NUREG-1275
Vol. 6

Operating Experience Feedback Report – Solenoid-Operated Valve Problems

Commercial Power Reactors

U.S. Nuclear Regulatory Commission

Office for Analysis and Evaluation of Operational Data

H. L. Ornstein

Reprinted September 1991

AVAILABILITY NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 2120 L Street, NW, Lower Level, Washington, DC 20555
2. The Superintendent of Documents, U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20013-7082
3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the Code of Federal Regulations, and Nuclear Regulatory Commission Issuances.

Documents available from the National Technical Information Service include NUREG series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, and transactions. Federal Register notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free, to the extent of supply, upon written request to the Office of Information Resources Management, Distribution Section, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, and are available there for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

NUREG-1275
Vol. 6

Operating Experience Feedback Report – Solenoid-Operated Valve Problems

Commercial Power Reactors

Manuscript Completed: December 1990
Date Published: February 1991

H. L. Ornstein

Office for Analysis and Evaluation of Operational Data
U.S. Nuclear Regulatory Commission
Washington, DC 20555

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

September 23, 1991

ADDRESSEES: ALL POWER REACTOR LICENSEES AND APPLICANTS

SUBJECT: OPERATING EXPERIENCE FEEDBACK REPORT, SOLENOID-OPERATED VALVE PROBLEMS AT U.S. REACTORS (GENERIC LETTER 91-15)

This generic letter informs addressees of a case study report of operating experience problems with solenoid-operated valves (SOVs) prepared by the Office for Analysis and Evaluation of Operational Data (AEOD) and published as NUREG-1275, Volume 6, "Operating Experience Feedback Report--Solenoid-Operated Valve Problems," February 1991 (copy enclosed). The case study integrates what has been learned over the past several years and provides an extensive assessment of SOV operating experience. The study describes deficiencies in design and application, manufacture, maintenance, surveillance testing and feedback of failure data, and concluded that problems with SOVs need additional attention by the industry. While the recommendations in the case study are not intended to establish regulatory requirements, many of the problems described in the report already are addressed by current environmental qualification and quality assurance rules.

In the study, several events are described in which SOV failures affected redundant safety components, multiple trains of safety systems or multiple safety systems. Three of the most significant events were isolated occurrences involving the failure to close of both main steam isolation valves (MSIVs) in the same line, the inability to start two redundant emergency diesel generators, and simultaneous failure of several BWR control rods to insert. The examples illustrate the vulnerability of safety-related equipment to common mode failure or degradation of SOVs. The NRC is concerned about the reliability of SOVs used in safety applications. As part of NRC's ongoing regulatory activities, inspections such as Safety System Functional Inspections (SSFIs) include the reliability of SOVs as well as other components required by safety related applications. The NRC also is providing technical advice to the Electric Power Research Institute's (EPRI) Nuclear Maintenance Application Center (NMAC) to assist in preparing an SOV maintenance guide. The first draft of the SOV maintenance guide is anticipated to be available towards the end of 1991.

It has been estimated that many hundreds of SOVs are in wide-spread use in each nuclear power facility. They are used in safety-related systems indirectly as pilot operators working with control system fluid (such as pneumatic or hydraulically operated isolation valves) and directly in fluid systems (such as to vent the reactor vessel head or to supply air to the starting system for emergency diesel generators). Many SOVs are also used in nonsafety-related systems that can significantly affect safety systems (such as plant instrument air drier systems). Over the years, many failures of plant systems and components have been attributed to SOV problems. To address specific SOV failures, the Nuclear Regulatory Commission (NRC) has issued numerous information notices and bulletins that provide the immediately attributed root cause for the failure. Because these communications frequently were focused on a specific failure, licensees may have made assessments and taken corrective actions that were focused on the specific failures and not on broader issues.

In the case study, the staff reviewed many SOV failures and degradations and discussed those having a similar failure mechanism, thereby showing how only slight differences frequently are all that separate operation from failure. Correcting only one obvious and specific deficiency at a time without awareness of other mechanisms for degradation may permit another problem in a short time to lead to unnecessary recurrent SOV failures. In addition, correcting problems only in SOVs used in the specific application in which the problem was found can allow similar SOV degradation to develop in other applications.

No specific action or written response is required by this generic letter. However, it is expected that recipients will review the information presented in the case study for applicability to their facilities and consider actions, as appropriate, to avoid similar problems. Since this generic letter and enclosure do not contain new or revised regulatory requirements, the Backfit Rule, 10 CFR 50.109, does not apply. If you have any questions about this matter, please contact one of the technical contacts listed below or the appropriate NRR project manager.

Sincerely,

James G. Partlow
Associate Director for Projects
Office of Nuclear Reactor Regulation

Enclosure:
NUREG-1275, Volume 6

Technical Contacts: H. Ornstein, AEOD
(301) 492-4439

J. Carter, NRR
(301) 492-1153

LIST OF RECENTLY ISSUED GENERIC LETTERS

Generic Letter No.	Subject	Date of Issuance	Issued To
91-14	EMERGENCY TELECOMMUNICATIONS	09/23/91	ALL HOLDERS OF OP LICENSES OR CONST. PERMITS
91-13	REQUEST FOR INFO RELATED TO RESOLUTION OF GI130, "ESSENTIAL SERVICE WATER SYS FAILURES AT MUTLI-UNIT SITES," PURSUANT TO 10CFR50.54(f)	09/19/91	LICENSEES AND APPLICANTS Braidwood, Byron Catawba, Comanche Peak Cook, Diablo, McGuire
91-12	OPERATOR LICENSING NAT. EXAMINATION SCHEDULE	08/27/91	ALL PWR REACTOR AND APPLICANTS FOR AN OPERATING LICENSE
91-11	RESOLUTION OF GENERIC ISSUES 48, "LCOs FOR CLASS 1E VITAL INSTRUMENT BUSES," and 49, "INTERLOCKS AND LCOs FOR CLASS 1E TIE BREAKERS" PURSUANT TO 10CFR50.54(f)	07/18/91	ALL HOLDERS OF OPERATING LICENSES
91-10	EXPLOSIVES SEARCHES AT PROTECTED AREA PORTALS	07/08/91	TO ALL FUEL CYCLE FACILITY LICENSEES WHO POSSESS, USE, IMPORT OR EXPORT FORMULA QUANTITIES OF STRATEGIC SPECIAL NUCLEAR MATERIAL
88-20 SUPP. 4	INDIVIDUAL PLANT EXAMINATION OF EXTERNAL EVENTS (IPEEE) FOR SEVERE ACCIDENT VULNERABILITIES - 10 CFR 50.54 (f)	06/28/91	ALL HOLDERS OF OLs AND CPs FOR NUCLEAR POWER REACTORS
91-09	MODIFICATION OF SURVEILLANCE INTERVAL FOR THE ELECTRICAL PROTECTIVE ASSEMBLIES IN POWER SUPPLIES FOR THE REACTOR PROTECTION SYSTEM	06/27/91	ALL HOLDERS OF OLs FOR BWRs
91-08	REMOVAL OF COMPONENT LISTS FROM TECHNICAL SPECIFICATIONS	05/06/91	ALL HOLDERS OF OLs OR CPs FOR NUCLEAR POWER REACTORS
91-07	GI-23 "REACTOR COOLANT PUMP SEAL FAILURES" AND ITS POTENTIAL IMPACT ON STATION BLACKOUT	05/02/91	ALL POWER REACTOR LICENSEES AND HOLDERS OF CPs

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

FIRST CLASS MAIL
POSTAGE & FEES PAID
USNRC

PERMIT No. G-67

ABSTRACT

This report highlights significant operating events involving observed or potential common-mode failures of solenoid-operated valves (SOVs) in U.S. plants. These events resulted in degradation or malfunction of multiple trains of safety systems as well as of multiple safety systems. On the basis of the evaluation of these events, the Office for Analysis and Evaluation of Operational Data (AEOD) of the U.S. Nuclear Regulatory Commission (NRC) concludes that the problems with solenoid-operated valves are an important issue that needs additional NRC and industry attention. This report also provides AEOD's recommendations for actions to reduce the occurrence of SOV common-mode failures.

CONTENTS

FIGURES

TABLES

APPENDICES

EXECUTIVE SUMMARY

The study analyzed recent U.S. light-water reactor experience (primarily 1984 to 1989) with solenoid-operated valves (SOVs). It focused on the vulnerability of safety-related equipment to common-mode failures or degradations of SOVs. The report presents information on over 20 representative events in which common-mode failures or degradations affected, or had the potential to affect, multiple safety systems or multiple trains of individual safety systems. While plant safety analyses may not have addressed such common-mode failures or degradations, operating experience indicates they are continuing to occur.

The study included common-mode SOV failures and degradations that cut across multiple trains of safety systems as well as multiple safety systems. Common-mode SOV failures have compromised front-line safety systems and important support systems such as emergency ac power, auxiliary feedwater, high-pressure coolant injection, and scram systems, resulting in reductions in safety margins. Many of the common-mode SOV failures and degradations observed were beyond the conditions analyzed in plant final safety analysis reports and are not modeled in present-day probabilistic risk assessments (PRAs).

The events in which common-mode failures of SOVs have affected multiple trains of safety systems or multiple safety systems are considered to be legitimate precursors to more significant events. They indicate that actions are needed to ensure that important plant systems function as intended in accordance with plant safety analyses and that plants are not subject to failures having the potential for serious consequences. Root causes of common-mode failures and degradations that have been observed and recommendations to reduce the occurrence of common-mode SOV failures are provided.

Analysis of operating data indicates that the underlying or root cause of many SOV failures are the licensees' lack of information or understanding of SOV requirements or capabilities. For example, most SOVs cannot tolerate contaminants, need preventive maintenance or periodic replacement, and have a propensity for rapid aging and deterioration when subjected to elevated temperatures. Compounding the problem is the fact that some SOV manufacturers do not provide the users with adequate guidance regarding proper SOV maintenance and operation. Further complicating the situation is the fact that many SOVs are "unrecognized" because they are provided as piece-parts of larger components. As a result, the licensees have a limited knowledge of the SOVs' operation and maintenance requirements, or their useful design life.

The report addresses widespread deficiencies that were found in design and application, manufacture, maintenance, surveillance testing, and feedback of failure data.

It is recommended for safety-related applications that licensees (1) verify the compatibility of SOV design and plant operating conditions, (2) verify the adequacy of plant maintenance programs, (3) ensure SOVs are not subjected to fluid contamination (e.g., instrument air), (4) review SOV surveillance testing practices, and (5) verify SOVs used in safety-related applications have been manufactured, procured, installed, and maintained commensurate with their safety functions.

Specific technical information supporting these broad recommendations is contained throughout the report. Specific recommendations are provided in Section 9, including a recommendation that an industry group take action to improve the mechanism for communicating SOV failure data to the manufacturers for early detection and resolution of potential generic problems. In addition, recommendations are given with regard to addressing the root causes of SOV failures. Such actions will assist in preventing common-mode SOV failures from reducing plant safety margins.

1 INTRODUCTION

All U.S. light-water reactors (LWRs) designs include solenoid-operated valves (SOVs) to perform safety-related and non-safety-related functions. SOVs are used to operate with ac or dc power to control the flow of hydraulic or pneumatic fluids under a wide variety of conditions. They are used to control process fluid either directly or indirectly as pilot controllers. It has been estimated that the population of SOVs in safety systems at U.S. LWRs is between 1,000 and 3,000 per plant (Ref. 1). Boiling-water reactors (BWRs) usually have more SOVs than pressurized water reactors (PWRs) because of the extensive use of SOVs in BWR scram systems.

Many SOVs used in nuclear power plants are dedicated/qualified valves, which have undergone rigorous qualification testing to standards such as the Institute of Electrical and Electronics Engineers (IEEE) Standards 323, 344, and 382, and are manufactured in accordance with the Nuclear Regulatory Commission (NRC) quality assurance requirements of Title 10 of the Code of Federal Regulations, Part 50 (10 CFR Part 50), Appendix B. However, cases have been found in which plants use commercial grade SOVs that have not been qualified to perform safety-related functions.*

This study was initiated in 1988 after several repetitive failures of SOVs were experienced at plants and after the simultaneous failure of four SOVs to operate on demand at Brunswick 2 on January 2, 1988 (Ref. 2). The Brunswick event resulted in a loss of containment integrity through two separate flow paths when two sets of redundant SOVs failed to close upon demand. The NRC Office for Analysis and Evaluation of Operational Data has reviewed and participated in followup work that the licensees, the NRC regional inspectors, and the valve manufacturers have performed following the SOV failures at Brunswick and several other plants.

A number of other significant operational events have occurred involving malfunctioning SOVs. Previous studies of SOV failures (Refs. 1, 3, 4, 5) discussed SOV failure rates and provided a characterization of the degradations or failures. This study addresses root causes and the generic nature of many of the observed failures.

The following are some of the significant common-mode failure events that reduced plant safety margins and that are discussed in this report.

*See NRC Information Notice 90-64, "Potential for Common-Mode Failure of High-Pressure Safety Injection Pumps or Release of Reactor Coolant Outside Containment During a Loss-of-Coolant Accident," October 4, 1990.

- simultaneous common-mode SOV failures that resulted in the failure of both emergency diesel generators to start at Perry
- simultaneous common-mode failures within the scram system at Susquehanna
- common-mode scram pilot solenoid valve failures that resulted in primary system leakage outside primary containment at Dresden
- losses of containment integrity at Kewaunee and Brunswick
- multiple safety relief valve and automatic depressurization system failures at Brunswick

Sections 5 and 6 of this report provide comprehensive reviews and evaluations of operational experience and potential safety implications associated with SOV problems at U.S. LWRs. This study provides several recommendations to address the major deficiencies that were noted during the review of the operating experience.

2 DESCRIPTION OF EQUIPMENT

There are many varieties of SOVs used at nuclear power plants which are manufactured by many different companies. The basis of SOV operation is predicated on changing the electrical status of the valve's electro-magnetic coil, which in turn causes a shift of the position of an internal core. The core acts to open or block the passageways inside the valve, changing the flow path within the valve. A simplified version of a two-way SOV is illustrated in Figure 1. Figures 2 through 4 illustrate more complex SOVs that are made by three different manufacturers.

SOVs are available for use over a wide range of temperature and pressure conditions for liquid and gas service. They are available with the following formats:

- normally open or normally closed
- fail open, fail closed, fail as is
- normally energized or normally de-energized
- ac or dc power, or both ac and dc power
- two-way valves, three-way valves, four-way valves
- direct lift, pilot assist, balanced disc, gate, modulating control

There is a wide range of sophistication and quality of SOVs. For example, mass-produced SOVs are available for home consumption for a few dollars each, whereas a limited production of high-quality SOVs are available at a much higher price. SOVs that are qualified for Class 1E nuclear service (meeting IEEE Standards 323, 344, 382;

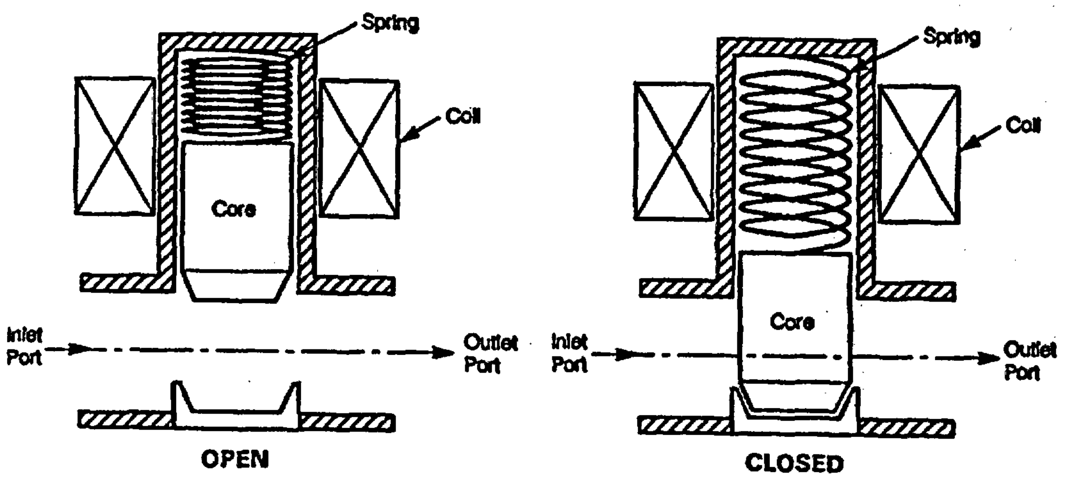


Figure 1 Simplified diagram of a two-way solenoid-operated valve

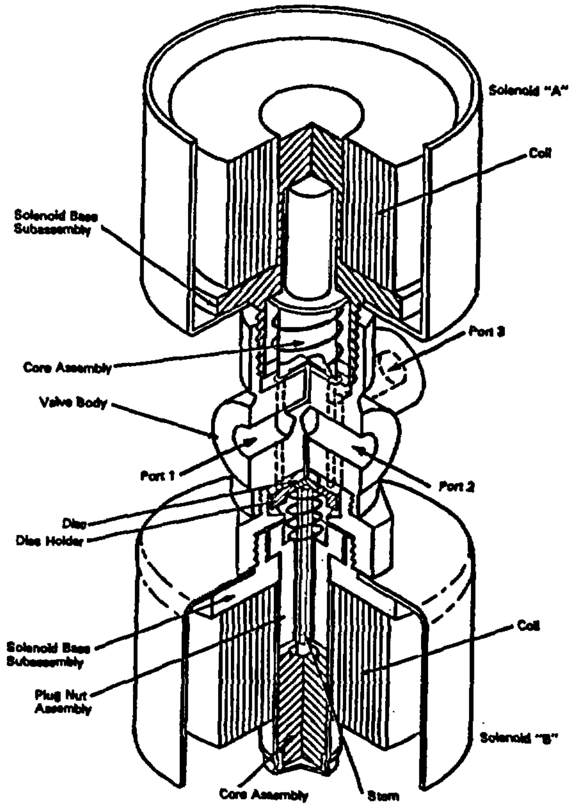


Figure 2 Isometric drawing of ASCO dual-coil 8323 solenoid-operated valve

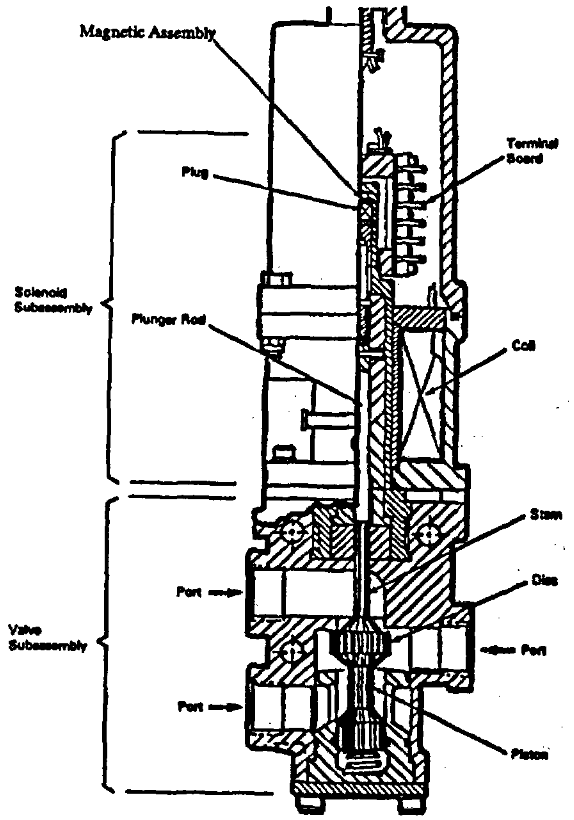


Figure 3 Schematic drawing of a Valcor solenoid-operated valve

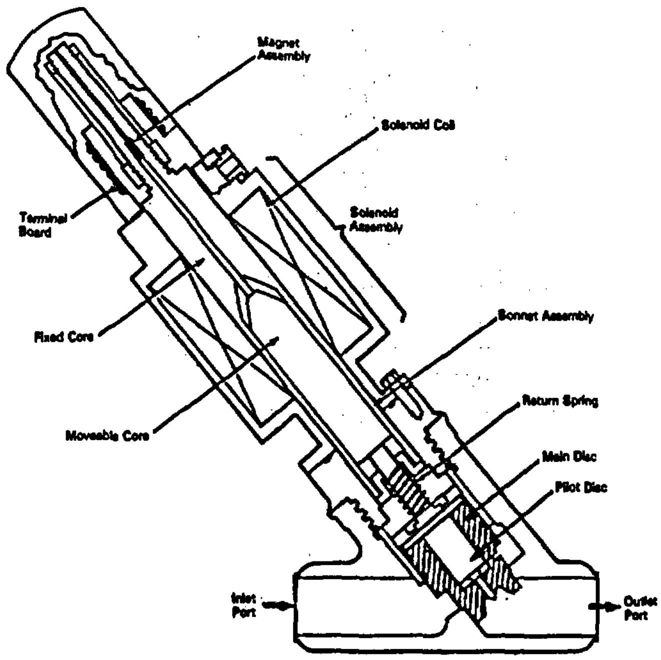


Figure 4 Schematic drawing of a Target Rock pilot-assisted solenoid-operated valve

American National Standards Institute [ANSI] N45.2; and 10 CFR Part 50, Appendix B, and 10 CFR Part 21 requirements; and having American Society of Mechanical Engineers [ASME] Section III N" or NPT" stamps) may cost several thousands of dollars.

3 USE OF SOLENOID-OPERATED VALVES

In many applications SOVs are used as alternates to motor-operated valves (MOVs). SOVs are frequently used as pilot operators to control air-operated valves (AOVs). The advantages of using SOVs instead of MOVs are that they generally have fewer moving parts, are compact, and may be easier to mount. They also have low power requirements and have fast response times. Some SOV manufacturers' literature states that SOVs have long qualified lives, have low initial and installed costs, and require low maintenance.

The use of AOVs, MOVs, and SOVs is a matter of preference of application that is determined by the utility, nuclear steam system supplier, and architect engineer; their specific utilization is not a licensing requirement.

A partial listing of places where SOVs are used in both safety and non-safety-related systems is provided below.

- BWR scram
- reactor coolant pump seal
- safety injection
- auxiliary feedwater
- primary containment isolation
- high-pressure coolant injection/reactor core isolation cooling
- high-pressure injection
- automatic depressurization
- emergency diesel generator
- instrument air
- chemical volume control/charging and letdown/boration
- pressurizer control
- steam generator relief (power-operated relief valves, atmospheric dump valves)
- low-temperature overpressurization protection
- decay heat removal/residual heat removal
- component cooling water
- service water
- reactor head vent
- reactor cavity/spent fuel/fuel handling
- torus and drywell/vent and vacuum
- emergency dc power
- main steam (main steam isolation valves/auxiliary boiler)
- reactor building/auxiliary building (ventilation and isolation)
- main feedwater
- condensate

4 SOLENOID-OPERATED VALVE FAILURE MODES: APPARENT AND ROOT CAUSES

Previous studies (Refs. 1, 3, 4, 5) have noted that details of the failure mechanisms, the apparent causes, or the root causes of SOV failures were not provided in approximately half of the licensee event reports (LERs) and nuclear plant reliability data system failure records for years 1978 through 1984.

Appendix A of this report provides a list of over 200 LERs describing SOV failures that occurred at U.S. LWRs between 1984 and 1989. Almost 100 of those LERs described multiple failures or degradations. The apparent and root causes of most (approximately 75 percent) of the SOV failures reported in LERs between 1984 and 1989 are given below. The percentage of LER failures attributed to those causes is shown in brackets.

- Coil failure or burnout was attributed to design or manufacturing deficiencies (early failure/end of life) or an error in application (type of current, voltage level, environmental conditions). [11%]

- Valve body failure or leakage was attributed to design or manufacturing deficiencies, such as excessive tolerances on internal parts; excessive wear/degradation of gaskets, O-rings, seals, or springs; or foreign materials preventing proper sealing. [13%]

- Passageway blockage, internal binding, and sticking were attributed to unidentified foreign substances coating valve internals or to contaminants such as dirt, corrosion products, desiccant, water or moisture, incorrect lubricants, excessive lubrication, or hydrocarbons. [14%]

- Electrical malfunctions were attributed to faulty internal wiring, reed switch shorts or external wiring with inadequate connections, splices, or grounds. [11%]

- Design errors or misapplications were attributed to incorrect valve configuration (normally open vs. normally closed, normally energized vs. normally de-energized), incorrect designation of "fail-safe" condition, incorrect electrical source (ac vs. dc, voltage level), incorrect designation of environmental conditions (temperature, moisture, radiation), incorrect designation of maximum operating pressure differential, incorrect material selection (incompatibility between elastomeric parts and process fluid contaminants), or incorrect valve orientation (horizontal vs. vertical). [13%]

- Installation errors were attributed to incorrect physical orientation (backwards, upside-down), electrical source (ac vs. dc voltage level), or inadequate electrical connections (e.g., loose connections, incorrect grounds). [7%]

- Maintenance errors were attributed to incorrect determination of useful life or time between overhauls, or inadequate preventive maintenance or incorrect preventive maintenance. [6%]

5 OPERATING EXPERIENCE: SIGNIFICANT EVENTS INVOLVING COMMON-MODE FAILURES OR DEGRADATION OF SOVS

The events described below were chosen as a representative set. Many of the events are viewed as precursors; that is, had the common-mode failures occurred under different circumstances or had the common-mode degradations worsened or persisted further without detection and correction, the plants would not have responded to design-basis events in accordance with the final safety analysis reports. These events should not be construed as being a complete set of common-mode failures and degradations of SOVs.

About 200 additional events are tabulated in Appendix A. Over 40% of the LERs in Appendix A involved multiple SOV failures or degradations. Many other SOV failures do not meet the threshold for NRC reporting required by 10 CFR 50.73 and as a result, are not captured in the LER data base.*

Many SOV failures which are not required to be reported in the LER data base are reported to the nuclear plant reliability data system (NPRDS) data base. Reference 1 noted that all SOV failures that were reported in LERs in 1978 to 1984 were also reported to NPRDS.

Safety-related SOVs at nuclear power plants have been manufactured by only a few companies; therefore, a reader should not attempt to judge a manufacturer's quality on the basis of the population of events described in the report concerning any particular manufacturer's product.

5.1 Design Application Errors

Representative operating experience illustrating design application errors associated with high ambient temperature, internal heatup from energization, incorrect operating pressure differential, and incorrect valve orientation are described below. Based on this experience, findings and recommendations relevant to design application errors are provided in Sections 7.1 and 9.1, respectively.

5.1.1 Ambient Temperatures

5.1.1.1 Main Steam Isolation Valves (MSIVs) at Perry—Excessive Heat From Steam Leaks

On October 29, 1987, while performing MSIV stroke time testing, three of the plant's eight MSIVs failed to

*Common-mode malfunctions of SOVs caused by multiple dc ground faults, as described in NRC Information Notice 88-86, Supplement 1 (Ref. 6), although not addressed as an issue in this report are included in Appendix A.

close within the allowable time of 5 seconds as designated in the plant's Technical Specifications. Two of the MSIVs were in the same main steamline. During subsequent testing, each of the three valves closed within allowable times of the Technical Specifications.

Since the valves all stroked satisfactorily subsequent to their initial failures, the licensee believed that the failures were due to the presence of impurities in the air pack SOVs controlling the MSIVs and that the impurities were apparently discharged during subsequent MSIV operation. As a result, the three MSIVs that had failed to meet their stroke closure time requirements were declared operable.

These MSIV air packs consist of a single-coil three-way SOV (ASCO NP8320), a dual-coil three-way SOV (ASCO NP8323), and three poppet type air pilot-operated valves (two-, three- and four-way, manufactured by C.A. Norgren Co.). A photograph of one of the Perry plant's MSIV air packs appears in Figure 5.

In response to NRC concerns, the licensee performed additional MSIV stroke testing. As a result, on November 3, 1987, the inboard and outboard MSIVs in one of the steam lines that had the earlier failures again failed to close within the required 5 seconds (outboard MSIV closed in 2 minutes and 49 seconds and the inboard MSIV closed in 18 seconds). Additional MSIV stroke tests were performed, and both MSIVs again closed within allowable times of the Technical Specifications.

Because of continued NRC concerns about MSIV reliability, the licensee shut down the plant and established a plan to determine the root cause of the MSIV failures (Refs. 7, 8, 9). Intense investigative efforts were conducted by the utility to determine the root cause of the MSIV failures. The failures of the MSIVs on October 29 and November 3, 1987, were attributed to the failure of the ASCO dual-coil Model NP8323 SOVs to shift position upon de-energization. The SOVs failed to shift position because of degradation of their ethylene propylene diene monomer (EPDM) seats and discs. The degradation was caused by high temperatures that had existed in the vicinity of the SOVs as a result of several steam leaks.

Originally, hydrocarbon impurities were suspected as having contributed to the degradation of the EPDM seats and discs. Samples of instrument air taken locally at the MSIVs were analyzed for particulates and hydrocarbon contamination. The analyses indicated that the air supply was free of particulates and condensible hydrocarbons. Further microscopic and spectral analyses performed at an independent laboratory (Ricerca) conclusively eliminated the possibility of impurities from hydrocarbon intrusion as a root cause of these failures (Ref. 10). However, as part of its corrective action to prevent future failures, the licensee took steps to improve the maintenance of the instrument air system. In addition, the licensee undertook an aggressive program to review the effects of all known steam leaks that could affect other safety-related equipment.

5.1.1.2 MSIVs at Crystal River 3—Thermal Aging—Incorrect Estimation of Ambient Temperatures

In April 1989, NRC inspectors reviewed the environmental qualification of electrical equipment at Crystal River 3. Their review found that errors had been made in the licensee's determination of the service life of 16 normally de-energized SOVs that are used to pilot the plant's MSIVs (Ref. 11).

The licensee's determination of SOV service life was made based on non-conservative estimates of the ambient temperature for the areas where the SOVs were located. The licensee's calculations did not consider the localized elevated temperatures that the SOVs were subjected to as a result of hot process piping. Recalculation of the service life of the SOVs using representative ambient temperatures reduced the estimated service life of the SOVs from 40 years to 8 years. As a result, the licensee is replacing those SOVs sooner than previously anticipated.

5.1.1.3 Millstone 2—Thermal Aging—Localized "Hot Spots" in Containment

In November 1988, an NRC inspection report (Ref. 12) noted that the Millstone 2 environmental qualification program recognized a significant reduction of the qualified lifetime of eight Valcor SOVs that are used for pressurizer and reactor vessel head vents. Originally the SOVs were calculated to have qualified lives of 40 years based on an ambient temperature of 120 °F. Although the plant's Technical Specifications require that the "primary containment average air temperature" does not exceed 120 °F, the licensee measured localized "hot spots" of 157 °F in the vicinity of the eight SOVs. The licensee determined that the increase in ambient temperatures from 120 °F to 157 °F shortened the lifetime of the SOVs from 40 years to 12 years. The problem of equipment degradation resulting from localized hot spots is not unique to Millstone 2. Reference 13 lists several other plants that have experienced localized thermal hot spots inside containment. In addition, NRC Information Notice 89-30 (Ref. 14) noted that similar heating events have been reported since 1982. The information notice alerted licensees to the potential for exceeding equipment's qualification specifications when the bulk temperatures are measured by a limited number of sensors that may not be representative of ambient temperatures in the vicinity of the SOVs.

