828.

REPORT SUMMARY

Background

Certain plant valves operate in extreme plant conditions that are challenging to valve operation. These conditions represent the extreme limits of design and operation and frequently result in failures that are considered premature. The Fossil Maintenance Applications Center (FMAC) and Nuclear Maintenance Applications Center (NMAC) membership identified these valves to include attemperators (desuperheating valves), feedpump discharge check valves, feedpump recirculation (miniflow) control valves, feedwater regulating valves, high pressure drain valves, atmospheric dump valve, condenser dump valves, and pressurizer spray valves.

Objectives

- To reduce plant events caused by valves used in applications that typically have a high failure rate due to extreme operating conditions
- To improve personnel training by providing information to help power plant personnel better understand these valves
- To provide effective methods of proper inspection, problem diagnosis, maintenance, and repair

Approach

Severe duty valves shared the main characteristic of fluid high pressure drop. This characteristic can result in a variety of problems including seat damage, through-wall erosion, mechanical failures, and the like. To determine what maintenance actions would be required, a survey of utility and industry failure databases was carried out to determine specific problems and commonly encountered failure mechanisms/causes. Using the results of the survey, a review of EPRI and industry literature, product information, and standards to identify various valve designs, applications, and maintenance practices was conducted. Based on this review, recommendations for condition monitoring/preventive maintenance, and troubleshooting methods were identified.

The vast number of designs encountered indicated that to provide specific valve design procedures was not practical. The results of the surveys showed that previous EPRI guides already existed that addressed many of the problems and would provide background information to facilitate the use of vendor technical manuals. Therefore, severe duty valve maintenance was presented in terms of what caused the failures, actions to prevent these failures, and what guides and valve designs exist that address these failures and actions.

Results

This guide is designed to be used by both maintenance and engineering personnel. It provides sufficient descriptive information to allow plant personnel to obtain a working knowledge of each valve. Failure modes and causes are identified to facilitate plant investigations of failure root causes. Other sections include troubleshooting, predictive techniques, and technology to aid in condition-based monitoring, special maintenance tasks, and preventive maintenance recommendations.

EPRI Perspective

Severe duty valves represent a major challenge to reliable plant operation. Focusing on maintenance of these valves can provide large benefits in meeting the reliability and efficiency requirement of future energy generation needs. While this guide was written to address specific valves identified by FMAC and NMAC membership, it can be used to address problems for other valves that see the severe operating conditions associated with fluid high pressure drop.

Keywords

Severe duty
High-pressure drop
Check valve
Feedwater
Steam
Cavitation

ACKNOWLEDGMENTS

EPRI would like to acknowledge the following individuals who contributed to the writing of this report:

Steve Benjamin	Salt River Project, Coronado Generating Station
Ray Chambers	EPRI
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Gary Foster	First Energy Nuclear Operating Company
Ken Hart	PPL Susquehanna LLC

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INTRODUCTION

1.1 Background

This guide consists of an overview and recommendation of maintenance practices for certain valves that operate in plant conditions challenging to valve operation. These challenging conditions represent the extreme limits of design and operation and frequently result in failures that are considered premature. The following valves are discussed in this guide:

- Attemperators (ATV) - desuperheating valves, fossil only
- Feedpump discharge check valves (FCV)
- Feedpump recirculation (miniflow) control valves (FMV) - includes condensate pump recirculation control valves
- Feedwater regulating valves (FRV)
- High-pressure drain valves (HDV)
- Atmospheric dump valves (ADV) - steam dump valves, nuclear only
- Condenser dump valves (CDV) - turbine bypass valves, steam dumps
- Pressurizer spray valves (PSV) - nuclear only

1.2 Characteristics of Severe Duty Maintenance

For the valves that function as control valves (ATV, FMV, FRV, CDV, and PSV), an Equipment Performance Information Exchange (EPIX) survey analysis showed that 79% of failures occurred in the actuator, accessory, or control signal functions. (EPIX data are not available for ATVs.) The EPIX analysis showed that only 14% of failures occurred in the valve. Little or no data exist for the non-control valve applications (FCV, HDV).

1.3 Guideline Approach

This guide was developed using the standard approach to NMAC maintenance guides. The valves listed in Section 1.1 were identified by FMAC and NMAC membership as severe duty valves. A review of these valves indicated that they shared the main characteristic of high pressure drop. The severe duty valves were analyzed in three groups:

- Control valves (Sections 3 and 4)
- Check valves (Section 5)
- Drain valves (Section 6)

To determine what maintenance actions were required, a survey of utility and industry failure databases was conducted to determine specific problems and commonly encountered failure mechanisms. The results are contained in Section 2 and Appendix C.

Using the results of Section 2, EPRI publications, industry literature, product information, and standards were reviewed to identify various valve designs, applications, and maintenance practices. Based on this review, recommendations were identified for condition monitoring, preventive maintenance (PM), and troubleshooting methods.

The results of the surveys described in Section 1.2 showed that previous EPRI guides already exist that address valve maintenance in general. The vast number of designs encountered indicated that it was not practical to provide specific valve design procedures. Therefore, severe duty valve maintenance is presented in terms of what caused the failures, the steps that should be taken to prevent these failures, and the existing guides and valve designs that address these failures.

1.4 Key Points

Throughout this report, key information is summarized in “Key Points.” Key Points are bold-lettered boxes that succinctly restate information covered in detail in the surrounding text, making the Key Point easier to locate.

The primary intent of a Key Point is to emphasize information that will allow individuals to take action for the benefit of their plant.

The Key Points are organized according to three categories: O&M Cost, Technical, and Human Performance. Each category has an identifying icon, as shown here, to draw attention to it when quickly reviewing the guide.

Key O&M Cost Point

Emphasizes information that will result in reduced purchase, operating, or maintenance costs.

Key Technical Point

Targets information that will lead to improved equipment reliability.

Key Human Performance Point

Denotes information that requires personnel action or consideration in order to prevent injury or damage or ease completion of the task.

Appendix B contains a listing of all key information in each category. The listing restates each Key Point and provides reference to its location in the body of the report. By reviewing the listing, users of this guide can determine if they have taken advantage of key information that the writers of this guide believe would benefit their plants.

2
FAILURE ANALYSIS

2.1 Introduction

In order to understand the maintenance scope of severe duty valves, EPIX failure data were obtained. The data covered all feedwater and dump valve failures from April 1, 1995, through March 18, 2005. No fossil data were available. However, because the power generation parts of a nuclear and fossil plant are similar, the EPIX data provide insight into expected fossil plant failures.

- The following valves were analyzed:
- Feedpump recirculation control valves (FMV) - feedwater pump miniflow
- Feedwater regulating valves (FRV)
- Atmospheric dump valves (ADV)
- Condenser dump valves (CDV)
- Feedpump discharge check valves (FCV)
- Pressurizer spray valve (PSV) [1]

The following valves within the scope of this guide did not have failure statistics that would be useful, but other information exists that will allow identification of failure modes and causes:

- High-pressure drain valves (HDV)
- Attemperator (ATV) - desuperheating valves, fossil plants

The analysis was divided into two groups:

- Valves with actuators (for example, FMVs, FRVs, ADVs, and CDVs)
- Valves without actuators (for example, discharge check valves)

2.2 Analysis of Valves with Actuators

2.2.1 Failure Modes

Overall, there were 352 failure records for valves with actuators. The failure modes (FM) are listed here:

- Closing failure – The valve did not respond to a demand to close.
- Opening failure – The valve did not respond to a demand to open.
- Set-point failure – The valve moved, but it did not go to the proper position.
- Non-demand failure – A failure was found that did not involve a demand signal (for example, during a test).
- Process control failure – The valve it did not control the process (such as flow).
- Internal leakage – Valve leakage occurred (involving such areas as the seat or piston rings).
- External leakage – Valve leakage occurred (involving such areas as body/bonnet gasket or packing).

The failure mode distribution is shown in Table 2-1. Percentage totals may not be exact due to rounding.

Figure 2-1
Failure Modes for Valves with Actuators

Failure Mode	Percent Failures for Service Indicated				
	Total	ADV	CDV	FMV	FRV
Process control	29	0	0	0	29
Opening	22	6	2	0	14
Non-demand	18	1	17	0	0
Closing	14	3	3	7	1
Set point	14	1	9	0	4
Internal leakage	3	0	3	0	0
External leakage	1	0	0	1	0

2.2.2 Failure Causes

Failure causes were determined based on the event description and failure mode. Failure causes were first determined to be valve, non-valve, or unknown. Valve and non-valve failure causes were then identified. Unknown causes were not further analyzed.

As a percent of the total valves analyzed, valve, non-valve, or unknown failures were distributed as shown in Table 2-2. A vast majority of severe duty valve failures (79%) for valves with actuators involved non-valve causes.

Table 2-1
Failure Cause Location

Failure Cause Location	Percent Failures
Non-valve	79
Valve	14
Unknown	8

Key O&M Cost Point

A vast majority of severe duty valve failures (79%) for valves with actuators involved non-valve causes.

Failure causes as percent of failure location (valve, non-valve) were distributed as shown in Tables 2-3 and 2-4. Total percentages may not be exact due to rounding.

Table 2-2
Failure Causes for Non-Valve Failures

Failure Cause	Failure Cause Percent of Non-Valve Failures for Service Indicated					
	All	ADV	CDV	FMV	FRV	PSV (1)
Signal	28	2	6	3	16	22
Positioner	22	2	6	2	12	44
Solenoid-operated valve (SOV)	16	0	9	1	5	0
Actuator	15	2	6	1	6	11
Air supply	12	2	4	1	4	0
Pressure transducer current to pneumatic (I/P), voltage to pneumatic (E/P)	5	1	1	0	3	22
Volume booster	1	0	1	0	0	0

(1) Percent failures for PSVs are based on nine failures. The referenced Institute of Nuclear Power Operations (INPO) study [1] did not contain sufficient information for failure mode analysis. Percentages for all other valves are based on 277 failures.

Only 28% of non-valve failures could be attributed to signal problems. The most problematic accessory was the positioner, followed by SOVs and the actuator itself.

Key O&M Cost Point

Only 28% of non-valve failures could be attributed to signal problems. The most problematic accessory was the positioner, followed by SOVs and the actuator itself.

A detailed description and recommended maintenance for the failure causes for non-valve failures is provided in Section 3.

Table 2-3
Failure Causes for Valve Failures

Failure Cause	Failure Cause Percent of Valve Failures for Service Indicated					
	All	**ADV**	**CDV**	**FMV**	**FRV**	**PSV** (1)
Plug/cage	19	15	4	0	0	17
Plug/seat	17	6	8	0	2	0
Plug/stem	17	2	6	0	8	17
Pilot	6	2	4	0	0	0
Stem	6	0	2	2	2	17
Body erosion	2	0	0	2	0	0
Packing	19	2	0	2	15	50
Foreign material exclusion (FME)	15	0	6	0	8	0

(1) Percent failures for PSVs are based on six failures. The referenced INPO study [1] did not contain sufficient information for failure mode analysis. Percentages for all other valves are based on 48 failures.

A detailed description and recommended maintenance for the causes of valve failures is provided in Section 4.

2.3 Analysis of Valves Without Actuators

Ten FCV failures were found in the EPIX database. Failure mode and cause analysis is contained in Tables 2-5 and 2-6.

Table 2-4
FCV Failure Modes

Failure Mode	Percent
Failed to close	70
Failed to open	0
Non-demand failure	10
External leakage	10
Internal leakage	10

Table 2-5
FCV Failure Causes

Failure Cause	Percent
Hinge pin wear	40
Unknown	20
Disc/seat not aligned	20
Hinge pin missing	10
Disc nut pin	10

Failure causes for FCVs are discussed in Section 5.

3
SEVERE DUTY NON-VALVE COMPONENT FAILURES

3.1 Introduction

This section reviews the failure causes for non-valve components for control valve type severe duty valves (that is, those with actuators). As identified in Section 2, non-valve components dominated failures (79%) for control valve type severe duty valves. Failure causes for non-valve components are shown in Table 3-1 (which duplicates Table 2-3).

Table 3-1
Non-Valve Failure Causes

Failure Cause	Failure Cause Percent of Non-Valve Failures for Service Indicated					
	All	**ADV**	**CDV**	**FMV**	**FRV**	**PSV**[(1)]
Signal	28	2	6	3	16	22
Positioner	22	2	6	2	12	44
Solenoid-operated valve (SOV)	16	0	9	1	5	0
Actuator	15	2	6	1	6	11
Air supply	12	2	4	1	4	0
Pressure transducer (I/P, E/P)	5	1	1	0	3	22
Volume booster	1	0	1	0	0	0

(1) Percent failures for PSVs are based on nine failures. The referenced INPO study [1] did not contain sufficient information for failure mode analysis. Percentages for all other valves are based on 277 failures.

The Institute of Nuclear Power Operations (INPO)[1] recently analyzed all air-operated valve (AOV) failures that occurred during the period January 2000 through September 2004. The percentage failures as reported in that study are compared with this report in Table 3-2.

Table 3-2
Comparison of Percent from Recent INPO Report

Report Source	Percent of Source Total for This Group	ADV	CDV	FMV	FRV
INPO	39(1)	2	4	4(2)	30
This report	100	11	34	8	47
This report (01/2000 – 09/2004 data only)	100	11	37	8	44

(1) 39% of valves in INPO report were ADVs, CDVs, FMVs, or FRVs.

(2) FMVs were reported by INPO as part of "other feedwater system valves," which is the percentage reported [1].

3.2 Signal

3.2.1 Mechanisms

Failures caused by signal problems included all failure mechanisms external to the valve and non-valve components. Most failure mechanisms were distributed as follows:

- Equipment failures 59%
- Maintenance related 11%
- Controller 27%
- Instrument, relay malfunction, inadequate design, fuse, power supply, switch contacts, inadvertent engineered safety features actuation system (ESFAS) signal, loss of power, power breaker, calibration, procedures, gain setting, incorrect jumper landed, set point too low, test equipment – less than 2% (in the order listed)

3.2.2 Maintenance Recommendations

The following publications will be helpful in guiding maintenance on control functions for the FRVs, FMVs, and ATVs:

- Power Supply Maintenance and Application Guide [2]
- Printed Circuit Board Maintenance, Repair, and Testing Guide [3]
- Feedwater I&C Maintenance Guide [4]
- Instrumentation and Control (I&C) Maintenance Experience Reference [5]
- Instrument Power Supply Tech Note [6]

3.3 Positioner

Of the components on the valve, positioner failures led all others. Failures were distributed as follows:

- FRVs 56%
- CDVs 28%
- Equipment failures 46% (5% vibration)
- Maintenance related 31% (16% calibration)
- Unknown 18%
- Design 2%

3.3.1 Mechanisms

- Failure mechanisms included the following:
- Feedback linkage/spring 23%
- Calibration 16%
- Pilot valve, cam follower/hub, FME, internal leakage, aging, beam assembly, digital positioner memory, inlet port failure, loose screw, manufacturing problems, potentiometer, and vibration – less than 2% (in the order listed)

3.3.2 Maintenance Recommendations

The following publications will be helpful in guiding maintenance on the positioner for FRVs, FMVs, and ATVs:

- Valve Positioner Principles and Maintenance Guide [7]
- Feedwater I&C Maintenance Guide [4]

3.4 Solenoid-Operated Valves

Failures due to SOVs were distributed as shown:

- CDVs 58%
- FRVs 30%
- Equipment failures 65% (Vibration 2%)
- Maintenance related 16%
- Unknown 14%
- Design 5%

3.4.1 Mechanisms

Failure mechanisms for all SOVs included:

- Aging 28%
- Coil failure 21%
- Incorrect installation/venting, FME, missing coil, diaphragm leak, grounded leads, and alignment – less than 2% (in the order listed)

3.4.2 Maintenance Recommendations

The following publications will be helpful in guiding maintenance on SOVs:

- *Solenoid Valve Maintenance Guide Revision of NP-7414* [8]
- *Feedwater I&C Maintenance Guide* [4]

3.5 Actuators

Failures due to actuators were distributed as follows:

- FRVs 43%
- CDVs 40%
- Equipment failures 43% (Vibration 7%)
- Maintenance Related 7%
- Unknown 7%
- Design 12%

3.5.1 Mechanisms

Failure mechanisms for actuators included:

- Bench set/calibration 17%
- Diaphragm leakage 7%
- Diaphragm incorrect 7%
- Stem connection, diaphragm leakage, stem seal aging, actuator motor, hydraulic oil leakage/low, hydraulic pump switch, incorrect for application, procedure, and adjusting nut – less than 2% (in the order listed)

3.5.2 Maintenance Recommendations

The following publication will be helpful in guiding maintenance on actuators:

- *Air-Operated Valve Maintenance Guide* [9]

Section 5 of the *Air-Operated Valve Maintenance Guide* contains a PM template suitable for application to severe duty valves. The PM selection should be based on “critical, high/low duty cycle, and severe service condition.” [9]

3.6 Air Supply

Failures due to air supply were distributed as follows:

- FRVs 35%
- CDVs 35%
- Equipment failures 61% (Vibration 29%)
- Maintenance related 35%
- Design 3%

3.6.1 Mechanisms

Failure mechanisms for actuators included:

- Tubing/fitting failure 34%
  (One failure clearly due to nearby maintenance, 25% due to vibration)
- Regulator 24%
  (Cracked, set point, wrong type, FME)
- Faulty relief valve, procedure, FME, accumulator leak, and disconnected lines – less than 2% (in the order listed)

3.6.2 Maintenance Recommendations

The following guides will be helpful in guiding maintenance on air supplies:

- *Assembling Threaded Connections* [10]
- *EHC Tubing/Fittings and Air Piping Application and Maintenance Guide* [11]
- *Air-Operated Valve Maintenance Guide* [9]

3.7 Pressure Transducer (I/P, E/P)

Failures due to pressure transducers were distributed as follows:

- FRVs 60%
- CDVs 27%
- Equipment failures 13% (Vibration 0%)
- Maintenance related 13%
- Unknown 47%
- Design 27%

3.7.1 Mechanisms

Failure mechanisms for actuators included:

- Midcycle calibration drift 27%
  (Although it can be argued that midcycle calibration is not a failure mechanism. The fact that it is occurring must be taken into account when establishing a calibration program.)
- Aging, initial calibration, loose connection, incorrectly placed, range jumper, and solder connection – less than 2% (in the order listed)

3.7.2 Maintenance Recommendations

Although not mentioned in the analysis, one feature that creates premature aging is the standard practice of mounting the pressure transducer directly above the bonnet without insulation to protect the device. A good practice is to insulate the top of the valve body and keep the pressure transducer temperature low.

The following guide will be helpful in guiding maintenance on pressure transducers:

- *Feedwater I&C Maintenance Guide* [4]

3.8 Volume Booster

Failures due to volume booster were distributed as follows:

- CDVs 75%
- FRVs 25%
- Equipment failures 50% (Vibration 0%)
- Maintenance Related 25%
- Unknown 25%

3.8.1 Mechanisms

Leakage accounted for all equipment failures. A procedural problem accounted for the remaining known cause.

3.8.2 Maintenance Recommendations

As with the pressure transducer maintenance recommendation in Section 3.7.2, a good practice is to insulate the top of the valve body and keep the volume booster temperature low.

The following publications will be helpful in guiding maintenance on volume boosters:

- *Feedwater I&C Maintenance Guide* [4]
- *Air-Operated Valve Maintenance Guide* [9]

3.9 Troubleshooting Matrix

Table 3-3 provides a symptom-based troubleshooting analysis to facilitate failure cause identification.

Table 3-3
Actuator Troubleshooting Matrix

	Problem								
Cause	**Guidance Reference**	**Erratic or Jerky Throttling**	**Failure to Fully Retract**	**Failure to Fully Extend**	**Cycling**	**Failure to Stroke**	**Sluggish/ Slow**	**Slow in Increasing Air Pressure Direction**	**Slow in Decreasing Air Pressure Direction**
Actuator supply pressure low	NP-7412R1 [9]		X	X		X	X		
Actuator supply pressure high	NP-7412R1 [9]	X				X(1)	X		X
Actuator supply erratic	NP-7412R1 [9]	X			X				
Unsteady signal	TR-105663 [4]	X			X				
Improper bench set	NP-7412R1 [9]		X	X					
Positioner	1003091 [7]	X			X	X	X	X	X
Wrong travel stops/calibration	NP-7412R1 [9]		X	X					

Table 3-3 (cont.)
Actuator Troubleshooting Matrix

	Problem								
Cause	**Guidance Reference**	**Erratic or Jerky Throttling**	**Failure to Fully Retract**	**Failure to Fully Extend**	**Cycling**	**Failure to Stroke**	**Sluggish/ Slow**	**Slow in Increasing Air Pressure Direction**	**Slow in Decreasing Air Pressure Direction**
Increased packing friction	NP-7412R1 [9]	X			X		X		
Actuator spring too large	NP-7412R1 [9]							X	
Actuator spring too small	NP-7412R1 [9]		X	X					X
Air leak (diaphragm, stem seal, or case joint)	NP-7412R1 [9]		X	X		X	X	X	X
Leaks	NP-7412R1 [9]		X	X		X	X	X	X
Solenoid valve failure	1007915 [8]				X	X	X		
Air supply tubing crimped, too small	NP-7412R1 [9]	X	X	X		X	X	X	X
Actuator too large	NP-7412R1 [9]	X			X				

Table 3-3 (cont.)
Actuator Troubleshooting Matrix

Cause	Problem								
	Guidance Reference	Erratic or Jerky Throttling	Failure to Fully Retract	Failure to Fully Extend	Cycling	Failure to Stroke	Sluggish/ Slow	Slow in Increasing Air Pressure Direction	Slow in Decreasing Air Pressure Direction
Increased packing friction	NP-7412R1 [9]	X			X		X		
Actuator spring too large	NP-7412R1 [9]							X	
Piston lubrication(2)	NP-7412R1 [9]		X	X		X	X		
Damaged cylinder or piston rings/seals	NP-7412R1 [9]	X	X	X	X	X	X		

(1) Can cause positioner to fail.

(2) Lack of lubrication permits the actuator supply air to migrate to the opposite side of the piston.

4
SEVERE DUTY CONTROL VALVE TYPE FAILURES

4.1 Introduction

This chapter describes the failures and recommended actions associated with control type valves used in severe duty control service. It does not address the non-valve components that are discussed in Section 3. The main characteristic that distinguishes severe duty control valves from other valves is high pressure drops. For some valves, low seat leakage requirements are critical. These valves include feedpump recirculation control valves/feedwater pump miniflow (FMFs), FRVs, ATVs, ADVs, and CDVs.

4.2 Failure Cause Analysis

The identified failure causes are shown in Table 4-1 (which duplicates Table 2-4). As expected, plug interaction with the cage, stem, or seat caused the greatest percentage of failures (53%). Of these failures, 41% involved steam service and 13% involved water service. Note that there were no plug/cage failures for water service.

Table 4-1
Analysis Results

Failure Cause	Failure Cause Percent of Valve Failures for Service Indicated					
	All	ADV	CDV	FMV	FRV	PSV (1)
Plug/cage	19	15	4	0	0	17
Plug/seat	17	6	8	0	2	0
Plug/stem	17	2	6	0	8	17
Pilot	6	2	4	0	0	0
Stem	6	0	2	2	2	17
Body erosion	2	0	0	2	0	0
Packing	19	2	0	2	15	50
FME	15	0	6	0	8	0

(1) Percent failures for PSVs are based on six failures. The referenced INPO study [1] did not contain sufficient information for failure mode analysis. Percentages for all other valves are based on 48 failures.

4.3 Plug/Cage

4.3.1 Design

A typical plug cage design used in severe duty steam applications is shown in Figure 4-1. Because of the high pressure drops involved, nearly all valves are of the balanced plug design to allow smaller air actuators (15 in. versus 45 in. [381 mm versus 1143 mm] diameter diaphragm for a typical ADV or CDV). Balanced plug designs are always characterized by a flow passage (balance port) from the bottom to the top of the plug and at least one piston ring. The balance port permits pressure on the top to be the same as on the bottom. Therefore, the only valve forces that the actuator has to overcome are those created by the pressure on the stem, packing friction, and the friction drag of the piston ring. The piston ring is needed to prevent flow (caused by the higher upstream pressure) from coming up and over the plug. In nearly all cases, the piston ring is made from carbon.

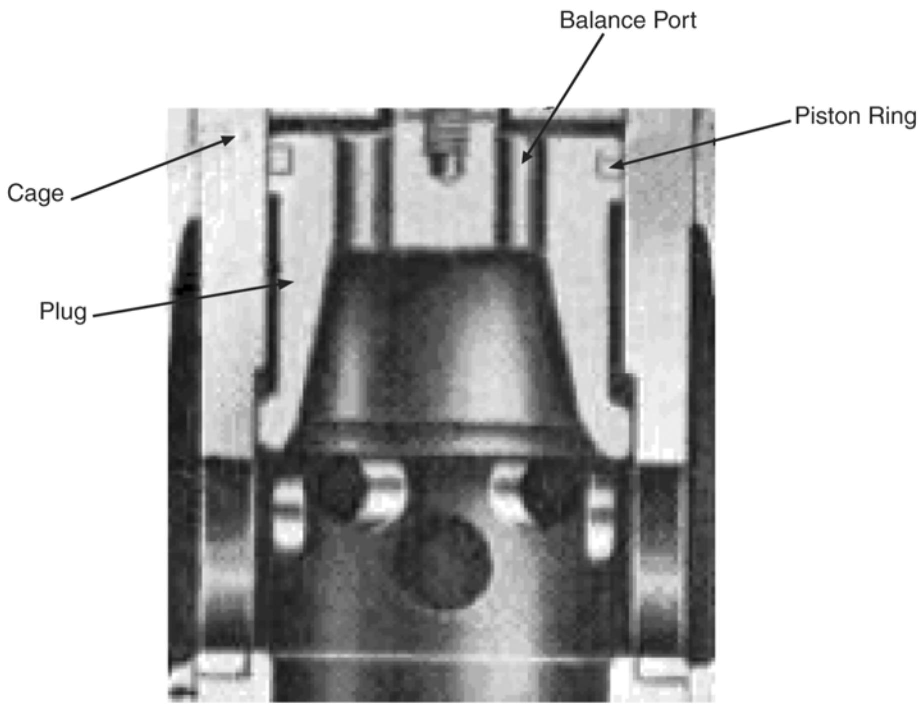

Figure 4-1
Balanced Port Design

4.3.2 Problems

Plug/cage problems reported in the EPIX database affected only valves in steam service. All reported failures involved the piston ring. The following list shows similar problems reported by other failure data that involve water service:

- Wrong size - The ring was too large.
- Broken - The ring failed in service.
- Twisting - One plant reported the twisting of piston ring of Control Components, Inc. (CCI) valves that were not pressurized with steam. This twisting caused an increase in friction between the cage and the piston ring.
- Wear - The ring degraded over time.
- Reverse flow - The piston ring was subjected to reverse flow that caused damage to the seal and eventually caused plug vibration and stem failure.
- Seating - The cage was not fully seated into the valve body prior to torquing.

4.3.3 Maintenance Recommendations

- Plug/cage failures dominated all valve failures for severe duty valves. One company experience suggests performing internal valve inspection for these valves every four to six years. This is based on internals shown in Figures 4-1 and 4-2. Valves using cavitation-resistant designs, as shown in Figure 4-7, should permit longer overhaul periods.

4.4 Plug/Stem Failures

4.4.1 Design

In most cases, a plug and stem are joined by threading and locking the stem to the plug. Locking is generally accomplished by using pin and/or tack welds.

4.4.2 Problems

Plug/stem failures were dominated by plug/stem separation or looseness usually caused by improper assembly, material failures, or failed tack welds. Special attention must be given to proper assembly. This is a very critical joint due to the high vibration and stresses. Plug/stem separation or looseness can result in:

- Plug side loading causing high friction between the plug/cage
- Failure to stroke
- Partial stroke

4.4.3 Maintenance Recommendations

Special attention must be given to proper assembly. This is a very critical joint due to the high vibration and stresses. Torque values should be used to ensure that engagement is correct. Some designs require that the stem bottom-out in the plug. They may have threading only part way, requiring thread cutting to ensure a tight fit. The vendor manual should be reviewed for the necessary criteria. If problems still occur, personnel should consider ordering preassembled plug/stems from the vendor. Pins must be of the proper material (type and strength). The pin installation should be checked closely, and all vendor requirements should be met. The pin should not be considered the primary anti-rotation prevention mechanism. Welding should be done using the appropriate filler metal and technique.

Key Technical Point

Plug/stem failures were dominated by plug/stem separation or looseness usually caused by improper assembly, material failures, or failed tack welds. Special attention must be given to proper assembly. This is a very critical joint due to the high vibration and stresses.

4.5 Plug/Seat Failures

4.5.1 Design

Nearly all seat designs use the standard cone-to-cone design with a differential angle. This permits the tight shutoff necessary for high plant thermal efficiency. The differential angle results in high contact stresses requiring seating materials with high hardness values, usually 30 or higher on the Rockwell C Scale.

4.5.2 Problems

Plug/seat problems resulted in failure to open. All failures involved binding of the plug (disc, piston) with the seat and were caused by material failures usually involving incorrect hardness. One failure involved a bonding action that could not be explained.

4.5.3 Maintenance Recommendations

Plug and seat hardness requirements are easy to measure. Hardness measurements should be part of the quality control inspection requirements in receiving.

4.6 Pilot Failures

4.6.1 Design

The ideal way to obtain tight shutoff is to use the upstream pressure to push the plug down on the outlet seat. As discussed in Section 4.3.1, this means that the actuator must be very large to provide the necessary opening forces. A common way to deal with this problem is to provide a small valve within the plug that closes the balance port. This valve is called a *pilot valve*. An example of a pilot valve design is shown in Figure 4-2.

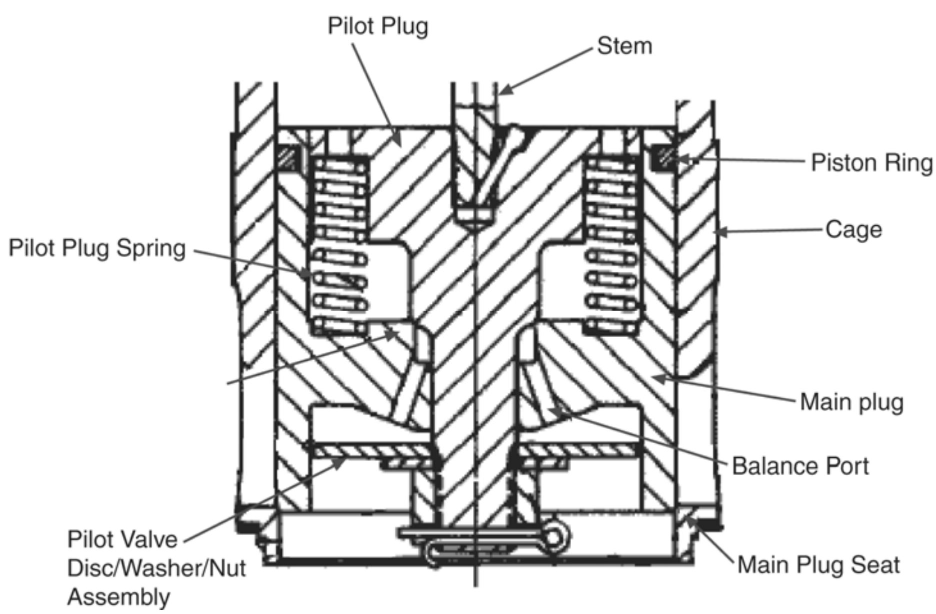

Figure 4-2
Pilot Valve Design

During operation, upstream pressure acts on the pilot plug. The pilot plug force is transmitted to the main plug seat through the main plug. When the valve starts to open, the pilot valve opens first, assisted by the pilot plug spring (in most designs, this force is required in addition to the actuator force to open the plug). This opens the balance ports and equalizes the pressure on the top and bottom of the main plug. The pilot valve disc then contacts the bottom of the main plug and lifts the main plug off the seat. Closure simply reverses the action. When the pilot valve closes, leakage around the piston ring allows the buildup of pressure.

Because the pilot valve plug is much smaller than the main valve plug, the actuator can be nearly as small as the balanced plug designs. Note that unlike the balance plug design, the piston ring serves primarily as a guide and does not seal so that pressure can build up on top of the plug when the valve is closed.

4.6.2 Problems

Pilot failures involved internal binding of the pilot valve, spring failure (broken), or improper assembly of the pilot valve disc/washer/nut assembly. Faulty procedures were also involved. Other failure data reported that binding occurred due to tolerance stack-ups because each individual part was ordered separately rather than as a matched assembly.

4.6.3 Maintenance Recommendations

Although relatively few problems occurred, procedures should be in place that provide detailed guidance on the proper assembly of the pilot plug. Although not identified in EPIX, it is essential to ensure that there is adequate travel for pilot opening before the pilot disc contacts the bottom of the main plug. Procedures should provide measurement values for this step.

4.7 Stem Failures

This section discusses failures of the stem only. Packing leaks caused by stems are discussed in Section 4.9.

4.7.1 Design

The stems for control valves typically thread into the plug (main or pilot) and are attached to the actuator using a split nut thread arrangement. Stroke adjustments are made using the actuator/stem connection. Stem material is usually a martensitic stainless steel (410) or austenitic stainless steel (316). Occasionally, other super alloys such as 17-4PH (630) are used. For proper operation, stem straightness is important, and vendors provide acceptance criteria.

4.7.2 Problems

Stem failures involve bent, vibration fatigued, or material failures. The bent stem was created by improper work practice in which the bonnet gasket and lower cage gasket were incorrectly installed within the valve (reversed with the thicker gasket placed on top). During the tightening of the bonnet bolts, the bonnet was able to cock over and bend the stem. Vibration fatigue occurred at the stem/actuator connection in an FMV, which had been in service for nine years. The material failure was caused by improper heat treatment, resulting in a brittle material fracture.

4.7.3 Maintenance Recommendations

The problems emphasize the importance of detailed assembly procedures to ensure satisfactory operation. In addition, stem straightness is critical enough that it should be verified before assembly and after it has been attached to the plug, if possible. As with the plug seat problems described previously, hardness checks should be performed at receiving.

4.8 Body Erosion

Body erosion was caused by cavitation conditions downstream of the valve. In the EPIX database, this phenomenon was limited to FMVs, but it is also known to occur in ATVs, FRVs, and PSVs. Because of the nature of the phenomenon, it never occurs in CDVs or ADVs. A comprehensive discussion on cavitation is contained in Section 4.11.

4.9 Packing Failures

4.9.1 Problems

Packing problems were associated with stroke or leakage problems. Packing failures primarily involved improper adjustment that resulted in either excessive friction or in-service consolidation (loss of preload). An instance of incorrect spacer and gland also caused problems. One event involved an incorrect packing spacer. Most of the packing failures involved FRVs. This is to be expected because FRV operation involves more stem movement than other valves in the EPIX survey. It would be expected that packing leakage would also be associated with ATVs for the same reason.

4.9.2 Maintenance Recommendations

Maintenance recommendations suggest considering consolidation, stuffing box depth, use of die-formed rings, live-loading, stem alignment, periodic retorquing, and the use of diagnostics. A general discussion of valve packing and methods to prevent leakage is contained in *Valve Stem Packing Improvements* [12] and *Valve Packing Performance Improvement* [13].

4.9.2.1 Consolidation

An important concept in packing a valve is consolidation. Consolidation involves the loss of packing stress due to the applied load as well as stem movement. As discussed in *Valve Stem Packing Improvements* [12] and *Valve Packing Performance Improvement* [13], consolidation of packing during service (in-service consolidation or creep) is the single most common reason for packing leaks. Testing has shown that when packing stress is less than 1.5 times the system pressure, leakage is very likely. For this reason, it is recommended [12, 13] that packing be consolidated before placing the valve in service. This involves torquing the gland nuts to achieve a packing stress of at least 1.75 times the system pressure, followed by cycling the valve approximately five times, retorquing between each cycle to reestablish the packing stress. This process is described in detail in Section 9 of EPRI’s guideline *Valve Packing Performance Improvement* [13].

Key Technical Point

In-service consolidation (or creep) is the single most common reason for packing leaks. To mitigate, the valve packing should be consolidated before placing the valve in service.

4.9.2.2 Stuffing Box Depth

Consolidation will not be effective unless the number of rings of packing is optimized. For valves without a lantern, boxes should accommodate five rings of packing. Older valves came with boxes that would accept twice that number or more. Research shows that providing five rings of packing is optimal [12]. To reduce the number of rings required, a high-density carbon spacer is used at the bottom of the box. Such spacers are readily obtainable from the packing supplier.

Key Technical Point

Consolidation will not be effective unless the number of rings of packing is optimized. This usually means limiting the number of rings to five. For older valves with deep stuffing boxes, this involves the use of a high-density carbon spacer.

4.9.2.3 Die-Formed Rings

In a five-ring configuration, the use of die-formed graphite rings for the middle three rings provides a cost-effective packing system. The upper and lower rings are made from braided graphite or a composite material because the die-formed rings will extrude into the gland/stem, gland/box, and stem/box gaps.

4.9.2.4 Live-Loading

EPRI's *Valve Packing Performance Improvement* [13] also suggests other improvements to the type and arrangement of packing. While preservice consolidation has substantially improved packing system performance, live-loading (which was introduced in the 1980s) is highly recommended for control valve operations involving frequent stem movement, such as for FRVs and ATVs. Live-loading minimizes the loss of packing stresses caused by stem movement induced by in-service consolidation. The principles and engineering of live-loaded packing can be found in EPRI's *Valve Stem Packing Improvements* [12]. Established packing suppliers can also assist in live-loaded designs.

4.9.2.5 Stem Alignment

The high-density carbon bushing material used as a spacer at the bottom of the stuffing box to obtain the five-ring depth can also be used to correct stem alignment problems. This is done by placing a carbon bushing at the gland end of the box. If a spacer already exists, it is replaced such that the excess stuffing box depth is filled with equal lengths of carbon bushing material below and above the packing [13].

Key Technical Point

High-density carbon bushing material can be used to correct stem alignment problems. The busing is placed just under the packing gland.

4.9.2.6 Periodic Packing Retorque

There are cases when periodic retorquing can be used as an effective PM technique if experience or conditions dictate. This must be done with care to avoid excessive stem friction and valve malfunction. Diagnostic equipment should be used where stem friction can be a problem (such as with AOVs) by comparing the original stem friction with friction after retorquing.

If access makes retorquing difficult, live-loading is recommended.

Key O&M Cost Point

Severe duty AOVs that are difficult to retorque due to location should be live-loaded.

4.9.2.7 Diagnostics

The use of diagnostic equipment to properly set up a severe duty AOV is vital. Diagnostic equipment can be used to measure packing drag and to ensure proper installation, consolidation, and packing load. These valves go through severe stroking cycles and are particularly susceptible to wear and loss of packing load. By keeping good records of these values, diagnostic equipment can be used as a predictive maintenance tool to determine the amount of loss during service. This information can be used to establish retorquing PM or live-loading processes as discussed previously. Section 10 of *Feedwater I&C Maintenance Guide* [4] and Section 6 of *Air-Operated Valve Maintenance Guide* [9] contain descriptions of diagnostic equipment use.

In addition, while it is necessary to ensure that packing load is sufficient to prevent packing leaks, too much packing load will create problematic high packing friction. High packing friction contributes to stiction, which creates dead time, leading ultimately to the hunting action associated with a limit cycle. This means that control can be very challenging. Hunting also increases packing wear. Diagnostic equipment will facilitate tuning of the final control element that will minimize this hunting during operation. For a further discussion of these problems, see Section A.4 of EPRI's *Valve Positioner Principles and Maintenance Guide* [7].

Key O&M Cost Point

The use of diagnostic equipment to properly set up a severe duty AOV is vital. It can be used as a predictive maintenance tool to determine the amount of packing load loss during service and the need for retorquing or live-loading. In addition, it will facilitate tuning of the final control element, which will improve position control and reduce packing wear during operation.