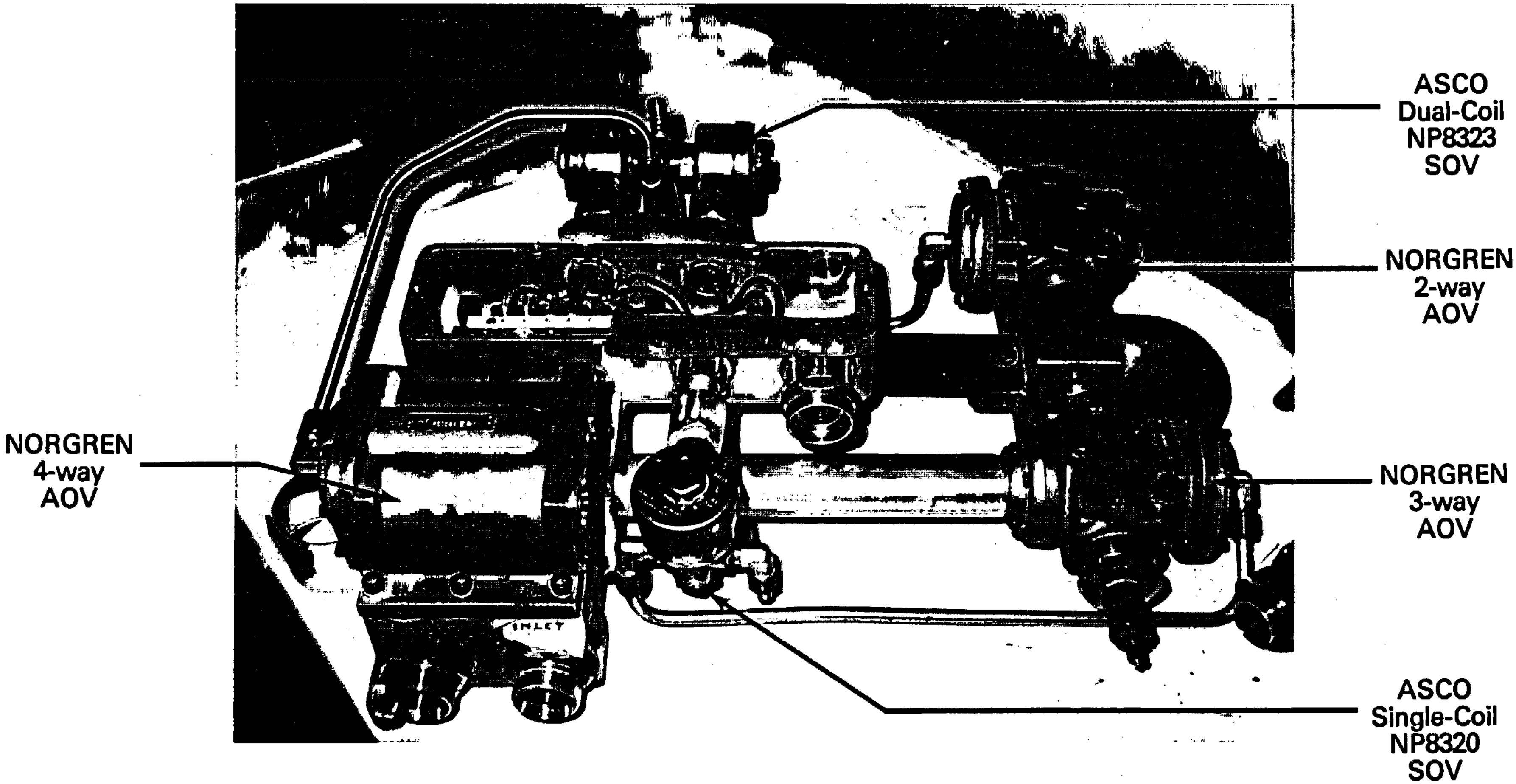


Figure 5 MSIV air pack from Perry Nuclear Power Plant, November 1987

5.1.2 Heatup From Energization

5.1.2.1 Grand Gulf 1—MSIVs—Thermal Aging (Self-Heating From Energization)

On August 14, 1989, following a reactor trip, one MSIV (inboard "B" line) failed to close upon demand (Refs. 15, 16, 17). The MSIV did close about 30 minutes later. The failure of the MSIV to close was attributed to the failure of an ASCO dual-coil NP8323 SOV, a piece-part of the MSIV air pack. The licensee's investigation found a piece of EPDM from the SOV's disc on the SOV's outlet port screen. The licensee concluded that the piece had been lodged in the SOV's internals, thereby keeping the SOV from venting control air and hence keeping the MSIV from closing. It is believed that after a piece of the EPDM disc material became dislodged from the internals, the MSIV closed.

Subsequent inspections by the licensee of the eight ASCO dual-coil NP8323 SOVs piloting the MSIVs disclosed that all eight had degraded seats. Initial visual inspection did not reveal the degradations that became apparent under microscopic examination. The EPDM seats of all eight SOVs had cracks. However, on six of them, the raised portion of the seat, formed by the annular impression made by the seat of the exhaust port, was missing. It appeared that six of the eight SOVs had experienced similar sloughing of material from the seat.

The failure of August 14, 1989, is believed to have been caused by a piece of the EPDM disc material that had been extruded into the SOV's exhaust port vent hole. The extruded material had separated from the disc as a result of the adhesive and frictional forces when the normally energized SOV was de-energized. The frictional and adhesive forces eventually led to the tearing off of the extruded parts of the EPDM discs.

The extrusion of EPDM discs is discussed in General Electric Company (GE) Service Information Letter (SIL) 481 (Ref. 18). SIL 481 notes that the intrusion of the disc into its exhaust port may account for previous events involving the sticking of similar EPDM dual-coil SOVs, but tearing of the discs had not been observed previously. It is believed that the tearing and overall degradation of the dual-coil SOVs' EPDM discs at Grand Gulf was symptomatic of thermal degradation resulting from the excessive time the EPDM materials were exposed to high service temperatures. The EPDM discs had been operating at elevated temperatures as a result of the energization of the dual coils. The local temperatures inside the SOVs near the EPDM discs were approximately 325 °F inside the inboard SOVs in a 135 °F drywell and 305 °F inside the outboard SOVs in a 125 °F steam tunnel. The SOVs had been in service for approximately 4.5 years. However, the qualified lives of the degraded EPDM discs are estimated to have been 2.2 years for the inboards and 3.2 years for the outboards based upon environmental temperatures of 135 °F for the inboard SOVs and 125 °F for the outboards SOVs.*

The NRC issued an information notice (Ref. 19) on this event, noting the life-shortening effects of self-heating from coil energization. Subsequently, ASCO issued a service bulletin (Ref. 20) providing licensees with heatup data for all their nuclear qualified SOVs (NP series).**

5.1.2.2 North Anna 1 and 2 and Surry 1 and 2—Thermal Aging (Self-Heating From Energization)

In December 1986, Virginia Electric and Power Co. (Vepco, now known as Virginia Power) requested ASCO to provide information regarding the effects of "self-heating" in continuously energized SOVs. ASCO's response indicated that a significant increase in temperature would occur and that the temperature increase could result in a significant reduction in the qualified life of the SOVs. The licensee recognized that previous estimates of SOV service life did not account for the effects of self heating (Refs. 21, 22). The licensee evaluated the affected SOVs and determined that, contrary to previous analyses, 125 SOVs would require replacement at North Anna 1 and 2 between the 1987 and 1989 refueling outages (Ref. 23). The SOVs affected piloted air-operated valves, many of which served containment isolation functions. The systems affected were safety injection, reactor coolant, main steam, component cooling water, containment vacuum, radiation monitoring, sampling systems, instrument air, post accident hydrogen removal, heating and ventilation, steam generator blowdown, gaseous vent, and aerated drains.

The licensee recognized that Surry 1 and 2 were similarly affected, and Vepco engineering informed personnel at the Surry station of this problem. Similarly, Surry 1 and 2 required early replacement of 58 ASCO SOVs because of self-heating.***

---

*Other EPDM discs in the same SOV that were exposed to slightly higher temperatures were estimated to have had qualified lives of 1.6 and 2.3 years, respectively.

**Since the preliminary case study report on solenoid valve problems was issued for peer review in June 1990, an additional event of interest occurred at Grand Gulf Unit 1 on July 27, 1990. The event involved the failure of one and the degradation of several SOVs that pilot the plant's main steam isolation valves (MSIVs). The licensee attributed the SOV failure (which resulted in one MSIV being unable to fast close) and the degradation of several similar SOVs that operate other MSIVs to increased drywell temperatures resulting from a safety relief valve leaking steam into the tail pipe. The local temperatures near the SOVs were about 10 °F higher than what was assumed when estimating the qualified lives of the SOVs. It appeared that this minor temperature increase was the primary reason for the premature failure and degradation of the SOVs. This failure occurred 11 months after these valves were installed although the service life had been estimated to be 1.1 years. More tolerant, longer service life components are needed. This event is illustrative of the problems described in this report and the need for industry action.

***Telecopy communication between W. Murray, Vepco, and H. L. Ornstein, NRC, December 19, 1989.

It is interesting to note that the licensee for North Anna station stated in a deviation report (Ref. 22) that these findings were not reportable because the "NRC and utilities are aware of this issue to some extent." In Reference 21, the licensee noted that it had learned of this problem initially from discussions with "industry representatives" at equipment qualification (EQ) seminars in late 1986.

5.1.3 Maximum Operating Pressure Differential (MOPD)—Multiple Plants

Many plants have experienced conditions in which SOVs failed or could have failed to perform safety-related functions because of excessive operating pressure differentials. Figure 6 is a schematic diagram of an SOV, illustrating how an operating pressure differential in excess of its maximum operating pressure differential (MOPD) can cause an SOV to malfunction. When the SOV is in the de-energized position, pressurized fluid enters the valve at port 2 and is blocked by the core assembly. If the pressure differential between ports 2 and 3 exceeds the MOPD, the overpressure could lift the core assembly, resulting in leakage of fluid from port 2 to port 1 and port 3.

In the energized position the core assembly is raised to block the exhaust port (port 3). However, the excess pressure would act to retard or prevent the core subassembly from dropping down (shifting) when de-energized. As a result, de-energizing the valve would not ensure the valve achieved its correct de-energized position (block off port 2).

For many SOVs, the MOPD rating does not appear on the nameplate or in the installation and maintenance instructions. Vendor catalogs need to be consulted to determine the MOPD ratings for the SOVs.

In May 1988, the NRC issued Information Notice 88-24 (Ref.24), which informed licensees of two SOV failures that were experienced at Kewaunee (Ref. 25) and of the potential for additional failures at Kewaunee and Calvert Cliffs 1 and 2 (Refs. 26-28). Subsequently, several licensees informed the NRC of similar discoveries at their plants, where the potential for overpressurizing SOVs existed, which could prevent the SOVs from performing their safety-related functions. At some plants, the task of verifying the potential for overpressurizing SOVs has been complicated by the fact that documentation is not readily available. For example, Millstone 1 and 2 (Ref. 29) and Crystal River 3 (Ref. 30), have reported that documentation to identify SOVs in containment is not readily available and that containment walkdowns are necessary for their identification.

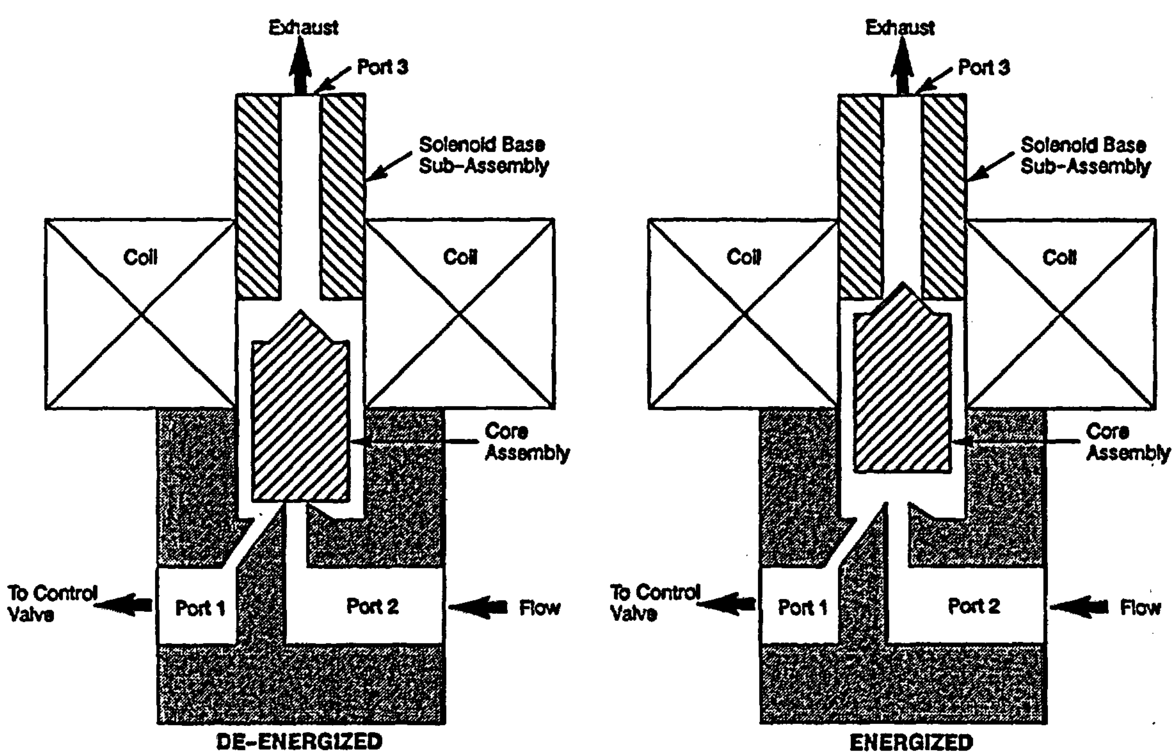


Figure 6 Schematic of a solenoid-operated valve illustrating effect of operating pressure differentials

It is not clear that all licensees have taken appropriate corrective action on the issue of SOV overpressurization as presented in Information Notice 88-24. This concern is predicated on the Crystal River 3 event (Ref. 30) and a followup discussion in which the licensee stated that its review of the potential for SOV overpressurization assumed the proper operation of in-line pressure regulators, it did not address the consequences of pressure regulator failures.* One of the events described in Information Notice 88-24 involved the discovery at Calvert Cliffs that several safety systems were vulnerable to single failures of pressure regulators in the air supply system.

One of the earliest SOV overpressurization failures that were reported occurred in 1980 at the Pilgrim plant. On October 7, 1980, and again on October 31, 1980, a safety relief valve (SRV) spuriously opened while the reactor was at power. On each occasion, the SRV did not reclose until the reactor was shut down and the reactor coolant system was depressurized. The spurious valve openings were caused by excessive pneumatic (nitrogen) supply pressure to the SOV controlling the SRV. The high nitrogen pressure exceeded the SOV's MOPD, causing the SOV to shift position, which caused the SRV to spuriously open.

The NRC issued an information notice and a bulletin based on these events. Information Notice 80-40 (Ref. 31) indicated that two-stage SRVs with Target Rock SOVs are susceptible to such MOPD malfunctions, whereas older three-stage SRVs having ASCO or AVC SOVs are not. In 1980, the NRC issued Bulletin 80-25 (Ref. 32) requiring licensees to review and upgrade their SRV pneumatic supply systems and/or SOVs to ensure that the SOVs operate within their maximum operating pressure. The bulletin required licensees to install protective devices (such as relief valves) to protect the SOVs against excessive supply pressures. The issue of overpressurization failures of SOVs in systems other than main steam were not addressed in the information notice or the bulletin.

The discovery of the potential for overpressurizing multiple SOVs at the Vogtle plant was reported in Reference 33. The report described a situation in which SOVs controlling the operation of all eight MSIVs could fail because of overpressurization of the hydraulic fluid resulting from overheating. The MSIV manufacturer (Rockwell) had noted that a small steamline break in the vicinity of the plant's MSIVs could cause an increase in the hydraulic fluid pressure in excess of the maximum operating pressure differential for the SOVs. These SOVs were manufactured by the Keane Company. As a result of SOV overpressurization, both MSIVs on one or more steamlines could allow uncontrolled blowdown of more than one steam generator following a main steamline or feedwater line break. Essentially, if the hydraulic actuator fluid for the MSIVs heated up by 12 °F the MSIVs would not have closed on demand. The licensee's corrective action was to replace the SOVs with others having higher MOPD ratings.

In November 1987, the Kewaunee plant experienced two SOV failures caused by overpressurization (Ref. 25). During review of these two SOV failures, the licensee found 58 additional SOVs that had the potential to fail to perform their safety-related functions as a result of overpressurization.

In April 1988, the licensee of Calvert Cliffs 1 and 2 found that 40 SOVs in the two units could fail to perform their safety-related functions as a result of overpressurization (Ref. 26).

In October 1980, Three Mile Island Unit 1 (Ref. 34) found that 11 SOVs were connected to line pressures in excess of the maximum dictated by the SOVs' MOPD. In the case of Kewaunee and Calvert Cliffs 1 and 2, it was found that failure of a nonqualified pressure regulator could result in the SOVs being subjected to supply pressures in excess of the maximum allowed by the SOVs' MOPD.

Seven reported events in which SOVs failed, or had the potential to fail, to perform their safety-related functions as a result of excessive operating pressure differentials are briefly described below.

(1) Vogtle 1, January 22, 1987 (Ref. 33)

  Eight main steam isolation valves could have failed to perform their safety function.

(2) Kewaunee, November 28, 1987 (Ref. 25)

  - One pressurizer relief tank makeup containment isolation valve failed to close.
  - One reactor coolant drain tank pump discharge header isolation valve failed. (Its redundant containment isolation SOV had the potential for similar failure.)
  - Fifty-eight other SOVs in safety-related applications were also found to have the potential for overpressure failure.

(3) Calvert Cliffs 1 and 2, April 14, 1988 (Refs. 26, 27, 28)

  The following 40 SOVs equally between Units 1 and 2, had the potential to fail:

*Telephone discussion between L. Kluit, Florida Power Corporation, and H. L. Ornstein, NRC, October 10, 1989.

- Eight auxiliary feedwater system
- Eight steam generator blowdown isolation system
- Six reactor coolant pump bleedoff isolation
- Eighteen safety injection system (fill and vent)

(4) Pilgrim 1, July 19, 1988 (Refs. 35, 36, 37)

The following six SOVs had the potential to fail as a result of overpressure:

- Four control room high efficiency air filtration system damper controls (two in each train)
- One standby gas treatment system damper control
- One primary containment system RCS sample line isolation valve

(5) Millstone 2, October 8, 1988 (Ref. 38)

One containment isolation valve failed as a result of an air pressure regulator that failed high.

(6) Millstone 1, 2, and 3, November 8, 1988 (Ref. 29)

Unit 1: The MOPD requirements of 16 SOVs in safety-related functions was unknown because of a lack of design information.

Unit 2: A total of 24 "harsh environment safety valves and their installed EEQ solenoid valves" had the potential to fail as a result of overpressure (one of the 24 had failed on October 8, 1988). The licensee also noted that the status of an unspecified number of safety-related SOVs was undetermined because the "data base is incomplete as to solenoid make and model number."

Unit 3: Approximately 20 SOVs installed in "safety valve configurations" had the potential to fail because of overpressurization.

Reference 29 did not list the specific systems in which of these SOVs were used. However, the licensee indicated that there are many additional inaccessible SOVs that also may be susceptible to overpressure failure. The licensee indicated that determination of such vulnerability would be made subsequent to future walkdowns when SOV nameplate data could be obtained.

(7) Crystal River 3, November 8, 1988 and January 5 and 11, 1989 (Refs. 30, 39, 40, 41)

The following five containment isolation valves had the potential to fail as a result of overpressure:

Two on secondary side steam generator blowdown lines (one per steam generator)

Two on secondary side steam generator sample lines (one per steam generator)

One on a reactor coolant pump seal controlled bleed-off line

5.1.4 Directional SOVs

On the basis of searches of the NRC data bases, at least six plants have observed inadvertent operation of safety-related Target Rock angle-type SOVs as a result of improper valve orientation. As shown in Figure 4, upstream fluid pressure at the inlet port of the angle-type SOV assists valve orientation; upstream fluid pressure at the inlet port of the angle-type SOV assists valve disc seating. However, many licensees also have learned from their own operating experiences and from followup discussions with the SOV manufacturer, that several different models of Target Rock angle-type SOVs used for isolation purposes are "unidirectional." That is, they will experience undesired seat lifting when the backpressure (pressure at the outlet port shown in Figure 4) is only 2 to 5 psi higher than the upstream or inlet pressure. As noted in Target Rock Operation Manual TRP 1571 J (Ref. 42), the manufacturer has been aware of this problem at nuclear plants since 1978. However, in the late 1970's, Target Rock developed an SOV for use as a bidirectional isolation valve (would not open inadvertently as a result of high backpressures). Target Rock considered the inadvertent seat lifting to be an architect engineer/licensee "application problem"—not an SOV problem.* The issue of unidirectional isolation SOVs is addressed in some, but not all, Target Rock SOV users manuals. For example, Reference 43 noted that the unidirectional qualities of the Target Rock angle-type SOVs are described in Target Rock Manual TRP 1571J (Ref. 42), which states that

> *Most solenoid valves because of the nature of the operation of the valve, will stop flow in only one (1) direction. By design, upstream pressure acts on the top of the disc, forcing it onto its seat, thereby creating a tighter seal. However, if downstream pressure rises above upstream pressure, the disc will tend to lift off of its seat, thereby allowing flow.*

Since Target Rock considered the inadvertent opening of unidirectional SOVs to be an application problem, not an

*Telephone discussion between T. D. Crowley, Target Rock Corporation, and H. L.Ornstein, NRC, January 24, 1990.

SOV problem, Target Rock did not issue field service notifications to alert owners of the SOVs affected by this problem. Target Rock recently provided AEOD with detailed information with regard to inadvertent opening and/or orientation of SOVs, which is attached as Appendix B to this report.

Plants that have experienced inadvertent openings of safety-related Target Rock SOVs are:

H.B. Robinson 2 (1980), unspecified number of SOVs

Arkansas Nuclear One Unit 1 (ANO-1) (1985), two SOVs

Arkansas Nuclear One Unit 2 (ANO-2) (1985), two SOVs

River Bend (1986) and (1989), 3 SOVs and 10 SOVs respectively

Harris 1 (1987), two SOVs

Hatch 2 (1988), 12 SOVs

The licensees re-oriented the SOVs to ensure that they would operate properly during accident conditions. The most recent events that occurred at River Bend are described below.

In April and May 1989, during testing conducted in response to NRC Generic Letter 88-14, "Instrument Air Supply System Problems Affecting Safety-Related Equipment" (Ref. 44), the River Bend station found 10 Target Rock SOVs used in safety-related applications that would inadvertently open during accident conditions upon loss of instrument air. The opening of those unidirectional SOVs would have resulted in the blowdown of safety-related accumulators and would have prevented safety-related equipment from performing its safety functions (Refs. 43, 45). For example:

- Inadvertent actuation of six unidirectional SOVs on loss of instrument air would result in bleeding down the safety-related accumulators in the control building, the auxiliary building, and the fuel building. The licensee postulated that rapid depletion of accumulators in the control building (in 3.7 minutes) would prevent proper operation of building dampers and would adversely affect cooling of safety-related equipment, control room cooling, and control room air filtration. Depletion of accumulators in the auxiliary building would affect building dampers resulting in the loss of cooling of safety-related switchgear. Depletion of accumulators in the fuel building would affect building dampers and would impact air filtration and prevent the maintaining of a negative building pressure.
- Two unidirectional SOVs in the standby service water system (ultimate heat sink) that could inadvertently open when subjected to accident conditions.
- Two unidirectional SOVs were found in the instrument air system that could inadvertently open on loss of instrument air. Such opening would prevent long-term operability of 16 safety relief valves, including those of the automatic depressurization system.

In Reference 43, the licensee also noted that several years earlier (1986) it had found three other Target Rock SOVs that had to be re-oriented as a result of inadvertent opening. The licensee had discovered that problem when the valves were subjected to leak rate testing. Those three SOVs had served as containment isolation valves in the containment hydrogen sampling system.

5.2 Maintenance

Representative operating experience illustrating maintenance problems associated with maintenance frequency, replacement versus rebuilding, contamination, and lubrication are described below. On the basis of this experience, findings and recommendations relevant to maintenance problems are provided in Sections 7.2 and 9.2, respectively.

5.2.1 Inadequate Preventive Maintenance

5.2.1.1 Dresden 3—Boiling Water Reactor (BWR) Scram System, Primary System Leak Outside Primary Containment

During recovery from a reactor scram at 81-percent power on September 19 1985, Dresden 3 experienced a leak of reactor coolant outside primary containment. The leakage path was through the scram outlet valves and the scram discharge volume (SDV) vent and drain valves (Refs. 46, 47, 48). The NRC issued Information Notice 85-95 (Ref. 49) to alert licensees to the potential for reactor coolant leakage into the reactor building that could result from scram solenoid valve problems. The information notice indicated that a similar event had occurred at Dresden 2 in 1972; however, at that time the licensee did not determine the root cause of the event.

After the reactor scrammed in September 1985, the control room operators attempted to reset the reactor protection system (RPS). RPS channel A was successfully reset, but channel B could not be reset.* This channel configuration allowed the scram pilot SOVs to vent air, resulting in reduced air header pressure. Excessive leakage resulting from SOV wear also contributed to the

*Channel B remained tripped because of stuck contacts on the reactor mode switch.

reduced air header pressure. The reduced air header pressure (38 psig) was sufficient to allow the SDV vent and drain valves to open (opening pressure ~8 to 15 psig), but it was not sufficient to enable the scram inlet and outlet valves to reclose (~42 psig required to close). For approximately 23 minutes, hot reactor coolant leaked outside primary containment into the reactor building. The leak resulted in elevated radiation levels on the first three floors of the reactor building.

In addition to the anomaly associated with the half scram configuration, degraded scram pilot SOVs contributed to the event. Testing showed that leaking scram pilot SOVs resulted in a combined SDV air header leak of 25 scfm. The licensee found widespread wear, aging, and hardening of the SOVs' O-rings and diaphragms.

The safety significance of these component failures at Dresden 3 is illustrated by the SDV degradations discussed below.

After a reactor scram, the SDV and the scram instrument volume are in direct contact with hot pressurized reactor water. A common-mode failure of the pilot SOVs controlling the scram discharge system vent or the drain valves could result in an uncontrolled release of reactor water outside primary containment until the scram is reset (see Figure 7). Such an event occurred at Hatch 2 in August 1982 (Ref. 50). Similarly a sluggish SOV piloting an SDV drain valve caused water hammer at Brunswick 1, which resulted in damaged pipe supports in the SDV drain system (Refs. 51, 52). As noted in Reference 47, a severe water hammer in the SDV system could result in an uncontrolled leak of reactor water outside the primary containment.

Discussion with GE has indicated that since Information Notice 85-95 was issued, BWR owners have made improvements in their SDV systems so that there are redundant SDV vent and drain valves at all U.S. BWRs vs. only one vent and one drain valve per SDV header prior to the modification.* However, it is not certain that all U.S. BWRs have manual handwheel overrides for the SDV vent and drain valves to limit reactor water leakage outside primary containment in the event of a common-mode failure of the SOVs piloting the SDV vent and drain systems.

*Telephone discussion between G. Strombach and E. Giebo, GE, and H. L. Ornstein, NRC, June 23, 1989

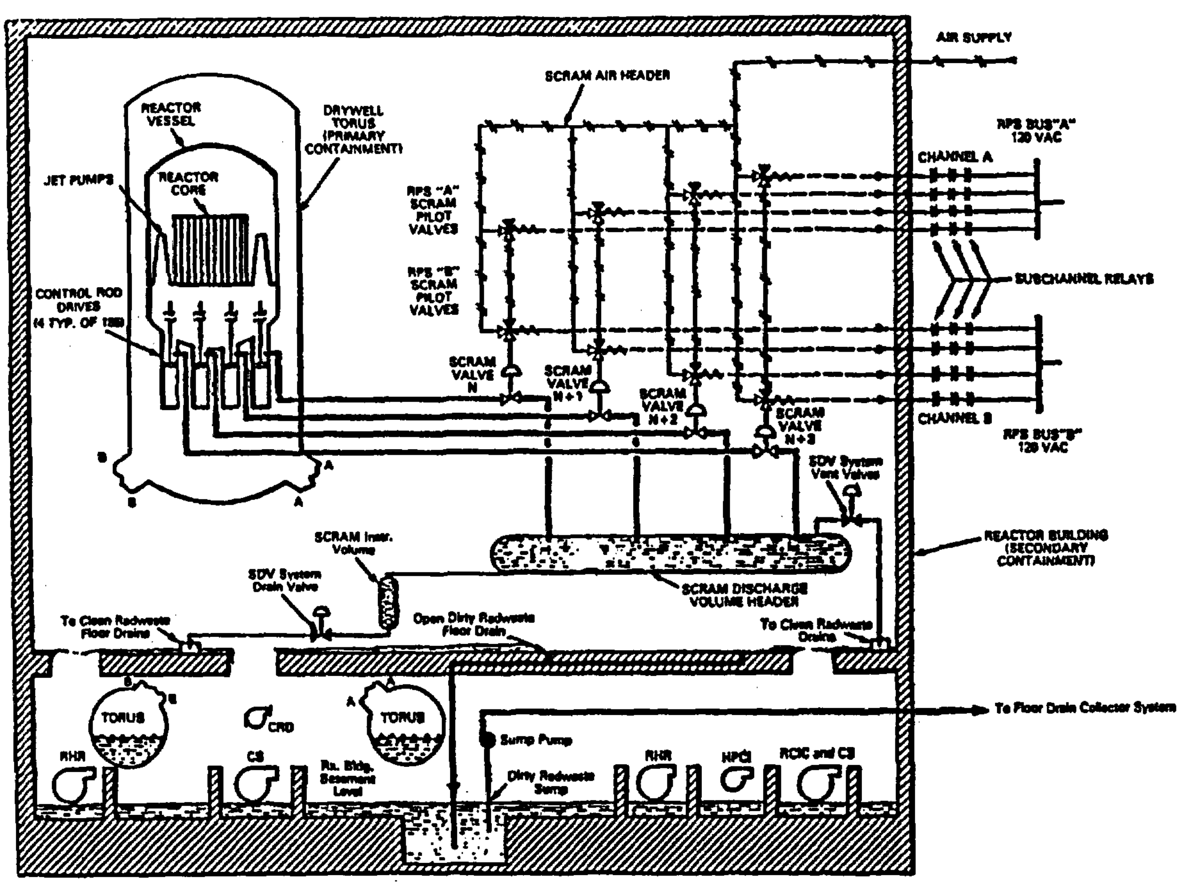


Figure 7 BWR scram system illustrating leakage path outside containment

5.2.1.2 Perry—Simultaneous Common-Mode Emergency Diesel Generator Failures

On February 27, 1987, the Perry nuclear plant experienced simultaneous common-mode failures of both emergency diesel generators (EDGs) (Ref. 53). The failures were attributed to excessive air leakage through SOVs on each EDG's control panel. The SOVs were Humphrey Products Model No. TOG2E1-3-10-35, which were supplied by Delaval as EDG piece-parts. The SOVs are three-way air control valves that are continuously energized while the EDGs are in the standby mode. The licensee had previously identified these SOVs for replacement because of observed air leakage. Work requests had been initiated for replacement of the SOVs, but at the time of their failures, the work requests had not yet been implemented.

Discussions with the licensee and the EDG manufacturer revealed the following information:*

- The failed SOVs had been in service for over 2 years after being in storage for 7 years.
- Inspection of the SOVs found that the elastomeric parts (Buna-N) were hardened.
- The failure was attributed to continuously energized operation and associated elevated temperatures.
- The Humphrey valves were purchased by Delaval as commercial valves and were upgraded/dedicated for nuclear service by Delaval. Delaval did not provide specific maintenance instructions for the SOVs.
- The changeout frequency of the SOVs is not specified in the Delaval Operator's Manual; however, Perry plant personnel stated that the changeout frequency could be implied from the manufacturer's control panel environmental qualification report.
- Although the SOV manufacturer has stated that SOV failures have occurred because of incorrect use of lubricants on the Buna-N parts, the licensee was not provided with any lubrication instructions.
- The Perry plant upgraded the SOVs to ones with Viton instead of Buna-N, and more recently, they replaced some of the Humphrey SOVs with electrical relays.

This event highlights the concern with regard to the vulnerability of other nuclear power plants having Delaval EDGs with Humphrey SOVs similar to the ones that failed at the Perry plant in February 1987.**

*Telecon H. L. Ornstein, NRC, and R. DiCola, Cleveland Illuminating Co., May 29–30, 1990. Telecon H. L. Ornstein, NRC, and D. Pesout and S. Owyoung, Cooper Industries (formerly Delaval), May 29–30, 1990.

5.2.2 Replacement Versus Rebuilding

5.2.2.1 MSIVs at Perry—Inadequate SOV Rebuild

After determining the cause of the MSIV failures of October 29 and November 3, 1987, (discussed earlier in Section 5.1.1.1) the licensee replaced or rebuilt the ASCO SOVs on the MSIV air packs. Because of the limited availability and long lead times for replacement parts (air packs and ASCO dual-coil NP8323 SOVs), rather than replace all of the MSIV air pack SOVs, the licensee had to rebuild some (rather than replace all) of the MSIV air pack SOVs. A description of the licensee's action is given below.

- One entire air pack was replaced for the inboard D MSIV.
- One dual-coil NP8323 SOV was replaced for the outboard D MSIV air pack.
- One dual-coil NP8323 SOV was replaced for an inboard MSIV that had not failed previously. It was replaced after inspection because it had been observed to have sustained heavy damage to the electrical coils as a result of moisture intrusion.
- Five dual-coil NP8323 SOVs were rebuilt, including the inboard B MSIV that had failed on October 29, 1987.

The licensee conducted increased surveillance and testing of the MSIVs after repairing and replacing the air pack SOVs. The licensee initiated monthly operability testing of the MSIV air pack SOVs, quarterly fast closure timing tests and inspections of the ASCO NP8323 dual-coil SOV experiencing the high temperatures.

On November 29, 1987, while performing operability testing, the ASCO dual-coil NP8323 SOV controlling the inboard B MSIV failed to change state when it was de-energized. Examination of the failed SOV found that the failure was caused by foreign particles in the SOV. Laboratory examination confirmed that the particles were EPDM from the SOV's O-ring, which had been replaced during the SOV's rebuilding process after the failure of November 3, 1987 (Refs 9, 10).

Apparently, during the original SOV rebuilding process, the licensee did not completely disassemble the ASCO dual-coil NP8323 SOV. As a result, small particles

**The NRC's Accident Sequence Precursor program quantified this event and estimated it to have a conditional core-damage probability of 2.3×10^{-4} (Ref. 54).

remained in the valve undetected until it (they) caused the SOV's failure.*

To preclude additional failures from foreign particles remaining from the rebuilding process, as had happened on November 29, 1987, the licensee replaced all eight ASCO dual-coil NP8323 SOVs with new ones. Furthermore, the licensee stated that is was going to modify its preventive maintenance program. In the future all Class 1E ASCO SOVs will either be replaced with new valves or undergo complete disassembly and cleanout to ensure that no particles remain or are introduced during the rebuilding process.