4.10 Foreign Material Failures

Foreign material failures involve the introduction of foreign material that usually can be traced to earlier maintenance. Prevention of foreign material intrusion requires extensive attention to all actions that can introduce foreign material. EPRI's *Foreign Material Exclusion Guidelines* [14] contains a detailed discussion of actions that will help establish conditions to minimize foreign material entry and failures.

4.11 Cavitation

Cavitation can be a problem for valves that control high pressure drop liquid (water). These valves include the FMV, ATV, FRV, and PSV (in order of likelihood). Cavitation as a phenomenon is still not fully understood, but the conditions that exist to cause cavitation are well known.

The boiling point of a liquid is a function of its pressure and temperature. For example, the boiling point of water at atmospheric pressure (14.7 psi absolute [101 kPa]) is 212°F (100°C). If the temperature of the water is 200°F (93°C), the corresponding boiling pressure is 11.5 psi absolute (79 kPa). Cavitation can occur any time that the pressure of a liquid flowing through a restriction is allowed to drop below the boiling point. The pressure drop occurs because the velocity of the liquid must increase through the restriction in order to keep the amount of mass flowing constant. However, when the velocity increases, the pressure must drop in order to keep the energy content of the liquid constant. If the velocity increase is sufficient (as with a smaller flow path area), boiling occurs. This boiling action is known as *flashing* (see Figure 4-3).

In a valve, the point of highest velocity (and hence lowest pressure) is called the *vena contracta*. If the pressure rises above the boiling point after the fluid has passed through the restriction, condensation occurs. This condensation is very rapid and involves the collapse of the bubbles of boiling liquid. The collapse is called *cavitation*.

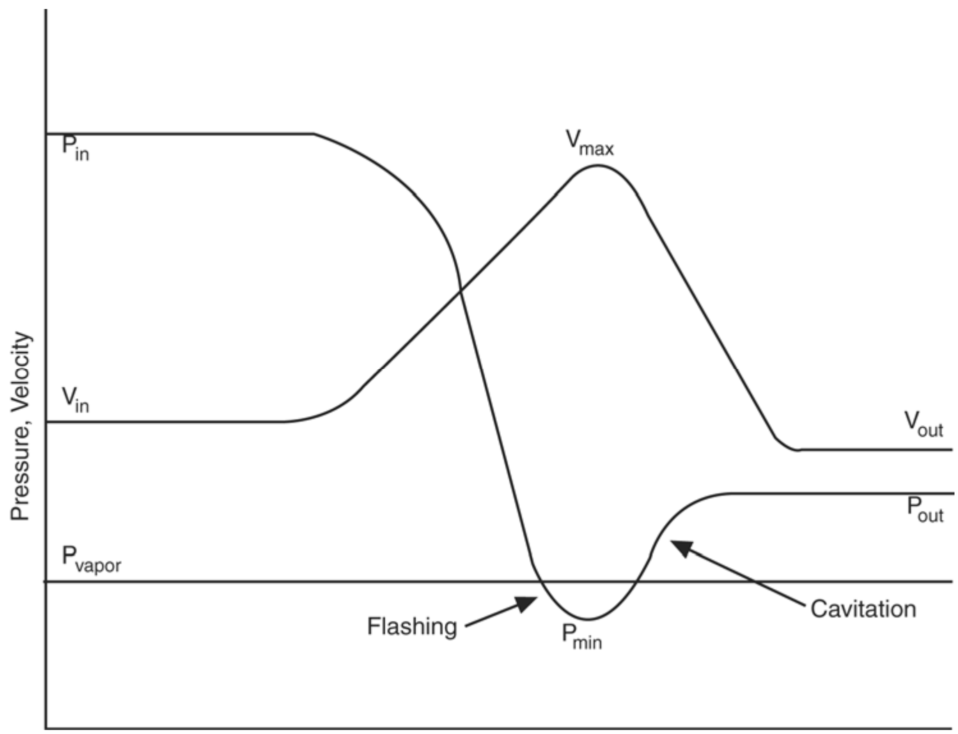

Figure 4-3
Flashing/Cavitation Formation

For valves, both flashing and cavitation can cause damage to the valve and/or the downstream piping. Flashing damage is characterized by smooth, scouring erosion of the damaged material. It occurs where the fluid velocity is the highest. The erosion damage occurs because the fluid is a mixture of vapor and liquid moving at a very high velocity with the droplets hitting the surface. This damage can occur at the valve seating surfaces or the downstream valve body. Typically, flashing damage doesn't occur to the downstream piping because the velocity is slower (pressure recovery has occurred). Usually, analysis of flow conditions will indicate a propensity to flashing, but unless cavitation occurs (with the characteristic noise discussed in the following paragraph), the occurrence of flashing and the resulting damage are difficult to detect without inspection. Flashing damage can be severe enough to cause body through-wall leaks.

Cavitation damage results from the collapse of the vapor bubbles near the material of the valve. The pressure associated with this collapse has been estimated to be as high as 1,000,000 psi (6895 MPa). If the bubble collapse occurs next to a component surface, damage will occur. There is no known material used in valve or piping construction that is immune to cavitation damage. If cavitation damage occurs, the conditions causing the damage must be corrected because material changes will not work. Unlike flashing, cavitation is rapid, so if cavitation damage is known to occur, early repair and correction are necessary. Fortunately, the bubble collapse results in a noise sometimes described as frying bacon, so the detection of cavitation is much easier. Like flashing, the existence of damage can be determined only by inspection. The collapse may be at a location in the flow stream where it can do no damage.

The two ways to control flashing and cavitation damage are:

- Design the flow path within the valve that allows the flashing/cavitation to exist at locations where it cannot do damage.
- Design the flow path within the valve so that flashing/cavitation is prevented.

4.11.1 No Damage Approach

The no damage approach is the simplest approach. It consists of directing the outlet of the valve port so that the flashing and cavitation take place away from valve surfaces. Generally, this involves a cage-style globe valve in which the flow comes from outside the cage perimeter through orifices that direct the flow to the center of the cage area. An example of this is shown in Figure 4-4.

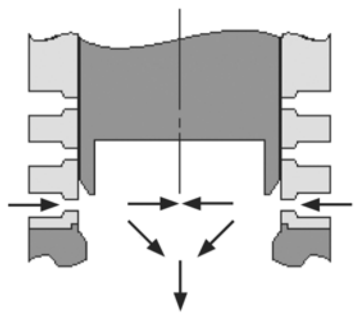

Figure 4-4
Controlled Valve Centerline Cavitation

One of the underlying assumptions for this approach is that the impact of the orifice outlet flows in the center will result in the velocity becoming low enough to allow the pressure to recover sufficiently to permit the cavitation to occur in the centerline region away from the body and/or cage. Occasionally, however, the cavitation region will occur further downstream inside the valve and can cause body deterioration in the bottom of the valve (see Figure 4-5).

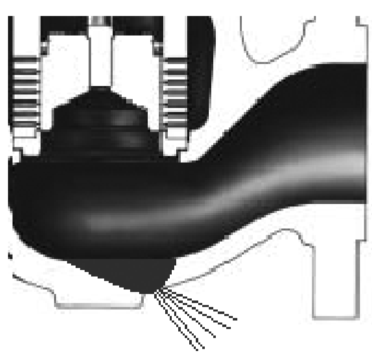

Figure 4-5
Cavitation Damage

4.11.2 Flashing/Cavitation Prevention

The most effective method to prevent damage to the valve/piping is to prevent the occurrence of flashing and, therefore, cavitation. The likelihood of the vena contracta pressure being below the vapor pressure is greater for higher pressure drops. If the pressure drop can be taken in small enough steps, it is possible to prevent the pressure from being below the vapor pressure. The pressure drops are shown in Figure 4-6. This means that flashing and cavitation cannot take place. This is the principle behind the multistage valve designs that are recommended for high pressure drop service.

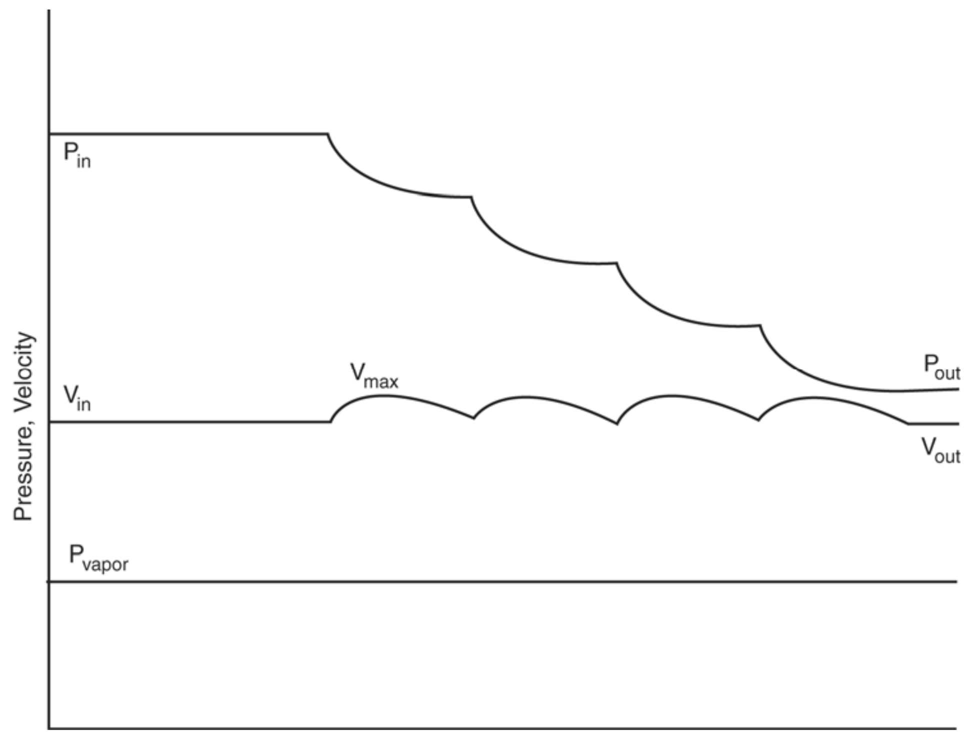

Figure 4-6
Pressure Drop in a Multistage Valve Design

Several examples of current multistage valve designs are shown in Figures 4-7 through 4-10.

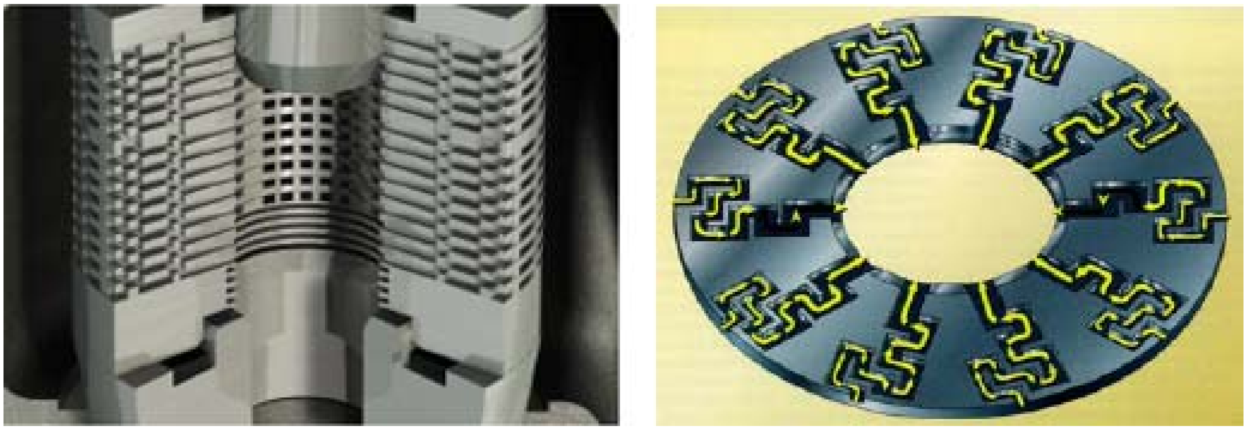

Figure 4-7
CCI Drag

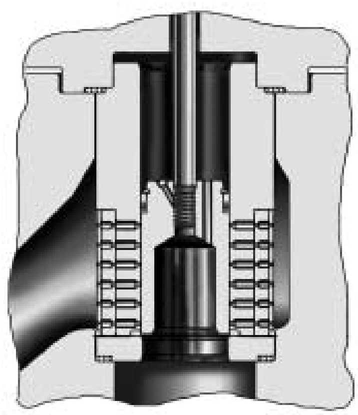

Figure 4-8
Fisher Cavitrol

Figure 4-9
Copes-Vulcan Hush

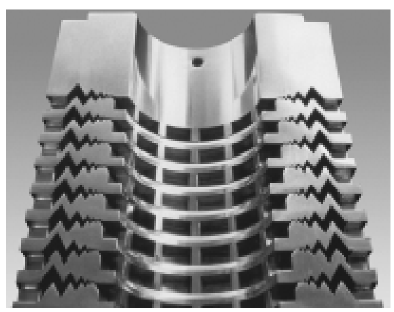

Figure 4-10
Valtek Tiger Tooth

4.12 Gasket Failures

4.12.1 Problems

Although gasket failures (such as body/bonnet and cage/body) were not reported, they are more likely on severe service valves, resulting in leakage that can cause a forced outage. Internal leakage (such as cage/body) can mean thermal losses or body erosion and subsequent through-body leakage.

4.12.2 Maintenance Recommendations

Gasket principles and installation information can be found in EPRI's *Assembling Bolted Connections Using Spiral-Wound Gaskets* [15] and *Pressure Seal Bonnet Valve Maintenance Guide* [16].

5
FEEDPUMP DISCHARGE CHECK VALVES

5.1 Introduction

Pumps operating in parallel that discharge to a common header require a check valve at the discharge to prevent reverse flow through a non-operating pump. In addition to diverting flow, reverse flow through a pump could result in mechanical damage to the pump, particularly the bearings.

Feedwater pumps typically are arranged in sets of two or three, operating in parallel to permit economical operation at less than full power and to provide redundancy in the event of the trip of one of the pumps. The differential pressure across a non-operating pump check valve represents one of the highest pressures experienced in the power plant. In addition, the dynamics of valves during operation at low flows and closure on the trip of one (or both) of the feedwater pumps represents one of the severest of valve operating transients. For these and other reasons, FCV maintenance is challenging.

5.2 EPIX Analysis

5.2.1 Results

Table 5-1 presents the failure causes of FCVs as previously presented in Table 2-6. It should be noted that the EPIX database search resulted in only 10 events. This section l discusses these events and also reviews other potential problems that would be associated with this application.

Table 5-1
FCV Failure Causes

Failure Cause	Percent
Hinge pin wear	40
Unknown	20
Disc/seat not aligned	20
Hinge pin missing	10
Disc nut pin	10

5.2.2 Discussion

The failure mechanism for all of the known causes shown in Table 5-1 was flow-induced disc flutter. Flutter is the result of operating at less than design flow. While feedwater systems operate at design flow most of the time, they can end up at off-design conditions for periods sufficient to permit damage to occur. A detailed discussion of low-flow operation is found in Section 5.3.1 of this report. Every check valve design is susceptible to disc flutter due to low-flow operation.

Because operating at off-design conditions cannot be prevented, maintenance strategies must focus on condition monitoring and appropriate preventive maintenance. Condition monitoring is described in Section 9 of EPRI's *Check Valve Maintenance Guide* [17]. A preventive maintenance program is described in Appendix A of this report.

5.3 Potential Problems

The operating conditions associated with FCVs can result in the following conditions:

- Operating at flow rates lower than design conditions. (This resulted in check valve damage, which was the cause of a very severe water hammer at a nuclear plant in 1985.)
- Water hammer that can occur after a pump trip.
- Flow-induced disc flutter due to pipe geometry.

5.3.1 Low Flow Operation

As indicated by the EPIX data, the primary source of wear to check valve internals is excessive disc movement. Wear will be minimal if the valves are selected and sized so that the disc is fully open and held firmly against the stop. The size and type of check is therefore selected based on the dominant operating condition (for example, full power feedwater flow). The only way to deal with lower flows is to make the valve smaller. However, that will result in higher, undesirable pressure drops.

The flow velocity required to fully open and firmly hold the disc against the stop, V_{min}, is the value of the velocity based on the inside diameter at the inlet to the valve for a fluid at a specific density. It is shown by the following equation:

$$V_{min} = C/\sqrt{\rho} \qquad \textbf{Equation 5-1}$$

Table 3-3 of *Application Guide for Check Valves in Nuclear Power Plants* [18] provides published values of the constant C for swing, tilting disc, and lift check valves, and is reproduced in Appendix B of that report. A method for determining C for swing check valves can be found in Section 14 of *Guide for the Application and Use of Valves in Power Plant Systems* [19]. If possible, the value should be confirmed by the valve manufacturer.

Based on the coefficients in Appendix B of the *Application Guide for Check Valves in Nuclear Power Plants* [18], and assuming cold water (ρ= 62.4 lb/ft [1000 kg/m^3]), swing check valves have V_{min} values from 7.6 to 20 feet/sec (2.3 to 6.0 m/sec) and lift checks of 4 to 5 feet/sec (1.2 to 1.5 m/sec). Because the density of water diminishes with higher temperature, V_{min} values increase.

As discussed in EPRI's th*e Application Guide for Check Valves in Nuclear Power Plants* [18], proper interpretation of the use of V_{min} is important. It is wrong to assume that a valve is misapplied and will be subjected to accelerated wear if it is operating at a velocity below $V_{min.}$ A review of 1200 check valve inspections conducted in the late 1980s at seven different nuclear units showed that only 15% of the valves operating below V_{min} had enough wear or fatigue problems to justify inspecting them at the next outage.

There is not enough experimental data available to assess how accurate the equation is for air and steam. In *Application Guide for Check Valves in Nuclear Power Plants* [18], it is reported that the velocities required to hold a disc firmly against the stop in air is less than predicted using C based on water tests.

Key Technical Point

Proper sizing of a check valve is such that the flow velocity maintains the disc firmly against the stop. Oversizing can be the result of plant designs that were incorrect or were never reconciled with the final design flows. It should not be assumed that the sizing is correct. When unusual wear is found, the size should be verified.

Key O&M Cost Point

The most important design consideration for check valves is proper sizing. Overemphasis on lowering pressure drop and plant operating costs by using larger sizes can result in check valves that flutter, causing hinge pin, disc post, or other wear. This wear can result in catastrophic valve failure and forced plant outages, more than offsetting the gains for the lower pressure drop.

5.3.2 Pump Trip (Water Hammer)

All systems that use two or more parallel operating pumps will have a check valve at the outlet of each pump. The check valve allows one pump operation by preventing the flow from returning to the pump suction header through the non-operating pump. If both pumps are operating and one is shut down or trips, flow in that pump ceases, and reverse flow conditions are created that cause the check valve to close. If the closure occurs after flow has reversed, a pressure rise above the operating pressure will occur in the pump discharge piping, which travels downstream. In the case of the feedwater pump, this would include the high-pressure feedwater heaters.

The pressure transient is called a *water hammer*. The magnitude of this water hammer is a function of how fast the flow in the system reverses and how fast the valve closes. The speed of flow reversal depends on numerous factors including the number of pumps, the specific speed of the pumps, the pipe length, and elevation change. These factors are practically impossible to change and will not be discussed further.

The speed of closure is important in order to minimize flow reversal. For typical pressures and temperatures existing at the discharge of a feedwater pump, the pressure increase is approximately 70 psi (483 kPa) for each foot per second change. The closure speed of the different types of check valves varies considerably. It is controlled by the weight of the disc, the forces closing the disc, the distance it must travel from full open to close, the valve orientation, and, if the disc is spring loaded, by the strength of the spring. Fast closing valves (without external operators) have the following properties:

- The disc (including all moving parts) is lightweight, with low inertial resistance to moving close.
- Closure is assisted by springs.
- The full stroke of the disc is short.

Swing checks are slow closing valves because they violate all three of these criteria. The tilting disc check valve improves on the time of closure by being more sensitive to velocity changes and having a smaller stroke than a swing check. The nozzle check has the fastest closure times because the closing element is very light, it is spring loaded, and the stroke is short. The spring can be selected to match the closing speed to the system requirement. Lift check valves with springs are similar to nozzle check valves in their closing times.

Key Technical Point

When water hammer is an issue, replacing the check valve with one that has a faster stroke time can help. A typical order of closure times (fastest to slowest) is nozzle check, lift check, tilting disc, and swing check.

5.3.3 Flow-Induced Disc Flutter Due to Pipe Geometry

Minimum flow requirements are discussed in Section 5.3.1. As indicated, being below minimum flow does not necessarily mean valve degradation. However, if flow disturbances (such as pipe geometry) exist, valve damage (such as hinge pin wear) can occur due to the fluttering caused by the geometry. While not a prevalent problem with feedwater pump discharge check valves, flow induced disc flutter due to pipe geometry should be considered when pump discharge piping has elbows upstream of the check valve.

Swing check and tilting disc check valves are the most sensitive to this problem because their discs rotate as the flow changes. In contrast, nozzle checks and lift checks, in which the disc face remains perpendicular to flow, are not sensitive to the problem.

Key Technical Point

If check valve minimum flow velocity analysis appears to support satisfactory operation, but wear and failures still occur, personnel should ensure that piping geometry is not creating abnormal velocity profiles that will cause disc flutter.

6
HIGH-PRESSURE DRAIN VALVES

6.1 Introduction

High-pressure drain valves were included in the severe valve category due to leakage. Boiler drains, main turbine drains, and steam line drains are examples of these valves. They operate in conditions similar to the severe duty control valve types described in Chapter 4. A high pressure drop occurs as lines are drained to atmospheric pressure tanks or main condenser. There are some differences, which are listed here:

- The valves are smaller (1 to 2 in. [25.4 to 50.8 mm]/DN 25–50).
- The valves are on/off.
- The fluid is primarily water or a mixture of water and vapor.
- Flashing almost always occurs. Cavitation is less likely to occur.
- Debris (corrosion products) is present in many cases.

6.2 Description of Designs Commonly Used

Most drain valves are of the “T” or “Y” pattern globe design. Sample designs are shown in Figures 6-1 and 6-2. These valves can be manually or power operated.

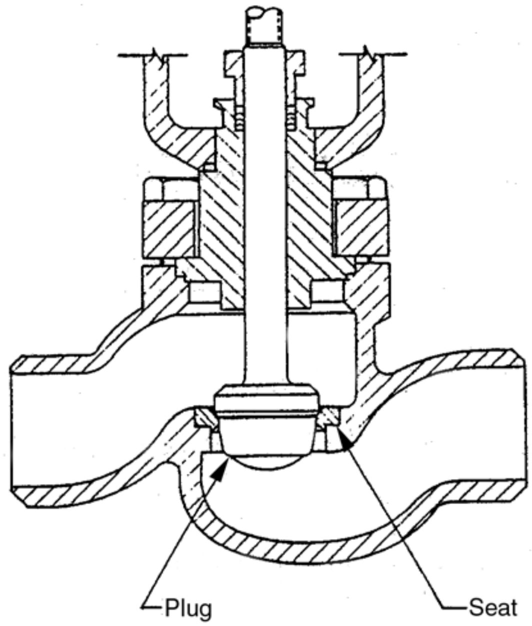

Figure 6-1
“T” Pattern Globe Valve

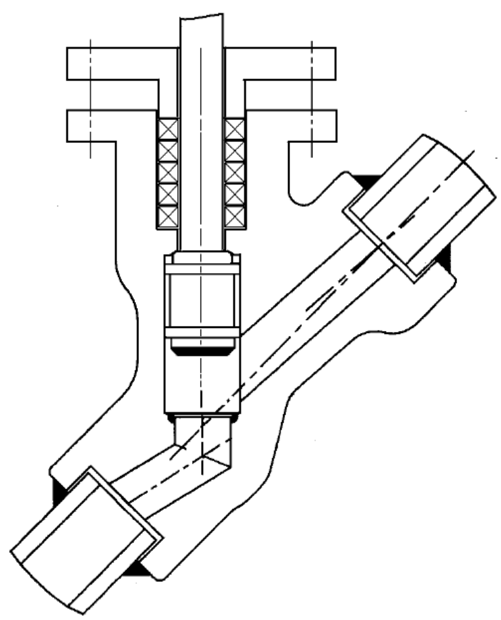

Figure 6-2
“Y” Pattern Globe Valve

6.3 Failure Modes

Only one EPIX event was identified for drain valves. The event was the failure of several main steam turbine drains to fully close, therefore allowing leakage. Corrective action was to change the valve with a new design.

6.4 Failure Causes

All leakage occurs due to the erosive effects of high fluid velocity. The precursors that allow this condition are described here:

6.4.1 Operator Actions

Plant operators do not fully close manual valves. This appears to be due to the amount of torque required to:

- Seat the valve against the very high pressures involved and
- Overcome the high packing stresses needed to prevent packing leakage

Plant operators had no way to know that the valve was not fully closed and whether sufficient seating force has been applied.

The result is, in effect, valve throttling and results in high velocity flow that cause flashing and/or cavitation damage as described in Section 4.11.

6.4.2 Improper Torque Settings

Similar to the manual valves (high delta pressure and/or high packing loads), the motor operator torque settings are too low, and the valve is not fully closed.

6.4.3 Erosion While Fully Open

The valve is fully open and passing wet steam and/or debris for a sufficient period of time to cause erosion seat damage. This creates small flow paths that exist when the valve is closed, even very tightly. This would explain why problems occur for power-operated valves that have been sized to overcome the forces discussed above in Section 6.4.1.

6.4.4 Throttling

The valve is intentionally throttled. The throttling would set up flashing/cavitation damage or result in conditions as described above.

6.5 Condition-Based Monitoring

The existence of leakage through drain valves is generally determined by the temperature of the valve outlet and/or downstream piping. Thermography is a cost-effective method [20]. Alternatively, thermocouples can be attached either permanently or temporarily for valves that are suspected to be leaking. Acoustic techniques also exist [21]. None of these methods, however, will give an accurate leakage rate.

6.6 Preventive Maintenance

Differences in designs and operating conditions are such that there are no standard preventive maintenance practices. Condition monitoring is the most effective maintenance practice. It is used to generate corrective orders to perform internal inspections for these valves based on the existing leakage. Trend analysis should be used to determine the need for periodic maintenance. Some valves have periodic PM performed based on history.

6.7 Problem Resolution

6.7.1 Downstream Orifice

The core problem is the high pressure drop across the valve seat. Reducing this pressure drop will reduce or eliminate the erosion that occurs. This can be done by installing an orifice downstream of the valve.

This orifice can be separate from the valve or integrated into the valve design. A useful rule for designing the orifice is to have each stage take no more than 40% of the inlet pressure to the stage. This will not only mitigate the pressure drop across the valve, but will eliminate much of the noise created by the sonic flow that exists when only the valve is absorbing the drop. If flashing is expected, the flow area of each stage must be able to accommodate the volumetric flow. For a 5000-psi (35-MPa) pressure drop, this approach will result in a seven-stage orifice.

6.7.2 Tandem Valves

If using a downstream orifice is not a desirable solution, another common approach is to use two valves in tandem or series. The downstream valve is intended to take the wear and tear and would be closed first (opened last). The upstream valve would affect the tight shutoff and would be opened first (closed last).

This approach may not avoid the problem described in Section 6.4.2, depending on the pressure drop observed across the upstream valve. Therefore, using a valve with a built-in orifice (one stage) can shift enough pressure drop to the downstream valve, protecting the seating surface of the upstream valve.

Another issue with tandem valves is that using this approach effectively doubles the number of valves to be closed. This can impact startups. Operators will be under pressure to close the drains; therefore, the upstream valve may not be closed effectively.

6.7.3 Ball Valves

Ball valves offer the following features that are advantageous for isolation:

- Closure requires only a 90-degree turn of the handle, affording rapid isolation.
- For manual valves, operators can rapidly determine if the valve is fully closed. No further tightening is possible.

Ball valves have become much more robust than in the past. Designs exist (for example, trunnion-mounted designs) that will operate under the extreme conditions required. Ball weight is supported by the thrust bearings instead of the seats as in the floating ball design, thus providing more uniform seating load and wear. However, bearings can experience high wear if abrasive solids are present in the fluid. This can cause the torque to increase, making it unsuitable for fluids contaminated with solids.

7
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A
FEEDWATER PUMP DISCHARGE CHECK VALVE PM PROGRAM

A.1 Recommended PM Program

The following PM program is based on *Preventive Maintenance Program, Volume 5: Check Valves* [22] and *Equipment Condition Monitoring Templates: Addendum to the Preventative Maintenance Basis TR-106857* [23]. Feedwater pump discharge check valves were assumed to be in critical, severe service.

Table A-1
PM Program

PM Task			Duty Cycle	
Type	**Task**	**Report Section**	**High**	**Low**
Time-directed	Partial internal	A.1.2	6 – 10Y	8 – 16Y
	Overhaul	A.1.3	AR	AR
Condition monitoring	See note*			
	Diagnostic tests	A.1.4	2Y	2Y

High duty cycle – Oscillations in flow conditions OR ≥ 100 check valve cycles per year
Low duty cycle – No oscillations AND <100 check valve cycles per year

AR - As required
OR - Operator rounds
Y - Periodicity in Years

*Note: These are large, critical valves that are in service 100% of the operating time. They are generally subject to past hinge pin wear and must be placed in a time-directed PM program at a frequency dictated by the wear historically seen (that is, as required). Condition monitoring should be limited to valves that have been performing satisfactorily and past inspections have confirmed no signs of flutter. Condition monitoring should be used only to confirm that past assumptions were correct and that nothing has changed.

A.1.1 Partial Internal Inspection

The partial internal inspection is designed to identify premature failures and to confirm the assumed wear rate and overhaul interval. The partial internal inspection is performed to discover degradation from loose, damaged (misaligned, bent, distorted, cracked, or chipped), or missing components, erosion, corrosion, wear, binding that restricts free movement, and the buildup of crud or debris on the body or disc seat areas. The inspection is capable of detecting such degradation affecting most parts of the valve. By observing free play and making available measurement, minor wear at a meaningful level is possible.

Table A-2
Partial Internal Inspection Objectives

Failure Location	Degradation Mechanism
Body	Erosion
Body	Corrosion
Disk	Wear - disk pin or post
Disk	Wear - disk pin or post
Disk	Disk detachment
Plug	Wear
Disk arm	Bent
Disk arm	Wear-post hole, hinge pin hole
Hinge pin	Wear
Hinge pin	Binding
Seat failure (body or disk)	Distortion, cracked seats
Seat failure (body or disk)	Crud buildup
Seat failure (body or disk)	Chipped seat(s)

Partial internal inspection of check valves should include the following activities:

- Inspect for external leakage (bonnet gasket or hinge pin cover).
- Inspect for external corrosion.
- Check for debris and any damage to the seat, hinge arm, and disk.
- Inspect for loose, damaged, or missing parts.
- Determine if the check arm and disk assembly move freely and easily.
- Inspect for damage, unusual wear, or cracked or missing disk pin or post.
- Inspect the disk arm disk, post hole, and disk hinge pin hole for unusual wear.
- Check for erosion and corrosion of the valve body, disk, disk arm, and hinge pin.
- Check for proper alignment of the disk or plug assembly and the seat.
- Inspect for cracked, chipped, or distorted seats.
- Inspect for crud build up.
- Clean and lubricate all parts as required.
- Manually full stroke the disk (ensure that there is no body interference and that the disk is properly centered in the valve).
- Ensure that the disk nut-locking device is tight and secure.

A.1.2 Overhaul

The overhaul is the only PM task that can provide complete information on clearances and the condition of all wear surfaces and internal parts. The overhaul includes the tasks that comprise the partial internal inspection.

Table A-3
Overhaul Objectives

Failure Location	Degradation Mechanism
Body	Erosion
Body	Corrosion
Disk	Disk detachment
Plug	Wear
Disk arm	Bent
Disk arm	Wear-post hole, hinge pin hole
Hinge pin	Corrosion
Hinge pin	Wear
Hinge pin	Binding
Seat failure (body or disk)	Distortion, cracked seats
Seat failure (body or disk)	Crud buildup
Seat failure (body or disk)	Chipped seat(s)

The overhaul should include all of the items listed for partial internal inspections. In addition, an overhaul is expected to completely refurbish and restore the check valve to the original equipment condition.

A.1.3 Diagnostic Tests

The diagnostic tests (acoustic, ultrasonic, and magnetic flux) are capable of detecting conditions that could give rise to failure of every one of the subcomponent groups. In general, the diagnostics give more specific information about failures that lead to internal leakage and structural failure than they provide for abnormal wear of the internals. In the latter case, the diagnostic tests could indicate the existence of unusual vibration or oscillation but cannot be specific about the degree of wear unless internal leakage or structural failures result.

Table A-4
Diagnostic Tests

Failure Location	Degradation Mechanism	Technique
Body	Erosion	Ultrasonic, mag flux
Disk	Disk detachment	Acoustic monitoring
Disk arm	Bent	Acoustic monitoring
Disk arm	Wear-post hole, hinge pin hole	Ultrasonic, mag flux
Hinge pin	Wear	Ultrasonic, mag flux
Hinge pin	Binding	Ultrasonic, mag flux
Seat failure (body or disk)	Distortion, cracked seats	Acoustic monitoring

B
CHECK VALVE MINIMUM VELOCITY COEFFICIENTS

The coefficients for check valve minimum velocity are shown in Table B-1. These coefficients should be used as described in Section 5 of this report.

Table B-1
Minimum Velocity Coefficients, C, Required for Full Disc Lift (from *Application Guide for Check Valves in Nuclear Power Plants* [18])

Table 3-3
Minimum Velocity Coefficients, C, Required for Full Disc Lift

Manufacturer	Swing Check	Tilting Disc	Lift Check
Crane	60	80, 5° Type 30, 15° Type	40, Horizontal 140, Y Pattern
Anchor/ Darling	75	135	32, Horizontal 113, Y Pattern
Rockwell/ Edward	Not Offered	91, 6" (600)* 91, 8" (600) 91, 10" (600) 91, 12" (600) 75, 14" (600) 105, 16" (600) 105, 18" (600) 105, 20" (600)	Horizontal 51, 3" (600) 58, 6" (600) 62, 12" (600) 75, 12" (900) Angle 54, 3" (600) 67, 6" (600) 72, 12" (600) 90, 12" (900)
Pacific	135 80 (60° Design)	No Published Data	Bolted Bonnet 40 Pressure Seal 32
Atwood & Morrill	80 (Based on One Test)	Not Offered	No Published Data
Walworth	134 to 158 (Based on One Test)	Not Offered	No Published Data
Velan	No Published Data	Not Offered	No Published Data
Aloyco	No Published Data	Not Offered	No Published Data

*(600) = ANSI Pressure Class 600, etc.

C
FAILURE DATA FOR VALVES WITH ACTUATORS

C.1 Introduction

This appendix contains the data used to perform the failure analysis reported in Sections 3 and 4. A total of 779 events were analyzed. Of those events, 352 were confirmed to fall within the scope of this report for non-valve failures (actuators and accessories). The 352 failures were broken down as follows:

Non-valve	277
Valve	48
Unknown	27

An additional 15 events for pressurizer spray valves were added during document reviews using *Review of Air-Operated Valve Related Events* [1].

C.2 Discussion

Five tables are included in this appendix:

- Table C-1 contains the data for non-valve failures (277) sorted by date.
- Table C-2 contains the data for non-valve failures (277) sorted by manufacturer.
- Table C-3 contains the data for valve failures (48) sorted by date.
- Table C-4 contains the data for valve failures (48) sorted by manufacturer.
- Table C-5 contains data for all pressurizer spray valves (15) from *Review of Air-Operated Valve Related Events* [1].

For the date, manufacturer, and model number, the data are as found in the EPIX database. The EPIX failure modes were simplified to Report Failure Mode to allow better understanding. The Report Failure Cause and Report Failure Mechanism are the result of analyzing the remaining data and the narrative. The narratives are not included due to their variation in scope and size and their limited usefulness in providing insight into the root causes.

Nuclear plant users seeking additional details for PSVs can refer to Review of Air-Operated Valve Related Events [1].

Table C-1
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
11/17/1996	CDV	Unaffected by failure	Non-demand failure	Air supply	Stem seal (aging)
1/9/1997	FRV	Failed to control	Control failure	Unknown	Bench set
1/9/1997	FRV	Failed to control	Control failure	Control	Stem/actuator connection loose
1/11/1997	ADV	Failed to remain open	Opening failure	Positioner	Adjusting nut
1/18/1997	FRV	Failed to open on demand (stuck closed)	Opening failure	Positioner	Override clevis
1/25/1997	FMV	Failed to close on demand (stuck open)	Closing failure	Unknown	Regulator body cracked
2/2/1997	CDV	Internal leakage due to being improperly seated	Internal leakage	Control	Faulty relief valve
2/15/1997	CDV	Internal leakage due to being improperly seated	Internal leakage	Air supply	Needle valve
2/16/1997	FRV	Failed to close within set-point tolerance	Set-point failure	Disc/stem	Regulator
2/27/1997	ADV	Failed to remain open	Opening failure	Disc/cage	Inadequate design
3/4/1997	CDV	Premature opening	Opening failure	Actuator	Inadequate design
3/4/1997	FMV	Failed to close on demand (stuck open)	Closing failure	Control	Controller
3/7/1997	FRV	Failed to control	Control failure	Unknown	Controller
3/8/1997	ADV	Found unavailable during non-demand observation	Non-demand failure	Air supply	Controller malfunction

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
3/11/1997	CDV	Unaffected by failure	Non-demand failure	SOV	Controller malfunction
3/16/1997	FRV	Failed to open on demand (stuck closed)	Opening failure	Positioner	Loss of power
3/26/1997	FRV	Failed to control	Control failure	Control	Controller (calibration)
3/29/1997	CDV	Unavailable, not failed	Non-demand failure	Pressure transducer	Controller (calibration)
3/29/1997	CDV	Unavailable, not failed	Non-demand failure	SOV	Plug ring
3/30/1997	CDV	Unavailable, not failed	Non-demand failure	SOV	Balance seal
3/31/1997	CDV	Unavailable, not failed	Non-demand failure	Unknown	Piston ring
4/10/1997	FRV	Failed to open on demand (stuck closed)	Opening failure	Actuator	Seat/disc bonding
4/10/1997	FRV	Failed to open on demand (stuck closed)	Opening failure	Pressure transducer	In-service consolidation
4/22/1997	CDV	Found unavailable during non-demand observation	Non-demand failure	Positioner	Loose
4/26/1997	FRV	Failed to control	Control failure	Control	Pilot plug stem galling against shield plate
5/6/1997	FRV	Failed to control	Control failure	Actuator	Feedback linkage
5/6/1997	FRV	Failed to control	Control failure	Control	Feedback linkage
5/14/1997	FRV	Failed to control	Control failure	Control	FME
5/30/1997	FRV	Failed to open on demand (stuck closed)	Opening failure	Control	Unknown

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
6/5/1997	FRV	Failed to control	Control failure	Actuator	Feedback linkage
6/10/1997	ADV	Failed to remain open (drifted off open seat)	Opening failure	Control	Calibration
6/20/1997	CDV	Unavailable, not failed	Non-demand failure	Control	Unknown
7/12/1997	CDV	Unavailable, not failed	Non-demand failure	Control	Unknown
7/19/1997	FRV	Failed to open on demand (stuck closed)	Opening failure	Positioner	Calibration
7/22/1997	FMV	Failed to close on demand (stuck open)	Closing failure	SOV	Unknown
8/7/1997	FRV	Failed to control	Control failure	Control	Aging
8/8/1997	CDV	Found unavailable during non-demand observation	Non-demand failure	Positioner	Failed to stroke
8/12/1997	ADV	Found unavailable during non-demand observation	Non-demand failure	SOV	Intermittent operation
8/16/1997	ADV	Failed to remain closed (drifted off closed seat)	Closing failure	Pilot	Incorrect installation
9/1/1997	FRV	Failed to control	Control failure	Volume booster	Coil failure
9/6/1997	FRV	Failed to open on demand (stuck closed)	Opening failure	Control	Coil failure
9/17/1997	CDV	Found unavailable during non-demand observation	Non-demand failure	Actuator	Coil failure
10/13/1997	FRV	Failed to open on demand (stuck closed)	Opening failure	Actuator	Coil failure