5.2.2.2 Brunswick 1—Safety Relief Valves, SOV Rebuilding Error Involving Excess Loctite

On July 1, 1987, while attempting to control pressure following an unplanned automatic reactor trip, an SRV failed to open on demand. Following shutdown, the licensee tested the SRVs that had not cycled during the trip recovery and found another SRV that did not open on demand (Refs. 55, 56).

The SRV failures were due to SOV failures. The two SOVs that had failed (Target Rock Model 1/2-SMS-A01) are used to port air to the SRVs' actuators, allowing remote-manual opening of the valves. The two SRVs that failed were part of the automatic depressurization system (ADS).

The failure of both safety relief valves to open on demand was attributed to excess Loctite RC-620 which was found in the internals of the related SOVs. Although two additional valves were found to have excess Loctite on the SOVs' internals, those valves did not exhibit signs of binding.

The licensee determined, with the assistance of the SOV manufacturer, that Loctite RC-620 had been used by the SOV manufacturer's field service representative while rebuilding the SOV during a previous outage. In Reference 53, the licensee noted that the manufacturer's (Target Rock) field service representative had rebuilt all of the Brunswick 1 SOVs that actuate 11 SRVs (seven ADS valves and four non-ADS valves). The licensee stated that the Target Rock field service representative had done SOV refurbishment work on the valves at Brunswick 1, but he had not done similar work on any SOVs that pilot SRVs at other plants. Target Rock field representatives service the Target Rock SRVs for all U.S. BWRs (except for Browns Ferry 1, 2, and 3) at Wyle Laboratories during the plants' refueling outages. Most plants send their SRVs and SOVs to Wyle for refurbishment every refueling outage. Some only send half of their SRVs and SOVs to Wyle for such refurbishment during each refueling outage.

The problem encountered with Loctite RC-620 was one of excessive application. Loctite RC-620 is an anaerobic adhesive. Curing takes place in the absence of air. The SOV manufacturer's refurbishment procedure specifies that Loctite RC-620 be applied to a locknut assembly beneath the valve plunger. The procedure cautions against application of excessive amounts of the adhesive. The licensee concluded that the SOVs had excess amounts of Loctite RC-620 applied to them, and that curing did not occur until after the valves were placed in the inerted containment. The licensee believed that, before curing, the excess adhesive migrated to the interior of the valves, bonding the SOVs' plungers to the bodies of the valves.

The licensee concluded that even though only two ADS SOVs were found to malfunction, two other ADS SOVs had similar bonding as a result of excess Loctite RC-620; however, those bonds were broken during the initial removal and handling of the SOVs when they were removed from the drywell and bench tested.

The licensee's assessment of the event (Ref. 55) concluded that a common-mode failure, the inoperability of all 11 SRVs as a result of Loctite RC-620 bonding of all SOVs by one vendor field service representative, is a reasonably credible event. The occurrence of a design-basis event under such conditions is outside the bounds of the plant's final safety analysis report.

The NRC issued Information Notice 87-48 (Ref. 56) to notify licensees of the event of July 1, 1987. A similar SRV failure occurred on July 25, 1980, at Pilgrim (Ref. 32). A Target Rock SRV failed to open on a manual demand signal. The failure was caused by excessive Loctite RC-620, which had caused the SRV's solenoid plunger to stick to the valve's bonnet. In this case, the excessive Loctite was used during the fabrication of the SRV, as opposed to the July 1, 1987 event at Brunswick in which the excess Loctite was applied during refurbishing.

5.2.2.3 Peach Bottom 3—Scram System, SOV Rebuilding Error Involving Excess Loctite

On November 17, 1983, a control rod was observed to have an excessive insertion time during a reactor scram (Refs. 57, 58). The sluggish control rod insertion was attributed to the failure of an SOV to shift position to allow control air to be exhausted from the control rod's hydraulic control unit.** As a result, the licensee replaced the scram pilot SOVs associated with the control rod that did not scram promptly and sent the scram pilot SOVs to GE for failure analyses.

*It is believed that one particle remained in the SOV, and that the particle broke up during subsequent SOV operation.

**The ASCO Model HVA-90-405 SOV, which was built by ASCO but was procured from GE is similar to the ASCO Model NP8316 valve.

On January 14, 1984, during a reactor scram, another control rod did not insert within the technical specification allowable time of 7 seconds. The second control rod had acted sluggishly during the reactor scram of November 17, 1983. However, because it was believed to have inserted within the technical specification allowable time on November 17, 1983, no maintenance was performed on its pilot SOVs at that time.

Subsequent to the second failure (January 14, 1984), the licensee undertook an extensive investigation. That investigation revealed that, contrary to previous findings, the second control rod also had failed to meet its allowable scram insertion time limit on November 17, 1983.

Laboratory analysis of the two pairs of SOVs associated with the slow inserting control rods revealed that one valve of each pair had a yellow varnish-like foreign substance on its core assembly. One of the SOVs that was found to have the foreign substance on it exhibited sticking during subsequent bench testing. The foreign substance was originally believed to be a silicone lubricant, but it was later identified to be Loctite 242. Loctite 242 had been introduced to the SOVs during the rebuilding process, in accordance with the supplier's (GE) recommendations. In its 1978 Service Information Letter (SIL) 128 (Ref. 59), GE had recommended that when rebuilding control rod drive (CRD) scram pilot valves, Loctite 242 adhesive/sealant should be used to secure the "acorn nut" on the solenoid housing to prevent it from loosening.

The Peach Bottom 3 failures were attributed to excess Loctite 242 that was used in the rebuilding process. It had appeared to be fully cured and the excess had not been wiped off. When the system returned to service, the Loctite 242 migrated and hardened and bonded the SOV's core plunger to its base assembly. After determining the source of the sticking, the licensee eliminated the use of Loctite 242 from its rebuilding process. Subsequently, GE issued supplementary SIL 128 (Ref. 60), which recommended that all BWR owners discontinue using Loctite 242 or any other chemical adhesive thread lockers on the acorn nut of the pilot SOVs.

GE had originally recommended using Loctite 242 to overcome loosening of the acorn nut, and ASCO had agreed. Following the sticking problems at Peach Bottom 3, ASCO made a design change and replaced the acorn nut with a nylon-lined locking nut that would not require adhesive thread lockers to remain tight.*

The common-mode failure potential for the scram system at some BWRs exists because some plants have used the same SOVs that are used to pilot the individual control rod hydraulic control units to pilot the scram discharge volume vent and drain valves. In the case of Peach Bottom 3, the potential for multiple simultaneous failure was compounded by the fact that the licensee had rebuilt all 370 control rod scram SOVs during the previous refueling outage. To reduce this common-mode failure potential, GE's SILs (Refs. 59, 60) recommended (not a binding requirement) that CRD pilot SOVs be rebuilt on a staggered basis from a "distributed checkerboard pattern."

*Telephone discussion between J. Shank, ASCO, and H. L. Ornstein, NRC, June 19, 1989.

5.2.3 Contamination

5.2.3.1 Brunswick 2 MSIVs—Excessive Heat and Poor Air Quality (Hydrocarbons)

On September 27, 1985, during surveillance testing at Brunswick 2, three of eight pneumatically operated MSIVs failed to fast close (Refs. 61, 62). There are two MSIVs in series in each of four parallel steamlines. Two of the valves that failed to fast close were on the same steamline. An investigation of the failures found that the MSIVs failed to close because of disc-to-seat sticking of the MSIV air pack SOVs (ASCO dual-coil Model NP8323). The internal O-rings on the SOVs also were found to be degraded; they were brittle, and several O-rings were stuck to the valve body. Several SOV discs came apart after becoming brittle: pieces of one SOV disc became wedged in the SOV's exhaust port, one disc stuck to the exhaust port, and another SOV lost a piece of its disc.

Laboratory analysis of the three failed SOVs showed the presence of a significant amount of hydrocarbon in them. The combination of hydrocarbons and elevated temperature caused the EPDM discs to swell and fill the SOVs' exhaust ports, which blocked the discharge of air in the air actuator and increased the frictional force opposing SOV core movement. The instrument air system was believed to have been the source of the hydrocarbon contamination.

Because of the susceptibility of the EPDM parts to hydrocarbon contamination, the licensee replaced all of the SOVs with the same model SOV having Viton discs and seals. Compared to EPDM, Viton is less susceptible to hydrocarbon contamination, but it is more susceptible to radiation damage.

This event was reported to Congress as an abnormal occurrence. The abnormal occurrence report categorized the event as one that resulted in "the loss of plant capability to perform essential safety functions such that a potential release of radioactivity in excess of 10 CFR Part 100 guidelines could result from a postulated transient or accident" (Ref. 63).

5.2.3.2 North Anna 1 and 2—Multiple Systems, Oil and Water Intrusion

While performing maintenance operations at North Anna on the morning of April 24, 1987, an operator error resulted in a service water intrusion into the Unit 1 and 2 instrument air systems (Refs. 64-67).* The licensee quickly recognized that the service water intrusion affected SOVs and pneumatic controllers including those in the auxiliary feedwater (AFW) systems, primary and secondary pressure control systems, and the SOVs required for containment isolation (trip valves) for both Units 1 and 2.

At the time of the event, Unit 1 was shutdown (mid-loop operation) and Unit 2 was operating at 100 percent power. The licensee's immediate response to the event was to blow down the affected instrument air lines while continuing to operate Unit 2.

About 2-1/2 hours after the intrusion occurred the licensee tested the Unit 2 AFW train A (motor-driven AFW pump). The air-operated discharge valve and the backpressure regulating valve both malfunctioned rendering train A inoperable. About 3 hours later the licensee tested train B satisfactorily.

Throughout the evening of April 24, 1987, the licensee continued to blow down instrument air lines until no moisture was observed. The AFW A discharge and pressure regulating valves were repaired on the evening of April 24, 1987, and were satisfactorily tested around midnight.

The cleanup procedure was not totally effective since there were low points in the instrument air system that had not or could not be drained. The residual water that remained in the low points of the instrument air system and the moisture and contaminants in the instrument air system resulted in widespread SOV failures for almost 2 years after the service water intrusion event. In addition to failures of freestanding" SOVs, there were dozens of control valve failures. The bulk of the control valves that failed were Fisher control valves. Integral to each Fisher control valve is an ASCO SOV. The Fisher control valve failures were essentially failures of the ASCO SOVs which are piece-parts of the control valves. Examination of plant equipment failure records noted that, between April 1987 and February 1989, there were approximately 50 Fisher control valve (ASCO SOV) failures. It appears that those failures resulted from poor quality air as a result of the April 24, 1987 water intrusion event and from poor maintenance of the instrument air system.

*Telephone discussions between J. Lewis and L. E. Wroniewiez, Vepco, and H. L. Ornstein, NRC, May 1989.

In addition to these failure records, NRC inspectors noted (Ref. 65) many ASCO SOV failures that had been observed during surveillance testing after April 24, 1987, were not reported and the SOVs were not repaired. The primary reason was that the SOVs that failed to operate during surveillance testing operated properly after being tapped ("mechanical agitation") by plant personnel. As a result of such practices, repetitive malfunctions were observed; the malfunctioning SOVs were not fixed or replaced expeditiously; and the root causes were not found or corrected on a timely basis. Characterization of the licensee's inservice testing practices regarding SOVs was cited in Reference 65 as follows:

> *The process of tapping on solenoid valves and repeated cycling of valves prior to running a satisfactory surveillance was considered an acceptable practice by the licensee.*

In a memorandum of February 10, 1988, the Chairman of the North Anna station Nuclear Safety and Operating Committee stated that successful stroking of the SOVs is an appropriate corrective action to remove contaminants because "cycling the affected valves blows the contamination from the lines and returns the SOVs to operable status" (Refs. 68, 69). The North Anna licensee's approach to maintenance of malfunctioning SOVs was not consistent with the valve manufacturer's recommendations. ASCO's installation and maintenance instructions and the licensee's telephone discussions with ASCO on February 4 and 5, 1988 advised the licensee that, after SOV contamination, the NP series SOVs should be inspected for corrosion, sediment or other contaminants, and cleaned accordingly.**

A meeting was held at NRC Region II offices on February 7, 1989, to discuss repetitive failures of the auxiliary feedwater system control valves (Ref. 70). The failures occurred in January 1989 as a result of moisture in the instrument air system. At the meeting, the licensee acknowledged that widespread failures of SOVs, control valves, and air-operated valves had occurred during the 21 months from the time of the service water intrusion into the instrument air system in April 1987. A large number of repetitive SOV and control valve failures were attributed to poor quality instrument air (oil and moisture contamination in addition to the April 1987 service water intrusion). The licensee noted that attention had been focused on the quantity of instrument air available without paying attention to its quality and indicated that subsequent to a review of their instrument air system, a program was initiated to clean or replace the affected equipment. The licensee also provided information on steps that were being taken to improve the instrument air

**Telephone discussions between F. Maiden and W. Murray, Vepco, and K. Thomas, ASCO, February 4 and 5, 1988.

system to ensure delivery of clean, dry, oil-free instrument air.

AEOD staff views the April 24, 1987, service water intrusion into the instrument air system as a significant precursor event. Although the air lines were blown down following the water intrusion, the event resulted in widespread degradation of SOVs, controllers, and air-operated valves that had the potential for disabling many systems needed to achieve safe shutdown. A large number of SOV and control valve failures occurred at both Units 1 and 2 between April 24, 1987, and January 1989 as a result of water, corrosion products, and residue from the service water intrusion and from impurities introduced by poor quality instrument air. Some of the systems that were affected by malfunctioning ASCO SOVs (freestanding or piece-parts of Fisher control valves) as a result of contamination of the instrument air system are listed below.

Unit 1 and 2:

- residual heat removal/low pressure safety injection
- main steam relief (PORVs)
- auxiliary feedwater
- component cooling water

Unit 2 only:

- containment isolation
- containment fan cooling
- main steam isolation

This event exemplifies the necessity for providing SOVs with clean, dry, oil-free air, and the need to thoroughly clean and inspect the equipment if water or other contaminant intrusions occur.

5.2.3.3 Susquehanna 1 and 2—Scram System, Oil and Water Contamination

The Susquehanna plants have experienced common-mode failures of SOVs that resulted in multiple failures of control rods to insert, slow insertion of multiple control rods, and repetitive failures of scram discharge volume vent and drain valves.* The SOV failures were linked to contaminants in the instrument air system (i.e., hydrocarbons, moisture, and particulates) and high temperatures. Because both Susquehanna units share a common instrument air supply, the common-mode failure potential that existed for both Unit 1 and Unit 2 scram pilot SOVs also existed for the SOVs that actuate backup scram valves for both units. The backup scram valves are intended to provide diverse scram capability to protect against common-mode failures. Although Unit 1 experienced the failures, the potential for such failures also existed at Unit 2; the scram and diverse scram systems of both units were vulnerable.

The Susquehanna SOV failures illustrate the potential for multi-plant common-mode failures leading to events that are beyond the plant safety analyses (i.e., failure of multiple control rods to insert and unisolated primary leak outside containment via the scram discharge volume). A summary of the Susquehanna SOV failures is given below.

On October 6, 1984, while Susquehanna 1 was operating at 60 percent power, two control rods failed to insert during individual rod scram testing. Further scram testing revealed that a total of four rods would not insert and nine additional rods hesitated before inserting. A similar event occurred previously at Susquehanna on June 13, 1984, when several control rods hesitated momentarily before inserting (Ref. 71). Two of the control rods that failed to insert on October 6 had not met the scram time requirements of the plant Technical Specifications on June 13. The licensee did not become aware of the June 13 malfunctions until the October 6 failures were investigated.

The October 6 failures were attributed to common-mode contamination of the instrument air system. The combination of contaminants (oil and/or moisture) and high temperatures (140 °F) caused the SOV internals to degrade and become stuck. The SOV polyurethane disc holder subassembly seats were found to be stuck to the SOV exhaust port orifice. This prevented air from the scram inlet and outlet valve operators from bleeding off through the SOV exhaust ports, which prevented the scram inlet and outlet valves from opening.

As reported in an NRC inspection report (Ref. 72), two independent laboratories examined the failed SOVs and concluded that the polyurethane parts degraded because of a combination of contamination in the instrument air and elevated temperature. The first laboratory (Franklin Institute) cited the failure mechanism as hydrolytic decomposition of the polyurethane seats as a result of a combination of moisture and elevated temperatures. The second laboratory (GE) indicated that polyurethane seat failure was caused by contamination of the instrument air with a synthetic diester oil (SDO, which is a plasticizer). Both Franklin Institute and GE recommended replacing the polyurethane seats with a seat material capable of operating at higher temperatures and having an improved resistance to contaminants. The recommended material was Viton. The licensee replaced all of the SOV polyurethane seats on control rods and all the backup scram valves for Units 1 and 2. About half of the SOV discs for the Unit 2 control rods had already been replaced in 1983 with Viton discs.

The licensee's investigation found that the SOVs for the scram discharge volume vent and drain valves on Unit 1

*At Susquehanna, each of the 185 control rods is piloted by one ASCO HV-176-816 SOV. Many other BWR control rods are piloted by other model ASCO SOVs, but two per control rod.

had polyurethane discs that also were susceptible to the same type of failure. Subsequently, the SOVs for the vent and drain valves also were replaced with different SOVs (made by a different manufacturer, having Viton discs).

The scram system degradation at Susquehanna on October 6, 1984, was reported to Congress as an abnormal occurrence (Ref. 73). The NRC staff concluded that the event involved a "major degradation of essential safety-related equipment," and demonstrated the plant's susceptibility to common-mode failure. The failure caused a reduction in the required 'extremely high probability' of shutting down the reactor in the event of an anticipated operational occurrence" (Ref. 73). Another scram discharge volume (SDV) system component failure attributed to contaminated air occurred at Susquehanna 1 on December 21, 1984 (Ref. 74). During surveillance testing, an SOV that controls the SDV vent and drain line isolation valves malfunctioned as a result of particulate matter that was lodged between the SOV's disc and seat. As a result, the SDV vent and drain valves were stuck open. Since the reactor was at power, if the SOV had failed to completely close after a scram, the potential for an unisolated primary leak outside containment would have significantly increased.

5.2.4 Lubrication

5.2.4.1 Multiple Plants—Manufacturing Error, Residue-Producing Lubricant

The Kewaunee nuclear power plant experienced three SOV failures on May 28, 1988 during surveillance testing (Ref. 75). Two of the SOVs were redundant containment isolation valves piloting the reactor coolant drain tank discharge header isolation valves. The third SOV that failed served as the pilot for the pressurizer relief tank makeup isolation valve. All three failed SOVs were nuclear qualified ASCO NP8314 DC valves that piloted air-operated valves. They were normally open, normally energized, and were designed to close (fail safe) on loss of instrument air or electrical power. The failures of the SOVs to shift position upon de- energization were attributed to an amber-colored residue inside the SOVs. The residue was found at the location where the SOV core assembly (plug) contacts the SOV body (solenoid base subassembly see Figure 6). The failed SOVs had been placed in service about 2 months before their failure. The local ambient temperature was about 110 °F. The licensee inspected two other ASCO NP8314 SOVs from the same manufacturing lot that were installed adjacent to the three SOVs that had failed. They had been installed at the same time as the ones that failed, but were operated in the de-energized mode. The de-energized SOVs had performed satisfactorily.

The licensee worked with ASCO and independently contracted two laboratories (Wyle Laboratories and Akron Rubber Development Laboratory) to determine the root cause of the failures. On the basis of these investigations, the licensee and ASCO concluded that the SOV failures were most likely caused by the degradation of a lubricant (International Products Corporation, "P-80" rubber lubricant) that had been introduced during the manufacturing process. P-80 is a water-based rubber lubricant used by ASCO personnel to facilitate SOV assembly. Although P-80 was an approved lubricant for use at ASCO's manufacturing facility, its use for the assembly of the NP8314 SOVs was not an explicitly approved procedure. P-80 product literature states that it provides "temporary slipperiness" for assembling rubber parts and that it is absorbed into the rubber "leaving no residue or harmful effect on the rubber." Subsequent to SOV assembly (using the P-80 lubricant), the SOVs were cleaned before leaving the manufacturer's facility; however, minute amounts of the P-80 lubricant remained trapped within the internal cavities of the SOV. From the laboratory results, it was concluded that the small amount of P-80 lubricant remaining in the SOVs migrated because of heatup from energization, and degraded into an amber-colored sticky residue that caused the SOV malfunctions. The investigation discounted Dow Corning 550 lubricant as the source of the residue that had been found inside the NP8314 SOVs. ASCO has discontinued using P-80 in the assembly of SOVs as a result of the investigation.

On October 18, 1988, based on the above determination, ASCO issued a 10 CFR Part 21 notification regarding the potential failures of NP8314 SOVs (Ref. 76). The notification accounted for 231 suspect SOVs that were sent to 17 U.S. LWRs, 76 suspect SOVs that were sent to suppliers who most likely shipped them to unspecified plants as piece-parts of other equipment between 1981 and 1988, and 9 suspect SOVs that were sent to Franklin Research Center (FRC) in 1986. The Fort Calhoun plant had received the largest number of suspect SOVs (79) in 1981. Several of those SOVs failed at Fort Calhoun in 1981 and 1982. Three of the SOVs that failed at Fort Calhoun were returned to ASCO for investigation. ASCO's investigation of those valves, incident report IR 3604, May 1982 (see NRC Vendor Inspection Report 99900369/88-01, Ref. 77), noted that the failures were due to sticking caused by a varnish-like residue. At that time, neither ASCO nor the Fort Calhoun licensee were able to identify the source of the "acrylate ester residue found on the plunger and sub-base assembly" of the energized NP8314 SOVs.

Fort Calhoun experienced a similar failure of another energized NP8314 SOV in March 1982. It was cleaned and returned to service (Ref. 78). The licensee stated that it would replace the internals of all the NP8314 SOVs using new spare-parts kits. Subsequently, the Fort Calhoun licensee provided 10 ASCO NP8314 SOVs that had been in continuously energized service for 18 months to FRC for use in an NRC-sponsored SOV aging research program (Ref. 79). FRC also purchased nine new NP8314 SOVs from ASCO, which were shipped in April 1986, to be used in NRC's SOV aging program (those SOVs were also listed in ASCO's 10 CFR Part 21 notification). Six of FRC's purchased SOVs, which were undergoing accelerated thermal aging, failed prematurely (failure to shift position) as a result of organic deposits (sticky substance). After the deposits were cleaned away with acetone and the SOVs were reassembled, they performed successfully for the duration of FRC's testing program. FRC's report (Ref. 79) also noted that organic deposits were found in the NP8314 SOVs received from Fort Calhoun. FRC believed that the sticky deposits that had prevented the SOVs from functioning were due to an organic compound that was introduced during the assembly of the valves; however, a detailed analysis and final determination of the source of the deposits were not pursued by FRC because of budgetary restraints. In the course of the NRC's SOV aging research program, ASCO had been apprised of the sticking problem, however ASCO did not find the source of the residue (P-80) until after the Kewaunee failures in 1988. The failures of the NP8314 SOVs indicate that P-80 was used to assemble the NP8314 SOVs as early as 1981 and as late as 1988.

A similar case, in which another SOV manufacturer used a lubricant to assist with SOV assembly, also resulted in subsequent SOV performance problems. As noted in Reference 80, Target Rock Corporation used castor oil as a lubricant to facilitate the assembly of its two-stage safety relief valves (SRVs). After investigating several SRV failures, it was found that castor oil, which was used to lubricate silicone rubber O-rings, caused swelling and accelerated degradation of the O-rings. Subsequently, Target Rock discontinued using castor oil as a lubricant. DAG-156 lubricant (carbon particles suspended in an alcohol base) was used to replace castor oil. We are not aware of any subsequent Target Rock SRV failures that have resulted from the use of DAG-156.

Target Rock informed the author of this case study during a visit to their facility (November 1988) that, paralleling the use of P-80 at ASCO, Target Rock had used "mineral oils" to facilitate SOV assembly. This practice was discontinued in the mid-1980s and DAG-156 was chosen as a replacement for mineral oils.

5.2.4.2 Catawba—Emergency Diesel Generators, Poor Quality Air and Lubrication With Vaseline

The Catawba nuclear power plant experienced common-mode failures of EDG starting air system inlet valves (Refs. 81, 82, 83). The EDGs were manufactured by Delaval. The air start system inlet valves, model T-3618, were made by California Controls Co. (Calcon). These two-stage air-operated valves each have a Circle Seal solenoid pilot valve that is normally closed and requires dc power to actuate the solenoid pilot to admit starting air into the EDG.

The licensee has reported five instances of common-mode failure of these valves. The valves stuck open when a sticky, slimy substance formed inside the poppet portion of the valve. The licensee determined that the substance was the silicone lubricant, Dow Corning 111, that was used on the valves. On five occasions, the licensee cleaned the valves and replaced the Dow Corning 111 with Vaseline petroleum jelly. Calcon's recommended lubricant is GE Silicone fluid G-322-L, which is significantly different from Dow Corning 111. The licensee did not check for the compatibility of Vaseline petroleum jelly with the Buna-N rubber used in the Calcon valve. Low nitrile Buna-N rubber degrades when in contact with petroleum-based products. After reviewing the EDG air start valve failures and other EDG pneumatic equipment failures (Calcon pressure sensors) the licensee concluded that the sticking was caused by moisture interacting with the Dow Corning 111 silicon lubricant. The source of the moisture was the starting air system, the root cause was inadequate dryer maintenance (the licensee's failure to changeout the spent desiccant).

Subsequently, the licensee upgraded its maintenance on the air dryers, thereby lowering the EDG starting air moisture content. In addition, the licensee cleaned the valves and replaced the Vaseline petroleum jelly with Dow Corning 111 lubricant. These actions in conjunction with more frequent changeout of the Calcon gas valve's elastomeric parts in accordance with the Delaval owners' group plant-specific recommendations appear to have eliminated the valve sticking problem. In addition, the licensee is preparing to change to the lubricant prescribed by the valve manufacturer (GE silicon fluid G-322-L).*

5.2.4.3 Common-Mode Failure of 16 MSIVs at Susquehanna 1 and 2—Incorrect Lubrication

In July 1986, the Susquehanna licensee reported excessive stroke time of the Unit 1 C outboard MSIV that resulted from a failure of an Automatic Valve Corporation (AVC) SOV (model C4988-8). The failure was attributed to "poor workmanship from the factory" and "improper lubrication, which would allow the valve piston to jam at a certain place in the valve." The failed AVC valve was replaced with a new one.

Five months later (December 1986), while performing monthly closing tests, the licensee found that the Unit 2 B inboard MSIV did not stroke properly as a result of a failure of another AVC SOV. The licensee shut down both units from 100 percent power and inspected the SOVs piloting all 16 MSIVs. The licensee found that the AVC SOVs on all 16 MSIVs were damaged. The

*Telephone discussion between R. M. McElwee (Duke Power Corporation) and H. L. Ornstein (NRC), June 25, 1990.

three-way and four-way valves and solenoid pilot valves on all 16 MSIVs had a hardened, sticky lubricant in their ports and on their O-rings. As a result, motion of all the SOVs was impaired, resulting in instrument air leakage and the inability to operate all of the MSIVs satisfactorily. The licensee also examined unused spares in the warehouse and found that the lubricant had dried out in those valves, leaving a residue. Several of the warehoused spares were bench tested. They were found to be degraded and they also leaked.

The original "approved" or "preferred" SOV lubricant (based upon equipment qualification testing) was Parker Super-O-Lube. However, later equipment qualification testing (1985) found that the Parker Super-O-Lube could cause SOVs in the MSIV air pack to malfunction. The Parker Super-O-Lube was found to break down to an adhesive, powdery substance when exposed to radiation fields greater than 1x10E6 rad. Because of the potential for breakdown of Parker Super-O-Lube and binding of the SOVs in the air packs, the licensee changed the SOV lubricant to E. F. Houghton SAFE 620.

In separate telephone conversations the SOV manufacturer (AVC) told the NRC staff that it had informed the utility that E. F. Houghton SAFE 620 lubricant attacks and degrades the aluminum in the AVC valves.* Nonetheless, in accordance with utility purchase orders, AVC shipped SOVs lubricated with E. F. Houghton SAFE 620 to two different utilities.

After the multiple failures occurred in December 1986, GE informed the licensee that the Parker Super-O-Lube is an acceptable lubricant if it is applied in a 'thin film.'" AVC and GE had concluded that the problem experienced with Parker Super-O-Lube in the 1985 qualification testing was due to excess lubricant."

On December 19, 1986, AVC sent NRC Region III a letter, which AVC believed served as a 10 CFR Part 21 notification (Ref. 84). However, the notification did not specifically state "Part 21 notification" and therefore was not disseminated accordingly to alert all other potentially affected utilities of the problem with E. F. Houghton SAFE 620 lubricant. The notification indicated that Commonwealth Edison also had purchased AVC valves lubricated with E. F. Houghton SAFE 620. Commonwealth Edison told NRC staff** that the AVC valves containing E. F. Houghton 620 lubricant were replacements for older model AVC SOVs that had been discontinued. Before being notified by AVC of the problem with E. F. Houghton SAFE 620 and before installing the valves, Commonwealth Edison replaced the SAFE 620 with Dow Corning Molykote 55M. The licensee had recognized that Parker Super-O-Lube was the lubricant that had been used in earlier equipment qualification testing and SAFE 620 was probably not an acceptable replacement.

Justification for the use of Molykote 55M instead of Super-O-Lube was based upon the licensee's engineering analysis that indicated the similarities between Molykote 55M and Super-O-Lube. In retrospect, a detailed examination of these two lubricants revealed they may have very different high-temperature behavior and, under similar operating conditions, the Molykote 55M would be more susceptible to dryout.*** Because of these differences, it is not clear that Molykote 55M is an acceptable "qualified" replacement for the Super-O-Lube.

With regard to problems of excessive lubricant and the application of a thin film of lubricant, it is interesting to note that a Commonwealth Edison plant had sticking problems with a similar AVC SOV several years earlier. In that case, the sticking was attributed to not having enough lubricant applied to the AVC valve.

5.2.4.4 Grand Gulf 1, LaSalle 1, and River Bend—MSIVs-Sticking SOVs, Foreign Unidentified Sticky Substance (FUSS), Lubricant Suspected

Between February 1985 and December 1989, the Grand Gulf 1, LaSalle 1, and River Bend nuclear power plants experienced sticking of ASCO dual-coil 8323 SOVs in the MSIV air packs (Refs. 9, 85-91). The SOV malfunctions were attributed to a sticky substance at the contact point of the plug nut and core assembly interface (see Figure 2). The SOV malfunctions impaired or prevented the MSIVs from closing within the times specified in the plant safety analyses.

Table 1 summarizes events where MSIV air pack SOVs have stuck at Grand Gulf, LaSalle, and River Bend.

In the case of LaSalle, it was demonstrated that the cohesive/adhesive force caused by the foreign sticky substance between the plug nut and the core assembly of an ASCO dual-coil NP8323 SOV was significant and could have been the cause of its failure. After the core assembly was held vertically, the plug nut was pressed against the core assembly, and then the plug nut let go, the adhesive forces from the foreign substance between the two surfaces

*Telephone discussions between T. Hutchins, AVC, and NRC (S. Israel, October 14, 1988, and H. L. Ornstein, April 12, 1989).

**Telephone discussion between M. Sievert, Commonwealth Edison Company, and H. L. Ornstein, NRC, April 12, 1989.

***Super-O-Lube consists of high molecular weight silicones whereas Molykote 55M is a lighter weight methyl silicone oil thickened with lithium soap having a lower dropping point than Super-O-Lube (where dropping point is an indication of the temperature limit at which the lubricant dries out).

Table 1 MSIV air pack SOV failures (sticking/FUSS/lubricant)

Plant/ event date	Description of SOV and corrective action	Number of stuck SOVs and location	Other SOVs having foreign unidentified sticky substance (FUSS)	Comments
Grand Gulf 1 2/10/85	ASCO HTX8323* (Viton). Replaced eight SOVs with ASCO NP8323 (having EPDM parts). See Section 5.1.2.1 for a discussion of the subsequent failures of the replacement valves caused by thermal aging from self-heating (August 1989).	Two outboard lines (A and C) one inboard line (D)	All others (five)	In subsequent testing at ASCO, only one of four additional valves malfunctioned (leakage). However, the failure of the outboard (C) line SOV was attributed to FUSS at the plug nut and core assembly interface.
LaSalle 1 12/16/87	ASCO NP8323 (Viton). Replaced eight SOVs with like.	One outboard line (C)	All others (seven)	Three of the valves that did not fail in the plant failed during subsequent testing at ASCO, attributed to FUSS at the plug nut and core assembly interface.
River Bend 9/30/88	ASCO NP8323 (EPDM). Replaced eight SOVs with like. Attempted to remove the factory coated lubricant (Dow Corning 550) from SOVs, but applied excessive amount of lubricant to O-rings while reassembling, causing two subsequent failures (December 1989).	Two inboard lines (B and C) (one inspected, FUSS found)	One unfailed inboard SOV inspected was found to have FUSS. Two outboard SOVs inspected found to have FUSS.**	Not all SOVs have been inspected. Some are being held for archival purposes. Two outboard SOVS were inspected at ASCO. The coil enclosures of both SOVs had evidence of moisture intrusion, indicative of localized steam heating.**
River Bend 12/1/89	ASCO NP8323 (EPDM). Replaced all NP8323's with new ones, but removed factory installed lubricant from all internal parts of the SOVs.	Two outboard lines (A and D), FUSS found on both.	One other SOV was inspected (inboard), it also had FUSS, but less than what was found on the failed outboards.	Licensee believes FUSS was from excessive application of Dow Corning 550, which was used by the licensee when lubricating the O-ring subsequent to removing the Dow Corning 550 from the SOVs' internal metallic parts subsequent to the 9/30/88 failures.***

*ASCO HTX8323 is not a nuclear-qualified SOV, it is a nonqualified commercial valve similar but not identical to the NP8323.
**Telephone discussion between J. Shank, ASCO, and H. L. Ornstein, NRC, May 8, 1989.
***Telephone discussion between V. Bacanskas, River Bend, and H. L. Ornstein, NRC, December 12, 1989.

were able to support the weight of the plug nut to prevent it from falling.*

Because the licensee suspected the Dow Corning 550 lubricant (applied to the SOVs internals at the factory) to be the cause of the sticking, the licensee considered removing the factory-installed lubricant from the eight new NP8323 SOVs that were installed after the failure of December 16, 1987. In consideration of ASCO's concern that, without the internal lubricant, ac powered SOVs could suffer fretting damage, the licensee installed the eight new NP8323-Viton SOVs as they were received from the manufacturer (without removing the lubricant). Those eight replacement SOVs have operated successfully through 1989.**

Subsequent to the failures of two ASCO dual-coil NP8323 SOVs at River Bend on September 30, 1988, the licensee replaced all eight dual-coil NP8323 SOVs with new ones. However, before installing the new SOVs, the licensee removed the factory-coated lubricant (Dow Corning 550) from their internal metallic parts. On December 1, 1989, two of those replacement SOVs failed as a result of sticking. The licensee attributed the sticking to FUSS which was believed (but not confirmed by laboratory analysis) to be Dow Corning 550 lubricant.

During followup of the failures of December 1, 1989, the licensee reviewed the procedures that were used in September 1988 to remove the factory applied lubricant. The licensee's review of those procedures indicated that although the Dow Corning 550 lubricant was removed from the internal metallic parts of the SOVs, the cleaning and reassembly procedures included a step in which the elastomeric parts of the SOVs were relubricated with the same Dow Corning 550 lubricant. Because there was more FUSS on the cleaned SOVs that failed in December 1989 than on the factory assembled SOVs that had failed September 1988, the licensee believed that the root cause of the December 1989 failures was the licensee's reapplication of excessive lubricant during the SOV cleaning and reassembly process.

Subsequent to the failures of December 1, 1989, the licensee's corrective action was to replace all eight NP8323 dual-coil SOVs with new ones, after removing all the factory applied lubricant from them, without relubricating the elastomeric parts.

*According to ASCO, the plug nut weighs about 1 ounce while the spring force is about 2 pounds. ASCO indicated that after a similar NP8323 SOV failure at WNP2, the licensee had performed a similar demonstration. The sticky substance at WNP2 was believed to be from excess lubricant (Dow Corning 550) that had been applied by the licensee when the SOVs were rebuilt.

**Telephone discussion between R. Lanksbury (NRC Sr. Resident Inspector at LaSalle Station) and H. L. Ornstein, NRC, December 22, 1989.

The inspection of the SOVs on the inboard and outboard MSIV air packs at all three plants indicated that in almost every case the SOVs, which had not failed, were degraded in a manner similar to the failed SOVs, but to a lesser degree. In each case, the licensee recognized the common-mode failure potential for compromising fast closure of inboard and outboard MSIVs on one or more steamlines and replaced all the 8323 SOVs on the inboard and outboard MSIV air packs.

The valve manufacturer and several laboratories conducted extensive inspections and tests on the 8323 SOVs that had been replaced. There are no simple explanations for these failures individually or as a group. The source(s) of the sticky substance(s) that resulted in multiple SOV failures is uncertain. There is major disagreement between the utilities, the SOV manufacturer, the reactor vendor and the laboratories regarding the root causes of the failures.

Internal SOV lubrication (by the manufacturer and in one case by the licensee) and poor air quality are primary suspects.

5.3 Surveillance Testing

On July 22, 1989, during scram time testing at the Perry nuclear power plant, plant personnel observed two control rods failed to meet their scram time testing requirements on initial attempts; however, when retested the rods operated satisfactorily. As a result, both control rods and their SOVs were declared to be operable. Subsequently, on November 25, 1989, one of those rods failed its timing test twice but was retested satisfactorily twice. As a result, it was declared operable. When the second control rod that also had failed twice on July 22, 1989, was retested on November 25, 1989, and failed, it was declared inoperable. At that time, the licensee conducted an investigation to determine the root cause of the test failures (Refs. 92, 93, 94).

The licensee's root cause analysis found that a manufacturing error had been made at ASCO (failure to upgrade polyurethane seats of the scram pilot SOVs with Viton), and that the Perry plant may not have responded adequately to a product recall notice that ASCO had sent them (Ref. 94).

It is significant that the licensee's surveillance testing program did not provide adequate guidance to the plant staff regarding actions to be taken when unsatisfactory surveillance test results are encountered.

5.4 Use of Non-Qualified SOVs

The H.B. Robinson plant which has Colt/Fairbanks-Morse EDGs experienced six EDG air start SOV failures during an 8-year period. There were five failures of one valve and one failure of an identical, redundant SOV. The SOVs were commercial grade valves, model X833-134, made by ASCO. The failures occurred from February 1, 1980, through March 28, 1988, and in each case the failures involved excessive air leakage. (One event is described in Appendix A, Docket No. 50-261 LER 87-028-01).

Four of the five failures of the same valve (DA-19B) were attributed to the SOV core and spring assembly. The first failure was attributed to wear of the core and spring assembly caused by excessive heat from the solenoid being constantly energized. The SOV was rebuilt (core and spring assembly were replaced). The SOV's second failure was again attributed to wear of the core and spring assembly. The SOV was rebuilt again (core and spring assembly replaced). The third malfunction of the same SOV occurred while attempting to start the diesel. The failure was attributed to misalignment of the solenoid header during previous repairs. The licensee's corrective action was to realign the solenoid header. Three months later the same SOV was again found to be leaking air. This fourth failure was attributed to wear of the core and spring assembly. The SOV was rebuilt again (core and spring assembly replaced). Five months later a redundant air start SOV (DA-23B) on the same diesel was found to be leaking air. It was rebuilt (spring and core assembly replaced). On March 28, 1988, the same SOV that had failed four times before (DA-19B) failed again. The fifth failure was attributed to a worn seat that resulted in air leakage. The valve was replaced rather that being rebuilt. AEOD staff is unaware of any subsequent failure of this replaced SOV.

Discussions with H.B. Robinson staff, and other licensees who's plants have Colt/Fairbanks-Morse EDGs, indicated that the licensees have received little, if any, guidance from the EDG supplier about preventive maintenance or replacement of the air start system SOVs. The SOVs that are used for the Colt/Fairbanks-Morse EDGs are commercial grade ASCOs that are supplied with limited maintenance or service life information; as such, these valves are not included in the manufacturer's defect and reporting program (10 CFR Part 21).

6 ANALYSIS AND EVALUATION OF OPERATIONAL EXPERIENCE

6.1 Common-Mode Failures

Examination of the events discussed in Section 5 and many of the SOV failures included in Appendix A of this report indicate that the potential exists for common-mode SOV failures that could compromise multiple trains of diverse safety systems. Such common-mode failures are not assumed in plant safety analyses.

While it is not practical or suggested to perform safety analyses for all combinations of common- mode SOV failures, it is feasible to take actions to reduce the likelihood for encountering common-mode SOV failures. Section 9 provides recommendations that address the systematic deficiencies in the design application operation and maintenance of SOVs noted in this report. Implementation of these recommendations will reduce the potential for common-mode SOV failures. The root causes of many common-mode SOV failures that have been observed thus far are given below.

(1) Design/Application Deficiencies

- incorrect specification of operating parameters such as MOPD (e.g., Section 5.1.3.) and valve orientation (e.g., Section 5.1.4)
- incorrect material selection such as incompatibility between SOV internal parts and fluids in contact with the SOV (e.g., Section 5.2.3.3)
- incorrect specification of ambient (non-accident) conditions (i.e., temperatures, radiation, and moisture) (e.g., Sections 5.1.1.2, 5.1.1.3)
- incorrect assessment of the life shortening effects of coil heating (e.g., Sections 5.1.2.1, 5.1.2.2)

(2) Inadequate Maintenance

- failure to replace or rebuild limited life pieceparts of the SOVs (e.g., gaskets, seals, diaphragms, springs, and coils) on a timely basis (e.g., Sections 5.2.1.1, 5.2.1.2)
- failure to rebuild SOVs correctly (e.g., Section 5.2.2.1)
- failure to maintain clean, dry instrument air, resulting in contaminants that cause long-term common-mode SOV degradation and failure (e.g., Sections 5.2.3.1, 5.2.3.2)
- excessive lubrication of SOV internals, contributing to SOV failures (e.g., Section 5.2.4.3)

(3) Installation Errors

- incorrect orientation (backwards, upside-down) installation at angles not in accordance with SOV qualification testing (e.g., Section 5.1.4., Appendix A)

- incorrect electric current (dc vs. ac) (e.g., Appendix A)

- inadequate terminal or junction box connections as a result of inadequate manufacturer's guidance or architect engineer's interpretation of manufacturer's guidance (e.g., Appendix A)

(4) **Manufacturing Defects**

- lubrication errors (e.g., Section 5.2.4.1)

- defective materials—body, plug, springs, elastomers (e.g., Ref. 77)

- tolerance/assembly errors such as incorrect spring size or stiffness (e.g., Ref. 77, Appendix A)

- faulty wiring/coil defects (e.g., Appendix A)

6.2 SOV Failure Rates

Utilization of existing SOV failure data can, at best, result in crude estimates of SOV failure rates for the following reasons:

(1) Not all SOV failures are documented. In many cases SOVs are viewed as expendable items, their failures are simply viewed as end of life, and replacements are installed without any failure reports.

(2) Unless SOV failures are associated with reactor trips or complete train failures of safety systems they are not required to be reported in the LER data base.

(3) SOVs that are subcomponents or piece-parts of other larger components or systems are not always reported as SOV failures in the nuclear plant reliability data system (NPRDS). For example, MSIVs, flow regulators, governors that fail to function properly because the related SOVs have failed have not been reported as SOV failures as such. We estimate that NPRDS contains explicit failure records for approximately 5 percent of the plants' safety-related SOVs.

Coupling the difficulties of obtaining some definable measure of SOV failure counts with the difficulty of assessing the number of successful SOV challenges or surveillance tests can, at best, lead to a crude estimate of SOV failure rates. Nonetheless, recognizing the shortcomings of estimating SOV failure rates, Table 2 lists SOV failure rates from several sources, including the results of this study's query of the NPRDS data for failures that occurred over a five year period (1985 through 1989).

The NPRDS data presented in Table 2 for the years 1985 through 1989 combined with demands based on quarterly testing indicate failure rates of about 7 to 9 times higher than earlier estimates which were used in WASH-1400 and in the NUREG-1150 methodology. The NPRDS failure records include only failures for the SOVs themselves, do not include the unrecognized SOVs used as piece-parts of NPRDS reportable components, and do not include any information on number of demands.

It should be noted that the SOV failure rate data listed in Table 2 does not distinguish between SOV size, energization mode, valve opening status, manufacturer, model, or type. In view of the wide range of SOV variations, the available failure data does not readily allow for the accurate prediction of individual SOV performance or failure rates.

In attempting to assess the trend in SOV failures, NPRDS SOV failure rates were evaluated for the years 1985 through 1989. The NPRDS data showed that the SOV individual failure rates have been increasing; that is the 1989 failure rates are 14-to-79-percent higher than those of 1985.

The estimation of common-mode or common-cause SOV failure rates are subject to greater uncertainties than the estimation of the random SOV failure rates. The SOV experience observed at U.S. LWRs in recent years indicates that in addition to an underlying randomness in SOV failure experience, there are additive biases which are introduced by the widespread systematic and programmatic deficiencies in the manufacture, selection, application, operation, maintenance, surveillance and testing of SOVs, which must be accounted for to accurately describe the actual industrywide experience. Failure to account for the biases introduced by the aforementioned widespread systematic and programmatic deficiencies results in underestimating the contribution of common-mode or common-cause failures. It is important to recognize that the SOV failures are mechanistic due to root causes described throughout this report. For example, when valves are misapplied, run at elevated temperatures, improperly maintained, etc., their early failure, degradation, and life shortening are assured. Under those conditions, the real SOV failure probabilities may approach 1.0 at plants with poor control of these devices.

Table 2 Estimates of SOV Failures to Operate

Source	Estimated failure rate
WASH-1400 (Tables III 2-1, 2-2)	$1x10^{-3}$/demand
This study (NPRDS data Jan 1985-December 1989) assuming quarterly testing	7.1 to $8.7x10^{-3}$/demand
NUREG-1150 methodology NUREG/CR-4550, Vol.1	$1.0x10^{-3}$/demand
Seabrook PRA	$2.4x10^{-3}$/demand
NUREG/CR-4550, Vol. 6 (Grand Gulf PRA)	$1.6x10^{-3}$/demand
NUREG/CR-4819, Vol. 1 (NPRDS data Sept 1978-July 1984)	$7x10^{-6}$/hr
This study (NPRDS data Jan 1985-Dec 1989)	6.5 to $7.9x10^{-6}$/hr*

*Hourly failure rates were calculated using an NPRDS report of 1074 failures among 5110 SOVs during 155.4 million cumulative hours (MCH) of SOV operation. The following is a breakdown of the SOV failure population and hours of operation used in the calculation:

	Valves	Failures	MCH of operation
Valves/solenoid operated	3536	753	115.
Valve operators/solenoid ac	723	140	19.7
Valve operators/solenoid dc	851	181	20.7

Common-cause, common-mode failures result. Under such conditions the average industry failure rates or typical treatment of common-cause/common-mode is not representative of such valves. This issue is further discussed in Section 8.

Any exercise aimed at obtaining, meaningful common-mode SOV failure rates based upon existing operating experience is a massive difficult one leading to interminable debate. Instead of continuing further on the highly debatable issue of quantifying such failure rates, we believe that the thrust of the nuclear community's efforts should concentrate on correcting the programmatic and systematic deficiencies associated with SOVs to reduce the likelihood for their common-cause and common-mode failures.

6.3 Maintenance Problems

6.3.1 Maintenance Problems—SOV Manufacturers' Contributions

Review of operating experience indicates that a substantive number of SOV failures are attributed to inadequate maintenance or refurbishment. As evidenced by several of the events discussed in Section 5, it is clear that utilities are not fully informed of SOV maintenance requirements. The neglect or oversight of SOV maintenance oftentimes comes from the SOV manufacturers' failure to provide SOV maintenance information to the SOV users or second-level manufacturers—such as EDG manufacturers (ALCO, Colt/Fairbanks-Morse, General Motors, Delaval, Cooper- Bessemer), valve manufacturers (Xomox), controller manufacturers (Fisher, Masoneilan), etc. Some SOV manufacturers are more prescriptive than others. Some manufacturers provide no guidance on preventive maintenance. One manufacturer (Valcor) varies its recommendations depending on whether the purchaser bought the "full documentation package."

Examples of the variation among SOV manufacturers' maintenance recommendations are discussed below.

ASCO—This manufacturer does not provide specific quantitative recommendations for SOV maintenance or refurbishment. This is even true for its nuclear qualified Class 1E valves. Quoting ASCO's installation and maintenance bulletin for NP8323 SOVs that were provided to purchasers between 1981 and 1989 (Ref. 95).

> *Preventive Maintenance*
>
> *1. Keep the medium flowing through the valve as free from dirt and foreign*

material as possible. Use instrument quality air, oil-free for Suffix "E".

2. *While in service, operate valve periodically to insure proper opening and closing.*

3. *Periodic inspection (depending upon medium and service conditions) of internal valve parts for damage or excessive wear is recommended. Thoroughly clean all parts. Replace any parts that are worn or damaged.*

4. *The valves may require periodic replacement of the coils and all resilient parts during their installed life to maintain qualification. The exact replacement period will depend on ambient and service conditions. Spare parts kits and coils are ordered separately (see Ordering Information). Consult ASCO for specific recommendations in connection with the replacement of parts.*

In 1989, ASCO upgraded the installation and maintenance instructions for their nuclear qualified Class 1E valves to reflect that the rebuilding kits for such SOVs were no longer available (Ref. 96). Those new instructions do cite use of the Instrument Society of America (ISA) air quality standard ISA S.7.3, but they are not specific with regard to preventive maintenance.

For example ASCO's upgraded 1989 instructions state that "while in service, the valve should be operated periodically to insure proper shifting." The word "periodically" is not defined in the new 1989 installation and maintenance instruction. In contrast, some earlier installation and maintenance instructions (1978 vintage) specified preventive maintenance to include monthly operation (Ref. 97). However, ASCO's qualification test report (Ref. 98) does note that the SOVs should be cycled periodically, at a minimum of once a year. The qualification test report notes that periodic cleaning and inspection should be done as outlined in the individual SOV installation and maintenance instruction sheet, but does not define periodic. ASCO's 1989 instructions further state, "do not exceed the qualified life of the valve...." However, determining the qualified life of the SOVs, especially normally energized ones, from the information provided can be a complex process that is not clearly outlined by the manufacturer.

Circle Seal and Ross—Circle Seal and Ross make SOVs that are used in several different EDG air start systems. Those valves are not supplied with any preventive maintenance or refurbishment recommendations. Lack of specific maintenance recommendations has contributed to multiple failures of the Circle Seal and Ross SOVs (see Section 6.3.2.1).

Humphrey—SOVs manufactured by this manufacturer that are used in EDG control panels are not supplied with any preventive maintenance or refurbishment instructions. (See Section 5.2.1.2 for a discussion of simultaneous common-mode failures that resulted in failure to start two EDGs).

Skinner Electric—This manufacturer's SOVs that are used in Woodward governors on BWR HPCI turbines are not provided with any preventive maintenance or refurbishment recommendations.

Sperry-Vickers—This manufacturer's SOVs that are used in the hydraulic controllers for BWR recirculation pumps and main turbine-trip systems are not provided with preventive maintenance or refurbishment recommendations.

Target Rock Corporation—This manufacturer's SOVs come with specific preventive maintenance and refurbishment recommendations.

Valcor—This manufacturer provides specific recommendations for maintenance or refurbishment of its N-stamped SOVs. However, it is possible to purchase the same valve without an N stamp.

6.3.2 Maintenance Problems—Contribution of the Unrecognized SOVs

In many cases plant maintenance and operations personnel are unaware of the presence of, or maintenance requirements of SOVs. This situation is common because there are many cases in which SOVs represent only a small portion of a larger system or component, and the information available to plant staff does not identify the care required for the SOV, which is "unrecognized" within the "overall system." Examples have been observed in

- emergency diesel generators: air start systems, governors, and cooling water control systems
- auxiliary feedwater and main feedwater systems: flow control regulators
- BWR high-pressure cooling injection (HPCI) systems: remote shutoff controls, governors
- instrument air dryers: desiccant column regeneration and cycling control systems

6.3.2.1 Unrecognized SOVs in Emergency Diesel Generators

The operation and maintenance manuals for the diesel engines and operator and maintenance personnel training are heavily weighted by the engine manufacturer's literature, which usually do not include information regarding the SOVs used in the EDG's auxiliary systems. Specific examples observed included those discussed below.

At a foreign reactor site, the EDG air start SOVs were not on any preventive maintenance program. Failure of one SOV due to aging of a Buna-N diaphragm was undetected until its redundant backup failed from the same cause. Failure of both SOVs resulted in failure of the EDG to start. As a result of this experience, the station added refurbishment or changeout of such resilient parts to all its EDG air start systems.* Similar failures have been observed at numerous U.S. plants, e.g., Three Mile Island 1** (Ref. 99), Ginna*** (Refs. 100, 101), Duane Arnold (Ref. 102).

During a trip to the Duane Arnold plant in reviewing SOV experience, the author learned that subsequent to the July 1982 diesel failure (Ref. 102), the Duane Arnold staff recognized the SOV's limited lifetime and the need for SOV refurbishment or replacement. As a result, the Duane Arnold personnel added SOV changeout to their preventive maintenance program. However, several years later, plant maintenance personnel made a decision to eliminate changeout of that SOV from their preventive maintenance program. The rationale for dropping such preventive maintenance was that the SOV was cycled only 7 seconds a month and such limited use did not seem to require maintenance. The basis for implementing the SOV's preventive maintenance and the previous failure, which resulted from age-related degradation, appeared to have been forgotten. Subsequently, we were informed that preventive maintenance on these SOVs would be reinstated.

While attending a TVA EDG training course applicable to seven plants (Browns Ferry 1, 2, and 3; Sequoyah 1 and 2; and Watts Bar 1 and 2), the author learned that maintenance literature for the General Motors Electro-Motive Division (GM-EMD) diesel engine supplied by Morris-Knudsen, does not include any instructions for refurbishment or changeout of the SOVs in the EDGs' air start and governor control systems.

*OECD NEA Incident Reporting System report number 0906.00, November 29, 1988, "Diesel Generator Failure to Start, Leibstadt Nuclear Power Plant, February 4, 1988."

**Facsimile Transmission, J. Shank, ASCO, to H. L. Ornstein, NRC, February 17, 1989.

***Rochester Gas & Electric Company, Ginna Station memorandum, "Failure of Solenoid Operated Valve 5933B 'A' Diesel Generator Air Start Valve ASV-1," from B. Popp, December 14, 1988.

6.3.2.2 Unrecognized SOVs in Auxiliary and Main Feedwater Systems

As noted in Section 5.2.3.2, a review of failure data at North Anna 1 and 2 showed that as a result of failure to recognize equipment needs, poor quality air was the root cause of the SOV/control valve failures. As a result, the licensee initiated a program for repairing and replacing the SOVs and control valves as well as upgrading the air system quality and enhancing plant personnel training and maintenance practices.

6.3.2.3 Unrecognized SOVs in BWR High-Pressure Coolant Injection Systems

The Duane Arnold licensee reported the failure of the remote shutoff control system, which is part of the turbine governor in the HPCI system (Ref. 103).

Discussion with plant personnel and the turbine manufacturer indicated a lack of communication between them regarding the potential for undetected failures of the SOVs. The licensee's report noted that the failure was caused by aging of the elastomeric parts of the SOV. Such an undetected failure could result in failure to start the HPCI system. Apparently, information provided by the turbine manufacturer (Dresser-Rand, formerly Terry Turbine) did not provide adequate maintenance information about the SOV supplied as an internal part to the Woodward governor (the SOV was manufactured by Skinner Electric Co.). The Skinner Electric maintenance instructions do not address preventive maintenance or service life requirements for the SOV. The Woodward governor service manual does not address SOV preventive maintenance or service life. Although the service information letters (SILs) provided by the nuclear steam supply system vendor (GE) address other aspects of HPCI turbine service, performance and maintenance, discussion with plant personnel and GE personnel indicated that maintenance, refurbishment or replacement of the SOVs are not addressed in any of GE's SILs.

6.3.2.4 Unrecognized SOVs in Instrument Air Dryers

Review of a leading instrument air dryer manufacturer's operation and maintenance manual (Pneumatic Products Corporation) indicated minimal guidance with regard to SOV maintenance. The SOVs are required to cycle every 5 minutes to ensure that the air flows through the correct desiccant stack to ensure proper air drying and acceptable outlet dew point values for the processed air. Failure of the SOVs could result in undetected high instrument air moisture content that could lead to degradation and malfunction of equipment utilizing instrument air, including hundreds of other SOVs that perform safety-related functions.

6.3.3 Maintenance Problems—Contributions of Utility Programs and Practices

Review of SOV failure reports and followup discussions with plant personnel, NRC inspectors, and SOV manufacturers showed that shortcomings in many utilities' SOV maintenance programs and practices were a major source of SOV failures. Some examples are discussed below.

During an NRC inspection, Brunswick plant staff stated that ASCO Class 1E SOVs with 30-year qualified lives did not require any preventive maintenance for 30 years (Ref. 104). The licensee did not recognize the fact that the resilient or elastomeric parts of the SOVs require more frequent replacement.

After finding that SOVs would not shift their position on demand during surveillance testing, it was common practice for plant personnel at the Brunswick and North Anna stations to tap the SOVs (mechanical agitation). If a SOV would change position when tested after the mechanical agitation, no further maintenance would be performed, and the SOV would be declared operable (Refs. 104, 105).

ASCO's valve engineering department product engineering manager visited the Susquehanna plant to assist the utility in finding the root cause of the failure of a rebuilt ASCO SOV that had failed after being returned to service. The ASCO manager's discussions with plant personnel revealed that subsequent to rebuilding the SOV, plant personnel bench tested the SOV with poor quality service air instead of clean, dry instrument air. Inspection of the SOV revealed that oil from the service air system had caused the SOV's second failure.*

Calvert Cliffs 1 and 2 plant instrument air SOV's maintenance is tracked by the station's reliability-centered maintenance (RCM) program. The RCM program has found that instrument air dryer SOVs have a mean time between failure of 10 months. However the plants' maintenance program calls for replacement of such SOVs on an annual basis.** The failure of the instrument air dryer SOVs can cause instrument air system degradation leading to common-mode failures of many other SOVs that perform safety-related functions.

6.3.4 Rebuilding Versus Replacement

Review of SOV failure data indicates that inadequate rebuilding of SOVs has been a significant cause of SOV failures. There is a broad range of complexity associated with rebuilding SOVs, depending on individual SOV manufacturer and model number. Additionally, there are variations among SOV manufacturers with regard to providing test apparatus to check the soundness of rebuilt SOVs; for example, Target Rock Corporation has marketed a test fixture for licensees to test their rebuilt SOVs.

Although some manufacturers provide values of acceptable coil voltages, leakage rates, etc., to enable users to check the conditions of their SOVs, some other manufacturers do not make such information available. Questions arise about the acceptability of new SOVs if acceptance criteria are not available.

Although ASCO notified licensees that it has discontinued selling rebuild kits for its nuclear power plant SOVs (NP series) (Ref. 106), it is continuing to sell rebuild kits for commercial SOVs and SOVs used in BWR scram systems (purchased through GE). Upon depletion of existing NP series SOV rebuilding kits, replacement will be the only option available for them.

In addition to focusing attention on the useful life of SOVs being governed by the elastomeric parts, special attention should be paid to the shelf life and on the actual manufacturing date of the elastomeric parts in the rebuild kits. For example, because of elastomeric (Buna-N) degradation observed in SOVs used in BWR scram systems, GE recommended (Ref. 59) that BWR scram system SOVs having Buna-N parts be rebuilt periodically. The frequency of rebuilding should be governed by the "useful life" of the elastomer ("useful life" being defined as the sum of shelf life and in-service life). Limited by the Buna-N parts, GE recommended a useful life of 7 years for scram system SOVs. The 7 years being from the time of kit manufacture, not from the time of rebuild.

As noted in Section 5, there have been several events in which common-mode failures resulted from incorrect rebuilding of SOVs. The potential for common-mode SOV failure resulting from rebuilding errors may be minimized by staggering the rebuilding (if possible) or by limiting the amount of SOV rebuilding done by any one individual (see Sections 5.2.2.2, 5.2.2.3).

7 FINDINGS

The root causes of most SOV problems are traceable to the lack of understanding of the capabilities and requirements of SOVs. Oftentimes plant operations and maintenance programs do not address the short lifetimes of the resilient elastomeric piece-parts of the SOVs (gaskets, seals, diaphragms, etc.). Maintenance programs also fail to address the low tolerance SOVs have for operating under adverse conditions that are significantly different than those of the controlled laboratory environment

*Telephone discussion, J. Shank, ASCO, and H. L. Ornstein, NRC, May 11, 1989.

**Telephone discussion, J. Osborne, Baltimore Gas and Electric Co., and H. L. Ornstein, NRC, April 21, 1989.

under which they were originally tested. In many cases, the manufacturers have not provided the end users with a full understanding of the sensitive nature of certain parts of the SOVs. Many users have learned, after using certain SOVs, that they are unforgiving with regard to contaminants and local environmental conditions.

Deficiencies in selection, operation, and maintenance of SOVs have resulted in hundreds of SOV failures, many of which were common-mode failures that cut across multiple trains of safety systems. The major findings in this case study regarding the root causes of common-mode SOV failures are described below.

7.1 Design Application Errors

7.1.1 Ambient Temperatures

Many common-mode SOV failures have resulted from subjecting SOVs to ambient temperatures in excess of their original design envelope. Such common-mode failures have resulted from localized steam leaks (see Section 5.1.1.1), incorrect estimates of ambient temperatures (see Sections 5.1.1.2, 5.1.1.3), and failure to account for ventilation system malfunctions (Ref. 107). Because the useful qualified lives of the short-lived parts of SOVs are halved by every temperature rise of 18 °F (Arrhenius theory-Refs. 108, 109), seemingly minor increases in ambient temperatures above those considered in the SOV design should not be allowed to prevail for extended time periods without running the risk of sustaining "seemingly" premature failures.

7.1.2 Heatup From Energization

Many common-mode SOV failures have occurred because the estimated service lives did not properly include the life-shortening effects of heatup resulting from continuous coil energization (see Sections 5.1.2.1, 5.1.2.2). Many licensees have been unaware of this situation. For example, by incorrectly using the certificates of compliance provided with ASCO's NP-1 nuclear qualified valves, licensees (Refs. 17, 21) have over-predicted the service life of continuously energized SOVs. Use of appropriate SOV heatup data in conjunction with Arrhenius theory (Refs. 108, 109) has been found to be acceptable.

7.1.3 Maximum Operating Pressure Differential

Many licensees have found misapplications in which SOVs could be or were subjected to operating pressure differentials that could or did prevent them from operating. Although NRC issued Information Notice 88-24 (Ref. 24) describing events, related to this issue, as noted in Section 5.1.3, there is no assurance that the issue of over-pressure that could result from pressure regulator failures has been appropriately addressed by all licensees for all safety-related applications.

7.1.4 Unrecognized SOVs Used as Piece-Parts

Many SOVs used in safety-related equipment are not given prominent attention because they are used as piece-parts of larger equipment. Specific preventive maintenance requirements are not readily available for them. Many SOV failures have occurred as a result of the lack of maintenance or replacement of such unrecognized SOVs (see Section 6.3.2).

7.1.5 Directional SOVs

Five licensees have reported experiencing undesirable spurious openings of safety-related SOVs at six plants as a result of high back-pressure. The licensees did not recognize or were not aware of the directional requirements of the valves (see Section 5.1.4). In addition to reports of SOV malfunctions that occurred because the valves were installed backwards, there are also reports of SOVs that were installed upside down or at improper angles (see Appendix A).

7.2 Maintenance

Operating experience has confirmed that SOV maintenance deficiencies can incapacitate multiple safety systems. The pervasiveness of maintenance deficiencies highlight the need for implementing aggressive SOV maintenance programs to prevent widespread common-mode failures. Specific maintenance problem areas are discussed below.

7.2.1 Maintenance Frequency

Lack of timely preventive maintenance (complete SOV replacement or rebuilding of short-lived piece-parts of SOVs) has resulted in many SOV failures (see Sections 5.1.2.1, 5.2.1.2, 6.3.2.1). Many SOV manufacturers have failed to provide the users with definitive information on the useful lifetime of the SOVs internal diaphragms, gaskets, O-rings, coils, etc. Some manufacturers indicate that periodically changing the elastomeric parts is necessary, without specifying the frequency of changes. Other manufacturers do not even mention that any changing is necessary. Similarly, there are wide variations among manufacturers with regard to specifying (or not specifying) the allowable shelf lives of their SOVs and SOV rebuild kits (see Sections 6.3.1 and 6.3.4).

7.2.2 Replacement Versus Rebuilding

Rebuilding or refurbishing certain models of several manufacturers' SOVs is a difficult task that can be made even more difficult if it is done in place, requiring the workers to wear decontamination or protective clothing. However, removal and reinstallation of N-stamped valves that are welded into the primary system are not simple, inexpensive tasks either.

Incorrect rebuilding or refurbishing of SOVs has caused many premature failures (see Sections 5.2.2.1, 5.2.2.2). Contributing to the difficulty of rebuilding or refurbishing SOVs correctly is the fact that many manufacturers do not provide adequate SOV documentation or testing apparatus to verify the effectiveness of the rebuilt or refurbished SOV. As a result, post-rebuild testing at many facilities merely involves cycling verification rather than performing appropriate tests normally performed by the manufacturer during initial SOV manufacture (see Section 6.3.4).