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
10/19/1997	CDV	Internal leakage due to being improperly seated	Internal leakage	Air supply	Unknown
11/16/1997	ADV	Failed to respond to open demand	Closing failure	Air supply	Coil Missing
11/25/1997	CDV	Operated, but not within specified parameters	Set-point failure	SOV	Fatigue failure (vibration)
12/1/1997	CDV	Unavailable, not failed	Non-demand failure	Control	Unknown
12/6/1997	FMV	Failed to close on demand (stuck open)	Closing failure	Positioner	Unknown
1/10/1998	FRV	Failed to control	Control failure	SOV	Unknown
1/16/1998	FRV	Failed to control	Control failure	Positioner	Incorrect for application
2/5/1998	FRV	Failed to open on demand (stuck closed)	Opening failure	Control	Undersized
2/9/1998	CDV	Unavailable, not failed	Non-demand failure	Control	Accumulator leak
2/22/1998	ADV	Failed to remain open	Opening failure	Pressure transducer	Diaphragm failure
2/25/1998	FRV	Failed to control	Control failure	Control	Inadequate hydraulic oil
2/28/1998	CDV	Found unavailable during non-demand observation	Non-demand failure	Positioner	Bench set
3/3/1998	FRV	Failed to control	Control failure	Actuator	Bench set
3/10/1998	FRV	Failed to control	Control failure	Control	Bench set
3/12/1998	FRV	Failed to open on demand (stuck closed)	Opening failure	SOV	Calibration

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
3/28/1998	CDV	Premature closed on demand (not stuck open)	Closing failure	Positioner	Unknown
4/1/1998	CDV	Operated, but not within specified parameters	Set-point failure	Positioner	Fitting broken
4/2/1998	ADV	Failed to open on demand (stuck closed)	Opening failure	Disc/cage	Port connectors
4/2/1998	FRV	Failed to control	Control failure	Packing	Regulator failure
4/14/1998	FRV	Failed to control	Control failure	Unknown	Regulator failure
4/14/1998	CDV	Found unavailable during non-demand observation	Non-demand failure	Air supply	FME
5/6/1998	ADV	Failed to remain open	Opening failure	Positioner	FME
5/25/1998	FRV	Failed to control	Control failure	Control	Incorrect regulator
6/9/1998	FMV	Failed to close on demand (stuck open)	Closing failure	Actuator	Tubing failure
6/10/1998	FRV	Failed to open on demand (stuck closed)	Opening failure	Control	Tubing failure
6/11/1998	FRV	Failed to control	Control failure	Air supply	Tubing failure
6/24/1998	FRV	Failed to open on demand (stuck closed)	Opening failure	Actuator	Tubing failure
7/2/1998	FRV	Failed to close within set-point tolerance	Set-point failure	FME valve	Tubing failure
7/17/1998	ADV	Failed to remain closed (drifted off closed seat)	Closing failure	Disc/cage	Card

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
8/14/1998	FRV	Failed to control	Control failure	Actuator	Card
8/17/1998	FRV	Failed to close within set-point tolerance	Set-point failure	Positioner	Card
8/22/1998	FRV	Failed to control	Control failure	SOV	Controller malfunction
8/31/1998	FRV	Failed to control	Control failure	Positioner	Controller malfunction
9/2/1998	FRV	Failed to control	Control failure	Air supply	Controller malfunction
9/5/1998	ADV	Failed to open on demand (stuck closed)	Opening failure	Disc/cage	Controller malfunction
9/18/1998	FRV	Failed to control	Control failure	Unknown	Controller malfunction
9/22/1998	CDV	Unavailable, not failed	Non-demand failure	Control	Controller malfunction
9/24/1998	ADV	Failed to remain open	Opening failure	Actuator	Controller malfunction
9/25/1998	FRV	Failed to close on demand (stuck open)	Closing failure	Actuator	Controller malfunction
9/30/1998	FRV	Failed to control	Control failure	Control	Controller malfunction
10/13/1998	FRV	Failed to control	Control failure	Air supply	Controller malfunction
10/17/1998	FRV	Failed to open on demand (stuck closed)	Opening failure	Control	Fuse
10/17/1998	CDV	Operated, but not within specified parameters	Set-point failure	Volume booster	Fuse
10/23/1998	FMV	Failed to close on demand (stuck open)	Closing failure	Control	Instrument failure

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
11/24/1998	ADV	Failed to open on demand (stuck closed)	Opening failure	Disc/stem	Instrument failure
11/26/1998	FRV	Failed to open on demand (stuck closed)	Opening failure	Control	Instrument failure
12/9/1998	FRV	Failed to control	Control failure	Positioner	Power breaker
12/10/1998	FRV	Failed to control	Control failure	Actuator	Power supply
12/19/1998	CDV	Internal leakage due to being improperly seated	Internal leakage	FME valve	Power supply
12/25/1998	FRV	Failed to control	Control failure	Air supply	Relay malfunction
12/30/1998	FRV	Failed to open on demand (stuck closed)	Opening failure	Positioner	Relay malfunction
1/9/1999	FRV	Failed to open on demand (stuck closed)	Opening failure	Control	Procedure
1/10/1999	FRV	Failed to control	Control failure	Control	Procedure
1/18/1999	FMV	External leakage	External leakage	Body erosion	Test equipment
2/1/1999	FRV	Failed to open on demand (stuck closed)	Opening failure	Positioner	Unknown
2/11/1999	FRV	Failed to control	Control failure	Control	Unknown
2/12/1999	CDV	Found unavailable during non-demand observation	Non-demand failure	SOV	Plug not seated at assembly
2/16/1999	FMV	Failed to close on demand (stuck open)	Closing failure	Control	Stem/plug not connected

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
2/19/1999	CDV	Unavailable, not failed	Non-demand failure	SOV	FME
2/27/1999	FMV	Failed to close on demand (stuck open)	Closing failure	SOV	Excessive friction
3/2/1999	CDV	Unaffected by failure	Non-demand failure	Actuator	Excessive friction
3/9/1999	CDV	Unavailable, not failed	Non-demand failure	Control	Incorrect packing spacer
3/12/1999	FRV	Failed to control	Control failure	Positioner	Leaking
3/12/1999	FRV	Failed to control	Control failure	Unknown	High leakage
3/14/1999	CDV	Found unavailable during non-demand observation	Non-demand failure	SOV	Beam assembly
3/30/1999	FMV	Failed to close on demand (stuck open)	Closing failure	Stem	Digital positioner memory
4/5/1999	FMV	Failed to close on demand (stuck open)	Closing failure	Control	Feedback spring
4/14/1999	CDV	Unaffected by failure	Non-demand failure	Air supply	Inlet port failure
4/15/1999	CDV	Unaffected by failure	Non-demand failure	Positioner	Internal diaphragm
4/20/1999	FRV	Failed to open on demand (stuck closed)	Opening failure	SOV	Internal leakage
4/21/1999	FMV	Failed to close on demand (stuck open)	Closing failure	Control	Loose screw
4/30/1999	FRV	Failed to control	Control failure	Actuator	Manufacturing problems
5/3/1999	FMV	External leakage	External leakage	Air supply	Pilot valve

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
5/4/1999	FRV	Failed to control	Control failure	Positioner	Pilot valve
5/7/1999	CDV	Unavailable, not failed	Non-demand failure	Control	Pilot valve
5/13/1999	FRV	Failed to control	Control failure	Unknown	Potentiometer
5/16/1999	FRV	Failed to control	Control failure	Positioner	Calibration
5/22/1999	CDV	Found unavailable during non-demand observation	Non-demand failure	SOV	Calibration
6/6/1999	FRV	Failed to control	Control failure	Unknown	FME
6/15/1999	CDV	Premature opening	Opening failure	Actuator	Pilot valve
6/21/1999	FRV	Failed to open on demand (stuck closed)	Opening failure	Pressure transducer	Unknown
6/21/1999	FRV	Failed to close within set-point tolerance	Set-point failure	SOV	Unknown
6/21/1999	FRV	Failed to close within set-point tolerance	Set-point failure	SOV	Feedback linkage
6/21/1999	FRV	Failed to close within set-point tolerance	Set-point failure	SOV	Pilot valve
6/24/1999	FRV	Failed to control	Control failure	Control	Calibration
7/4/1999	ADV	Failed to open on demand (stuck closed)	Opening failure	Positioner	Calibration
7/5/1999	ADV	Failed to respond to open demand	Closing failure	Air supply	Aging

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
7/5/1999	FRV	Failed to control	Control failure	Positioner	Incorrect venting
7/5/1999	FRV	Failed to close within set-point tolerance	Set-point failure	Unknown	Aging
7/5/1999	FRV	Failed to close within set-point tolerance	Set-point failure	Unknown	Aging
7/5/1999	ADV	Failed to open on demand (stuck closed)	Opening failure	Positioner	Coil failure
8/3/1999	FRV	Failed to control	Control failure	Control	FME
8/5/1999	CDV	Operated on required demand	Non-demand failure	Positioner	Unknown
8/5/1999	CDV	Unavailable, not failed	Non-demand failure	Control	Unknown
8/27/1999	FRV	Failed to close within set-point tolerance	Set-point failure	Control	Bent
9/22/1999	FRV	Failed to control	Control failure	Positioner	Unknown
9/22/1999	FRV	Failed to control	Control failure	Control	Unknown
9/23/1999	FRV	Failed to control	Control failure	Control	Unknown
9/29/1999	FMV	External leakage	External leakage	Air supply	Unknown
10/6/1999	FRV	Failed to control	Control failure	Plug/seat	Unknown
10/7/1999	FRV	Failed to open on demand (stuck closed)	Opening failure	Unknown	Unknown
10/7/1999	FRV	Failed to close within set-point tolerance	Set-point failure	FME valve	Unknown

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
10/9/1999	FRV	Failed to control	Control failure	SOV	Unknown
10/10/1999	FRV	Failed to control	Control failure	SOV	Unknown
11/2/1999	CDV	Unaffected by failure	Non-demand failure	Actuator	Unknown
11/7/1999	CDV	Internal leakage when fully seated	Internal leakage	Positioner	Unknown
11/19/1999	FRV	Failed to control	Control failure	Control	Diaphragm tear
11/26/1999	FRV	Failed to control	Control failure	Control	Regulator FME
12/14/1999	FRV	Failed to control	Control failure	Air supply	Tubing broken (nearby maintenance)
12/14/1999	FRV	Failed to close within set-point tolerance	Set-point failure	Positioner	Fitting broken
12/25/1999	FRV	Failed to control	Control failure	Air supply	Unknown
12/25/1999	CDV	Found unavailable during non-demand observation	Non-demand failure	SOV	In-service consolidation
12/26/1999	CDV	Unavailable, not failed	Non-demand failure	Air supply	Ferrule fitting
1/4/2000	FMV	Failed to close on demand (stuck open)	Closing failure	SOV	Tubing failed
1/16/2000	FRV	Failed to open on demand (stuck closed)	Opening failure	Control	N/A
1/27/2000	FRV	Failed to control	Control failure	Positioner	Unknown
1/27/2000	FRV	Failed to control	Control failure	Positioner	FME

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
1/28/2000	FRV	Failed to open on demand (stuck closed)	Opening failure	Disc/stem	Cam hub
2/9/2000	FRV	Failed to close on demand (stuck open)	Closing failure	Packing	Cam hub
3/18/2000	FMV	Failed to close on demand (stuck open)	Closing failure	Control	Diaphragm leak
3/19/2000	FRV	Failed to control	Control failure	Positioner	Feedback linkage
3/21/2000	CDV	Found unavailable during non-demand observation	Non-demand failure	Air supply	Calibration
3/30/2000	FRV	Failed to open on demand (stuck closed)	Opening failure	Control	Travel stops
4/3/2000	ADV	Failed to open on demand (stuck closed)	Opening failure	Disc/seat	Incorrect diaphragm
4/19/2000	FRV	Failed to control	Control failure	SOV	Fluid leak
4/22/2000	ADV	Failed to open on demand (stuck closed)	Opening failure	Actuator	Misalignment
5/2/2000	CDV	Unavailable, not failed	Non-demand failure	Control	Improper operations
5/11/2000	FMV	Failed to close on demand (stuck open)	Closing failure	Positioner	Unknown
5/25/2000	ADV	Failed to open within set-point tolerance	Set-point failure	Control	Diaphragm aging
6/10/2000	FRV	Failed to close on demand (stuck open)	Closing failure	Packing	Faulty relief valve

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
6/10/2000	FRV	Failed to control	Control failure	Actuator	Procedure
6/10/2000	FRV	Failed to open on demand (stuck closed)	Opening failure	Pressure transducer	Regulator
6/10/2000	CDV	Premature closed on demand (not stuck open)	Closing failure	SOV	Material failure
7/29/2000	FRV	Failed to open on demand (stuck closed)	Opening failure	Positioner	Procedure
8/6/2000	CDV	Unavailable, not failed	Non-demand failure	Disc/stem	Disconnected
8/21/2000	ADV	Failed to remain closed (drifted off closed seat)	Closing failure	Disc/seat	Regulator
8/22/2000	FRV	Failed to open on demand (stuck closed)	Opening failure	Control	N/A
8/26/2000	FRV	Failed to close within set-point tolerance	Set-point failure	Unknown	N/A
8/28/2000	CDV	Operated, but not within specified parameters	Set-point failure	Volume booster	N/A
8/29/2000	CDV	Operated on required demand	Non-demand failure	SOV	N/A
9/1/2000	FRV	Failed to control	Control failure	Air supply	N/A
9/4/2000	CDV	Internal leakage when fully seated	Internal leakage	Positioner	N/A
9/12/2000	FRV	Failed to control	Control failure	Positioner	N/A
9/16/2000	ADV	Failed to open within set-point tolerance	Set-point failure	Control	N/A

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
10/3/2000	FRV	Failed to control	Control failure	Positioner	N/A
10/9/2000	FRV	Failed to control	Control failure	Actuator	N/A
10/15/2000	FRV	Failed to control	Control failure	Control	N/A
10/21/2000	FRV	Failed to control	Control failure	Positioner	N/A
10/29/2000	FRV	Failed to close within set-point tolerance	Set-point failure	Packing	Stem/disc separation
11/22/2000	FRV	Failed to control	Control failure	Unknown	Weld failed
12/1/2000	FRV	Failed to control	Control failure	Actuator	Material failure
12/8/2000	ADV	Failed to remain open	Opening failure	Positioner	FME
12/14/2000	CDV	Operated, but not within specified parameters	Set-point failure	Actuator	Procedure
12/17/2000	ADV	Failed to respond to close demand	Closing failure	Disc/cage	Feedback linkage
12/17/2000	ADV	Failed to respond to close demand	Closing failure	Disc/cage	Feedback linkage
12/17/2000	ADV	Failed to respond to close demand	Closing failure	Pressure transducer	Unknown
12/24/2000	CDV	Unavailable, not failed	Non-demand failure	FME valve	Unknown
1/6/2001	FRV	Failed to open on demand (stuck closed)	Opening failure	Unknown	Zero adjust
1/9/2001	CDV	Premature opened on demand (not stuck closed)	Opening failure	SOV	Feedback linkage
1/13/2001	CDV	Operated, but not within specified parameters	Set-point failure	Disc/seat	Unknown

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
1/15/2001	CDV	Operated, but not within specified parameters	Set-point failure	Positioner	Feedback linkage
1/23/2001	CDV	Operated, but not within specified parameters	Set-point failure	Actuator	Solder connection
2/3/2001	FMV	Failed to close on demand (stuck open)	Closing failure	Positioner	Range jumper
2/4/2001	FRV	Failed to open on demand (stuck closed)	Opening failure	Pressure transducer	Aging
2/9/2001	FRV	Failed to control	Control failure	Actuator	Aging
2/28/2001	ADV	Failed to open on demand (stuck closed)	Opening failure	Actuator	Aging
3/11/2001	FRV	Failed to open on demand (stuck closed)	Opening failure	Control	Aging
3/12/2001	FMV	Failed to close on demand (stuck open)	Closing failure	Control	Aging
3/17/2001	FRV	Failed to open on demand (stuck closed)	Opening failure	Pressure transducer	Diaphragm leak
3/19/2001	CDV	Unavailable, not failed	Non-demand failure	Positioner	Pilot disc
4/2/2001	CDV	Found unavailable during non-demand observation	Non-demand failure	Actuator	Design
4/4/2001	FRV	Failed to control	Control failure	Air supply	Aging
4/10/2001	FRV	Failed to close within set-point tolerance	Set-point failure	FME valve	Coil failure

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
4/13/2001	CDV	Unavailable, not failed	Non-demand failure	Unknown	PM
4/27/2001	FRV	Failed to open on demand (stuck closed)	Opening failure	Control	Unknown
4/29/2001	FMV	Failed to close on demand (stuck open)	Closing failure	Control	Aging
5/2/2001	FRV	Failed to control	Control failure	Disc/stem	Coil failure
5/8/2001	ADV	Failed to open on demand (stuck closed)	Opening failure	Disc/cage	Coil failure
5/9/2001	FRV	Failed to control	Control failure	Control	Piece part
5/12/2001	FRV	Failed to open on demand (stuck closed)	Opening failure	Pressure transducer	Unknown
5/19/2001	CDV	Operated, but not within specified parameters	Set-point failure	Actuator	Unknown
5/22/2001	CDV	Unavailable, not failed	Non-demand failure	Stem	Material failure
6/7/2001	CDV	Unaffected by failure	Non-demand failure	Disc/stem	Disc weld
6/20/2001	FMV	Failed to close on demand (stuck open)	Closing failure	Positioner	Unknown
6/26/2001	FRV	Failed to control	Control failure	Packing	Actuator motor
6/26/2001	FRV	Failed to control	Control failure	Actuator	Actuator motor
7/2/2001	FRV	Failed to control	Control failure	Positioner	Hydraulic pump switch
7/9/2001	CDV	Found unavailable during non-demand observation	Non-demand failure	SOV	Hydraulic pump switch

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
8/9/2001	CDV	Operated, but not within specified parameters	Set-point failure	Disc/seat	Calibration
9/8/2001	CDV	Unaffected by failure	Non-demand failure	Actuator	Procedure
9/8/2001	ADV	Failed to respond to close demand	Closing failure	Actuator	Unknown
9/9/2001	CDV	Operated on required demand	Non-demand failure	SOV	Stem/actuator not connected
9/11/2001	FRV	Failed to control	Control failure	Positioner	Stem connection
10/3/2001	FMV	Failed to close on demand (stuck open)	Closing failure	Actuator	Improper operations
10/4/2001	FRV	Failed to control	Control failure	Air supply	Improper operations
10/11/2001	FMV	Failed to close on demand (stuck open)	Closing failure	Air supply	Accumulator leak
10/20/2001	CDV	Operated, but not within specified parameters	Set-point failure	Pilot	Faulty relief valve
10/23/2001	CDV	Unavailable, not failed	Non-demand failure	Control	Power grounded
10/26/2001	FRV	Failed to control	Control failure	Air supply	Controller malfunction
10/26/2001	FRV	Failed to open on demand (stuck closed)	Opening failure	Air supply	Controller malfunction
11/3/2001	CDV	Operated, but not within specified parameters	Set-point failure	Actuator	Controller malfunction
11/5/2001	CDV	Operated on required demand	Non-demand failure	SOV	Controller malfunction
11/20/2001	CDV	Operated on required demand	Non-demand failure	SOV	Controller malfunction