Discussions with plant personnel have revealed that many licensees, (e.g., Perry, River Bend, Salem, Grand Gulf, and Duane Arnold) have chosen to discontinue rebuilding certain SOVs because improper rebuilding can result in subsequent SOV failures and costly down-times. In general, licensees have reacted favorably to ASCO's recent decision to discontinue supplying rebuild kits for its NP-1 nuclear qualified SOVs (Ref. 109, 110). ASCO's decision to discontinue supplying SOV rebuild kits was based on field experience, which indicated that many ASCO SOV failures were caused by inadequate rebuilding techniques.

7.2.3 Contamination

Many common-mode SOV failures have been caused by contaminants in the fluids that flow through SOVs, instrument air in particular (see Sections 5.2.3.1, 5.2.3.2, 5.2.3.3).

SOV contamination resulting from particulates, moisture, and hydrocarbons in the instrument air system have been a major source of common-mode SOV failures. In many plants contaminants were introduced during original construction. Many contamination problems have resulted from poor design or maintenance of the instrument air systems. Some SOVs are more tolerant of contamination than others. For example, some SOVs can operate with contaminated air if the degree of contamination is within the tolerance level of the SOVs. However, satisfactory performance of most small SOVs for air-pilot service require virtually contaminant-free air.

Many SOV failures are clearly attributed to subjecting the SOVs to conditions beyond which they are designed, such as particulates, moisture, hydrocarbons, etc. Contributing to the problem is the fact that some manufacturers have specified the need for clean air or instrument quality air without quantification (e.g., maximum allowable particle sizes and dew points).

Although licensees are taking actions to improve the quality of their plants' air systems, there is concern for the residual effects of previous air system contamination (Section 5.2.3.2). Long-term SOV degradation such as deterioration of EPDM parts as a result of hydrocarbon intrusion, formation of varnish-like deposits from heatup of hydrocarbons, and residue formation from the interaction of moisture, silicone lubricant, and heat, are areas of concern.

7.2.4 Lubrication

Improper lubrication has resulted in many common-mode SOV failures. The improper lubrication has been attributed to manufacturing errors (see Section 5.2.4.1) as well as licensee errors. Errors include the wrong choice of lubricant (see Sections 5.2.4.2, 5.2.4.3), unauthorized use of incorrect lubricant (see Section 5.2.4.1), and use of excessive amounts of lubricant (see Section 5.2.4.4).

7.3 Surveillance Testing

Several cases (see Section 6.3.3) have been reported in which SOVs failed to actuate on demand during surveillance testing, however, subsequent tapping (mechanically agitating) the SOVs would enable them to actuate. As a result, the SOVs were declared operable without addressing the cause of the original failures, thus leaving the SOVs in degraded states vulnerable to future failures upon demand.

Similarly, as noted in Section 5.3, incorrect surveillance testing led operators to operate a BWR with multiple failed scram pilot SOVs.

7.4 Verification of the Use of Qualified SOVs

The issue of environmental qualification of Class 1E electrical equipment and SOVs has been addressed by utilities in response to Bulletins 79–01, 79–01A, and 79–01B (Refs. 112–114). Nonetheless, there are many instances in which SOVs that were assumed in safety analyses to operate to mitigate design-basis events, have been procured as commercial grade SOVs of questionable quality and are not being maintained in a manner commensurate with their intended safety function.

Examples have been found where commercial grade, nonqualified SOVs are being used in safety-related applications without appropriate verification of product quality and design control. In many instances the SOVs lack verification that they can withstand the accident conditions postulated in plant safety analyses (See Ref. 115). A common problem appears to be categorization of the SOVs for use in EDG air systems. In many cases the original equipment that contained SOVs as piece-parts was certified or qualified to meet Class 1E requirements, whereas the individual replacement SOVs were not (see Section 5.4).

7.5 Redundancy and Diversity

The root causes of many common-mode failures of safety-related SOVs have eluded many licensees' detailed failure analyses (see Section 5.2.4.4). In many such instances the search for the origins of foreign unidentified sticky substances (FUSS) have been inconclusive and corrective actions were limited to cleaning or replacing the failed SOVs (e.g., Brunswick [Ref. 2] and Franklin Institute [Ref. 79]). In some cases, the licensees discounted instrument air system contamination (oil, water, dirt) as the cause of the FUSS, but plant operating history indicated a prior history of air system contamination that could have been a contributor to the problem. Similarly, the SOV manufacturing process (see Section 5.2.4.1) and the licensee's rebuilding process (see Sections 5.2.2.1, 5.2.2.2, 5.2.2.3, Section 6.3.3) have been found to be the sources of contaminants that caused common-mode SOV malfunctions.

Staggering the maintenance, testing, and replacement of redundant SOVs may represent a simple way of preventing common-mode failures of redundant SOVs. In addition, if the root causes of persistent common-mode SOV failures cannot be found, or cannot be eliminated, the need for SOV diversity (with regard to model, energization mode, failure mode, or manufacturer) becomes apparent. (See Appendix C for a discussion of an example of such a problem with the ASCO NP8323 SOVs used for MSIV control at many BWRs.)

7.6 Feedback of Operating Experience

On the basis of visits to several of the major SOV manufacturers' facilities (e.g., ASCO, June 1988; Target Rock, November 1988; Valcor, December 1988; and AVC, February 1990), discussions with other SOV manufacturers (e.g., Circle Seal and Skinner Electric), and extensive discussions with manufacturers whose equipment utilize SOVs as piece-parts (e.g., Fisher Controls, Dresser-Rand/Terry Turbine, Xomox Valves, California Controls, and Colt/Fairbanks-Morse), it was found that there is no structured operational data feedback mechanism from the licensees to the SOV manufacturers regarding SOV failures that have occurred at nuclear power plants. SOV manufacturers are not aware of many failures of safety-related equipment that may have been caused by generic manufacturing or design deficiencies of the SOVs. Conversely, when licensees purchase SOVs commercially, without 10 CFR 50, Appendix B, and 10 CFR Part 21 requirements, they are not fully apprised by the manufacturers of generic defects that are discovered subsequent to delivery. In one case, a major SOV manufacturer did not provide generic SOV defect information to the end user because the manufacturer failed to understand or properly implement the 10 CFR Part 21 requirements that were applicable to its SOVs (Ref. 77) (also see Sections 5.1.2.2, 5.2.4.3).

8 CONCLUSIONS

Operating experience has demonstrated that common-mode failures and degradations of SOVs can compromise multiple trains of multiple safety systems. The fact that hundreds, and in many cases thousands, of SOVs permeate all important systems at all U.S. LWRs, highlights the necessity for reducing common-mode SOV problems that could significantly reduce plant safety.

8.1 Safety Significance/Risk Assessments

Operating experience has shown that common-mode SOV failures have the propensity to cut across multiple trains of safety systems, as well as across multiple safety systems. Cross-train and cross-system SOV failures are a safety concern because while credible, they are not addressed in plant safety analyses.

Operating experience shows that SOVs are vulnerable to numerous common-mode failure mechanisms and their failures can adversely affect numerous safety systems. Examples given in Section 5 are illustrative of such common-mode SOV events that resulted in reduced safety margins. For example,

- simultaneous common-mode SOV failures that resulted in the failure of both EDGs to start at the Perry plant (Section 5.2.1.2)
- simultaneous common-mode failures within the scram system at Susquehanna (Section 5.2.3.3)
- common-mode scram pilot solenoid valve failures that resulted in primary system leakage outside primary containment at Dresden (Section 5.2.1.1)
- common-mode failures of two SOVs and the potential failures of 58 additional SOVs in multiple systems at Kewaunee (Section 5.1.3)

- common-mode degradation of SOVs affecting safety injection, reactor coolant, main steam, component cooling, and other systems at North Anna and Surry (Section 5.1.2.2)
- simultaneous common-mode failures of MSIVs to close on demand at Perry (Section 5.1.1.1) and Brunswick (Section 5.2.3.1)
- common-mode failures of 16 MSIVs at Susquehanna (Section 5.2.4.3)
- simultaneous common-mode failures of SRV/ADS valves at Brunswick (Section 5.2.2.2)
- common-mode orientation errors affecting ultimate heat sink, ADS SRVs, equipment cooling, control room cooling, and other systems at River Bend (Section 5.1.4)
- More than 30 inadvertent common-mode openings of incorrectly oriented SOVs at six plants (Section 5.1.4)
- repetitive common-mode EDG failures at Catawba (Section 5.2.4.2)
- common-mode potential for failures of SOVs in auxiliary feedwater, reactor coolant, and safety injection systems at Calvert Cliffs (Section 5.1.3)

These common-mode SOV failures and degradations represent conditions that reduced the plants' margins of safety. The occurrence of a design basis event during such times of vulnerability could lead to core damage or to serious offsite effects. Since SOVs are key components in many plant safety systems, their ability to function is required to mitigate accidents. Therefore, it is concluded that SOV problems represent a significant safety concern.

Section 5 provides representative examples of over 20 recent events involving common-mode failures or degradations of over 600 SOVs in important plant systems.* Additional data is presented in Appendix A. The common-mode failures and degradations cut across multiple trains of safety systems as well as multiple safety systems. The recurrence of common-mode failures or degradations emphasize the need for timely resolution. Although plant safety analyses do not address common-mode, multiple train/multiple safety system failures, operating experience indicates that they continue to occur. The common-mode SOV failures and degradations that have occurred, which compromised safety systems such as emergency ac power, auxiliary feedwater, high pressure coolant injection, and scram systems, are illustrative of the safety significance of SOV problems.

*There have been many other similar events. The events chosen here are intended to be illustrative. They are not a complete set of all such events.

The high expectation that SOVs will meet their functional goals in reactor applications implies a tightly controlled process that eliminates programmatic and systematic deficiencies and results in only random failures. These expectations discount the possibility of interdependent failures between similar devices.

These basic concepts also apply to quantifying hardware failures in probabilistic risk assessments. NUREG-1150 provides estimates of the risks of the five studied plants. It is a set of modern PRAs, having the limitations of all such studies. These limitations relate to the quantitative measurements of certain types of human actions, variations in the management and organization, failure rates of equipment, especially to common-cause effects such as maintenance, environment, design and construction errors, and aging. In the context of SOVs in NUREG-1150, random failure rates were assumed for valves as a whole. In some cases, the valves were operated or triggered by action from a solenoid operator. The modeling detail in NUREG-1150 did not extend down to the SOV itself. Also, and consistent with the level of detail usually done in risk studies, cross-system common-mode failures were not modeled.

It is beyond the scope of this SOV case study to calculate the change in risk that might attend cross-system common-mode failures and systematic component deficiencies. Indeed, the author is not aware of any risk study where this has been done. For this reason, we cannot at present meaningfully calculate the increase in risk that one could expect from the observed higher failure rates from the NPRDS study. On the other hand, it is reasonable to suppose that if the SOVs were designed, installed, and maintained in the environment for which they were intended, that the failure rates would be diminished.

8.2 Need for Action

The root causes of common-mode SOV failures are not self-correcting, they will not be fixed unless corrective actions are taken. Responding in a meaningful way to the SOV problems presented in this report will require considerable nuclear industry resources.

On the basis of the analysis of operating data, it is concluded that the SOV problems outlined in this report need to be addressed to ensure that the margins of safety for U.S. LWRs remain at the levels perceived during original plant licensing. Generic and plant-specific actions are needed to correct the SOV problems in order to restore the plants' safety margins to their original perceived values.

The NRC, to date, has issued 37 generic communications pertaining to SOV problems (see Appendix D). Those generic communications alerted licensees to specific SOV problems. On the basis of this study, AEOD believes that an integrated comprehensive program is needed. Only in this manner will the root causes of SOV problems described in this report be fixed. It is concluded that integrated implementation of the recommendations provided in Section 9 would reduce the likelihood of common-mode SOV failures eroding the margins of safety at LWRs.

9 RECOMMENDATIONS

Using a plant specific prioritization scheme based on the risk significance of the safety systems, corrective actions need to be taken to address the root causes of SOV failures. Such efforts will result in improved SOV performance, increased SOV reliability, thus reducing the potential for common-mode failures. To reduce the potential for common-mode failures, attention should be focused on certain aspects of SOVs. The actions discussed below need to be initiated to ensure that the plants retain their margins of safety. Using a plant specific risk based priority methodology, the primary focus of these efforts should be on safety-related systems and their support systems that are required for safe operation and shutdown. Such a program would provide the greatest return in improving safety margins.

The recommendations should be implemented because the controls on the design, fabrication, installation, and maintenance practices associated with SOVs are not commensurate with the importance of the safety functions to be performed. The controlling parameters that serve as reference bounds for design and utilization of these components have not provided assurance that these devices meet their functional goals. This study catalogs programmatic and systematic deficiencies such as incorrect designs, actual ambient temperatures outside of the design bases, unaccounted for self-heating of the solenoids, use of the wrong lubricants, and inadequate surveillance practices. Taken in total, this experience does not provide assurance that the SOVs will satisfactorily perform their safety functions. In addition, the biased, nonrandom, concurrent failures of redundant SOVs depicted by this experience are inconsistent with the single failure criterion which is a bulwark in reactor safety.

9.1 Design Verification

Licensees should review SOV design specifications and actual operating conditions to verify that all SOVs assumed to operate in plant safety analyses are operated within their design service life. The reviews should ensure that

- life-shortening effects of elevated ambient temperatures are considered in the determination of SOV service life (Section 7.1.1)
- life-shortening effects of heatup resulting from *coil energization* are appropriately accounted for in the determinations of SOV service life (Section 7.1.2)
- the potential for overpressure resulting from pressure regulator failure or for hydraulic fluid heatup has been considered in the selection of the SOVs (Section 7.1.3)

In addition to verifying the adequacy of the high visibility SOVs that perform direct safety-related functions, similar verification should be made for unrecognized SOVs that are used as piece-parts of flow regulators, governors, emergency diesel generator support systems, et cetera (Section 7.1.4).

Licensees also should verify that directional SOVs are installed in orientations that will ensure satisfactory operation of the safety-related equipment that is dependent upon them (Section 7.1.5).

9.2 Maintenance

Licensees should implement SOV maintenance programs to replace or refurbish SOVs* on a timely basis. Thermal aging that results from elevated ambient conditions and heatup from continuous coil energization should be considered when establishing the frequency of replacement or refurbishment. (Section 7.2.1.)

Because of the limited lives of their elastomeric or resilient parts, SOVs should be replaced or refurbished prior to the end of plant life in accordance with the manufacturers' recommendations. In the absence of specific manufacturers' recommendations for replacement or refurbishment intervals and in absence of applicable failure data, changeout of short-lived elastomeric and resilient materials (or complete valve replacement) should be done on the basis of material shelf life, and manufacture date. However, changeout of elastomeric parts or complete SOV replacement should be done more frequently if operating conditions exceed the originally envisioned design conditions or if field failure experience so dictates.

To reduce the potential for common-mode failures, consideration should be given to staggering the maintenance of redundant SOVs.

Licensees should review their programs for rebuilding SOVs (with the exception of coils, which are generally replaced) because certain SOVs are difficult to rebuild

*SOVs in safety-related systems and systems that support safety-related systems.

and test properly, and improperly rebuilt SOVs can degrade plant safety.

Numerous utilities have found that in many instances it is cost beneficial to replace SOVs rather than to rebuild them. However, if licensees choose to continue to rebuild their SOVs, they should obtain or develop test equipment to enable verification that the rebuilt SOVs meet all the performance specifications of the original SOVs. (Section 7.2.2.)

Aggressive actions should be included in the SOV maintenance program to ensure that fluids flowing through SOVs, instrument air in particular, are maintained free of contaminants. If operational experience indicates a pattern of SOV malfunctions resulting from contamination (such as moisture or hydrocarbon intrusion), the affected licensees should consider replacing SOVs that have been affected by previous air system degradation or fluid contamination assuming that the root causes of the contamination problems have been corrected (for example, instrument air contamination problems were to be addressed by licensees' actions in response to Generic Letter 88-14 [Ref. 44]). (Section 7.2.3.)

SOV manufacturers' lubrication instructions should be adhered to. Licensees should avoid substitution of similar but not identical lubricants. However, if substitutions are made, their compatibility with all associated hardware should be verified. (Section 7.2.4.)

9.3 Surveillance Testing

Licensees should emphasize the importance of surveillance testing, root-cause failure analysis, and timely repair or replacement of malfunctioning SOVs in their operation and maintenance personnel training (Section 7.3).

Licensees should review, and if appropriate, modify their surveillance testing procedures. Procedures should expressly prohibit mechanical agitation (tapping) of SOVs as a technique to assist successful operation during surveillance testing. Procedures should include actions to be taken when unsatisfactory test results are encountered, as well as a requirement to analyze and evaluate the causes of the unsatisfactory results before declaring the component back in service, even though subsequent retest results may be satisfactory.

To minimize the potential for common-mode failures affecting multiple SOVs, consideration should be given to staggering surveillance testing of redundant SOVs.

9.4 Verification of the Use of Qualified SOVs

Licensees should review all SOVs in safety-related applications (as well as applications that support safety-related systems), particularly EDGs, to ensure (1) that they meet 10 CFR Part 50, Appendix B, and appropriate Class 1E requirements and (2) that they have been installed and maintained appropriately to operate in a manner consistent with the assumptions of the plants' safety analyses (Section 7.4). If there is doubt regarding the acceptability of safety-related SOVs, they should be replaced with appropriately qualified ones.

9.5 Redundancy and Diversity

Licensees should consider performing maintenance, testing, and replacement of redundant SOVs (such as MSIVs for BWRs and containment isolation valves for all types of LWRs) on a staggered basis so that system failures are minimized (Section 7.5). Additional consideration should be given to using diverse SOVs (different design or manufacturer).

9.6 Feedback of Operating Experience

To improve SOV reliability, an industry group such as the Institute of Nuclear Power Operations should initiate an SOV failure feedback program. The program should alert SOV manufacturers to failures of their equipment by making failure records of their specific SOVs available to them. The NPRDS data base would be a logical source from which to provide this information. (Section 7.6.)

10 REFERENCES

1. V. P. Bacanskas, G. C. Roberts, G. J. Toman, "Aging and Service Wear of Solenoid-Operated Valves Used in Safety Systems of Nuclear Power Plants, Volume 1. Operating Experience and Failure Identification," Oak Ridge National Laboratory, NUREG/CR-4819, ORNL/Sub 83-28915/4/V1, March 1987.

2. Carolina Power & Light Company, Licensee Event Report 50-324/88-001, Revision 5, Brunswick Steam Electric Plant Unit 2, February 19, 1990.

3. Burns and Roe, "Investigation of Valve Failure Problems in LWR Power Plants," ALO-73, April 1980.

4. W. H. Hubble, C. F. Miller, "Data Summaries of Licensing Event Reports of Valves at U.S. Commercial Nuclear Power Plants, January 1, 1976 to

December 31, 1978," EG&G Idaho, Inc., NUREG/CR-1363, EGG-EA-5125, June 1980.

5. Institute of Electrical and Electronics Engineers, "IEEE Maintenance Good Practices for Nuclear Power Plant Electrical Equipment; Work-in-Progress Report, Evaluation of Maintenance and Related Practices for Solenoid-Operated Valves in Nuclear Power Generating Stations," IEEE Power Engineering Society, Nuclear Power Engineering Committee, Subcommittee 3, Working Group 3.3, 1988.

6. U.S. Nuclear Regulatory Commission, Information Notice 88-86, Supplement 1, "Operating With Multiple Grounds in Direct Current Distribution Systems," March 31, 1989.

7. U.S. Nuclear Regulatory Commission, Inspection Report 50-440/87-024, Perry Nuclear Power Plant Unit 1, January 22, 1988.

8. Cleveland Electric Illuminating Company, Licensee Event Report 50-440/87-073, Revision 1, Perry Nuclear Power Plant Unit 1, June 3, 1988.

9. U.S. Nuclear Regulatory Commission, Information Notice 88-43, "Solenoid Valve Problems," June 23, 1988.

10. U.S. Nuclear Regulatory Commission, Inspection Report 50-440/87-027, Perry Nuclear Power Plant Unit 1, February 10, 1988.

11. U.S. Nuclear Regulatory Commission, Inspection Report 50-302/89-09, Crystal River Unit 3, June 7, 1989.

12. U.S. Nuclear Regulatory Commission, Inspection Report 50-336/88-22, Millstone Nuclear Station, Unit 2, November 8, 1988.

13. U.S. Nuclear Regulatory Commission, memorandum from J. W. Craig to A. C. Thadani, Subject: Status of TI 2515/98 'High Temperature Inside Containment/Drywell in BWR and PWR Plants,'" March 13, 1989.

14. U.S. Nuclear Regulatory Commission, Information Notice 89-30, "High Temperature Environments at Nuclear Power Plants," March 15, 1989.

15. U.S. Nuclear Regulatory Commission, 10 CFR 50.72 Report 16313, Grand Gulf Unit 1, August 14, 1989.

16. U.S. Nuclear Regulatory Commission, Region II Daily Report, August 15, 1989.

17. System Energy Resources, Inc., Licensee Event Report 50-416/89-013, Grand Gulf Unit 1, September 13, 1989.

18. General Electric Company, Service Information Letter 481, Category 2, "Malfunction of ASCO Solenoid Valves for MSIVs," February 14, 1989.

19. U.S. Nuclear Regulatory Commission, Information Notice 89-66, "Qualification Life of Solenoid Valves," September 11, 1989.

20. Automatic Switch Company (ASCO), "Field Notification Concerning the Qualified Life of ASCO Catalog NP-1 Valves," October 27, 1989.

21. Virginia Electric and Power Company, memorandum from P. T. Knutsen, "Self Heating Effects in ASCO Solenoid Valves," February 3, 1987.

22. Virginia Electric and Power Company, North Anna Power Station, Deviation Report 87-105, February 4, 1987.

23. Virginia Electric and Power Company, memorandum from P. T. Knutsen, "ASCO SOVs To Be Replaced at North Anna Power Station Units 1 and 2," March 16, 1987.

24. U.S. Nuclear Regulatory Commission, Information Notice 88-24, "Failures of Air-Operated Valves Affecting Safety-Related Systems," May 13, 1988.

25. Wisconsin Public Service Corporation, Licensee Event Report 50-305/87-012, Revision 1, Kewaunee Nuclear Power Plant, March 4, 1988.

26. U.S. Nuclear Regulatory Commission, 10 CFR 50.72 Report 12013, Calvert Cliffs Units 1 and 2, April 14, 1988.

27. U.S. Nuclear Regulatory Commission, 10 CFR 50.72 Report 12015, Calvert Cliffs Units 1 and 2, April 14, 1988.

28. U.S. Nuclear Regulatory Commission, Inspection Report 50-317/88-07 and 50-318/88-08, Calvert Cliffs Nuclear Power Plant Units 1 and 2, June 3, 1988.

29. Northeast Utilities, memorandum from S. E. Scace to E. Abolafia, "Failure of Air Operated Valves Affecting Safety Related Systems, NRC IN 88-24, NOA 9673, CR 0488-24, Revision 0," November 8, 1988.

30. Florida Power Corporation, Licensee Event Report 50-302/89-01, Revision 2, Crystal River Unit 3, June 7, 1989.

31. U.S. Nuclear Regulatory Commission, Information Notice 80–40, "Excessive Nitrogen Supply Actuates Safety-Relief Valve Operation To Cause Reactor Depressurization," November 7, 1980.

32. U.S. Nuclear Regulatory Commission, Office of Inspection and Enforcement, Bulletin 80–25, "Operating Problems With Target Rock Safety Relief Valves at BWRs," December 19, 1980.

33. Georgia Power Company, Licensee Event Report 50–424/87–002, Vogtle Electric Generating Plant Unit 1, February 23, 1987.

34. Metropolitan Edison Co., Licensee Event Report 50–289/80–018, Three Mile Island Unit 1, November 4, 1980.

35. U.S. Nuclear Regulatory Commission, 10 CFR 50.72 Report 12890, Pilgrim Nuclear Power Station Unit 1, July 19, 1988.

36. U.S. Nuclear Regulatory Commission Region I Daily Report, July 20, 1988.

37. Boston Edison Company, Licensee Event Report 50–293/88–021, Pilgrim Nuclear Power Station, August 18, 1988.

38. U.S. Nuclear Regulatory Commission, Inspection Report 50–336/88–22, Millstone Nuclear Power Station Unit 2, November 8, 1988.

39. U.S. Nuclear Regulatory Commission, Inspection Report 50–302/89–01, Crystal River Unit 3, April 13, 1989.

40. U.S. Nuclear Regulatory Commission, 10 CFR 50.72 Report 14442, Crystal River Unit 3, January 7, 1989.

41. U.S. Nuclear Regulatory Commission, 10 CFR 50.72 Report 14467, Crystal River Unit 3, January 11, 1989.

42. Target Rock Corporation, Operation Manual, TRP 1571J, May 23, 1978.

43. Gulf States Utilities Company, Licensee Event Report 50–458/89–022, River Bend Unit 1, June 1, 1989.

44. U.S. Nuclear Regulatory Commission, Generic Letter 88–14, "Instrument Air Supply System Problems Affecting Safety-Related Equipment," August 8, 1988.

45. Gulf States Utilities Company, Licensee Event Report 50–458/89–024, River Bend Unit 1, June 19, 1989.

46. U.S. Nuclear Regulatory Commission, Preliminary Notification, PNO–III–85–84, September 20, 1985.

47. U.S. Nuclear Regulatory Commission, Region III Daily Report, September 24, 1985.

48. Commonwealth Edison Company, Licensee Event Report 50–249/85–018, Dresden Nuclear Power Station Unit 3, October 1, 1985.

49. U.S. Nuclear Regulatory Commission, Office of Inspection and Enforcement, Information Notice 85–95, "Leak of Reactor Water to Reactor Building Caused by Scram Solenoid Valve Problem," December 23, 1985.

50. U.S. Nuclear Regulatory Commission, Office for Analysis and Evaluation of Operational Data, Case Study AEOD/C403, "Edwin I. Hatch Unit No. 2 Plant Systems Interaction Event on August 25, 1982," May 1984.

51. Carolina Power & Light Company, Licensee Event Report 50–325/79–074, Brunswick Steam Electric Plant, Unit 1, November 16, 1979.

52. U.S. Nuclear Regulatory Commission, Office of Inspection and Enforcement, Bulletin 80–14, "Degradation of BWR Scram Discharge Volume Capability," June 12, 1980.

53. Cleveland Illuminating Company, Licensee Event Report 50–440/87–009, Perry Nuclear Power Plant, March 27, 1987.

54. U.S. Nuclear Regulatory Commission, "Precursors to Potential Severe Core Damage Accidents," 1987 Status Report, NUREG/CR–4674, Vol. 7, July 1989.

55. Carolina Power & Light Company, Licensee Event Report 50–325/87–020, Revision 1, Brunswick Steam Electric Plant Unit 1, March 31, 1988.

56. U.S. Nuclear Regulatory Commission, Information Notice 87–48, "Information Concerning the Use of Anaerobic Adhesive/Sealants," October 9, 1987.

57. Philadelphia Electric Company, Licensee Event Report 50–278/83–018, Peach Bottom Unit 3, February 10, 1984.

58. U.S. Nuclear Regulatory Commission, Office of Inspection and Enforcement, Information Notice

84–53, "Information Concerning the Use of Loctite 242 and Other Anaerobic Adhesive/Sealants," July 5, 1984.

59. General Electric Company, Service Information Letter 128, Revision 1, Supplement 1, Category 1, "Preventive Maintenance for CRD Scram Pilot Valves," August 1978.

60. General Electric Company Service Information Letter 128, Revision 1, Supplement 1, Revision 2, Category 1, "Preventive Maintenance for CRD Scram Pilot Valves," dated March 2, 1984.

61. Carolina Power & Light Co., letter from P. W. Howe to J. N. Grace, U.S. Nuclear Regulatory Commission, Subject: Docket Nos. 50–325 and 50–324, Brunswick Steam Electric Plant Units 1 and 2, "Failure of ASCO 8323 A36E Double Solenoid Valves," October 15, 1985.

62. Carolina Power & Light Company, Licensee Event Report 50–324/85–008, Brunswick Unit 2, October 25, 1985.

63. U.S. Nuclear Regulatory Commission, "Report to Congress on Abnormal Occurrences, October-December 1985," NUREG–0090, Volume 8, Number 4, May 1986.

64. Virginia Electric and Power Company, North Anna Station Deviation Report 87-379, April 24, 1987.

65. U.S. Nuclear Regulatory Commission, Inspection Report 50–338/88–02 and 50–339/88–02, North Anna Power Station Units 1 and 2, March 14, 1988.

66. Virginia Electric and Power Company, Licensee Event Report 50–338/89–002, North Anna Unit 1, February 7, 1989.

67. Virginia Electric and Power Company, North Anna Power Station, memorandum, "Water Intrusion Into Instrument Air System Event—April 1987," by T. L. Porter, August 8, 1988.

68. Virginia Electric and Power Company, North Anna Power Station, memorandum from M. L. Bowling, "Justification for Continued Operation, Unit 2 for ASCO CCW Trip Valves," February 10, 1988.

69. Virginia Electric and Power Company, North Anna Power Station, memorandum from D. A. Heacock, "Justification for Continued Operation, Revision 1," February 9, 1988.

70. U.S. Nuclear Regulatory Commission, Region II, "Notice of Significant Meeting," February 2, 1989.

71. U.S. Nuclear Regulatory Commission, Inspection Report 50–387/84–35 and 50–388/84–44, Susquehanna Steam Electric Station, November 15, 1984.

72. U.S. Nuclear Regulatory Commission, Inspection Report 50–387/85–09 and 50–388/85–09, Susquehanna Steam Electric Station, April 15, 1985.

73. U.S. Nuclear Regulatory Commission, "Report to Congress on Abnormal Occurrences, October-December 1984," NUREG–0090, Volume 7, 4, May 1985.

74. U.S. Nuclear Regulatory Commission, Inspection Report 50–387/84–38 and 50–388/84–37, Susquehanna Steam Electric Station, February 27, 1985.

75. Wisconsin Public Service Corporation, Licensee Event Report 50–305/88–07, Revision 1, Kewaunee Nuclear Power Plant, May 19, 1989.

76. Automatic Switch Co., letter from J. P. Weaver to T. E. Murley, U.S. Nuclear Regulatory Commission, "Potential Failures of NP8314 Series Valves," October 18, 1988.

77. U.S. Nuclear Regulatory Commission, Inspection Report 99900369/88–01, Automatic Switch Company, August 30, 1988.

78. Omaha Public Power District, Licensee Event Report 50–285/82–006, Fort Calhoun Station Unit 1, April 7, 1982.

79. V. P. Bacanskas, G. J. Toman, S. P. Carfagno, "Aging and Qualification Research on Solenoid Operated Valves," Franklin Research Center, NUREG/CR–5141, August 1988.

80. General Electric Company, Service Information Letter 196, Supplement 10, Category 1, "SRV Failures To Open On Manual Demand and Air Operator Seal Failures," April 1981.

81. Duke Power Company, Licensee Event Report 50–414/87–031, Catawba Nuclear Station Unit 2, January 20, 1988.

82. U.S. Nuclear Regulatory Commission, Inspection Report 50–413/88–20 and 50–414/88–20, Catawba Nuclear Station Units 1 and 2, June 7, 1988.

83. U.S. Nuclear Regulatory Commission, Inspection Report 50–413/89–07 and 50–414/89–07, Catawba Nuclear Station Units 1 and 2, April 20, 1989.

84. Automatic Valve Corporation (AVC), letter from T. Hutchins to J. Keppler, U.S. Nuclear Regulatory Commission Region III, December 19, 1986.

85. Mississippi Power & Light Company, Licensee Event Report 50–416/85–007, Revision 2, Grand Gulf Nuclear Station Unit 1, October 2, 1985.

86. U.S. Nuclear Regulatory Commission, Information Notice 85–17, Supplement 1, "Possible Sticking of ASCO Solenoid Valves," October 1, 1985.

87. Commonwealth Edison Company, LaSalle County Station, "30 Day Report on the Failure of Main Steam Isolation Valve (MSIV) Pilot Solenoid Valve 1B21F028C," prepared by Sargent & Lundy, January 14, 1988.

88. U.S. Nuclear Regulatory Commission, Inspection Report 50–373/87-035, LaSalle County Station Unit 1, January 1988.

89. Gulf States Utilities Company, Licensee Event Report 50–458/88–023, River Bend Station, Unit 1, October 31, 1988.

90. U.S. Nuclear Regulatory Commission 10 CFR 50.72 Report 13591, September 30, 1988.

91. Gulf States Utilities Co., River Bend Station, "Analysis of Components in an ASCO Solenoid Valve," Franklin Research Center, Report P–741–1, February 9, 1989.

92. U.S. Nuclear Regulatory Commission, 10 CFR 50.72 Report 17201, November 27, 1989.

93. U.S. Nuclear Regulatory Commission, Region III Daily Report, December 4, 1989.

94. Cleveland Illuminating Company, Licensee Event Report 50–440/89–030, Perry Nuclear Power Plant, December 26, 1989.

95. Automatic Switch Co., "Installation and Maintenance Instructions," Bulletin 8323, Form No. V5972R1, 1981.

96. Automatic Switch Co., "Installation & Maintenance Instructions," Series NP8323, Form No. V6653, 1989.

97. Automatic Switch Co., "Installation and Maintenance Instructions," Bulletin 8344, Form No. V–5976, 1978.

98. Automatic Switch Co., Test Report No. AQR–67368, Revision 1, "Report on Qualification of Automatic Switch Co. (ASCO) Catalog NP–1 Solenoid Valves for Safety-Related Applications in Nuclear Power Generating Stations," August 19, 1983.

99. U.S. Nuclear Regulatory Commission, Inspection Report 50–289/88–28, Three Mile Island Nuclear Station Unit 1, February 2, 1989.

100. U.S. Nuclear Regulatory Commission, Region I Daily Report, December 9, 1988.

101. U.S. Nuclear Regulatory Commission, Inspection Report 50–244/88–25, Ginna Nuclear Plant, February 2, 1989.

102. Iowa Electric Light and Power Company, Licensee Event Report 50–331/82–039, Duane Arnold Energy Center, July 6, 1982.

103. Iowa Electric Light and Power Company, Licensee Event Report 50–331/85–002, Duane Arnold Energy Center, February 27, 1985.

104. U.S. Nuclear Regulatory Commission, Inspection Report 50–325/88–25 and 50–324/88–25, Brunswick Units 1 and 2, September 26, 1988.

105. U.S. Nuclear Regulatory Commission, Inspection Report 50–338/88–02 and 50–339/88–02, North Anna 1 and 2, March 14, 1988.

106. Automatic Switch Co., Service Bulletin, "Discontinuation of Rebuild Kits for ASCO 'NP' Series Valves," May 23, 1989.

107. Commonwealth Edison Company, Licensee Event Report 50–237/88–022, Dresden Nuclear Power Station, Unit 2, December 13, 1988.

108. D. V. Paulson, T. A. Shook, V. P. Bacanskas, S. Carfagno, "Equipment Qualification Research Test Program and Failure Analysis of Class 1E Solenoid Valves," Franklin Research Center, NUREG/CR-3424, FC 5569-309/315, November 1983.

109. S. P. Carfagno, R. J. Gibson, "A Review of Equipment Aging Theory and Technology," Franklin Research Center, EPRI NP–1558, September 1980.

110. Automatic Switch Company, "Field Notification of Discontinuation of NP8323 Valve Line," August 3, 1989.

111. Automatic Switch Company, "Revised Field Notification of the Discontinuation of NP–8323 Valve Line," October 27, 1989.

112. U.S. Nuclear Regulatory Commission, IE Bulletin 79-01, "Equipment Qualification of Class 1E Equipment," February 5, 1979.

113. U.S. Nuclear Regulatory Commission, IE Bulletin 79–01A, Supplement A to IE Bulletin 79–01,

"Environmental Qualification of Class 1E Equipment," Deficiencies in the Environmental Qualification of ASCO Solenoid Valves," June 6, 1979.

114. U.S. Nuclear Regulatory Commission, IE Bulletin 79-01B, Supplement B to IE Bulletin 79–01, "Environmental Qualification of Class 1E Equipment," January 14, 1980.

115. U.S. Nuclear Regulatory Commission, Information Notice 90-64 "Potential for Common-Mode Failure of High-Pressure Safety Injection Pumps or Release of Reactor Coolant Outside Containment During a Loss-of-Coolant Accident," October 4, 1990.

INDUSTRY CODES AND STANDARDS

American National Standards Institute (ANSI) Standard N45.2, "Quality Assurance Program Requirements for Nuclear Facilities," applicable edition.

American National Standards Institute/American Society of Mechanical Engineers (ANSI/ASME), Boiler and Pressure Vessel Code, Section III, "Rules for Construction of Nuclear Power Plant Components," applicable edition.

The Institute of Electrical and Electronics Engineers, Inc. (IEEE), 345 East 47th Street, New York, N.Y. 10017.

——, IEEE Standard 323, "IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Station."

——, IEEE Standard 344, "IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Station."

——, IEEE Standard 382, "IEEE Standard for Qualification Safety-Related Valve Actuators."

——, IEEE Standard 627, "IEEE Standard for Design Qualification of Safety Systems Equipment Used in Nuclear Power Generating Stations."

APPENDIX A

SOV FAILURES REPORTED IN LICENSEE EVENT REPORTS 1984 through 1989

This appendix describes the licensee event reports of approximately 200 solenoid-operated valve failures that occurred at U.S. light-water reactors between 1984 and 1989. A legend for the following table is provided below; followed by a definition of each failure category.

Legend:

DOC NO.	docket number
LER	licensee event report number
REP FL	repetitive failure
TP/OUT	cause reactor trip or plant outage
FC	failure category

Failure Categories:

00	Other
01	Coil Failure
02	Valve Body Failure/Leakage
03	O-Ring/Gasket/Plug/Seat/Diaphragm/Spring Failures/Leakage
04	Lubricant/Lubrication
05	"Sticking"
06	Internal Wiring/Reed Switch/Contacts
07	External Wiring
08	Installation/Maintenance Error-Physical (Backwards, Upside-Down, etc.)
09	Installation/Maintenance Error-Electrical (Loose Contacts, ac vs. dc, etc.)
10	Excessive Environment Temperature
11	Moisture Intrusion (Electrical Shorts/Grounding/Open Circuits)
12	Contaminants (Dirt, Water, Rust, Hydrocarbons, Desiccants, etc.)
13	MOPD (Maximum Operating Pressure Differential)
14	Design Error (Other Than MOPD)
15	Equipment Qualification-Seismic
16	Equipment Qualification-Radiation
17	Inadequate Maintenance/Excessive Time Between Replacement or Overhaul
18	End of Life/Normal Wear
19	Still Under Investigation
20	Unknown
21	Unspecified
22	Personnel Error
23	Minimum Operating Pressure Differential
24	Required Closing/Opening Time Specifications Not Met
26	Leakage Unspecified
27	Assembly Error (Plug/Diaphragm/Spring etc.)
28	Equipment Qualification (Electrical)

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
206	San Onofre 1	12/30/86	86-014-01	One	Ground fault, moisture in junction box	Feedwater & Safety Injection System	Not Specified	Not Specifi ed	Moisture in junction box	No	New junction box installed	Corrective action taken on failed junction box and seven other vulnerable ones.	LER 87-001	No	11
206	San Onofre 1	01/17/87	87-001	One	Ground fault	Feedwater	Not Specified	Not Specifi ed	Inadequate installation/v ibration	Yes	Eliminated ground,tighten ed connections	Vibration caused loosening of terminal box conduit locking ring	None	No	07
206	San Onofre 1	11/10/87	87-016-01	Seven failures of four valves	Slug sticking	Containment Isolation, Containment Spray,Chargi ng	ASCO	206-380	Licensee attributed sticking to Dow Corning 550 lubricant	Yes	Secured SOVs in safety position, cleaned valves and initiated weekly testing	Conducted extensive investig. Repetitive common-mode failures could have rendered independent trains of multiple systems inop.	Insp Rpt 89-24	No	05
206	San Onofre 1	12/01/87	87-017	Two	Not Specified	Safety injection vent	Not Specified	Not Specifi ed	Unknown	No	Repaired or replaced SOV	SOV required for venting SIS to avoid water hammer	None	No	19
206	San Onofre 1	12/16/87	87-018	One	Ground fault moisture in SOV housing	Plant cooling water	Not Specified	Not Specifi ed	Loose screws and inadequate seal. Root cause not specified	Yes	The ground was eliminated by removing the water inside the solenoid housing and resealing the housing.	The loose screws were probably stripped from excessive tightening. Ref. Docs. LERs 206/86-014/01, and 361/87-001,031	See comments	No	11

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
206	San Onofre 1	02/15/88	88-004-02	One	SOV sleeve and position indicatio n switch	Safety Injection	Target Rock	80EE-00 1	Still under investigation	Yes	SOV was replaced. Modified maintenance procedures(inc luding implementation of mfr's recommend for new reed switch calibration	SOV failure prevented bleed off from double disc gate valve bonnet.	LER 206/81-020	No	19
206	San Onofre 1	03/03/89	89-008	None	None	Containment fire suppression	Not Specified	Not Specifi ed	Design error	No	Design modification made	Discovered that a single SOV could degrade containment spray system,resultin g in containment overpressure during a LOCA	None	No	14
206	San Onofre 1	08/23/89	89-026	One	Failed to shift, "sticking slug"	Recirc system (safety injection/co ntainment spray)	ASCO	206-380	Suspect lubricant	Yes	Replaced SOV	None	LER 87-016	No	05
213	Haddam Neck	11/02/84	85-005	Two	Failed to shift "stuck"	Auxiliary Feedwater System	ASCO	NP8320	Unknown	No	SOV retested acceptably, declared operational, more frequent cycling tests planned	SOVs failed during testing. SOVs required for auto-initiation of AFW	None	No	05

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
213	Haddam Neck	09/10/85	85-024	One	Failed to shift "stuck"	Auxiliary Feedwater System	ASCO	NP8320	Unknown	Yes	Replaced SOVs. Initiated more frequent periodic cycling	Cause of sticking has not been determined. Same SOVs as in LER 85-005	LER 85-005	No	05
213	Haddam Neck	01/14/88	88-001	Four incipients	SOV operating mode	Containment Isolation - Steam Generator Blowdown	Not Specified	Not Specifi ed	Design Deficiency	No	Corrected circuit design, rather than changing the SOVs	Installed SOVs close upon deenergizing instead of opening upon deenergizing per design. Condition existed for seven years	None	No	08
219	Oyster Creek	10/16/84	84-022	Three	Diaphragm	Scram Discharge Volume	Not specified	Not specifi ed	Installed diaphragm backwards. Inadequate SOV rebuilding and inadequate post-maintenan ce test	No	Install diaphram correctly and develop improved post-maintenan ce testing	Caused slow closure of 3 air-operated SOV vent and drain valves	None	No	27
220	Nine Mile Pt 1	06/14/84	84-013	Three	Seat leakage(2),mispoai tioned wires	Main steam	Dresser/C onsol. Electroma tic	1525VX	Wear and contaminants suspected	Yes	1 refurbished, 2 replaced	Retest of all 6 valves found all to be leaking due to material lodged in the seat area (see LER 84-014)	LER 84-014	No	03
220	Nine Mile Pt 1	06/17/84	84-014	Six	5 seat leakage / 1 stuck open due to foreign matt	Main steam	Dresser / Consol. Electroma tic	1525 VX	Foreign material intrusion (source not stated)	Yes	Cleaned and refurbished SOVs	Retest of all 6 SOVs (LER 84-013) found all to be leaking due to foreign material lodged in the seat area	84-013	No	12

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
220	Nine Mile Pt 1	11/01/85	85-021	One plus two incipients	Jammed springs	Main steam	Dresser/Consol. Electromatic	1525VX	Wear	Yes	Replaced all three valves	None	None	No	03
237	Dresden 2	07/17/87	87-023	One	Internal passageway restriction	Feedwater (FWRV)	ASCO	8300	Wear	Yes	Replaced SOV	SOV is a piecepart of the FWRV.	None	Yes	18
245	Millstone 1	12/24/85	85-034-01	Between three and six	1 core spring, many discs	Control rod drive	ASCO	Not specified	Deterioration of the Buna-N discs and a detached spring.	Yes	SOVs rebuilt, upgraded SPSV maintenance program per GE SIL 128	Failure of three control rods to scram was attributed to failure of three to six associated scram pilot solenoid valves.	None	No	17
245	Millstone 1	06/06/87	87-015-02	One	Excessive leakage	Containment isolation - post accident sampling	Target Rock	Not Specified	Plunger tube scored	No	Replaced plunger tube	None	None	No	03
247	Indian Point 2	01/04/84	84-001	One	Failed closed	Containment purge	ASCO	Not Specified	Not Specified	No	Replaced SOV	None	None	No	21
247	Indian Point 2	11/27/84	84-022	Two	Not Specified	AFW Steam	Not Specified	Not Specified	Not Specified	No	Reconnected power leads to SOVs	SOVs control AFW turbine inlet steam isolation valves	None	No	09
247	Indian Point 2	02/02/87	87-003-01	One	Sluggish performance	Condensate (storage tank isolation)	Not Specified	Not Specified	Design deficiency (sizing)	No	Enlarged SOV orifice and cleaned regulator	SOV controls AOV. Slow closure attributed to orifice size. Debris could have also contributed.	None	No	24

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
249	Dresden 3	01/12/85	85-001	One	Manual operator	Main turbine	Sperry Vickers	FSDG454 012A	Grease contaimination	No	Replaced SOV	SOV controls overspeed trip	None	Yes	04
249	Dresden 3	09/10/85	85-018-01	One Hundred Eighteen	Diaphrams , O-rings, seals	Scram	ASCO	Not Specifi ed	Wear	Yes	Rebuilt and replaced SOVs, modified procedures, upgraded system	Common-mode failures resulted in primary system leak outside primary containment. See Section 5.2.1.7 of this report	None	Yes	03
249	Dresden 3	08/07/87	87-013	One	Coil	Feedwater	ASCO	8300	Shorted coil	No	Replaced SOV	SOV controls FWRV air operator	None	Yes	01
250	Turkey Point 3	12/02/84	84-031	One	Not Specified	Containment isolation (nitrogen supply)	ASCO	Not specifi ed	Not Specified	No	Replaced SOV	None	LER250/84-09,020	No	03
250	Turkey Point 3	12/13/84	84-034	One	Not specified	CVCS (isolation valve)	ASCO	Not Specifi ed	Not Specified	Yes	Replaced SOV	SOV controls AOV. Ref. Documents: LER 250/84-032, 251/84-009,84-0 20	See Comments	No	02
250	Turkey Point 3	01/13/85	85-002	One	Clogged SOV air filters	Not Specified	Not Specified	Not Specifi ed	Not Specified	No	Cleaned air filters on this and other similar SOVs in both units 3 and 4	Similar occurrences: LER 250-84-034, LER 250-84-031, LER 251-84-020, LER 251-84-009, and LER 250-83-016	None	No	17
250	Turkey Point 3	01/27/86	86-005	Two	Not Specified	Main steam (MSIV)	ASCO	8316	1 internal interference, 1 bent contact pins at fuse block.	No	Replaced 1 SOV, fuse block pins were straightened on other SOV.	2 independent SOV failures discovered during testing. MSIV couldn't be closed	None	Yes	09

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
250	Turkey Point 3	08/03/86	86-031	One	Not specified	Auxiliary/emergency feedwater	ASCO	206-381	Water entering the SOV	No	SOV replaced	Similar occurrences: LER 251-84-020, and LER 251-84-009	See comment	Yes	03
250	Turkey Point 3	01/03/87	87-002	One	Coil	Component Cooling Water	ASCO	8316	Not Specified	No	Replaced SOV	None	None	NO	01
250	Turkey Point 3	09/13/87	87-023	One	Internal wiring	Steam Generator Blowdown	Target Rock	300525-1	Faulty wires going to Reed switch	No	Not Specified	None	None	Yes	06
251	Turkey Point 4	07/15/87	87-015-01	One	Ground fault	Containment Isolation (pressurizer sampling)	Not Specified	Not Specified	Deterioration of insulating tape from "normal ageing"	No	Cleaned and retaped wiring connections	SOV is a piece-part of AOV	None	No	18
251	Turkey Pt 4	09/15/89	89-011	One	Plunger stuck in mid-position	Feedwater	ASCO	Not Specified	Foreign materials from plant modifications	No	Replace SOV. Develop cleanliness controls for instrument air system tubing	Foreign materials were metal particles and thread sealant	None	No	12
254	Quad Cities 1	02/05/85	85-001	Two	Connection to SOV power lead	HPCI	Barksdale	178250HC204	Faulty terminal connection and vibration	No	Repair terminal connections and secure wires to SOV housing	Failure of HPCI turbine tripend reset SOVs	None	No	07
254	Quad Cities 1	04/03/87	87-006-01	One	Wiring connection to coil	High Pressure Coolant Injection	Barksdale	1018433ACP1	Vibration/inadequate connection/inadequate support	Yes	Replaced coils on failed SOV and three others replaced at units 1 and 2	HPCI inoperable. Replaced SOV coils with newer model, also added wiring restraint to all four SOVs.	LER 85-001	No	07

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
254	Quad Cities 1	07/07/89	89-011	One	Blocked exhaust port	Emergency diesel generator fire protection	Not Specified	Not Specified	Failed to remove manufacturer's protective pipe plug and also failed to perform post maintenance operability test	No	Remove protective pipe plug and test SOV for operability	System had been inoperable fo 51 weeks	None	No	08
255	Palisades	04/10/86	86-017-01	Three fail + three incipients	Valve seat leakage	Reactor Coolant - (head vent)	Target Rock	80B-001	Metal shavings in valve seat area.	Yes	Repaired SOVs and system flushed to remove remaining metal shavings	Discusses spurious openings of Target Rock SOVs	None	Yes	12
255	Palisades	01/14/87	87-001-01	Eight	Inadequate isolation logic	Containment isolation(hydrogen monitoring)	Not Specified	Not Specified	AE design error	No	Isolation logic modified	None	None	No	14
259	Browns Ferry 1	07/03/86	86-022	Six incipients	Not Specified	ECCS	Rockwell/ Atwood-Morrill	Not Specified	Design error	No	Remove air supply to affected actuator	Potential for overpressurizing low pressure systems due to use of non qualified SOVs (six in each of three Browns Ferry units)	None	No	14
260	Browns Ferry 2	08/31/87	87-007-01	Potential failures all 3 units	Loss of SOV function	Containment Drywell Control Air	Not Specified	Not Specified	Design error	Yes	Replace SOVs with qualified ones	Use of non-qualified SOVs could prevent primary containment isolation. All 3 Browns Ferry units affected.	None	No	14

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
260	Browns Ferry 2	06/06/89	89-018	One	Valve seats	Emergency diesel generator air start	Salem	812-6	Corrosion debris from starting air system	Yes	Replaced SOV	Upgraded EDG air sys, did maint. on it prior to event, but debris was be there from before. Preceded by 2 similar events(see ref)	LER 259/86-008	No	12
261	H.B. Robinson 2	05/13/87	87-007	Two	Not Specified	Not Specified	ASCO	Not Specified	Inadequate installations of conduit seals	Yes	Install correct seals	Incorrectly installed conduit seals at entrance to several harsh environment 1E qualified SOVs. Potential for moisture intrusion	None	No	14
261	H.B. Robinson 2	07/15/87	87-020	One	Electrical short	Feedwater (FWRV)	Not specified	Not Specified	Water trapped in SOV condolet	No	Wire was repaired and water removed from the condulet. Other SOVs examined for similar problems.	SOV is piece-part of FWRV	None	Yes	11
261	H.B. Robinson 2	11/05/87	87-028-01	Two	SOV internals	Diesel Generator Starting Air	Not Specified	Not Specified	Internal wear	No	Replaced SOVs	SOV failures caused venting of starting air	None	No	18
263	Monticello	10/25/89	89-032	One	Loose terminal screw	Main steam (MSIV)	Not Specified	Not Specified	Not Specified	No	Tighten terminal screw and inspect similar SOVs	None	None	No	09

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
265	Quad Cities 2	06/28/85	85-015	One	Not Specified	Reactor Bldg. Vent. System	Versa	See comment	Not Specified	No	SOV replaced	VGS-4422-U-10-3 1-38C	None	No	20
265	Quad Cities 2	02/18/87	87-004	One	Not specified	Containment vacuum	ASCO	8317	"Solenoid rusted and corroded" (reason/source not stated)	No	Replaced SOV	SOV is piece-part of vacuum breaker air test cylinder	None	No	21
265	Quad Cities 2	09/18/87	87-012	One plus two incipients	Not specified	Containment Vacuum Relief	ASCO	8317	Unknown	Yes	Not Specified	SOV is piece-part of vacuum breaker air test cylinder	LER 87-004	No	20
265	Quad Cities 2	12/10/87	87-020	One	Not Specified	Main Turbine Control Fluid	Sperry Vickers	F3-SDG4 54-0124	Not Specified	No	Rplaced SOV	None	None	Yes	02
265	Quad Cities 2	04/06/89	89-001	One	Not Specified	Turbogenerator	Not Specified	Not Specified	Not Specified	No	Rebuilt SOV	Failed SOV controls turbine master trip solenoid	LER 87-020	Yes	21
266	Point Beach 1	06/01/89	89-003	One	Not Specified	Containment isolation (SG blowdown sampling)	ASCO	8302	Not Specified	No	Replace SOV	None	None	No	21
270	Oconee 2	06/05/89	89-005	Two potential	Inadequate cable sealing	RCS sampling	Target Rock	Not Specified	Failed to meet EQ requirements for potentially submerged valves	No	Resealed connectors	Units 1 and 3 were suspected to have the same installation deficiencies	None	No	28
271	Vermont Yankee	08/18/87	87-009-01	Not Specified	Seat leakage	Automatic Depressurization	ASCO	206-381	Dirt/corrosion products from the air supply	Yes	SOV cycled	None	None	No	12
272	Salem 1	12/31/84	84-029	One	Faulty electrical connection and seat leakage	Feedwater (FWRV)	ASCO	Not Specified	Not Specified	Yes	Replaced SOV	SOV is a piece-part of FWRV	None	Yes	09

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
272	Salem 1	01/31/86	86-003	One	Seat leakage	Feedwater (FWRV)	ASCO	Not Specified	Probably contaminated air	Yes	Two SOVs were replaced	SOV is a piece-part of the FWRV. Dirt and moisture were detected in air lines causing other associated failures	None	Yes	12
272	Salem 1	02/20/86	86-006	One	Broken wire	Feedwater (FWRV)	Not specified	Not Specified	Installation error and vibration	No	Replaced wire and checked similar SOVs	None	None	Yes	09
272	Salem 1	04/08/86	86-007	Eighteen incipients	Electrical connectors	Post accident sampling	Not Specified	Not Specified	Design/installation error, inadequate installation procedures	No	Install required connectors	18 SOVs on units 1 and 2 had inadequate connectors	None	No	14
275	Diablo Canyon 1	01/02/85	85-001	Two	SOV "stuck open"	Main turbine (overspeed protection)	Not Specified	Not Specified	Not Specified	No	Replaced SOV	None	None	Yes	21
275	Diablo Canyon 1	07/24/87	87-011	None	Not Specified	Containment isolation	Not Specified	Not Specified	Procedural inadequacies	No	Perform necessary verification. Upgrade procedures	Failure to verify penetration isolation subsequent to SOV replacement.	None	No	22
277	Peach Bottom 2	04/27/84	84-008	One	Not Specified	Containment isolation (SBGT)	ASCO	8320	Not specified	No	Replaced SOV	Potential existed for a single failure to have prevented the fulfilment of the safety function of the SBGT system	None	No	19

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
277	Peach Bottom 2	01/24/86	86-003	Two	DC coils	Main Steam (MSIV)	Automatic Valve Company (AVC)	Not specified	Under investigation	No	The failed DC solenoids were replaced.	Failure of 2 DC SOVs in 2 separate lines caused closure of MSIVs	None	Yes	19
277	Peach Bottom 2	05/29/87	87-008	Three	Not Specified	Control room ventilation/ radiation monitoring	Not Specified	Not Specified	Piping configuration error	No	Reconnected tubing to SOVs properly	Sample lines to three SOVs had been connected incorrectly. Affected control rooms at both units 2 and 3	None	No	20
277	Peach Bottom 2	10/05/89	89-023	One	Binding of SOV slug	Main steam (MSIV)	Automatic Valve Company (AVC)	6910-20	Inadequate manufacturer's installation instructions	No	Replaced SOV and revised installation and maintenance procedures	Reference LERs 277/86-003, 278/85-018, 278/86-016	See comments	Yes	27
278	Peach Bottom 3	09/30/85	85-015-01	One	Leaked	ADS backup nitrogen	Target Rock	Not Specified	Not Specified	Yes	Replaced SOV with an upgraded one	Previous similar occurrences reported in LERs 277/85-01 and 278/85-05	See Comments	No	03
278	Peach Bottom 3	07/11/84	85-018	One	DC coil	Main steam (MSIV)	Automatic Valve Co.	Not specified	Reason for coil failure not specified	Yes	Task force recomended testing of DC solenoids more often and analyze cause of future failures.	DC SOV failure coupled with momentary loss of AC power resulted in MSIV closure	None	Yes	01
278	Peach Bottom 3	07/19/86	86-016	One	Coil	Main Steam (MSIV)	Automatic Valve Corp. (AVC)	Not Specified	Reason for coil failure not specified	Yes	The dc coil on each MSIV's SOV was replaced.	Similar reactor scrams in 1985 and 1986(defective dc coil coupled with ac power interruption): LERs 278/85-018, 277/86-03	See comments	Yes	01

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
280	Surry 1	03/28/84	84-007	None	Not Specified	Feedwater (FWRV)	Not Specified	Not Specified	Maintenance had been done without approved procedures inadequate post maintenance testing	No	Reconnected IA lines to proper SOV ports	Instrument air lines were connected to the wrong ports of 5 SOVs at Surry units 1 and 2	None	No	08
280	Surry 1	11/12/87	87-031	One	SOV wiring blocked isolation valve operator	Containment isolation	Masoneilan (SOV unspecified)	3500 series	Improper installation	No	Secured SOV	Wiring to unspecified SOV caused mechanical binding of containment isolation valve's operator	None	No	09
281	Surry 2	01/27/88	88-001-01	Two	SOV leakage	Containment isolation(pressurizer vapor space sampling)	Target Rock/ASCO	86V-001/206-380	Cause of SOV leakage not specified. Cause of wrong lead lifting: electrical maintenance "personnel error"	Yes	Repair or replace SOVs	Electricians trying to isolate leaking SOVs lifted wrong leads	None	No	26
281	Surry 2	02/02/88	88-002-01	Two	Seat leakage	Reactor coolant sampling isolation	Valcor	V526-5683-19	Impurities in reactor coolant system water prevented complete seat closure. Impurities also caused pitting of valve internals	No	SOVs replaced. Initiated program to enhance material exclusion controls	None	LER 88-001	No	12

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
285	Fort Calhoun	05/01/86	86-003-01	Two	Failure positions of SOVs reversed	Waste gas	Not Specified	Not Specifi ed	Personnel error	No	Return SOVs to correct failure positions	Fail closed SOVs had been changed to fail open, resulting in volume control tank leakage to auxiliary building.	None	No	22
286	Indian Point 3	02/11/87	87-002	One	Coil	Containment leakage control	ASCO	8308	Not Specified	Yes	The failed solenoid valve replaced with one of a higher temperature design. 3 similar SOV coils were also replaced.	The design of no. 34 static inverter was improved to allow isolation of single branch circuits if a short circuit develops.	LER 85-001-00	Yes	11
293	Pilgrim	07/19/88	88-021	Four incipients	Potential for exceeding MOPD limits	Primary containment, control rm,+ turb bldg HVAC/SGTS	ASCO	8320 and NP8320	Design error	No	Replace SOVs with ones rated for higher MOPD	Failure of pressure regulator would result in inoperability of 4 SOVs due to exceeding MOPD limits	None	No	13
293	Pilgrim	01/27/89	89-004	Two suspected	Not Specified	Containment isolation	ASCO	NP8320	Not Specified	No	Repaired leaks and replaced 2 SOVs	Failure of 2 AOVs due to air system leaks. 2 SOVs were replaced as a precaution against exceeding MOPD limits of the SOVs	LER 89-002	Yes	21

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
293	Pilgrim	05/03/89	89-015	One	Coil	Main Steam (MSIV)	Automatic Valve Corp. (AVC)	6910-02 0	"Random failure"	No	Replaced SOV assembly	None	None	Yes	01
295	Zion 1	08/08/85	85-029	Two	"Stuck" pilot valve	EDG building ventilation	Not specified	Not specifi ed	Not specified	Yes	Replaced SOVs	40 such valves used in both units. Common-mode failures found during testing. Additional CMFs ocurred next day at unit 2.	LER 304/85-015	No	05
295	Zion 1	10/16/88	88-020	One	Plunger stuck in mid-posit ion	Service water	ASCO	8320	Foreign material (piece of SOV's elastomeric seat had broken off)	Yes	Replaced SOV	SOV did not go to "fail safe" position when de-energized. Upon safety injection could have resulted in reduced essential SW flow	None	No	12
295	Zion 1	01/12/89	89-001	One	Failed to shift	Ventilation (service water building)	ASCO	8320	Weakened coil	Yes	Replaced SOV	None		No	01
295	Zion 1	11/22/89	89-022	One	Plunger failed to open	Service water building ventilation	ASCO	8320	"Weakened coil"	Yes	Replaced SOV	None	LER 295/89-001	No	01
298	Cooper	08/18/86	86-018	One	Not Specified	Reactor Recirculatio n System	Not Specified	Not Specifi ed	Not Specified	No	Not Specified	None	None	No	21
302	Crystal River 3	01/05/89	89-001-02	None	Not Specified	Multiple systems	ASCO	8320/NP 8316/83 20	Design error-MOPD	Yes	Replaced SOVs with others having higher MOPD rating	See section 5.1.3 of this report for additional info. Reference documents: LER 78-054, 83-023, 88-013	See comments	No	13

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
302	Crystal River 3	04/07/89	89-012	Eight incipient	None	Containment isolation (RX cavity cooling system)	ASCO	8320	Design error	Yes	Replace SOV coils with coils having correct temperature ratings	8 SOVs were affected. Reference documents: LER 78-054, 83-023, 88-013, 89-001	See comments	No	14
302	Crystal River 3	04/18/89	89-015	One incipient	Not Specified	Reactor coolant pump seal bleed off	Not Specified	Not Specified	Inadequate seismic installation	No	Modified SOV supports	None	None	No	15
302	Crystal River 3	09/26/89	89-034	Many potentially affected	Electrical power supplies	HVAC, containment isolation, Main steam (MSIV)	Not Specified	Not Specified	Design error	No	Modified power supplies	Intermingling of 1E and non-1E power sources to SOVs	None	No	09
302	Crystal River 3	09/06/89	89-035-01	25 potential safety related	Coil under-rated (DC voltage)	Containment cooling, containment isolation, NSCCCW, EDG	Not Specified	Not Specified	Incorrectly specified operating voltage	Yes	Replace SOVs with correctly specified DC voltages	None	None	No	14
304	Zion 2	07/11/84	84-015	Not Specified	Internal leakage	Main steam (MSIV)	Keane	51-170	Licensee could not find cause of failure	No	Three SOVs to be replaced with environmentally qualified SOVs	None	None	No	26
304	Zion 2	08/09/85	85-015	Two	"Stuck" pilot valve	EDG building vent	Not specified	Not Specified	Not specified	Yes	The valves were replaced.	Common-mode failures found during testing. Also occurred on unit 1 the previous day. 40 such valves on units 1 and 2.	LER 295/85-029	No	05

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
304	Zion 2	02/03/87	87-001	One	O-Ring	Main steam (MSIV)	Chicago Fluid Power	NSV1-16-C-XP	Manufacturing defect or damage during installation	No	Replaced SOV	None	None	Yes	08
305	Kewaunee	07/02/84	84-013	One	Coil	Auxiliary building special ventilation	Johnson	V-24	Not Specified	Yes	The Johnson valves were to be replaced with ASCO NP8320 SOVs as they failed.	SOV failures resulted in initiating safeguards equipment. 59 such SOVs remaining would be replaced with ASCOs at next outage	82-03,28, 81-34	No	01
305	Kewaunee	12/16/84	84-020	One	Coil	Auxiliary building special ventilation	Johnson	V-24	"Burnt out" coil, root cause not specified	Yes	The Johnson SOV was replaced with an ASCO NP8320.	Due to repetitive failures of these Johnson SOVs, they were all being replaced with ASCO NP8320 SOVs on an as-fail basis	LER 84-13	No	01
305	Kewaunee	02/11/85	85-005	One	Coil	Auxiliary building special ventilation	Johnson	V-24	Coil "burnt out," root cause not stated	Yes	Replaced SOV with an ASCO	Due to repetetive failures of these Johnson SOVs, they were all being replaced with ASCO NP8320 SOVs on an as-fail basis.	LER 84-013,020	No	01
305	Kewaunee	11/28/87	87-012-01	Two failed plus 58 incipients	Failed to shift	Containment Isolation-Pzr relief,make-up,RCDT discharge	ASCO	NP8314	Design error. Conditions exceeded SOVs' MOPD limits	Yes	Replace SOVs and correct regulator settings so that MOPD ratings will not be exceeded	See Section 5.1.3 of this report	None	No	13

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
305	Kewaunee	05/28/88	88-007-01	Three plus seven incipients	Failed to shift	Containment Isolation (pzr relief, makeup isolation)	ASCO	NP8314	Manufacturing error (unauthorized use of incorrect lubricant)	No	Cleaned and refurbished the affected SOVs	Initiated an extensive root cause analysis. See Section 5.2.4.1 of this report.	LER 87-012-01	No	05
309	Maine Yankee	08/10/86	86-005-01	One	Ground fault	Cardox Fire Protection system	Chemetron	5-020-0 074-8	Not Specified	No	Replaced SOV	SOV failure tripped Cardox system power supply breaker, thereby disabling the Cardox system.		No	21
309	Maine Yankee	05/23/88	88-005-02	Four incipients	Not Specified	HPSI/chargin g pump suction vent	R.G. Laurence	620WA24 DCSW	Design error	No	Modified system	SOVs in high rad. fields not environ. qual. Failure could cause uncontrolled release of radioactivity to non qual. systems.	None	No	16
311	Salem 2	01/28/85	85-001	One	Failed to shift	Emergency diesel generator	Masoneill an	Not Specifi ed	SOV installed backwards	No	Reinstalled correctly and revised maintenance procedures	SOV is a piecepart of EDG cooling water flow control valve	None	No	08
311	Salem 2	05/22/89	89-011-01	None	Not Specified	Main steam (isolation valve)	Not Specified	Not Specifi ed	Inadequate surveillance testing	No	Modified testing circuitry	Testing deficiencies would prevent detection of SOV failure Deficiency existed at unit 2 also	Not Specified	Yes	14