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
11/25/2001	ADV	Failed to open within set-point tolerance	Set-point failure	Control	Controller malfunction
12/1/2001	FRV	Failed to control	Control failure	Control	Controller malfunction
12/9/2001	CDV	Operated on required demand	Non-demand failure	SOV	Instrument failure
12/23/2001	CDV	Premature opened on demand (not stuck closed)	Opening failure	Control	Instrument failure
12/24/2001	FRV	Failed to control	Control failure	Air supply	Relay malfunction
12/31/2001	FMV	Failed to close on demand (stuck open)	Closing failure	Control	Switch contacts
1/2/2002	FRV	Failed to open on demand (stuck closed)	Opening failure	Actuator	Gain setting
1/18/2002	CDV	Operated, but not within specified parameters	Set-point failure	Disc/cage	Incorrect jumper landed
2/9/2002	FRV	Failed to control	Control failure	Unknown	Maintenance actions
3/4/2002	CDV	Premature closed on demand (not stuck open)	Closing failure	SOV	ESFAS signal
3/4/2002	CDV	Internal leakage when fully seated	Internal leakage	Positioner	Unknown
3/4/2002	FRV	Failed to control	Control failure	Positioner	Set point too low
3/12/2002	ADV	Failed to respond to open demand	Closing failure	Air supply	N/A
3/12/2002	ADV	Failed to open within set-point tolerance	Set-point failure	Air supply	Unknown

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
3/22/2002	CDV	Operated, but not within specified parameters	Set-point failure	Positioner	N/A
3/28/2002	FMV	Failed to close on demand (stuck open)	Closing failure	SOV	N/A
4/8/2002	CDV	Unaffected by failure	Non-demand failure	SOV	Design
4/23/2002	CDV	Premature opened on demand (not stuck closed)	Opening failure	Volume booster	Aging
5/8/2002	CDV	Premature closed on demand (not stuck open)	Closing failure	Pressure transducer	Plug ring
5/10/2002	CDV	Unavailable, not failed	Non-demand failure	Air supply	Plug ring
5/20/2002	FRV	Failed to open on demand (stuck closed)	Opening failure	Actuator	Material failure
5/29/2002	CDV	Premature opening	Opening failure	Control	Material failure
6/3/2002	CDV	Found unavailable during non-demand observation	Non-demand failure	Positioner	Stem/Disc separation
6/3/2002	FRV	Failed to open on demand (stuck closed)	Opening failure	SOV	Stem/plug not connected/loose
6/3/2002	ADV	Failed to remain open	Opening failure	Disc/seat	Unknown
6/3/2002	CDV	Premature closed on demand (not stuck open)	Closing failure	SOV	Aging
6/7/2002	FRV	Failed to open on demand (stuck closed)	Opening failure	Positioner	Cam follower

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
6/27/2002	FRV	Failed to open on demand (stuck closed)	Opening failure	Unknown	Feedback linkage
6/30/2002	CDV	Operated, but not within specified parameters	Set-point failure	Disc/seat	Feedback linkage
7/2/2002	CDV	Operated, but not within specified parameters	Set-point failure	FME valve	Feedback spring
8/30/2002	FMV	External leakage	External leakage	Packing	Pilot valve
9/4/2002	CDV	Unaffected by failure	Non-demand failure	Disc/stem	FME
9/14/2002	FRV	Failed to open on demand (stuck closed)	Opening failure	Control	Unknown
9/19/2002	CDV	Internal leakage when fully seated	Internal leakage	Positioner	Unknown
10/4/2002	FRV	Failed to open on demand (stuck closed)	Opening failure	Actuator	Vibration
10/9/2002	FRV	Failed to control	Control failure	Positioner	Procedure
11/2/2002	FRV	Failed to control	Control failure	FME valve	Unknown
11/12/2002	ADV	Failed to open on demand (stuck closed)	Opening failure	Air supply	Aging
11/15/2002	FRV	Failed to open on demand (stuck closed)	Opening failure	Pressure transducer	Feedback linkage
1/22/2003	FMV	Failed to close on demand (stuck open)	Closing failure	Unknown	Calibration
1/31/2003	FRV	Failed to control	Control failure	Positioner	Incorrect for application (mid-cycle cal drift)

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
2/5/2003	FRV	Failed to control	Control failure	Disc/stem	Incorrect for application (midcycle cal drift)
2/21/2003	FRV	Failed to open on demand (stuck closed)	Opening failure	Control	Incorrect for application (midcycle cal drift)
2/24/2003	FRV	Failed to control	Control failure	Control	Incorrect for application (midcycle cal drift)
3/1/2003	CDV	Operated, but not within specified parameters	Set-point failure	Actuator	Unknown
3/16/2003	CDV	Premature closed on demand (not stuck open)	Closing failure	SOV	Unknown
3/31/2003	FRV	Failed to control	Control failure	Control	Unknown
4/29/2003	FRV	Failed to control	Control failure	SOV	Unknown
5/27/2003	CDV	Unavailable, not failed	Non-demand failure	Control	Unknown
6/9/2003	CDV	Premature closed on demand (not stuck open)	Closing failure	Positioner	Sticking
6/11/2003	FRV	Failed to open on demand (stuck closed)	Opening failure	Positioner	Electrical leads grounded
6/15/2003	CDV	Operated on required demand	Non-demand failure	Positioner	FME
6/21/2003	CDV	Premature opening	Opening failure	Control	Coil failure
7/25/2003	FRV	Failed to open on demand (stuck closed)	Opening failure	Positioner	Unknown
8/5/2003	FRV	Failed to open on demand (stuck closed)	Opening failure	Control	Unknown

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
8/18/2003	CDV	Operated, but not within specified parameters	Set-point failure	Disc/seat	Unknown
8/26/2003	CDV	Operated, but not within specified parameters	Set-point failure	Actuator	Unknown
8/29/2003	CDV	Premature closed on demand (not stuck open)	Closing failure	Pressure transducer	Unknown
9/4/2003	FRV	Failed to control	Control failure	Control	Incorrect diaphragm
9/11/2003	CDV	Found unavailable during non-demand observation	Non-demand failure	SOV	Incorrect diaphragm
9/30/2003	CDV	Operated, but not within specified parameters	Set-point failure	Air supply	Diaphragm leakage
10/14/2003	FRV	Failed to control	Control failure	Packing	Diaphragm leakage
10/15/2003	FRV	Failed to control	Control failure	Positioner	Leakage
10/26/2003	FRV	Failed to open on demand (stuck closed)	Opening failure	Pressure transducer	Stem seal (aging)
10/27/2003	ADV	Failed to remain open (drifted off open seat)	Opening failure	Control	No fluid
11/8/2003	FMV	External leakage	External leakage	Air supply	Procedure
11/23/2003	FRV	Failed to maintain valve closed	Closing failure	Unknown	Debris
12/1/2003	CDV	Operated, but not within specified parameters	Set-point failure	Unknown	Plugged filter
12/9/2003	FRV	Failed to control	Control failure	SOV	Needle valve

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
12/14/2003	CDV	Unavailable, not failed	Non-demand failure	Control	Tubing failed
2/13/2004	FRV	Failed to control	Control failure	Packing	Relay malfunction
2/28/2004	CDV	Premature closed on demand (not stuck open)	Closing failure	SOV	Limit switch
2/28/2004	FRV	Failed to control	Control failure	Control	Relay
3/6/2004	CDV	Operated, but not within specified parameters	Set-point failure	Unknown	Switch contacts
3/20/2004	FRV	Failed to control	Control failure	Unknown	Calibration
3/30/2004	FRV	Failed to open on demand (stuck closed)	Opening failure	Control	Aging
3/30/2004	CDV	Operated, but not within specified parameters	Set-point failure	Control	Piston ring
4/3/2004	ADV	Failed to open on demand (stuck closed)	Opening failure	Packing	Material failure
4/3/2004	FRV	Failed to control	Control failure	Control	Material failure
4/9/2004	FMV	Failed to close on demand (stuck open)	Closing failure	Positioner	Material failure
4/14/2004	FRV	Failed to control	Control failure	Pressure transducer	Unknown
4/21/2004	ADV	Failed to open on demand (stuck closed)	Opening failure	Control	Stem/plug not connected/loose
4/26/2004	CDV	Operated, but not within specified parameters	Set-point failure	Air supply	FME

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
5/2/2004	FRV	Failed to control	Control failure	Positioner	FME
5/11/2004	FRV	Failed to control	Control failure	Control	Unknown
5/14/2004	FRV	Failed to control	Control failure	Unknown	FME
5/15/2004	CDV	Operated, but not within specified parameters	Set-point failure	Actuator	Follower incorrect
6/3/2004	FRV	Failed to open on demand (stuck closed)	Opening failure	Positioner	Pilot spring
6/6/2004	FRV	Failed to control	Control failure	Positioner	Calibration
6/19/2004	FRV	Failed to control	Control failure	Stem	Valve clip
7/13/2004	ADV	Failed to respond to open demand	Closing failure	Actuator	Calibration
8/13/2004	CDV	Unavailable, not failed	Non-demand failure	SOV	Calibration
8/15/2004	CDV	Internal leakage due to being improperly seated	Internal leakage	Control	Unknown
8/29/2004	CDV	Operated, but not within specified parameters	Set-point failure	Unknown	Aging
8/30/2004	CDV	Operated, but not within specified parameters	Set-point failure	Air supply	Alignment
9/1/2004	CDV	Operated, but not within specified parameters	Set-point failure	Unknown	Vent port blocked
9/22/2004	CDV	Premature closed on demand (not stuck open)	Closing failure	SOV	Aging
9/24/2004	CDV	Unavailable, not failed	Non-demand failure	Pilot	Unknown

Table C-1 (Cont.)
Non-Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
10/2/2004	CDV	Premature opened on demand (not stuck closed)	Opening failure	Unknown	Unknown
10/24/2004	CDV	Operated, but not within specified parameters	Set-point failure	Air supply	Unknown
11/10/2004	CDV	Unavailable, not failed	Non-demand failure	Actuator	Unknown
11/26/2004	CDV	Unaffected by failure	Non-demand failure	Actuator	Unknown
12/6/2004	CDV	Operated, but not within specified parameters	Set-point failure	Disc/cage	Unknown
12/27/2004	CDV	Unaffected by failure	Non-demand failure	Actuator	Unknown
1/19/2005	CDV	Operated on required demand	Non-demand failure	Pressure transducer	Leakage
2/17/2005	FRV	Failed to control	Control failure	Control	Procedure