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
313	ANO 1	05/06/85	88-001	Two	Lifting of plunger (spurious actuation)	Post accident sampling	Target Rock Corp.	80E-001/81P-006N	Design error	No	SOVs were reoriented correctly	Incorrectly oriented SOVs could open upon small increases in backpressure. See Section 5.1.4 of this report	LER 368/88-001	No	08
317	Calvert Cliffs 1	04/01/87	87-007-03	Four incipients	Unqualified electrical connectors	Auxiliary Feedwater	Not Specified	Not Specified	Design error	No	Deficient electrical connections were upgraded with EQ qualified ones	Two SOVs on each unit found to have inadequate (EQ) electrical connections	None	Yes	28
317	Calvert Cliffs 1	08/22/89	89-015	None	None	Iodine filter dousing system	Not Specified	Not Specified	Design error (Q list classification)	No	Replace with seismically qualified SOVs	SOV failure could prevent iodine filters from performing their function	None	No	15
317	Calvert Cliffs 1	11/13/89	89-020	None	Not Specified	Salt water cooling	Not Specified	Not Specified	Design error (Q list classification)	No	Replace with seismically qualified SOVs and power sources	4 SOVs in safety system not able to withstand seismic event power sources for 5 safety-related SOVs not seismically qualified	None	No	15
318	Calvert Cliffs 2	09/05/86	86-006-01	One	Seat leakage	Main Steam (atmospheric dump)	ASCO	8300	Not specified	No	SOV internals were replaced	None	None	No	03
321	Hatch 1	12/07/85	85-043-01	Not Specified	Seat leakage	Containment isolation-multiple systems	Not specified	Not specified	Normal equipment use or wear	Yes	Leaking valves in 42 penetrations repaired,rebuilt, or replaced.	None	LER 84-017	No	18

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
321	Hatch 1	04/15/87	87-004	One incipient	Not Specified	Main control room environmental control	Not Specified	Not Specified	AE design deficiency	No	Redesign main control room environmental control system	Single SOV failure could compromise control room hability	None	No	14
321	Hatch 1	03/18/87	87-005	Two	1.Missing lock nut 2.Stuck plunger	Containment ventilation	ASCO	NP8321	Unspecified	Yes	1. Installed a missing lock nut./ 2. No corrective action taken on stuck SOV because it tested okay subsequent to failure.	2 damper failures. (1 caused by missing lock nut on SOV, 1 caused by stuck SOV plunger)	LER 85-015-01	No	00
322	Shoreham	11/15/89	89-009	None	Not Specified	Containment isolation (RX building standby ventilation)	ASCO	206-832 206-380	Design error, SOVs were oriented incorrectly	No	Reorient SOVs to correct positions (vertical vs. horizontal)	Common-mode failures having potential to prevent fulfillment of safety function	None	No	08
323	Diablo Canyon 2	08/14/85	85-019-01	Three	Incorrect wiring to SOV	Main Steam (MSIV)	Not Specified	None	Personnel error(incorrect undocumented wiring change)	Yes	Replaced SOV	Undetected SOV failure caused 5 month loss of 1 train of ESFAS actuation of MSIVs	LER 85-014	No	07
323	Diablo Canyon 2	12/21/85	85-022	One	Open circuit	Feedwater	Not specified	Not Specified	Improper wiring installation and bumped junction box	No	The wiring connection was properly reteriminated other similar SOVs' terminations were inspected.	SOV is a piecepart of the FWRV	LER 275/85-030	Yes	09

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
324	Brunswick 2	09/27/85	85-008	Three	Disc-to-seat sticking	Main steam (MSIV)	ASCO	8323	Hydrocarbon, water and high temperatures caused degradation of seat material.	No	Replaced SOVs	Common-mode failures. See Section 5.2.3.1 of this report.	None	No	12
324	Brunswick 2	10/15/85	85-011-01	Two	DC coil	Main Steam (MSIV)	ASCO	NP8323	Licensee suspected chloride corrosion	No	Replaced SOVs. Extensive failure analysis initiated.	None	None	Yes	01
324	Brunswick 2	01/02/88	88-001-05	Four	Failed to shift	Containment isol./drywell floor and eqpmt drain sumps	ASCO	206-832	Still under investigation. Found debris and oil film on one SOV. Suspect high temperatures from self heating of energized SOVs	Yes	Replace SOVs. Performing extensive failure analysis	Four previous similar failures had been experienced	Insp Rpt 88-06	No	19
324	Brunswick 2	06/17/89	89-009-01	One	Failed to shift	Drywell purge and vent	ASCO	Not specified	Suspected that foreign particulates found in the SOV had attacked elastomeric parts of the SOV	No	Replaced SOV	Extensive analysis of root cause was not totally conclusive	None	No	12
325	Brunswick 1	02/28/87	87-005-02	Two	Discs	Containment isolation	Valcor	V52645-5683-14	Not Specified	No	Replaced SOVs	SOV leakage found during LLRT	None	No	03
325	Brunswick 1	07/01/87	87-019	One	Stuck plunger	Main Steam (MSRV)	Target Rock	1/2-SMS-A-01	Excess Loctite used by manufacturer's field rep	Yes	Refurbished SOV	See Section 5.2.2.2 of this report	LER 87-020-01	No	17

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
325	Brunswick 1	07/03/87	87-020-01	Four	Stuck plunger	Main steam (MSRV)	Target Rock	1/2-SMS -A-01	Excess Loctite used by manufacturer's field rep	No	Replaced SOVs	See Section 5.2.2.2 of this report	LER 87-019	No	17
327	Sequoyah 1	05/18/84	87-020	Not Specified	Not Specified	Not Specified	Not Specified	Not Specifi ed	Design error	No	Plant modifcations to protect vulnerable 1E equipment	1E SOVs were not protected from water spray which could emanate from pipes which were vulnerable to an SSE	None	No	14
328	Sequoyah 2	08/30/84	84-014-02	One	Seat leakage	Feedwater	ASCO	8320	Design Error	No	Replaced SOV	An incorrectly selected SOV failed when put in service where its MOPD limits were exceeded	None	No	13
328	Sequoyah 2	06/11/88	88-026-01	Two	Incorrect external wiring	Auxiliary feedwater level control	Not Specified	Not Specifi ed	Inadequate maintenance configuration control	Yes	Reconnected SOVs correctly	Incorrect external wiring to 2 SOVs	None	No	07
328	Sequoyah 2	06/06/88	88-027-01		Not Specified	Auxiliary feedwater	Not Specified	Not Specifi ed	Inadequate electrical maintenance	Yes	Replaced diodes missing from external circuitry connecting 2 SOVs	None	None	No	07
331	Duane Arnold	01/10/84	84-004	Two	Blockage of internal passagewa y	Standby filtration	ASCO	8316	Restriction in SOV discharge path. (Adaptor elbow and possibly foreign material or moisture from instrument air). Ageing also	No	Removed restrictions,p lanned to rebuild SOVs and to upgrade air system	Restrictions prevented valve from satisfying its minimum operating pressure differential requirement	None	No	23

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
331	Duane Arnold	01/28/85	85-002-00	One	Diaphragm	High pressure coolant injection	Skinner Electric	L2DB515 0	End of life/excessive time between maintenance	No	Replaced SOV	None	None	No	17
331	Duane Arnold	05/27/88	88-005	One	Not Specified	Fire Suppression	Electro-M anual (Chemetro n Corp.)	2010008 3	Design error and inadequate post maintenance testing	No	Replaced SOV	Licensee had upgraded SOV with an incorrect one. Deficiency was not found during post maintenance testing.	None	No	14
331	Duane Arnold	03/05/89	89-008	One	Coil	Main steam (MSIV)	ASCO	NP8323	Moisture intrusion from steam leak / inadequate torqueing of enclosure fasteners	No	Replaced SOV. Tightened enclosure covers of other similar SOVs.	7 other similar SOVs were subject to moisture intrusion failure due to common-mode torqueing deficiency	None	Yes	11
333	Fitzpatrick	08/20/85	85-022	One	Electrica l fault	Main steam (MSIV)	ASCO	Not Specifi ed	Maintenance personnel error in external wiring	No	SOVs replaced and rewired correctly	AC coil had been connected to DC source and DC coil had been connected to AC source	None	Yes	09
333	Fitzpatrick	11/22/85	85-027-01	One	SOV unable to seat properly	Main steam (MSIV)	ASCO	NP8323	Brass sliver due to cross threading air line fitting	No	Cleaned/refurb ished SOV check other for similar problem	MSIV unable to close	None	No	12
333	Fitzpatrick	08/03/89	89-013	None	Not Specified	Containment isolation	Not Specified	Not Specifi ed	Design error	No	Correct wiring error	None	None	No	07

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
334	Beaver Valley 1	06/07/88	88-007	One	Not Specified	Diesel generator air start	Johnson	Not Specifi ed	Not specified	No	Replaced SOV	EDG air start SOV failed	None	No	22
336	Millstone 2	12/31/86	86-021	Two	Broken springs in SOVs	Reactor Coolant Head Vent	Valcor Engg Corp.	V526-60 42-3A	Suspect hydrogen embrittlement	No	Replaced 17-7 PH springs of all similar Valcor SOVs	Prior to event these SOVs had been leaking and had been isolated	None	No	03
336	Millstone 2	01/02/87	87-002	One	Diaphragm leakage	Main feedwater (FWRV)	ASCO	8262	Not specified	Yes	Inspected and replaced	None	None	Yes	02
338	North Anna 1	02/02/84	84-005	6 failed and 54 incipients	Electrica l-moistur e intrusion	Containment isolation -hydrogen control/pass	Valcor and ASCO	Valcor 526seri es	Inadequate conduit sealing methods did not meet mfrs specs to meet IEEE-324 qualifications	No	Replaced failed SOVs and sealed all deficient conduit seals	6 SOVS failed and 54 SOVs were installed incorrectly in both units	None	No	09
338	North Anna 1	07/28/84	84-014	One	Not Specified	Main steam	Copes Vulcan	Not Specifi ed	Not Specified	No	Overhauled SOV	Slow closure resulted in steam generator overfill	None	No	24
338	North Anna 1	11/23/87	87-020	Two	Not Specified	Main Steam (Atmospheric Dump Valves)	Copes-Vul can	Not Specifi ed	Not Specified	No	Water induction circuits were de-energized in order to start the condensate pumps and begin secondary system recovery actions.	To prevent recurrence of this type event, an evaluation to install additional level switches will be performed.	None	No	02

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
338	North Anna 1	01/08/88	88-002	One	Not Specified	Condenser waterbox vacuum	Not Specified	Not Specifi ed	Not Specified	Yes	Replaced SOV	None	None	Yes	21
338	North Anna 1	03/11/88	88-011	Nine	Sluggish operation	Containment isolation	ASCO	NP-1 series	Design error	Yes	Reworked SOVs to meet manufacturer's instructions	Failure to follow manufacturer's installation instructions modified the SOVs' performance and qualification.	LER 339/87-15-01	No	14
338	North Anna 1	03/15/88	88-012	One	Not Specified	Component Cooling Water	ASCO	Not Specifi ed	Not Specified	Yes	SOV from 1-CC-TV-103A was installed on 1-CC-TV-103B, and the SOV from 1-CC-TV-103B was refurbished and installed on 1-CC-TV-103A	None	LER 88-011	No	02
338	North Anna 1	07/19/89	89-014	One	O-ring	Turbogenerat or (EHC)	Parker-Ha nnefin	MRFN16M X0834	O-ring pinched during SOV refurbishment by turbine manufacturer's maintenence team	No	Replace O-ring	Supplemental info obtained from licensee 5/16/90, H.L. Ornstein/ C.W. Allen	LER 88-013	Yes	03
339	North Anna 2	04/16/86	86-007	One	Not Specified	Reactor coolant (letdown isolation)	Masoneila n	Not Specifi ed	Not Specified	No	Replaced solenoid	Licensee stated that the "solenoid was degraded"	None	No	21

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
344	Trojan	04/16/87	87-009	Not Specified	Not Specified	Reactor coolant (PORV)	Not Specified	Not Specified	Design/installation error	No	Replaced splices which did not meet EQ installation requirements	None	None	No	28
346	Davis-Besse	09/11/84	84-013-01	One	Not Specified	Main steam (Atmospheric Vent)	Control Component International	Not Specified	Not Specified	Yes	Replace or refurbish SOV	SOV is a piece-part of the atmospheric vent valve's air-operated controller	None	No	21
346	Davis-Besse	01/03/86	86-006-01	Thirty-two incipients	Coil	Not specified	ASCO	Not specified	Failure to perform preventive maintenance when required	No	Replaced SOV coils	Coils on EQ SOVs had been in service beyond their qualified lifetime	None	No	17
346	Davis-Besse	12/07/87	87-015	One	SOV vented air	Instrument air dryer	ASCO	1179237	Not Specified	No	Replaced SOV, instrument air dryers replaced with upgraded ones	Failure of SOV caused loss of instrument air/reactor trip. O-rings on several SOVs in turbine bypass system also found degraded	None	Yes	21
348	Farley 1	01/18/87	87-005	Two	Not Specified	Containment isolation (containment sump discharge)	ASCO	8316	Unknown	No	1 SOV closed on additional attempts. Inboard SOV to be inspected subsequent to shutdown.	Redundant SOVs in one penetration failed to close	None	No	20

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
348	Farley 1	07/21/87	87-012	84 incipients at each unit	Inadequate electrical install. (splices/terminals)	Not Specified	Not Specified	Not Specified	Root cause of inadequate splices and terminations not stated	No	All accessible SOVs'installations modified to an approved EQ splice and termination configuration on a priority basis.	84 SOVs at each unit were found not to be installed in accordance with EQ requirements (splices and junction box connections)	None	No	28
352	Limerick 1	05/09/88	88-017	One	leakage-slug stuck in mid-position	Reactor Bldg Ventilation	ASCO	8316	Not Specified	No	Replaced SOV	Licensee could not determine cause of SOV failure. Called a "component failure of unknown cause"	None	No	20
352	Limerick 1	03/14/89	89-019	None many incipients	Electrical failure/moisture intrusion potential	RX building ventilation	Not Specified	Not Specified	Design error (EQ). Inadequate conduit sealing for HELB environment	No	Sealed electrical conduits	Potential for common-mode failures	None	No	07
354	Hope Creek	08/28/86	86-063	12 incipients	Not Specified	Containment Atmosphere Control	ASCO	NP8316	Design error	No	Replaced all twelve SOVs with ones having a higher MOPD rating.	Failure of non-Q regulators could have caused failures of the SOVs.	None	No	13
354	Hope Creek	02/24/87	87-018-01	One	Failed to shift	Main Steam (MSIV)	Automatic Valve Corp. (AVC)	Not Specified	Foreign material inside SOV body, manufacturing defect, and inadequate installation	No	Replaced failed SOV and its manifold assembly. Replaced 7 SOVs for other MSIVs. Sent failed SOV to supplier (GE) for analysis	Foreign material in SOV,Plunger in SOV not per design (incorrect length), mounting screws on junction box were loose.	LER 87-037,038	No	03

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
354	Hope Creek	10/10/87	87-047	One	Failed to shift	Main Steam (MSRV)	Target Rock	Not Specified	Inadequate protection of MSRVs during plant construction	No	The malfunctioning SRV and its SOV piece-part were replaced in kind.	Failure caused by intrusion of sandblasting grit which was used during plant construction	None	No	12
361	San Onofre 2	01/09/86	86-004	Two	Coil	Feedwater	Not specified	Not Specified	Moisture intrusion - faulty conduit connection	No	The valves were replaced and visual inspections made of the conduit connections of similar SOVs	None	None	Yes	11
361	San Onofre 2	12/17/87	87-031-01	One	Corrosion of power leads and terminal block	Main Feedwater (MFIV)	Marotta Scientific Controls Inc.	MV233C / MV238C	Inadequate maintence instructions	Yes	Replaced SOV, terminal block,and power leads. Sealed conduit connections properly.	Water and foreign material intrusion (inadequately sealed conduit connection)	LER 206/86-004	Yes	12
366	Hatch 2	09/21/84	84-021	One	Gasket	Main Steam (MSIV)	ASCO	Not Specified	Not Specified	No	Replaced gasket	None	None	Yes	03
366	Hatch 2	04/22/87	87-008	One	Stuck plunger	Feedwater turbine	Not Specified	Not Specified	Suspected inadequate lubrication or corrosion	No	Inspected and exercised SOV. Deferred repair or replacement to future outage	None	None	No	05
366	Hatch 2	01/20/88	88-004	Numerous	Leakage	Containment isolation (many systems)	Target Rock	75F-009 /7567F	Inadequate instructions/ normal use and wear	No	Reverse orientation of many SOVs/ replace failed o-rings	See Section 5.1.4 of this report	LER 366/86-020	No	08

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
366	Hatch 2	02/12/88	88-007	Twelve	Not Specified	Containment Isolation - Torus Drywell Vacuum Breaker	Target Rock	73K-001/75F-009	Inadequate instructions/ design deficiency	No	Reversed orientation/for unit one installed stronger springs	See Section 5.1.4 of this report	None	No	08
368	ANO 2	04/24/87	87-003	Two	Seat leakage	Reactor Coolant (pressurizer high point vent)	Not Specified	Not Specified	Seat leakage	No	Replaced SOV and installed a collector for any future leakage	Concern for leak causing corrosion damage to other components	None	No	03
368	ANO 2	04/29/85	88-001	Two	Leakage	Containment isolation (pass)	Target Rock	80E-001	Backwards installation due to inadequate installation instructions	No	Reinstalled SOVs in reversed orientation	See section 5.1.4 of this report for additional info	None	No	08
368	ANO 2	02/16/89	89-003	One incipient	Not Specified	Containment isolation (hydrogen analyzer sampling)	Target Rock	74F	Design error- incorrect assessment of SOV life-failure to account for heatup due to energization	No	Refurbished SOV. Checked others for similar design error	Valve had exceeded EQ life 6 years prior to discovery of problem	None	No	14
369	McGuire 1	07/23/84	84-023	One	Seat deformation	Main Feedwater	Borg Warner	Not Specified	Hydraulic fluid was leaking	No	Adjusted SOV and modified system	None	None	Yes	03
369	McGuire 1	09/19/85	85-028	One plus three incipients	Cable termination sealing	Post accident sampling	Valcor	526-5295-45	Personnel error (installation not performed per installation specification)	No	All four valves were repaired, resealed. Wiring on all other Valcor 526 series SOVs at station to be upgraded and seals replaced	Similar valves checked at Unit 2, and found to be okay	None	No	11

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
369	McGuire 1	04/15/87	87-009	One	System perturbation	Main turbine	Not Specified	Not Specified	Modification of design and maintenance	No	Change maintenance schedule to avoid testing while at power.	System operation logic and time of preventive maintenance had beenchanged. Both factors contributed to a reactor trip.	None	Yes	00
370	McGuire 2	06/24/85	85-018-01	One SOV two malfunctions	Coil and short circuit	Main feedwater	Borg-Warner	Not Specified	1- coil failure - not specified. 2- short circuit - water spray onto open electrical box	No	1- replaced SOV. 2- dried water from SOV, electrical box	Second failure occurred prior to complete installation of replacement SOV	None	Yes	01
370	McGuire 2	08/27/86	86-017	One	Coil	Main Feedwater	Borg Warner	Not Specified	Not Specified	Yes	SOV coil was replaced and original coil was sent to the manufacturer for analysis.	None	LER 85-018-01	Yes	01
373	LaSalle 1	08/29/84	84-051	One SOV (3 malfunctions)	Electrical ground	Main steam (MSRV)	Crosby Valve	IMF-2	SRV lifted due to short to ground. Reason for short not specified	No	Replaced SOV	SRV lifted spuriously three times	None	No	11
373	LaSalle 1	02/02/85	85-008	Four	Diaphragms	Reactor building ventilation	ASCO	8316	Diaphragms lost their resilience	Yes	Rebuilt SOVs, cycling frequency to be increased	Will change SOVs to nuclear qualified NP8316 model	None	No	03
373	LaSalle 1	03/12/87	87-013	Six incipients	Not Specified	Main Steam (MSRV)	Not Specified	Not Specified	High drywell temperature	No	Analyze effects of high drywell temperature	Three SOVs declared inoperable. Three SOVs suspect due to high local temperatures	None	No	10

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
374	LaSalle 2	06/08/84	84-033	One plus many incipients	Passageway blocked	Containment isolation	ASCO	206-832	SOV was improperly positioned	No	Repositioned SOV	Other similarly affected SOVs were repositioned or replaced	None	No	08
374	LaSalle 2	11/20/84	84-076	One	Coil	Turbine Steam Bypass	Not Specified	Not Specified	Junction box was full of water of unknown origin	No	Replaced SOV	None	None	No	11
374	LaSalle 2	07/31/86	86-013	None - Many incipients	Electrical connections	CRD, RCS recirc, RCIC, service water, floor drain, air	ASCO	See comments	Design error	Yes	Repaired all affected electrical terminations to meet qualification requirements	1E equipment used unqualified electrical connections. SOV model nos. HVA-206, NP206, NP-8320, NP-8323	LER 86-012	No	28
374	LaSalle 2	01/17/87	87-002	One	Leakage	Feedwater	Valcor	V52660-5292-16	Root cause of corrosion, dirt and o-ring deformation not stated	Yes	Refurbished SOV	SOV body and stem corroded, SOV filled with dirt, and o-ring was deformed	None	No	12
382	Waterford	12/11/87	87-028	One	SOV "stuck open"	Main Steam (MSIV)	Fluid Control Inc.	7WXP4774-600K865	Not Specified	No	Replaced SOV	SOV failed during testing. LER noted previous unrelated SOV failure due to open coil.	None	Yes	05
387	Susquehanna 1	02/25/84	84-010	One	SOV "stuck open"	Main steam (MSRV)	Not Specified	Not Specified	Not Specified	No	Replaced SOV	SOV stuck open causing SRV to remain open	None	Yes	05
387	Susquehanna 1	06/13/84	84-044	Several repetetive failures	Discs, seats	Control Rod Drive	ASCO	HV-176-816	Contamination of the air system and elevated temperatures	Yes	Refurbished SOVs, upgraded disc material from polyurethene to Viton	See Section 5.2.3.3 of this report	None	No	12

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
387	Susquehanna 1	07/06/87	87-023	One	Coil	Containment Vacuum Relief	Circle Seal Controls	Not Specified	"Burned open" coil	Yes	Replaced coil	Open coil found on same vacuum breaker in 10/82. A unit 2 vacuum breaker also had a similar Circle Seal SOV coil failure in 4/87	None	No	01
387	Susquehanna 1	02/04/89	89-006	Three	"Mechanically bound"	Suppression chamber drywell vacuum breaker	Circle Seal Controls	Not Specified	Root cause analysis planned but not complete yet	Yes	Replaced failed SOV and eight similar ones	One SOV failed, however two similar SOVs had "problems" ("problems" not specified)	LER 87-023	Yes	19
388	Susquehanna 2	01/10/87	87-001	Two	Not Specified	Reactor Building Chilled Water	ASCO	Not Specified	Not Specified	No	Replaced SOV	None	None	Yes	02
388	Susquehanna 2	02/27/89	89-003	One	Not Specified	Containment isolation (recirculation pump chilled water	ASCO	Not Specified	Not Specified	Yes	Replaced SOV	Licensee shut down plant instead of continuing operation at reduced power per tech specs	LER 84-036	No	21
389	St. Lucie 2	08/16/89	89-006	One	Not specified	Hydrogen sampling	Valcor	52600-515	Not specified	No	Replaced SOV	None	None	No	21
395	Summer	06/29/86	86-011	One	Electric connector	Feedwater (FWIV)	Not Specified	Not Specified	Oxidation of connector pins	No	Electrical connector and SOV were replaced.	None	None	Yes	07
395	Summer	12/02/88	88-012-01	None many incipients	Ground faults	Main Steam and Feedwater	ASCO	Not Specified	Design deficiency	No	Isolated SOV contacts to prevent spurious actuations	Found that ground faults could cause spurious SOV actuations	None	No	14

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
395	Summer	02/17/89	89-003-01	None, 3 incipients	Electrical grounding	Main steam (MSIV)	Not Specified	Not Specified	Incorrectly designed isolation relay	No	Modified wiring	Common-mode failure potential for all 3 MSIVs	LER 88-012	No	07
397	WNP 2	03/22/84	84-027-02	Fifteen	Ground faults	Main steam (MSRV)	Not Specified	Not Specified	SOV susceptibility to spurious actuation due to ground faults	Yes	Replaced defective SOVs. Tested potentially affected SOVs. Voltage spike suppression diodes were installed on all MSRV+ADS SOVs	Events at WNP occurred during startup testing. Common-mode failure potential. Previous similar events at La Salle + Susquehanna	LER 84-027-01	No	14
397	WNP 2	07/23/85	85-050	Two failures (1 SOV)	Diaphragm /seat leakage	Fire protection	Not Specified	Not Specified	Root cause of diaphragm leakage not specified. Backwards bonnet due to inadequate maintenance	No	1- Replaced diaphragm/valve seat. 2- backwards bonnet "repaired"	None	None	No	08
400	Shearon Harris 1	02/08/88	88-006	Two	Failed to close	Emergency service water pump seal water supply	Target Rock	79Q-024	Source of debris accumulation not specified	Yes	The failed SOVs were repaired. No statement made about actions taken for removal of debris or prevention of additional debris	Common-mode failure affecting both trains of Emergency Service Water	None	No	12
400	Shearon Harris 1	05/13/88	88-012	Four	Failed to shift or fully close	Emergency service water seal water supply	Target Rock	79Q-024	Debris in water	Yes	Repaired SOVs and blocked off source of debris	Common-mode failure, repetetive of event described in LER 88-06-01. Two of the failed SOVs had failed as described inthat LER.	88-006-01	No	14

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
400	Shearon Harris 1	09/09/88	88-026	Eleven or more	Internal /reed switch wiring	Containment isolation (many systems)	Target Rock	Eleven models	Manufacturing deficiency	No	Unqualified parts of 1E harsh env. SOVs replaced with qualified ones. Corrective action for non-harsh env. SOVs not specified.	Common-mode failure potential for 1E SOVs for harsh environments. SOVs for ex-containment also deficient.	None	No	06
409	La Crosse	12/03/84	84-022	One	Seat leakage	Isolation Condenser	ASCO	8210	Not Specified	Yes	Replaced SOV	None	None	No	03
409	La Crosse	04/20/85	85-008	One	Coil	Control Rod Drive	Royal Industrie s	Not Specifi ed	Not Specified	Yes	Replaced SOV	None	LER 81-13	Yes	01
409	La Crosse	05/17/85	85-012	One	Seat	Control Rod Drive	Royal Industrie s	Not Specifi ed	Root cause of metal chip in SOV seat not specified	Yes	Replaced SOV	None	None	Yes	12
409	La Crosse	07/08/86	86-020	One	Coil	Control Rod Drive	Royal Industrie s	Not Specifi ed	Uncertain, water intrusion or random coil failure suspected	Yes	Replaced SOV	There have been 7 previous scrams due to the scram solenoid shorting out.	LER 85-08	Yes	01
409	La Crosse	07/19/86	86-024	One	Electrica l short	Reactor cavity ventilation	ASCO	8300	Personnel error-splashed water on SOV	No	Replaced SOV	ESFAS actuation, cascading event	None	No	11
409	La Crosse	12/09/86	86-036-01	One	Coil	Control Rod Drive	Royal Industrie s	Not Specifi ed	Uncertain, ageing or moisture intrusion suspected	Yes	Replaced several SOVs. Replacement of SOVs will be included in CRDM preventive maintenance program	There have been 8 previous scrams due to these SOV failures. SOV that failed was about 20 years old.	LER 85-08,86-0 20	Yes	18

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
410	Nine Mile Pt 2	06/22/88	88-025	Numerous internal parts	Hydraulic Control Unit	Feedwater	Keane	33896	Foreign object in SOV, due to manufacturing deficiency or failure to install filter screen	No	Replaced SOV, also replaced similar SOVs in other trains because of serious degradation of their internals	SOV is piece-part of level control valve	None	Yes	03
410	Nine Mile Pt 2	09/15/88	88-046	None with potential for four	Inadequate control circuit separation	Control building ventilation	Not Specified	Not Specified	Design error	No	Modified Circuitry	Single failure could result in loss of both divisions of control room air filtration	None	No	14
414	Catawba 2	10/11/86	86-045	One	Failed to shift	AFW (steam admission to turbine)	Not Specified	Not Specified	SOV incorrectly installed per an incorrect design drawing	No	Reconnected SOV properly	SOV failure defeated manual start capability of AFW turbine	None	No	08
414	Catawba 2	06/27/86	87-031	Eight	O-rings, seals	Emergency diesel generator	Calcon	T-3618	Poor quality air and improper lubrication	Yes	Clean SOVs, improve air quality, use correct lubricant	Common-mode failures. See Section 5.2.4.2 of this report	None	No	04
416	Grand Gulf 1	02/10/85	85-007-02	Three	Core-plug nut sticking	Main Steam (MSIV)	ASCO	8323	FUSS	No	Replaced all 8 MSIV SOVs	See section 5.2.4.4	None	Yes	05
416	Grand Gulf 1	09/25/85	85-038-01	One	Coil	Drywell equipment drain	ASCO	8320	Excessive corrosion within the coil housing believed to be caused by water which entered during plant construction	No	Failed SOV replaced with a duplicate	Licensee stated that the SOV did not need to be environmentally sealed	None	No	11

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
416	Grand Gulf 1	07/30/86	86-026-01	One	Coil	Control Rod Drive	ASCO	1050602 5P1	Particulate accumulation on the valve seating surface	No	Replaced SOV, system filters to be checked and sampled for particulates	Particulate accumulation resulted in an inavertent control rod withdrawal	None	No	12
416	Grand Gulf 1	01/08/87	87-001	One	SOV failed in mid-posit ion	Offgas sampling	ASCO	8320	Not specified	No	Not specified	Modified system - specific actions taken regarding SOV not stated	None	No	00
416	Grand Gulf 1	03/15/88	88-010	One	Loose terminal box connectio n to SOVs	Control Rod	ASCO	Not Specifi ed	Cause of loose connection not found	No	The loose terminal connection was cleaned & tightened. Other SOV terminal connections checked, all were okay	Licensee to evaluate design change to improve reliability of power leads	None	Yes	07
416	Grand Gulf 1	08/14/89	89-013	One and seven degraded	Elastomer seats	Main steam	ASCO	NP8323	Cracked and deformed seats due to excessive time between changeouts	Yes	Replace or refurbish all affected SOVs	See Section 5.1.2.1 of this report	LER 416/85-007	Yes	17
423	Millstone 3	09/06/86	86-051	Not Specified	"Failed electrica lly"	Feedwater	Not Specified	Not Specifi ed	Intermittent open circuit, root cause unknown, suspect vibration and steam impingement from a packing leak	No	All local terminations on the SOV wiring to be checked for tightness during the next shutdown.	None	None	Yes	01

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
423	Millstone 3	03/07/87	87-008	One	Coil (open circuit)	Feedwater	Skinner Electric	V5H6620 0	Cause for open circuit not specified	Yes	Replaced SOV	SOV was operating within its "design life"	LER 86-051	Yes	00
423	Millstone 3	05/06/87	87-024	One	SOV would not shift within spec	Emergency diesel generator air start	Circle Seal Controls	N2990-9 617	Not specified	No	Failed air start SOV and the diesel's redundant SOV were replaced with new ones	Failed SOV resulted in slow (out of spec) EDG starting time	None	No	20
423	Millstone 3	09/23/87	87-034	One	Coil	Feedwater	Skinner Electric	V5H6620 0	Root cause of coil failure (open circuit) not determined. Coil was within its "qualified life"	Yes	Replaced SOV	SOV controls hydraulic oil flow to FWIV	LER 87-08/86-0 51	Yes	01
424	Vogtle 1	01/22/87	87-002	Eight incipients	Potential for MOPD	Main Steam	Keane	Not specifi ed	Design error	No	Installed a relief valve on each hydraulic system to limit pressure to below MOPD limits	Potential for common-mode MOPD failures due to heatup of hydraulic fluid. See Section 5.1.3 of this report.	None	No	13
424	Vogtle 1	04/24/88	88-013	One	Coil	Feedwater	Skinner Electric	V5H6559 0	Coil burnout	No	Replaced SOV and similar SOV on other train of FWIV control system	SOV is a piece-part of AOV controlling FWIV	None	No	01
440	Perry	06/30/86	86-030	One	Seat leakage	Containment Vessel and Drywell Purge	ASCO	8320	Suspected dust from instrument air prevented proper valve sealing	Yes	Replaced SOV	Another valve on same air line was found to have a similar problem	None	No	12