Table C-2
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Anchor/Darling Valve Co.	DWG 93-13079	Pressure transducer	Unknown	8/29/2003	CDV
Asco Electrical Prod. Co. Inc.	DESIGN EWP	SOV	Unknown	6/21/1999	FRV
Atwood & Morrill Co. Inc./Xomox	20904-F	Control	No fluid	10/27/2003	ADV
Atwood & Morrill Co. Inc./Xomox	20904-F	Control	Tubing failed	12/14/2003	CDV
Automatic Switch Co. (ASCO)	Not yet determined	Control	Diaphragm aging	5/25/2000	ADV
Bailey Controls Div.	AP21200	Actuator	Procedure	6/10/2000	FRV
Bailey Controls Div.	AP21200	Air supply	Aging	4/4/2001	FRV
Bailey Controls Div.	AP21200	Positioner	Procedure	7/29/2000	FRV
Bailey Controls Div.	AP21200	Pressure transducer	Unknown	12/17/2000	ADV
Bailey Controls Div.	AP21200	Pressure transducer	Aging	2/4/2001	FRV
CDC Valve Co./Continental Disc Corp.	CDCHI-100	Actuator	Controller malfunction	9/25/1998	FRV
CDC Valve Co./Continental Disc Corp.	CDCHI-100	Air supply	FME	4/14/1998	CDV
Control Components International	100D	SOV	Unknown	4/29/2003	FRV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Control Components International	108573-3	Unknown	Debris	11/23/2003	FRV
Control Components International	922701027	Control	Relay	2/28/2004	FRV
Control Components International	922701027	Control	Material failure	4/3/2004	FRV
Control Components International	922701027	Unknown	N/A	8/26/2000	FRV
Control Components International	A51212	Actuator	Excessive friction	3/2/1999	CDV
Control Components International	A51212	SOV	Intermittent operation	8/12/1997	ADV
Control Components International	A9-10-16WAX16WA	Air supply	Tubing failure	6/11/1998	FRV
Control Components International	A9-10-16WAX16WA	Unknown	Regulator failure	4/14/1998	FRV
Control Components International	A9-3X6BWX6BW	Air supply	Unknown	3/12/2002	ADV
Control Components International	B2A9-8-8BW-48WF-31MQ	Unknown	Unknown	10/2/2004	CDV
Control Components International	B2G5-8-12P6-15ESC1	Actuator	Material failure	12/1/2000	FRV
Control Components International	B3A6-12-12BW-18BW-31	Disc/seat	Feedback linkage	6/30/2002	CDV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Control Components International	B3A6-12-12BW-18BW-31	FME valve	Feedback spring	7/2/2002	CDV
Control Components International	B3G9-10-12P8-12P8-31	Air supply	Pilot valve	5/3/1999	FMV
Control Components International	B3G9-10-12P8-12P8-31	FME valve	Tubing failure	7/2/1998	FRV
Control Components International	B3G9-10-12P8-12P8-31	Positioner	Calibration	6/6/2004	FRV
Control Components International	B3G9-10-12P8-12P8-31	SOV	Internal leakage	4/20/1999	FRV
Control Components International	B3G9-10-12P8-12P8-31	SOV	Material failure	6/10/2000	CDV
Control Components International	CCI DWG 1094B3	Positioner	Hydraulic pump switch	7/2/2001	FRV
Control Components International	D-100	Air supply	Calibration	3/21/2000	CDV
Control Components International	D-100	Pressure transducer	Stem seal (aging)	10/26/2003	FRV
Control Components International	DRAG-M5G9-X5-X8P(2)-X8P	Control	Aging	4/29/2001	FMV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Control Components International	DWG NO-922501043	Air supply	Plug ring	5/10/2002	CDV
Control Components International	DWG NO-922501043	Control	Unknown	7/12/1997	CDV
Control Components International	DWG NO-922501043	Control	Controller malfunction	11/25/2001	ADV
Control Components International	DWG NO-922501043	Disc/stem	Disconnected	8/6/2000	CDV
Control Components International	DWG NO-922501043	FME valve	Unknown	12/24/2000	CDV
Control Components International	DWG NO-922501043	Packing	Stem/disc separation	10/29/2000	FRV
Control Components International	DWG NO-922501043	Positioner	Calibration	5/16/1999	FRV
Control Components International	DWG NO-922501043	SOV	ESFAS Signal	3/4/2002	CDV
Control Components International	DWG NO-922501043	Unknown	Unknown	10/7/1999	FRV
Control Components International	EWT-8	Control	Diaphragm Leak	3/18/2000	FMV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Control Components International	EX05-14-18WA-18WA-13	Control	Calibration	6/24/1999	FRV
Control Components International	M1G5-14-18BW-18BW	Positioner	Unknown	5/11/2000	FMV
Control Components International	M2A5X6X8WAX 8WA72ML46	Positioner	Pilot disc	3/19/2001	CDV
Control Components International	M2C978RF36SP 436M41	Actuator	Tubing failure	6/24/1998	FRV
Control Components International	M3A610X8BW31 MT31	Positioner	Override clevis	1/18/1997	FRV
Control Components International	MC FWR VLSFWR-001	Unknown	Switch contacts	3/6/2004	CDV
Control Components International	MC FWR VLVSFWR-001	Actuator	Bench set	3/3/1998	FRV
Control Components International	M-S-D VLVS2SV-042	Positioner	Pilot Spring	6/3/2004	FRV
Control Components International	PD932-64BW	Control	Tubing failure	6/10/1998	FRV
Control Components International	PD932-64BW	SOV	Fatigue failure (vibration)	11/25/1997	CDV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Control Components International	PDA9160-256BW	Air supply	Procedure	11/8/2003	FMV
Control Components International	PDA9160-256BW	Air supply	FME	4/26/2004	CDV
Control Components International	PDA9160-256BW	Air supply	Unknown	10/24/2004	CDV
Control Components International	PDA9160-256BW	Disc/stem	Disc weld	6/7/2001	CDV
Control Components International	PDA9160-256BW	Positioner	Pilot valve	5/4/1999	FRV
Control Components International	PDA9160-256BW	Positioner	Unknown	3/4/2002	CDV
Control Components International	PDA9160-256BW	Positioner	Unknown	9/19/2002	CDV
Control Components International	PDA964-96BW	Actuator	Manufacturing problems	4/30/1999	FRV
Control Components International	PDA964-96BW	Control	Bent	8/27/1999	FRV
Control Components International	PDA964-96BW	Packing	Pilot valve	8/30/2002	FMV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Control Components International	PDA964-96BW	Positioner	Unknown	3/28/1998	CDV
Control Components International	PDA964-96BW	SOV	Unknown	1/10/1998	FRV
Control Components International	PDA964-96BW	Unknown	FME	6/6/1999	FRV
Control Components International	TB-BP VLVS1SB-006	Control	Unknown	6/20/1997	CDV
Control Components International	TB-BP VLVS1SB-006	Control	Accumulator leak	2/9/1998	CDV
Control Components International	TB-BP VLVS1SB-009	Control	Unknown	8/5/1999	CDV
Control Components International	TB-BP VLVS1SB-021	Control	Incorrect packing spacer	3/9/1999	CDV
Control Components International	TB-BP VLVS2SB-009	Control	Pilot valve	5/7/1999	CDV
Controls Components	27043-1	Volume booster	Coil failure	9/1/1997	FRV
Copes - Vulcan Inc.	100D	Positioner	Unknown	11/7/1999	CDV
Copes - Vulcan Inc.	14-in. 900#	Air supply	Needle valve	2/15/1997	CDV
Copes - Vulcan Inc.	14-in. 900#	Air supply	Controller malfunction	3/8/1997	ADV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Copes - Vulcan Inc.	14-in. 900#	Positioner	Unknown	12/6/1997	FMV
Copes - Vulcan Inc.	D	Actuator	Feedback linkage	5/6/1997	FRV
Copes - Vulcan Inc.	D	Air supply	Ferrule fitting	12/26/1999	CDV
Copes - Vulcan Inc.	D	Air supply	Accumulator leak	10/11/2001	FMV
Copes - Vulcan Inc.	D	Air supply	Controller malfunction	10/26/2001	FRV
Copes - Vulcan Inc.	D	Air supply	Relay malfunction	12/24/2001	FRV
Copes - Vulcan Inc.	D	Control	Feedback linkage	5/6/1997	FRV
Copes - Vulcan Inc.	D	Control	Unknown	12/1/1997	CDV
Copes - Vulcan Inc.	D	Control	Instrument failure	11/26/1998	FRV
Copes - Vulcan Inc.	D	Control	Aging	3/11/2001	FRV
Copes - Vulcan Inc.	D	Control	Instrument failure	12/23/2001	CDV
Copes - Vulcan Inc.	D	Control	Unknown	3/31/2003	FRV
Copes - Vulcan Inc.	D	Control	Unknown	8/5/2003	FRV
Copes - Vulcan Inc.	D	Disc/cage	Inadequate design	2/27/1997	ADV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Copes - Vulcan Inc.	D	Disc/seat	Incorrect diaphragm	4/3/2000	ADV
Copes - Vulcan Inc.	D	Disc/stem	Instrument failure	11/24/1998	ADV
Copes - Vulcan Inc.	D	Disc/stem	Coil failure	5/2/2001	FRV
Copes - Vulcan Inc.	D	Positioner	N/A	3/22/2002	CDV
Copes - Vulcan Inc.	D	Positioner	Incorrect for application (mid-cycle cal drift)	1/31/2003	FRV
Copes - Vulcan Inc.	D	Positioner	FME	5/2/2004	FRV
Copes - Vulcan Inc.	D	SOV	Unknown	7/22/1997	FMV
Copes - Vulcan Inc.	D	SOV	Unknown	10/9/1999	FRV
Copes - Vulcan Inc.	D	SOV	Unknown	10/10/1999	FRV
Copes - Vulcan Inc.	D	Unknown	Controller	3/7/1997	FRV
Copes - Vulcan Inc.	D	Unknown	Weld failed	11/22/2000	FRV
Copes - Vulcan Inc.	D-100	Actuator	Vibration	10/4/2002	FRV
Copes - Vulcan Inc.	D-100	Air supply	Controller malfunction	10/13/1998	FRV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Copes - Vulcan Inc.	D-100	Air supply	Inlet port failure	4/14/1999	CDV
Copes - Vulcan Inc.	D-100	Air supply	Unknown	12/25/1999	FRV
Copes - Vulcan Inc.	D-100	Air supply	N/A	9/1/2000	FRV
Copes - Vulcan Inc.	D-100	Air supply	Aging	11/12/2002	ADV
Copes - Vulcan Inc.	D-100	Control	Stem/actuator connection loose	1/9/1997	FRV
Copes - Vulcan Inc.	D-100	Control	Faulty relief valve	2/2/1997	CDV
Copes - Vulcan Inc.	D-100	Control	Controller (calibration)	3/26/1997	FRV
Copes - Vulcan Inc.	D-100	Control	Aging	8/7/1997	FRV
Copes - Vulcan Inc.	D-100	Control	Bench set	3/10/1998	FRV
Copes - Vulcan Inc.	D-100	Control	Controller malfunction	9/22/1998	CDV
Copes - Vulcan Inc.	D-100	Control	Controller malfunction	9/30/1998	FRV
Copes - Vulcan Inc.	D-100	Control	Fuse	10/17/1998	FRV
Copes - Vulcan Inc.	D-100	Control	Instrument failure	10/23/1998	FMV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Copes - Vulcan Inc.	D-100	Control	Procedure	1/9/1999	FRV
Copes - Vulcan Inc.	D-100	Control	Procedure	1/10/1999	FRV
Copes - Vulcan Inc.	D-100	Control	Unknown	2/11/1999	FRV
Copes - Vulcan Inc.	D-100	Control	Regulator FME	11/26/1999	FRV
Copes - Vulcan Inc.	D-100	Control	Aging	3/12/2001	FMV
Copes - Vulcan Inc.	D-100	Control	Piece part	5/9/2001	FRV
Copes - Vulcan Inc.	D-100	Control	Switch contacts	12/31/2001	FMV
Copes - Vulcan Inc.	D-100	Control	Stem/plug not connected/loose	4/21/2004	ADV
Copes - Vulcan Inc.	D-100	Disc/cage	Port connectors	4/2/1998	ADV
Copes - Vulcan Inc.	D-100	Disc/seat	Unknown	6/3/2002	ADV
Copes - Vulcan Inc.	D-100	Disc/stem	Regulator	2/16/1997	FRV
Copes - Vulcan Inc.	D-100	FME valve	Power supply	12/19/1998	CDV
Copes - Vulcan Inc.	D-100	FME valve	Coil failure	4/10/2001	FRV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Copes - Vulcan Inc.	D-100	Packing	Diaphragm leakage	10/14/2003	FRV
Copes - Vulcan Inc.	D-100	Pilot	Incorrect installation	8/16/1997	ADV
Copes - Vulcan Inc.	D-100	Pilot	Unknown	9/24/2004	CDV
Copes - Vulcan Inc.	D-100	Positioner	Failed to stroke	8/8/1997	CDV
Copes - Vulcan Inc.	D-100	Positioner	Feedback linkage	1/15/2001	CDV
Copes - Vulcan Inc.	D-100	Positioner	Unknown	6/20/2001	FMV
Copes - Vulcan Inc.	D-100	Positioner	Set point too low	3/4/2002	FRV
Copes - Vulcan Inc.	D-100	Positioner	Stem/disc separation	6/3/2002	CDV
Copes - Vulcan Inc.	D-100	Positioner	FME	6/15/2003	CDV
Copes - Vulcan Inc.	D-100	Positioner	Unknown	7/25/2003	FRV
Copes - Vulcan Inc.	D-100	Positioner	Leakage	10/15/2003	FRV
Copes - Vulcan Inc.	D-100	Positioner	Adjusting nut	1/11/1997	ADV
Copes - Vulcan Inc.	D-100	Pressure transducer	Controller (calibration)	3/29/1997	CDV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Copes - Vulcan Inc.	D-100	Pressure transducer	Unknown	4/14/2004	FRV
Copes - Vulcan Inc.	D-100	Pressure transducer	Leakage	1/19/2005	CDV
Copes - Vulcan Inc.	D-100	SOV	Plug ring	3/29/1997	CDV
Copes - Vulcan Inc.	D-100	SOV	Balance seal	3/30/1997	CDV
Copes - Vulcan Inc.	D-100	SOV	Calibration	3/12/1998	FRV
Copes - Vulcan Inc.	D-100	SOV	Plug not seated at assembly	2/12/1999	CDV
Copes - Vulcan Inc.	D-100	SOV	N/A	8/29/2000	CDV
Copes - Vulcan Inc.	D-100	SOV	Controller malfunction	11/5/2001	CDV
Copes - Vulcan Inc.	D-100	SOV	Controller malfunction	11/20/2001	CDV
Copes - Vulcan Inc.	D-100	Stem	Material failure	5/22/2001	CDV
Copes - Vulcan Inc.	D-100	Unknown	Regulator body cracked	1/25/1997	FMV
Copes - Vulcan Inc.	D-100	Unknown	Piston ring	3/31/1997	CDV
Copes - Vulcan Inc.	D-100	Unknown	PM	4/13/2001	CDV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Copes - Vulcan Inc.	D-100	Unknown	Maintenance actions	2/9/2002	FRV
Copes - Vulcan Inc.	D-100	Unknown	FME	5/14/2004	FRV
Copes - Vulcan Inc.	D-100	Unknown	Vent port blocked	9/1/2004	CDV
Copes - Vulcan Inc.	D-100-12-in., M-142676	Control	Coil failure	6/21/2003	CDV
Copes - Vulcan Inc.	D-100-160	Actuator	Calibration	7/13/2004	ADV
Copes - Vulcan Inc.	D-100-160	Air supply	Coil Missing	11/16/1997	ADV
Copes - Vulcan Inc.	D-100-160	Positioner	Controller malfunction	8/31/1998	FRV
Copes - Vulcan Inc.	D-100-160	SOV	Controller malfunction	8/22/1998	FRV
Copes - Vulcan Inc.	D-100-160	SOV	FME	2/19/1999	CDV
Copes - Vulcan Inc.	D-176720	Control	Unknown	9/22/1999	FRV
Copes - Vulcan Inc.	D-176720	Packing	Relay malfunction	2/13/2004	FRV
Copes - Vulcan Inc.	D-176720	Positioner	Internal diaphragm	4/15/1999	CDV
Copes - Vulcan Inc.	D-176720	Positioner	Unknown	8/5/1999	CDV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Copes - Vulcan Inc.	D-176720	Positioner	N/A	9/4/2000	CDV
Copes - Vulcan Inc.	D-176720	Pressure transducer	Plug ring	5/8/2002	CDV
Copes - Vulcan Inc.	DESIGN HSV	Actuator	N/A	10/9/2000	FRV
Copes - Vulcan Inc.	DWG NO-922501043	Control	Stem/plug not connected	2/16/1999	FMV
Copes - Vulcan Inc.	E-300	Control	Feedback spring	4/5/1999	FMV
Copes - Vulcan Inc.	E-300	Positioner	Cam follower	6/7/2002	FRV
Copes - Vulcan Inc.	M-133346	Volume booster	Fuse	10/17/1998	CDV
Copes - Vulcan Inc.	P-200	Control	Power grounded	10/23/2001	CDV
Copes - Vulcan Inc.	P-200	FME valve	Unknown	11/2/2002	FRV
Copes –Vulcan Inc.	D-100	Positioner	Leaking	3/12/1999	FRV
Crane Valve Prod/Chapman	AU-391	Control	Incorrect for application (mid-cycle cal drift)	2/24/2003	FRV
Dynex - Rivett Inc.	6645-06-T-V-72	SOV	Calibration	5/22/1999	CDV
English Electric	Style 5	Control	Calibration	6/10/1997	ADV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Fisher Controls Co. Inc.	34B2042X012	SOV	Aging	9/22/2004	CDV
Fisher Controls Co. Inc.	475-ENA-16	Control	N/A	1/16/2000	FRV
Fisher Controls Co. Inc.	475-ENA-16	Unknown	Calibration	3/20/2004	FRV
Fisher Controls Co. Inc.	476D	Plug/seat	Unknown	10/6/1999	FRV
Fisher Controls Co. Inc.	476L	Control	Diaphragm tear	11/19/1999	FRV
Fisher Controls Co. Inc.	476L	Positioner	Feedback linkage	3/19/2000	FRV
Fisher Controls Co. Inc.	476L-5-16-ENA	Control	Controller	3/4/1997	FMV
Fisher Controls Co. Inc.	478L-16-5-ENA	Actuator	Unknown	11/2/1999	CDV
Fisher Controls Co. Inc.	52A7147 (16-in.)	Actuator	Unknown	12/27/2004	CDV
Fisher Controls Co. Inc.	52A7147 (16-in.)	Control	Incorrect diaphragm	9/4/2003	FRV
Fisher Controls Co. Inc.	52A7147 (16-in.)	Positioner	Power breaker	12/9/1998	FRV
Fisher Controls Co. Inc.	52A7148 (4-in.)	Positioner	Electrical leads grounded	6/11/2003	FRV
Fisher Controls Co. Inc.	52B5685	Packing	Faulty relief valve	6/10/2000	FRV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Fisher Controls Co. Inc.	667-80	Control	FME	5/14/1997	FRV
Fisher Controls Co. Inc.	667-87	Air supply	Tubing broken (nearby maintenance)	12/14/1999	FRV
Fisher Controls Co. Inc.	667-87	Positioner	Unknown	1/27/2000	FRV
Fisher Controls Co. Inc.	67 SERIES	Actuator	Seat/disc bonding	4/10/1997	FRV
Fisher Controls Co. Inc.	67 SERIES	Actuator	Design	4/2/2001	CDV
Fisher Controls Co. Inc.	67 SERIES	Air supply	Improper operations	10/4/2001	FRV
Fisher Controls Co. Inc.	67 SERIES	Control	Undersized	2/5/1998	FRV
Fisher Controls Co. Inc.	67 SERIES	Packing	Cam hub	2/9/2000	FRV
Fisher Controls Co. Inc.	67 SERIES	Pilot	Faulty relief valve	10/20/2001	CDV
Fisher Controls Co. Inc.	67 SERIES	Positioner	Material failure	4/9/2004	FMV
Fisher Controls Co. Inc.	67 SERIES	Pressure transducer	In-service consolidation	4/10/1997	FRV
Fisher Controls Co. Inc.	D-100	Disc/seat	Regulator	8/21/2000	ADV
Fisher Controls Co. Inc.	DESIGN AC	Positioner	Loss of power	3/16/1997	FRV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Fisher Controls Co. Inc.	DESIGN AC	Volume booster	Aging	4/23/2002	CDV
Fisher Controls Co. Inc.	DESIGN CC	Air supply	Unknown	10/19/1997	CDV
Fisher Controls Co. Inc.	DESIGN DBQ	Positioner	Sticking	6/9/2003	CDV
Fisher Controls Co. Inc.	DESIGN ED	Actuator	Procedure	12/14/2000	CDV
Fisher Controls Co. Inc.	DESIGN ED	Air supply	Relay malfunction	12/25/1998	FRV
Fisher Controls Co. Inc.	DESIGN ED	Control	Unknown	9/23/1999	FRV
Fisher Controls Co. Inc.	DESIGN ED	Control	Unknown	5/11/2004	FRV
Fisher Controls Co. Inc.	DESIGN ED	Disc/stem	Cam hub	1/28/2000	FRV
Fisher Controls Co. Inc.	DESIGN ED	SOV	Tubing failed	1/4/2000	FMV
Fisher Controls Co. Inc.	DESIGN ED	SOV	Stem/actuator not connected	9/9/2001	CDV
Fisher Controls Co. Inc.	DESIGN ED	SOV	Instrument failure	12/9/2001	CDV
Fisher Controls Co. Inc.	DESIGN ED	SOV	N/A	3/28/2002	FMV
Fisher Controls Co. Inc.	DESIGN ED	Volume booster	N/A	8/28/2000	CDV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Fisher Controls Co. Inc.	DESIGN EHD	Actuator	Solder connection	1/23/2001	CDV
Fisher Controls Co. Inc.	DESIGN EHD	Actuator	Unknown	8/26/2003	CDV
Fisher Controls Co. Inc.	DESIGN ELD	Pressure transducer	Diaphragm failure	2/22/1998	ADV
Fisher Controls Co. Inc.	DESIGN ENA	Actuator	Controller malfunction	9/24/1998	ADV
Fisher Controls Co. Inc.	DESIGN ENA	Actuator	Unknown	5/19/2001	CDV
Fisher Controls Co. Inc.	DESIGN ENA	Air supply	Stem seal (aging)	11/17/1996	CDV
Fisher Controls Co. Inc.	DESIGN ENA	Air supply	Controller malfunction	9/2/1998	FRV
Fisher Controls Co. Inc.	DESIGN ENA	Control	Pilot plug stem galling against shield plate	4/26/1997	FRV
Fisher Controls Co. Inc.	DESIGN ENA	Control	Aging	3/30/2004	FRV
Fisher Controls Co. Inc.	DESIGN ENA	Disc/cage	Unknown	12/6/2004	CDV
Fisher Controls Co. Inc.	DESIGN ENA	Disc/stem	FME	9/4/2002	CDV
Fisher Controls Co. Inc.	DESIGN ENA	Disc/stem	Incorrect for application (mid-cycle cal drift)	2/5/2003	FRV
Fisher Controls Co. Inc.	DESIGN ENA	Packing	Actuator motor	6/26/2001	FRV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Fisher Controls Co. Inc.	DESIGN ENA	Positioner	Loose	4/22/1997	CDV
Fisher Controls Co. Inc.	DESIGN ENA	Positioner	Incorrect for application	1/16/1998	FRV
Fisher Controls Co. Inc.	DESIGN ENA	Positioner	N/A	10/21/2000	FRV
Fisher Controls Co. Inc.	DESIGN ENA	Positioner	Stem connection	9/11/2001	FRV
Fisher Controls Co. Inc.	DESIGN ENA	Positioner	FME	5/6/1998	ADV
Fisher Controls Co. Inc.	DESIGN ENA	SOV	Controller malfunction	3/11/1997	CDV
Fisher Controls Co. Inc.	DESIGN ENA	SOV	Excessive friction	2/27/1999	FMV
Fisher Controls Co. Inc.	DESIGN ENA	SOV	Design	4/8/2002	CDV
Fisher Controls Co. Inc.	DESIGN ENA	SOV	Needle valve	12/9/2003	FRV
Fisher Controls Co. Inc.	DESIGN ENA	Unknown	Controller malfunction	9/18/1998	FRV
Fisher Controls Co. Inc.	DESIGN ET	Body erosion	Test equipment	1/18/1999	FMV
Fisher Controls Co. Inc.	DESIGN ET	Control	Piston ring	3/30/2004	CDV
Fisher Controls Co. Inc.	DESIGN ET	Stem	Digital positioner memory	3/30/1999	FMV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Fisher Controls Co. Inc.	DESIGN WED	Control	Coil failure	9/6/1997	FRV
Fisher Controls Co. Inc.	DESIGN WED	Control	Inadequate hydraulic oil	2/25/1998	FRV
Fisher Controls Co. Inc.	DESIGN EWD	Stem	Valve clip	6/19/2004	FRV
Fisher Controls Co. Inc.	DESIGN EWP	Actuator	Unknown	11/10/2004	CDV
Fisher Controls Co. Inc.	DESIGN EWP	Control	Improper operations	5/2/2000	CDV
Fisher Controls Co. Inc.	DESIGN EWP	Control	Controller malfunction	12/1/2001	FRV
Fisher Controls Co. Inc.	DESIGN EWP	Control	Unknown	5/27/2003	CDV
Fisher Controls Co. Inc.	DESIGN EWP	Disc/cage	Feedback linkage	12/17/2000	ADV
Fisher Controls Co. Inc.	DESIGN EWP	Disc/cage	Feedback linkage	12/17/2000	ADV
Fisher Controls Co. Inc.	DESIGN EWP	Positioner	Card	8/17/1998	FRV
Fisher Controls Co. Inc.	DESIGN EWP	Positioner	Fitting broken	12/14/1999	FRV
Fisher Controls Co. Inc.	DESIGN EWP	Positioner	FME	1/27/2000	FRV
Fisher Controls Co. Inc.	DESIGN EWP	Pressure transducer	Unknown	6/21/1999	FRV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Fisher Controls Co. Inc.	DESIGN EWP	Pressure transducer	Regulator	6/10/2000	FRV
Fisher Controls Co. Inc.	DESIGN EWP	SOV	Feedback linkage	6/21/1999	FRV
Fisher Controls Co. Inc.	DESIGN EWP	SOV	Pilot valve	6/21/1999	FRV
Fisher Controls Co. Inc.	DESIGN EWP	SOV	Aging	6/3/2002	CDV
Fisher Controls Co. Inc.	DESIGN EWP	Unknown	Aging	7/5/1999	FRV
Fisher Controls Co. Inc.	DESIGN EWP	Unknown	Aging	7/5/1999	FRV
Fisher Controls Co. Inc.	DESIGN EWT	Actuator	Card	8/14/1998	FRV
Fisher Controls Co. Inc.	DESIGN HSV	Actuator	Tubing failure	6/9/1998	FMV
Fisher Controls Co. Inc.	DESIGN HSV	Actuator	Procedure	9/8/2001	CDV
Fisher Controls Co. Inc.	DESIGN HSV	Actuator	Follower incorrect	5/15/2004	CDV
Fisher Controls Co. Inc.	DESIGN HSV	Air supply	Unknown	9/29/1999	FMV
Fisher Controls Co. Inc.	DESIGN HSV	Air supply	Alignment	8/30/2004	CDV
Fisher Controls Co. Inc.	DESIGN HSV	Control	Loose screw	4/21/1999	FMV
Fisher Controls Co. Inc.	DESIGN HSV	Control	N/A	9/16/2000	ADV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Fisher Controls Co. Inc.	DESIGN HSV	Control	N/A	10/15/2000	FRV
Fisher Controls Co. Inc.	DESIGN HSV	FME valve	Unknown	10/7/1999	FRV
Fisher Controls Co. Inc.	DESIGN HSV	Unknown	Bench set	1/9/1997	FRV
Fisher Controls Co. Inc.	DESIGN HSV	Unknown	Calibration	1/22/2003	FMV
Fisher Controls Co. Inc.	DWG NO-922501043	Actuator	Improper operations	10/3/2001	FMV
Fisher Controls Co. Inc.	EWT-8	Actuator	Coil failure	10/13/1997	FRV
Fisher Controls Co. Inc.	EWT-8	Control	Unknown	8/15/2004	CDV
Fisher Controls Co. Inc.	EWT-8	Disc/cage	Card	7/17/1998	ADV
Fisher Controls Co. Inc.	EWT-8	Positioner	Calibration	7/19/1997	FRV
Fisher Controls Co. Inc.	EWT-8	Positioner	Range jumper	2/3/2001	FMV
Fisher Controls Co. Inc.	EWT-8	SOV	Limit switch	2/28/2004	CDV
Fisher Controls Co. Inc.	SS-79	Actuator	Unknown	11/26/2004	CDV
Fisher Controls Co. Inc.	SS-79	Positioner	Procedure	10/9/2002	FRV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Fisher Governor Co. / Fisher Controls	473-1-4-5	Actuator	Unknown	3/1/2003	CDV
Fisher Governor de Mexico	476L-5-HSV	Air supply	Diaphragm leakage	9/30/2003	CDV
Fisher Governor de Mexico	476L-5-HSV	Positioner	N/A	10/3/2000	FRV
General Electric Company	769E405	Actuator	Pilot valve	6/15/1999	CDV
General Electric Company	823E891 DWG	Actuator	Feedback linkage	6/5/1997	FRV
General Electric Company	842E764	Actuator	Inadequate design	3/4/1997	CDV
General Electric Company	DRWG.836E144	SOV	Unknown	3/16/2003	CDV
General Electric Company	DWG.804E664	Control	Incorrect regulator	5/25/1998	FRV
General Electric Company	DWG.883E707/8	SOV	Incorrect diaphragm	9/11/2003	CDV
General Electric Company	None	SOV	In-service consolidation	12/25/1999	CDV
ITT Conoflow/Div. ITT Fluid Tech.	510QMCA2EBO ZJ	Control	FME	8/3/1999	FRV
ITT Conoflow/Div. ITT Fluid Tech.	510QMCA2EBO ZJ	Positioner	Unknown	9/22/1999	FRV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
ITT Conoflow/Div. ITT Fluid Tech.	510QMCA2EBO ZJ	Positioner	N/A	9/12/2000	FRV
ITT Conoflow/Div. ITT Fluid Tech. Corp.	V510	Actuator	Actuator motor	6/26/2001	FRV
ITT Conoflow/Div. ITT Fluid Tech. Corp.	V510	Unknown	High leakage	3/12/1999	FRV
Leslie Co.	AEROFLOW	Control	Unknown	9/14/2002	FRV
Leslie Co.	AEROFLOW	Control	Incorrect for application (mid-cycle cal drift)	2/21/2003	FRV
Leslie Co.	AEROFLOW	Packing	Material failure	4/3/2004	ADV
Leslie Co.	AEROFLOW	SOV	Beam assembly	3/14/1999	CDV
Leslie Co.	AEROFLOW	SOV	Stem/plug not connected/loose	6/3/2002	FRV
Limitorque Corp.	SB-1	Unknown	Plugged Filter	12/1/2003	CDV
Limitorque Corp.	SB-1	Unknown	Aging	8/29/2004	CDV
Linduse Division	LD 233-56	Positioner	Unknown	2/1/1999	FRV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Masoneilan International Inc.	20700	Positioner	FME	12/8/2000	ADV
Masoneilan International Inc.	2X871	Actuator	Controller malfunction	11/3/2001	CDV
Masoneilan International Inc.	2X871	Control	Unknown	5/30/1997	FRV
Masoneilan International Inc.	2X871	Unknown	Zero adjust	1/6/2001	FRV
Masoneilan International Inc.	38-18	Actuator	Power supply	12/10/1998	FRV
Masoneilan International Inc.	40400	Actuator	Aging	2/28/2001	ADV
Masoneilan International Inc.	40400	Actuator	Gain setting	1/2/2002	FRV
Masoneilan International Inc.	40400	Disc/cage	Incorrect jumper landed	1/18/2002	CDV
Masoneilan International Inc.	40400	Disc/seat	Calibration	8/9/2001	CDV
Masoneilan International Inc.	40400	Disc/seat	Unknown	8/18/2003	CDV
Masoneilan International Inc.	40400	Positioner	Fitting broken	4/1/1998	CDV
Masoneilan International Inc.	40400	Positioner	Relay malfunction	12/30/1998	FRV
Masoneilan International Inc.	40400	Positioner	Calibration	7/4/1999	ADV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Masoneilan International Inc.	40400	Positioner	Coil failure	7/5/1999	ADV
Masoneilan International Inc.	40400	SOV	Calibration	8/13/2004	CDV
Masoneilan International Inc.	41000	Actuator	Coil failure	9/17/1997	CDV
Masoneilan International Inc.	41000	Actuator	Misalignment	4/22/2000	ADV
Masoneilan International Inc.	41000	Air supply	Controller malfunction	10/26/2001	FRV
Masoneilan International Inc.	41000	Control	Travel stops	3/30/2000	FRV
Masoneilan International Inc.	41000	Control	Material failure	5/29/2002	CDV
Masoneilan International Inc.	41000	Pressure transducer	Feedback linkage	11/15/2002	FRV
Masoneilan International Inc.	85	Pressure transducer	Diaphragm leak	3/17/2001	FRV
Masoneilan International Inc.	85	Pressure transducer	Unknown	5/12/2001	FRV
Masoneilan International Inc.	85	SOV	Fluid leak	4/19/2000	FRV
Masoneilan International Inc.	900	Disc/cage	Controller malfunction	9/5/1998	ADV
Masoneilan International Inc.	900	Disc/cage	Coil failure	5/8/2001	ADV
Mesker, George L Co.	8-in. x 4-in.	Actuator	Material failure	5/20/2002	FRV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Mesker, George L Co.	8-in. x 4-in.	SOV	Feedback linkage	1/9/2001	CDV
Mesker, George L Co.	8-in. x 4-in.	SOV	Hydraulic pump switch	7/9/2001	CDV
N/A for subcomponent	N/A for subcomponent	Air supply	Aging	7/5/1999	ADV
N/A for subcomponent	N/A for subcomponent	Positioner	Incorrect venting	7/5/1999	FRV
Parker Hannifin Corp.	GE DWG. 801E344	Actuator	Unknown	9/8/2001	ADV
Rockwell Mfg Co.	FIG 607MY	Disc/seat	Unknown	1/13/2001	CDV
Valtek Inc.	MARK-I-X	Actuator	Aging	2/9/2001	FRV
WKM Div / ACF Ind Inc.	70-11-3R3	Positioner	Bench set	2/28/1998	CDV
WKM Div / ACF Ind Inc.	70-19-9	Control	Unknown	4/27/2001	FRV
WKM Div / ACF Ind Inc.	70-19-9	Control	Procedure	2/17/2005	FRV

Table C-2 (Cont.)
Non-Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
WKM Div / ACF Ind Inc.	70-19-9	Unknown	Potentiometer	5/13/1999	FRV
WKM Div / ACF Ind Inc.	70-19-9	Unknown	Feedback linkage	6/27/2002	FRV
WKM Div / ACF Ind Inc.	8-in. x 4-in.	Air supply	N/A	3/12/2002	ADV
Worthington Corp/McGraw-Edison	70-70771	Packing	Regulator failure	4/2/1998	FRV
Yarway Corp.	5405	Control	N/A	8/22/2000	FRV

Table C-3
Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
2/16/1997	FRV	Failed to close within set-point tolerance	Set-point failure	Disc/stem	Regulator
2/27/1997	ADV	Failed to remain open	Opening failure	Disc/cage	Inadequate design
8/16/1997	ADV	Failed to remain closed (drifted off closed seat)	Closing failure	Pilot	Incorrect installation
4/2/1998	ADV	Failed to open on demand (stuck closed)	Opening failure	Disc/cage	Port connectors
4/2/1998	FRV	Failed to control	Control failure	Packing	Regulator failure
7/2/1998	FRV	Failed to close within set-point tolerance	Set-point failure	FME valve	Tubing failure
7/17/1998	ADV	Failed to remain closed (drifted off closed seat)	Closing failure	Disc/cage	Card
9/5/1998	ADV	Failed to open on demand (stuck closed)	Opening failure	Disc/cage	Controller malfunction
11/24/1998	ADV	Failed to open on demand (stuck closed)	Opening failure	Disc/stem	Instrument failure
12/19/1998	CDV	Internal leakage due to being improperly seated	Internal Leakage	FME valve	Power supply
1/18/1999	FMV	External leakage	External Leakage	Body erosion	Test equipment
3/30/1999	FMV	Failed to close on demand (stuck open)	Closing failure	Stem	Digital positioner memory
10/6/1999	FRV	Failed to control	Control failure	Plug/seat	Unknown

Table C-3 (Cont.)
Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
10/7/1999	FRV	Failed to close within set-point tolerance	Set-point failure	FME valve	Unknown
1/28/2000	FRV	Failed to open on demand (stuck closed)	Opening failure	Disc/stem	Cam hub
2/9/2000	FRV	Failed to close on demand (stuck open)	Closing failure	Packing	Cam hub
4/3/2000	ADV	Failed to open on demand (stuck closed)	Opening failure	Disc/seat	Incorrect diaphragm
6/10/2000	FRV	Failed to close on demand (stuck open)	Closing failure	Packing	Faulty relief valve
8/6/2000	CDV	Unavailable, not failed	Non-demand failure	Disc/stem	Disconnected
8/21/2000	ADV	Failed to remain closed (drifted off closed seat)	Closing failure	Disc/seat	Regulator
10/29/2000	FRV	Failed to close within set-point tolerance	Set-point failure	Packing	Stem/disc separation
12/17/2000	ADV	Failed to respond to close demand	Closing failure	Disc/cage	Feedback linkage
12/17/2000	ADV	Failed to respond to close demand	Closing failure	Disc/cage	Feedback linkage
12/24/2000	CDV	Unavailable, not failed	Non-demand failure	FME valve	Unknown

Table C-3 (Cont.)
Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
1/13/2001	CDV	Operated, but not within specified parameters	Set-point failure	Disc/seat	Unknown
4/10/2001	FRV	Failed to close within set-point tolerance	Set-point failure	FME valve	Coil failure
5/2/2001	FRV	Failed to control	Control failure	Disc/stem	Coil failure
5/8/2001	ADV	Failed to open on demand (stuck closed)	Opening failure	Disc/cage	Coil failure
5/22/2001	CDV	Unavailable, not failed	Non-demand failure	Stem	Material failure
6/7/2001	CDV	Unaffected by failure	Non-demand failure	Disc/stem	Disc weld
6/26/2001	FRV	Failed to control	Control failure	Packing	Actuator motor
8/9/2001	CDV	Operated, but not within specified parameters	Set-point failure	Disc/seat	Calibration
10/20/2001	CDV	Operated, but not within specified parameters	Set-point failure	Pilot	Faulty relief valve
1/18/2002	CDV	Operated, but not within specified parameters	Set-point failure	Disc/cage	Incorrect jumper landed
6/3/2002	ADV	Failed to remain open	Opening failure	Disc/seat	Unknown
6/30/2002	CDV	Operated, but not within specified parameters	Set-point failure	Disc/seat	Feedback linkage
7/2/2002	CDV	Operated, but not within specified parameters	Set-point failure	FME valve	Feedback spring
8/30/2002	FMV	External leakage	External leakage	Packing	Pilot valve

Table C-3 (Cont.)
Valve Events Showing Failure Types

Date	Application	EPIX Failure Mode	Report Failure Mode	Report Failure Cause	Report Failure Mechanism
9/4/2002	CDV	Unaffected by failure	Non-demand failure	Disc/stem	FME
11/2/2002	FRV	Failed to control	Control failure	FME valve	Unknown
2/5/2003	FRV	Failed to control	Control failure	Disc/stem	Incorrect for application (mid-cycle cal drift)
8/18/2003	CDV	Operated, but not within specified parameters	Set-point failure	Disc/seat	Unknown
10/14/2003	FRV	Failed to control	Control failure	Packing	Diaphragm leakage
2/13/2004	FRV	Failed to control	Control failure	Packing	Relay malfunction
4/3/2004	ADV	Failed to open on demand (stuck closed)	Opening failure	Packing	Material failure
6/19/2004	FRV	Failed to control	Control failure	Stem	Valve clip
9/24/2004	CDV	Unavailable, not failed	Non-demand failure	Pilot	Unknown
12/6/2004	CDV	Operated, but not within specified parameters	Set-point failure	Disc/cage	Unknown

Table C-4
Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Control Components International	B3A6-12-12BW-18BW-31	Disc/seat	Feedback linkage	6/30/2002	CDV
Control Components International	B3A6-12-12BW-18BW-31	FME valve	Feedback spring	7/2/2002	CDV
Control Components International	B3G9-10-12P8-12P8-31	FME valve	Tubing failure	7/2/1998	FRV
Control Components International	DWG NO-922501043	Disc/stem	Disconnected	8/6/2000	CDV
Control Components International	DWG NO-922501043	FME valve	Unknown	12/24/2000	CDV
Control Components International	DWG NO-922501043	Packing	Stem/disc separation	10/29/2000	FRV
Control Components International	PDA9160-256BW	Disc/stem	Disc weld	6/7/2001	CDV
Control Components International	PDA964-96BW	Packing	Pilot valve	8/30/2002	FMV
Copes - Vulcan Inc.	D	Disc/cage	Inadequate design	2/27/1997	ADV
Copes - Vulcan Inc.	D	Disc/seat	Incorrect diaphragm	4/3/2000	ADV
Copes - Vulcan Inc.	D	Disc/stem	Instrument failure	11/24/1998	ADV
Copes - Vulcan Inc.	D	Disc/stem	Coil failure	5/2/2001	FRV
Copes - Vulcan Inc.	D-100	Disc/cage	Port connectors	4/2/1998	ADV
Copes - Vulcan Inc.	D-100	Disc/seat	Unknown	6/3/2002	ADV

Table C-4 (Cont.)
Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Copes - Vulcan Inc.	D-100	Disc/stem	Regulator	2/16/1997	FRV
Copes - Vulcan Inc.	D-100	FME valve	Power supply	12/19/1998	CDV
Copes - Vulcan Inc.	D-100	FME valve	Coil failure	4/10/2001	FRV
Copes - Vulcan Inc.	D-100	Packing	Diaphragm leakage	10/14/2003	FRV
Copes - Vulcan Inc.	D-100	Pilot	Incorrect installation	8/16/1997	ADV
Copes - Vulcan Inc.	D-100	Pilot	Unknown	9/24/2004	CDV
Copes - Vulcan Inc.	D-100	Stem	Material failure	5/22/2001	CDV
Copes - Vulcan Inc.	D-176720	Packing	Relay malfunction	2/13/2004	FRV
Copes - Vulcan Inc.	P-200	FME valve	Unknown	11/2/2002	FRV
Fisher Controls Co. Inc.	476D	Plug/seat	Unknown	10/6/1999	FRV
Fisher Controls Co. Inc.	52B5685	Packing	Faulty relief valve	6/10/2000	FRV
Fisher Controls Co. Inc.	67 SERIES	Packing	Cam hub	2/9/2000	FRV
Fisher Controls Co. Inc.	67 SERIES	Pilot	Faulty relief valve	10/20/2001	CDV
Fisher Controls Co. Inc.	D-100	Disc/seat	Regulator	8/21/2000	ADV
Fisher Controls Co. Inc.	DESIGN ED	Disc/stem	Cam hub	1/28/2000	FRV
Fisher Controls Co. Inc.	DESIGN ENA	Disc/cage	Unknown	12/6/2004	CDV
Fisher Controls Co. Inc.	DESIGN ENA	Disc/stem	FME	9/4/2002	CDV
Fisher Controls Co. Inc.	DESIGN ENA	Disc/stem	Incorrect for application (mid-cycle cal drift)	2/5/2003	FRV

Table C-4 (Cont.)
Valve Events by Manufacturer, Failure Cause, and Mechanism

Manufacturer	Model	Report Failure Cause	Report Failure Mechanism	Date	Application
Fisher Controls Co. Inc.	DESIGN ENA	Packing	Actuator motor	6/26/2001	FRV
Fisher Controls Co. Inc.	DESIGN ET	Body erosion	Test equipment	1/18/1999	FMV
Fisher Controls Co. Inc.	DESIGN ET	Stem	Digital positioner memory	3/30/1999	FMV
Fisher Controls Co. Inc.	DESIGN EWD	Stem	Valve clip	6/19/2004	FRV
Fisher Controls Co. Inc.	DESIGN EWP	Disc/cage	Feedback linkage	12/17/2000	ADV
Fisher Controls Co. Inc.	DESIGN EWP	Disc/cage	Feedback linkage	12/17/2000	ADV
Fisher Controls Co. Inc.	DESIGN HSV	FME valve	Unknown	10/7/1999	FRV
Fisher Controls Co. Inc.	EWT-8	Disc/cage	Card	7/17/1998	ADV
Leslie Co.	AEROFLOW	Packing	Material failure	4/3/2004	ADV
Masoneilan International Inc.	40400	Disc/cage	Incorrect jumper landed	1/18/2002	CDV
Masoneilan International Inc.	40400	Disc/seat	Calibration	8/9/2001	CDV
Masoneilan International Inc.	40400	Disc/seat	Unknown	8/18/2003	CDV
Masoneilan International Inc.	900	Disc/cage	Controller malfunction	9/5/1998	ADV
Masoneilan International Inc.	900	Disc/cage	Coil failure	5/8/2001	ADV
Rockwell Mfg Co.	FIG 607MY	Disc/seat	Unknown	1/13/2001	CDV
Worthington Corp/McGraw-Edison	70-70771	Packing	Regulator failure	4/2/1998	FRV

Table C-5
Pressurizer Spray Valve Failures

Date	Problem Component Note	Failure Cause Note	Item Note
11/14/01	Controller	Signal	76
1/9/02	Controller	Signal	87
12/31/01	Feedback linkage	Positioner	86
3/6/00	I/P converter	Transducer	9
12/18/00	I/P converter	Transducer	44
11/8/00	Limit switch	Actuator	37
3/28/03	Positioner	Positioner	128
7/29/03	Positioner	Positioner	137
10/19/03	Positioner	Positioner	144
2/26/01	Packing	Packing	51
1/16/02	Packing	Packing	88
9/10/02	Packing	Packing	109
4/20/04	Seat leak	Stem	156
9/21/02	Stem/disc assembly	Plug/stem	112
11/4/02	Valve internals	Plug/cage	115

D

SUMMARY OF KEY POINTS

The following list provides the location of Key Points information in this report.

Key O&M Cost Point

Emphasizes information that will result in reduced purchase, operating, or maintenance costs.

Referenced Section	Page Number	Key Point
2.2.2	2-3	A vast majority of severe duty valve failures (79%) for valves with actuators involved non-valve causes.
2.2.2	2-4	Only 28% of non-valve failures could be attributed to signal problems. The most problematic accessory was the positioner, followed by SOVs and the actuator itself.
4.9.2	4-9	Severe duty AOVs that are difficult to retorque due to location should be live-loaded.
4.9.2	4-10	The use of diagnostic equipment to properly set up a severe duty AOV is vital. It can be used as a predictive maintenance tool to determine the amount of packing load loss during service and the need for retorquing or live-loading. In addition, it will facilitate tuning of the final control element, which will improve position control and reduce packing wear during operation.
5.3.1	5-3	The most important design consideration for check valves is proper sizing. Overemphasis on lowering pressure drop and plant operating costs by using larger sizes can result in check valves that flutter, causing hinge pin, disc post, or other wear. This wear can result in catastrophic valve failure and forced plant outages, more than offsetting the gains for the lower pressure drop.

Key Technical Point

Targets information that will lead to improved equipment reliability.

Referenced Section	Page Number	Key Point
4.4.3	4-4	Plug/stem failures were dominated by plug/stem separation or looseness usually caused by improper assembly, material failures, or failed tack welds. Special attention must be given to proper assembly. This is a very critical joint due to the high vibration and stresses.
4.9.2	4-8	In-service consolidation (or creep) is the single most common reason for packing leaks. To mitigate, the valve packing should be consolidated before placing the valve in service.
4.9.2	4-8	Consolidation will not be effective unless the number of rings of packing is optimized. This usually means limiting the number of rings to five. For older valves with deep stuffing boxes, this involves the use of a high-density carbon spacer.
4.9.2	4-9	High-density carbon bushing material can be used to correct stem alignment problems. The busing is placed just under the packing gland.
5.3.1	5-3	Proper sizing of a check valve is such that the flow velocity maintains the disc firmly against the stop. Oversizing can be the result of plant designs that were incorrect or were never reconciled with the final design flows. It should not be assumed that the sizing is correct. When unusual wear is found, the size should be verified.
5.3.2	5-4	When water hammer is an issue, replacing the check valve with one that has a faster stroke time can help. A typical order of closure times (fastest to slowest) is nozzle check, lift check, tilting disc, and swing check.
5.3.3	5-5	If check valve minimum flow velocity analysis appears to support satisfactory operation, but wear and failures still occur, personnel should ensure that piping geometry is not creating abnormal velocity profiles that will cause disc flutter.

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ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

Electric Power Research Institute (EPRI)

RÉSUMÉ

Objectifs

- Réduire les événements de centrale provoqués par des soupapes utilisées dans les applications qui ont type un taux de défaillance élevé dû aux conditions de fonctionnement extrêmes
- Améliorer la formation du personnel en fournissant des informations au personnel des centrales pour mieux comprendre ces soupapes
- Fournir des méthodes effectives d'inspection, de diagnostic de problème, d'entretien, et de dépannage, appropriées

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目的

- 過酷な使用条件のため故障率の高い弁による事象を減らすこと
- このら弁をよりよく理解するため、発電所員を助ける情報を提供することによって、研修を推進すること。
- 適切な点検、問題診断、保全、および修理のための有効な方法を提供すること

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Objetivos

- Para reducir los eventos causados por las válvulas usadas en aplicaciones que usualmente tienen un alto índice de falla por causas de extremas condiciones de operación en las plantas
- Para perfeccionar el entrenamiento del personal ofreciendo información al personal de la planta eléctrica para que puedan entender mejor estas válvulas
- Para ofrecer métodos efectivos de inspección, de diagnosis de problema, de mantenimiento, y de reparación

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