NUREG-1275

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
440	Perry	09/16/86	86-062	One	Leaking by relief port	Reactor water cleanup	Not Specified	Not Specified	Not Specified	No	Cycled to stop leaking. Subsequently repaired the valve	None	None	No	03
440	Perry	02/27/87	87-009	Two	Air leakage (through elastomeric parts)	Emergency Diesel Generator Control Air	Humphrey Products	TOG2E1-3-10-35	Failure due to extended service with high local temperatures and continuous energization. SOVs in svc two years and never had PM	Yes	Replaced Both SOVs. Returned failed SOVs to EDG manufacturer for analysis. Will upgrade preventive maintenance and elastomers	Simultaneous common-mode failure of both diesels. Delay in repairing leaking SOVs contributed. See Section 5.2.1.2 this report.	None	No	17
440	Perry	10/29/87	87-073-01	Five SOVs on two occasions	Elastomeric seats, discs, etc	Main steam (MSIV)	ASCO	NP8323	Heat and moisture from steam leaks	Yes	Replaced or refurbished SOVs	Common-mode failures. See Section 5.1.1.1 of this report for additional information	Insp Rpt 87-024	Yes	10
440	Perry	03/10/88	88-010	One	Core shaft wear	Auxiliary Building Ventilation	ASCO	8320	Inadequate (no) preventive maintenance for this SOV (replace when fail). Valve had been in service for over 5 years	No	Replaced SOV. Instituted a preventive maintenance program upgrade to replace those SOVs every 2 years	Failure of SOV results in loss of RWCU room cooling	None	No	17
440	Perry	02/03/89	89-004	One	Not Specified	Auxiliary building ventilation	ASCO	8320	Not Specified	Yes	Replaced SOV	Licensee investigating root cause	LER 88-010	No	19

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
440	Perry	11/25/89	89-030	Two plus many "suspect"	Seat	Scram	ASCO	HV176-816-1	Manufacturing defect	Yes	Replace failed and "suspect" SOVs	Common-mode failures. See Section 5.3 of this report for additional information	None	No	03
454	Byron 1	01/29/86	86-003	One	Spurious operation	Main steam	Not Specified	Not Specified	Ground fault	No	Replaced other electrical equipment associated with the ground faults	None	None	Yes	07
456	Braidwood 1	09/15/89	89-010	One	Coil	Containment Isolation (hydrogen analyzer)	Valcor	V526-5395-1	Coil leads labeled backwards	No	Replaced with different model SOV	Also replaced 5 other similar SOVs. Licensee investigating source of mislabeling (manufacturer vs. plant)	None	No	09
458	River Bend	05/02/89	89-022	Ten potential	Spurious opening	Affected many systems. Air,ADS/SRV, Main Steam(MSIV)	Target Rock	77kk-013	Backwards installation due to inadequate installation instructions	Yes	SOVs reinstalled in reverse orientation	See Section 5.1.4 of this report for additional details	LER 89-024	No	14
458	River Bend	04/06/89	89-024	Potential for six	Spurious opening	Affected many systems. Inst air accums. See comment	Target Rock	77KK-013	Backwards installation - design error. Inadequate installation instructions.	Yes	Reversed orientation of SOVs	Potential common-mode failures. Six SOVs had the same installation deficiency. See section 5.1.4 of this report	LER 89-022	No	08

SOLENOID-OPERATED VALVE FAILURE DATA

DOC NO.	PLANT NAME	EVENT DATE	LER NUMBER	NO. OF FAILURES	FAILED PART	SYSTEM	MANUFACT	MODEL NO.	ROOT CAUSE	REP FL	CORRECTIVE ACTION	COMMENTS	REFERENCE DOCUMENTS	TP/ OUT	FC
461	Clinton	03/06/87	87-009	One	SOV failed in mid position	Fuel Building Ventilation	Not Specified	Not Specified	Not Specified	No	Replaced SOV	None	None	No	03
461	Clinton	04/14/89	89-019	Not Specified	Electrical connections	Main steam (MSIV)	Seitz	Not Specified	Design error (EQ). Inadequate electrical connector sealing	No	Install heat shrink tubing per EQ requirements	Failed to meet EQ installation requirements	None	No	08
461	Clinton	11/29/89	89-037	One	O-rings	Vacuum relief	GPE Controls (SOV unspecified)	LD240-420 (GPE)	Inadequate preventive maintenance	No	Refurbished SOV, replaced O-rings	No scheduled preventive maintenance program. Failure discovered during stroke testing	None	No	03
483	Callaway	01/02/85	85-001	One	Not Specified	Feedwater	Not Specified	Not Specified	Licensee considered this to be a random failure	Yes	Replaced SOV	SOV is a piece-part of FWIV hydraulic operator	None	Yes	00
483	Callaway	02/20/86	86-002-01	None	Electrical connectors	Reactor head vent and chemical volume control	Not Specified	Not Specified	Construction and startup program deficiencies	Yes	Not Specified	On 2 occasions licensee found it had not installed environmentally qualified connectors on SOVs as required (3 SOVs)	None	No	28
528	Palo Verde 1	08/08/85	85-052	Two or more incipients	potential insulation breakdown /shorts to ground	Post accident sampling	Airmatic	Not Specified	Design error	No	Affected SOVs were shielded to reduce post accident radiation	SOVs control air-operated sample flow control valves	None	No	14

APPENDIX B

TARGET ROCK CORPORATION INFORMATION REGARDING SPURIOUS OPENING AND VALVE ORIENTATION*

*Please note the American Society of Mechanical Engineers has granted the NRC permission to reproduce ASME Technical Paper 81-PVP-39 (pages B-15 through B-21) by telecopy dated February 12, 1991.

Target Rock Corporation, 1966E Broadhollow Rd., P.O. Box V, Farmingdale, N.Y. 11735-0917

SUBSIDIARY, CURTISS-WRIGHT CORPORATION

July 12, 1990

Dr. Hal Ornstein
U.S. Nuclear Regulatory Comm.
AEOD MNB 9715
Washington, D.C. 20555

Subject: Preliminary Case Study Report on Solenoid Valve Problems at U.S. Light Water Reactors.

Dear Dr. Ornstein,
The subject report was reviewed and the following comments relative to spurious opening and/or valve orientation are hereby offered.

In Section 5.1.4, two separate basic problems were discussed. Solution, by re-orientation of the valve in one type problem is not necessarily the fix for the other.

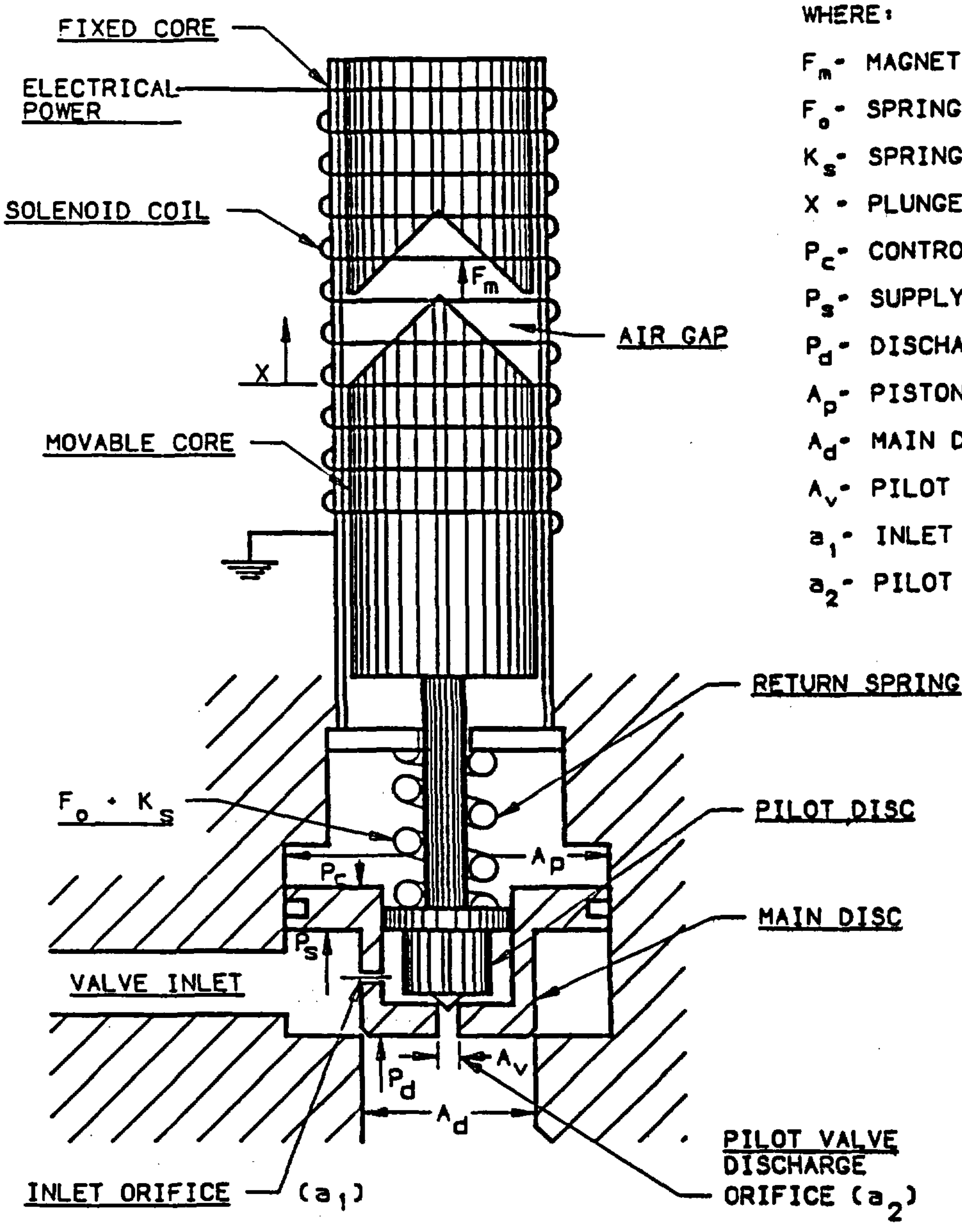
The two basic problems are:

1. Unexpected short term (spurious) opening of a unidirectional valve.
2. Unexpected reverse pressurization (long term) opening of a unidirectional valve.

Figure 1 is a representative sketch of a unidirectional valve. The figure depicts a closed, de-energized valve, wherein inlet pressure (Ps), enters radially inward, and provides an upward force on the piston portion of the main disc. Control pressure (Pc) acting in opposition, negates this lifting force and additionally provides valve closure force by its effect on the disc port area (Ad). With the pilot valve closed, Pc equals Ps. At the introduction of an inlet pressure surge, supply pressure is momentarily higher than control pressure, until control pressure re-establishes equality with supply pressure by the flow of fluid thru the inlet orifice (a1). Consequently there is a time delay in equalization of these pressures. Should the lifting force exceed the closure forces, the valve will lift. The valve will remain open until the downward force overcomes the lifting force, where upon the valve again closes, and the closure force builds up to full value again.

FAX: (516) 293-4949 Telephone: (516) 293-3800 EASYLINK: 5106000141

TYPICAL PILOTED SOLENOID VALVE CONFIGURATION



WHERE:

F_m - MAGNETIC ATTRACTIVE FORCE
F_o - SPRING LOAD FORCE
K_s - SPRING RATE
X - PLUNGER DISPLACEMENT
P_c - CONTROL PRESSURE
P_s - SUPPLY PRESSURE
P_d - DISCHARGE PRESSURE
A_p - PISTON AREA
A_d - MAIN DISC SEAT AREA
A_v - PILOT VALVE SEAT AREA
a_1 - INLET ORIFICE AREA
a_2 - PILOT VALVE EFFECTIVE AREA

PILOT VALVE

(MAGNETIC) FORCE UP - F_m

FORCE DOWN - $F_o + K_s \cdot X + (P_c - P_d) \cdot A_v$

MAIN DISC

FORCE UP - $P_s (A_p - A_d) + P_d \cdot A_d$

FORCE DOWN - $P_c \cdot A_p$

FIGURE 1

The problem is most severe when the first of two valves mounted in series opens rapidly, permitting full supply pressure to be sharply introduced to the second valve. In the reactor head vent application, full 2500 PSI fluid pressure may suddenly be applied to the second valve when the upstream valve is opened. This has caused short burst valve opening as evidenced at the H. B. Robinson 2 plant for example.

The anomaly was immediately analyzed and simulation tested as reported in the Target Rock Report # 2866. A series of presentations were made, specifically to Westinghouse and Combustion Engineering. Westinghouse Engineers produced an ASME paper on the subject and thus made it available for all utilities. Target Rock had offered the attached memo, V. Liantonio to D. Vater, which introduced these documents and were sent in response to all utilities upon request. Note that one suggested fix is to rotate the valve on the pipe axis to direct the bonnet tube downward. This permits the bonnet tube and central chamber to be filled with condensate (water) which offsets the valve spurious opening action.

Improper Flow Direction - also addressed under 5.1.4.1 entitled "Incorrect Orientation" is the concern with valve mounting direction relative to flow direction. Following normal instructions, the flow through a unidirectional valve is over the disc. However, there have been applications where the Architect Engineers (AE) have deliberately opted to install valves such that normal flow is under the disc and intentionally require the valve to operate as a check valve. This option was selected because of limitations of the other choices. These other choices are : a) Balanced disc design b) Miniaturized disc with heavy return spring; and (c) Standard unidirectional disc with a check valve installed through the disc.

(a) In the case of a balanced disc, the piston area is designed equal to the seating area. As a result, inlet pressure "sees" the same area in opposite directions, resulting in a zero differential force. When inlet pressure is introduced under the disc it is ducted above the piston by a large transfer hole through the disc. Hence, equalized forces result with flow under the disc. Consequently, with flow introduced in either direction, the pressure times area forces are balanced, and spurious opening would not take place, nor will the valve open simply by direction of flow. The force balance, however, can only be effective within reasonable limits of machining tolerances. As the pressure differential across the valve increases, minor differences in piston area compared to disc seating area cause large force inbalances. Nor full ported valves, pressure differentials beyond 500 psi require abnormal machining precision and thus not generally used.

(b) A Simple design that can be controlled with flow in either direction is a direct acting design using a small disc and a heavy spring. In this way pressure may be applied in either direction, with the spring force selected high enough to overpower the pressure times seating area force. The limitation, of course, is the valve full flow capacity which may be 100 to 200 times smaller than available in a piloted design.

(c) Check valve in disc - since in most applications, it is simply required that the valve not permit flow in a reverse direction, a check valve in the main disc has been provided. The check valve will permit valve downstream pressure to enter the control chamber (above the piston of a unidirectional disc) whenever the downstream pressure is higher than control pressure. This builds up control pressure to keep the disc closed. In this design, flow, normally over the disc, is controlled by pilot valve command; while flow, introduced under the disc, will build up control pressure and keep the valve closed (for emergency only).

Note that there may be some other areas of the subject report that could generate additional comments. These will be offered as soon as possible.

Very truly yours,
TARGET ROCK CORPORATION

Vito Liantonio

Vito Liantonio
Manager, Application
Engineering Group

VL/so
Attachments
cc: R. Langseder
K. Wenzel
T. Crowley
E. Bajada
R. Glazier
S. Karidas
File - NRC

MEMO

October 2, 1984

TO: D.K. Vater

FROM: V. Liantonio

SUBJECT: Spurious Opening of Pilot Operated Solenoid Valves

REFERENCES: 1) Target Rock Report #2866; Solenoid Valve Response to Inlet Pressure Transient, 12/17/80

2) ASME Publication 81-PVP-39, April 1981, Spurious Opening of Hydraulic-Assisted, Pilot Operated Valves - An Investigation of the Phenomenon.

The two referenced documents provide an adequate understanding of the subject phenomenon. The design of most pilot assisted valves will develop a transiently applied force tending to open the valve when a rapidly applied pressure increase is sensed at the valve inlet. The most effective deterrent to this action is to maintain the valve filled with liquid. The pressure build up in a liquid filled control chamber is fast enough to prevent valve opening for all practical pressure transient rates applied to the valve inlet. Also, one of the easiest methods to achieve this is to mount the valve with the bonnet tube directed downward, or as a minimum, below the horizontal.

The worse case scenario is one where the bonnet tube is filled with a gas (usually air at atmospheric pressure) and a pressure build up occurs at the valve inlet. The pressure build up, however, was required (per Reference 1) to occur at a rate of 250 psi/sec or higher. This build up must also exceed two times the pressure existing in the control chamber, immediately prior to the application of the pressure increase. Should transient pressure buildup be predictably slow, therefore, no special consideration is required.

Recommendations:

1 - For valves discharging liquid to ambient (as is the case of the last valve in the chain of reactor head vent valves), mount the valve with the bonnet tube below the horizontal.

2 - Where possible, maintain positive pressure at the valve discharge port (See Reference 1).

3 - Locate valves discharging to ambient where spurious opening will not compromise personnel or plant safety.

Vito Liantonio
Manager, Engineering

VL/cj

cc: Messrs: D.M. Pattarini
Code Engineers

Attachments - References 1 and 2.

COPY NO.

REPORT NO. 2366
PROJECT NO. 792-59
DATE 12/17/80
TOTAL PAGES 8

SOLENOID VALVE RESPONSE TO INLET PRESSURE TRANSIENT TESTS CONDUCTED AT TARGET ROCK CORP. 11/13/80 thru 11/15/80

TARGET ROCK CORPORATION

EAST FARMINGDALE, LONG ISLAND, N. Y.

PREPARED BY	TARGET ROCK CORPORATION EAST FARMINGDALE, LONG ISLAND, N. Y.	PAGE i
CHECKED BY		REPORT 2966
APPROVED BY		PROJECT 792-59

REVISIONS

LETTER	DESCRIPTION	DATE	BY	APP.	LIST OF EFFECTIVE REVISIONS OF PAGES NO.	-	A	B	C	D	E	F	G	
-----	First Issue	12/17/80	RAW [signature]	[signature] 12/23/80	TITLE	x								
					i	x								
					1	x								
					2	x								
					3	x								
					4	x								
					5	x								
					6	x								
					7	x								
					8	x								

Static Condition A) The test valve and piping system was flushed with water to remove most of the trapped air. Some quantity of air probably was retained in the upper region of the valve bonnet tube since this area is out of the normal flow stream. (see Table I for test data).

Static Condition B) The test valve and piping system was drained, purged with air, then pressurized at 500 psig with Argon gas. Some small quantity of water probably was retained in the area of the valve disc due to the bonnet tube position of approximately 40° from vertical. (see Table II for test data)

Static Condition C) The test valve and piping system was drained, purged with air, and vented to establish atmospheric conditions within the system. (see Table III for test data)

RESULTS:

STARTING AT STATIC CONDITION (A): (Ref. Table I)

A series of pressure transients were initiated after establishing a water filled system at 0 psig. or slightly higher to prevent the entrance of air. The piping system was reduced to this pressure level before each transient test.

The transients were conducted by increasing the pressure within the piping from 0 psig to: 100, 200, 300, 400, 500, 750, 1000, 1500, 2000, and 2500 psig. At each pressure level, at least one test was conducted at a transient rate of 2500 psi per second.

STARTING AT STATIC CONDITION (C):(Ref. Table III)

These tests were conducted with the valve and piping drained and purged with air prior to each transient as in (B) above, except the system was at atmospheric pressure prior to introducing water at pressures of 100, 150, 200, 300, 450, 500, 700, 800, and 900 psig.

The transient rates varied from 250 to 2750 psig per second.

At a number of these test points, the main disc lifted momentarily, allowing various amounts of water to flow before re-seating against upstream pressure. Because of the limited flow capability of the test facility, when the disc opened, the pressure transient rate could not be maintained. Because of this, the accuracy of the rate of pressure change measured from the actual recording of the test may be in error.

In some cases, an increase in the transient rate did not result in increased water flow through the valve.

A review of the data indicates that the Condition at which a pressure transient is most likely to cause the valve disc to momentarily open, is one where the valve and piping is charged with air at atmospheric pressure prior to a pressure transient that introduces water into the system at a rate in excess of 250 psi per second.

Water filled systems and air filled systems pressurized to 500 psig, appear to be able to withstand far greater pressure transient rates than air filled systems at atmospheric pressure without causing the valve disc to momentarily open.

TRC FORM 61693

One transient test was conducted starting at 500 psig static pressure within the system. The pressure was then increased to 1500 psig. At a rate of 7750 psi per second, there was no evidence of water flow through the valve during this test, indicating that the valve disc remained seated.

Of the 18 pressure transient tests conducted, only one resulted in water flow from the valve outlet. This test was conducted in the range of 0 to 100 psig at a rate of 1700 psi per second. This test was initiated immediately after bleeding the accumulator to atmospheric pressure and recharging to 100 psig. Apparently air entered the piping system during this operation causing the valve disc to memoentarily lift during the following test. Three additional tests were conducted at this pressure level at rates of 2000, 2250, and 2750 psi per second with no evidence of water flow from the valve outlet.

STARTING AT STATIC CONDITION (B): (Ref. Table II)

After purging, the valve and piping system was charged with gas (Argon) at 500 psig. These conditions were established prior to each pressure transient.

The transients were conducted by introducing water into the piping system at pressures of 1500, 1600 and 1900 psig at rates of 2000, 2500, 3000, 3750, 4000 and 5500 psi per second.

There was no evidence of water flow from the valve outlet during these tests.

TRV FORM E1093

TABLE I

WATER FILLED SYSTEM PRIOR TO TRANSIENT TESTS

TRANSIENT NO.	STATIC PRESSURE PRIOR TO TRANSIENT PSIG (H_2O)	SYSTEM PRESSURE @ COMPLETION OF TRANSIENT PSIG	TRANSIENT PRESSURE RATE PSI/SEC.	WATER ACCUMULATION TOTAL C.C.
1	Atmospheric	1000	750	None
2	Atmospheric	1000	5350	None
3	Atmospheric	1500	3500	None
4	Atmospheric	1500	11,000	None
5	500	1500	7750	None
6	Atmospheric	2000	4750	None
7	Atmospheric	2500	7000	None
8	Atmospheric	750	5500	None
9	Atmospheric	500	4250	None
10	Atmospheric	400	3750	None
11	Atmospheric	300	2500	None
12	Atmospheric	200	1000	None
13	Atmospheric	200	1000	None
14	Atmospheric	200	3750	None
15	Atmospheric	100	1700	215
16	Atmoshperic	100	2000	None
17	Atmoshperic	100	2750	None
18	Atmoshperic	100	2250	None

TOY POST 11092

TABLE II

GAS CHARGED SYSTEM PRIOR TO TRANSIENT TESTS

TRANSIENT NO.	STATIC PRESSURE PRIOR TO TRANSIENT PSIG	SYSTEM PRESSURE @ COMPLETION OF TRANSIENT PSIG	TRANSIENT PRESSURE-RATE	WATER ACCUMULATION TOTAL C.C.
1	500	1500	2000	None
2	500	1500	2500	None
3	500	1500	3000	None
4	500	1500	3000	None
5	500	1500	3000	None
6	500	1600	3750	None
7	500	1900	4000	None
8	500	1900	5500	None

TABLE III

AIR FILLED SYSTEM PRIOR TO TRANSIENT TESTS

TRANSIENT NO.	STATIC PRESSURE PRIOR TO TRANSIENT PSIG (AIR)	SYSTEM PRESSURE @ COMPLETION OF TRANSIENT PSIG	TRANSIENT PRESSURE RATE PSI/SECOND	WATER ACCUMULATION TOTAL C.C.
1	Atmospheric	700	1750	1750
2	Atmospheric	700	1900	380
3	Atmospheric	800	2500	300
4	Atmospheric	900	2000	85
5	Atmospheric	900	1250	20
6	Atmospheric	900	1200	None
7	Atmospheric	300	1000	505
8	Atmospheric	450	1000	385
9	Atmospheric	500	1500	95
10	Atmospheric	500	750	None
11	Atmospheric	300	1900	110
12	Atmospheric	300	2750	25
13	Atmospheric	300	250	None
14	Atmospheric	300	1100	35
15	Atmospheric	300	1750	25
16	Atmospheric	300	1500	85
17	Atmospheric	300	500	None
18	Atmospheric	300	600	20
19	Atmospheric	200	2100	None
20	Atmospheric	200	1750	50
21	Atmospheric	200	2000	70
22	Atmospheric	200	500	None
23	Atmospheric	200	900	12
24	Atmospheric	200	750	None
25	Atmospheric	150	1250	None
26	Atmospheric	100	1000	None
27	Atmospheric	100	1200	None
28	Atmospheric	100	1200	None

TGV POST E1693

PREPARED BY	TARGET ROCK CORPORATION EAST FARMINGDALE LONG ISLAND, N. Y.	PAGE 8 OF 8
CHECKED BY		REPORT 2966
APPROVED BY		PROJECT 792-59

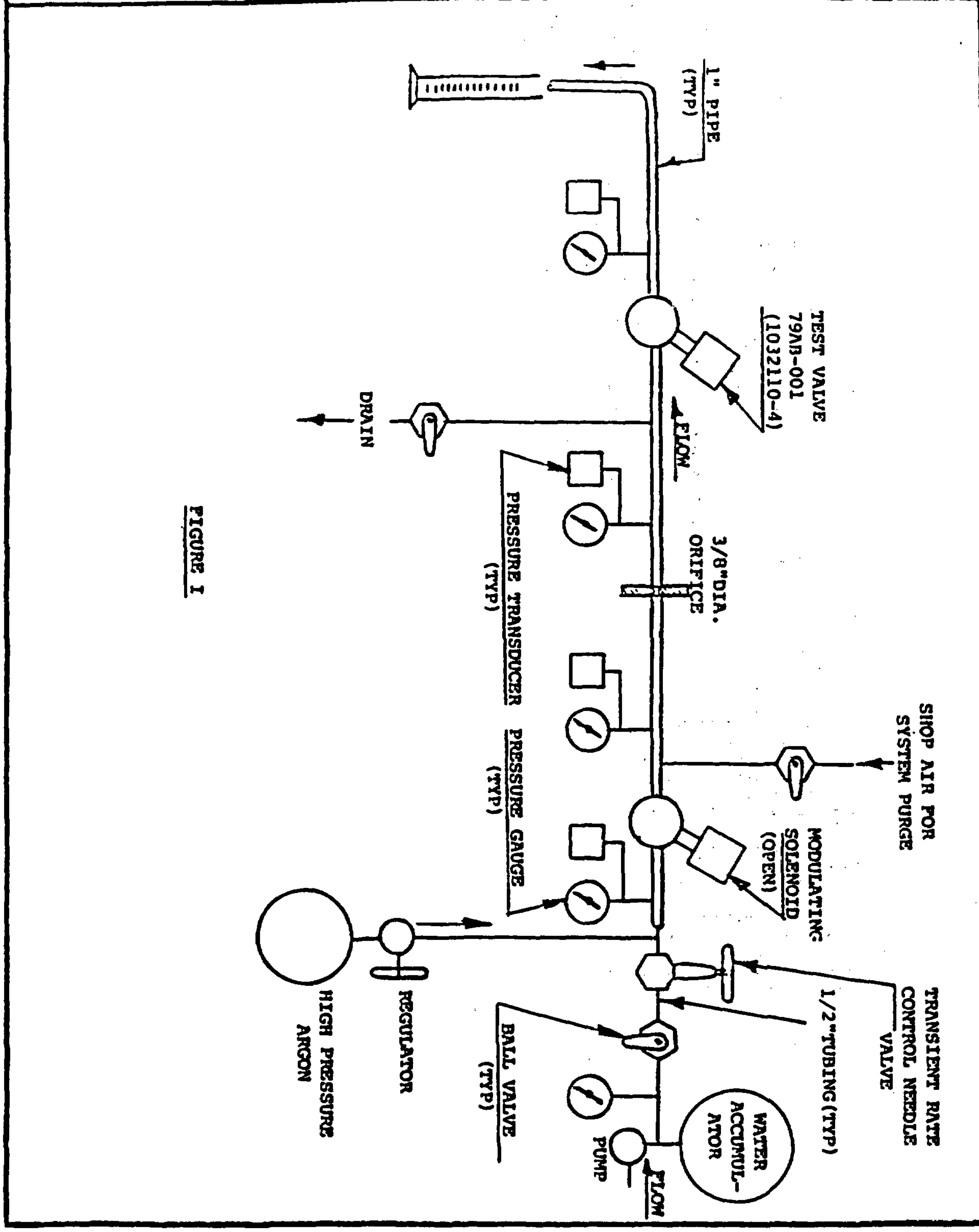


FIGURE I

TDV FOST 11893

AN ASME PUBLICATION
$4.00 per copy $2.00 to ASME Members

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
345 E 47 St., New York, N.Y. 10017

Spurious Opening of Hydraulic-Assisted, Pilot-Operated Valves— An Investigation of the Phenomenon

L. I. Ezekoye
Senior Engineer

E. J. Rusnica
Manager

Auxiliary Equipment Engineering,
Westinghouse Electric Corp.,
Pittsburgh, Pa.

This paper investigates the spurious opening phenomenon of hydraulic-assisted, pilot-operated valves. The equations governing the valve response were developed to provide an insight into the phenomenon. Sensitivity studies were then performed to demonstrate the possibility of this type of valve spuriously opening under certain pressure transient events. The deductions were later confirmed by tests to show how a typical pilot-operated valve might respond to pressure transients in water solid and compressible fluid media. The significance of this phenomenon is discussed in terms of its effect on valve usage.

NOMENCLATURE

A_o	= orifice area
A_p	= piston area
A_s	= plug seat area
C	= discharge coefficient
F_o	= spring preload
g	= acceleration due to gravity
K_a	= pneumatic spring constant
K_s	= mechanical spring constant
n	= polytropic exponent
P_c	= steady-state chamber pressure
P_i	= steady-state inlet pressure
P_{it}	= inlet transient pressure
P_f	= chamber pressure at force reversal point (p_{it}/α)
P_o	= valve outlet pressure
V_a	= air volume
V_{ai}	= initial air compressed volume
V_{at}	= air flow volume
V_c	= control chamber volume
V_p	= piston displacement volume
V_w	= water flow volume
Y	= compressible flow expansion factor
ΔP_{cr}	= critical pressure drop
ρ	= density
τ	= time (sec)
δ	= displacement
α	= ratio of pressure surge to steady-state pressure
ΣF	= sum of forces

INTRODUCTION

The demands for nuclear valves to withstand adverse environment of radiation and temperature and at the same time be able to sustain high seismic loads have spurred innovative use of fluid media to assist conventional electric operators in valve actuation. This class of valves is generally referred to as hydraulic-assisted, pilot-operated valves. Figures 1a and 1b and 2a and 2b show two versions of the valve design. Basically, the valve incorporates a pilot valve in conjunction with system differential pressure across the valve to open or close the valve port. The pilot valve can be external, as in Figure 1a, or internal as in Figure 2a. Although these valves are usually electric solenoid-operated, they could be pneumatic, or even manual.

Referring to Figure 1a, with the pilot valve closed, the control chamber pressure builds up to inlet pressure value. The resulting force differential on the main valve plug plus the force on the compression spring closes the valve. With the pilot valve open, as in Figure 1b, there is a direct flow path between the control chamber to the valve outlet port. The chamber pressure subsequently drops to the level of downstream pressure. A pressure differential builds up across the main valve plug, thus opening the valve. In the second version of hydraulic-assisted, pilot-operated valve, the pilot valve is internal. Referring to Figure 2a, with the pilot valve closed, the pressure in the control chamber increases to the level of the inlet pressure. When the control chamber pressure force exceeds the inlet pressure force, the force differential closes the valve, shutting off flow. However, when the pilot valve is open, as shown in Figure 2b, the control chamber is vented. The venting creates an opening pressure differential across the main valve plug, opening the valve.

Contributed by the Pressure Vessels & Piping Division of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS for presentation at the Joint Conference of the Pressure Vessels and Piping, Materials, Nuclear Engineering and Solar Divisions, June 21-25, 1981, Denver, Colorado. Manuscript received at ASME Headquarters April 6, 1981.

Copies will be available until March 1, 1982.

Use of this type of valve offers significant advantages over conventional motor-or air-operated globe valves in certain applications. Chief among them are weight reduction and overall valve compactness with a low center of gravity. Valve weight and center of gravity contribute significantly to piping stresses and to the attendant corrective piping support cost. Therefore, lightening the valve weight and reducing the center of gravity are very desirable features in valve design. Another significant advantage is the fact that the valve can be totally electric-operated thus permitting IEEE qualification and still provide fast fail-safe closure capability. These, and other advantages, have contributed to the increasing usage of these valves in nuclear power plants.

However, there are inherent and latent limitations with this valve as with any other valve. This paper investigates one of these limitations which is the potential for the valve to spuriously open under severe step-up pressure transients. Spurious opening phenomenon is defined as a closed valve suddenly opening and reclosing without a signal or electric power input. This phenomenon has been called "hicupping" and "burping". It was first noted by the authors to occur when valves of this type were subjected to severe step-up pressure transients. In this paper, we shall develop valve response equations in various fluid media to show when the valve would open.

RESPONSE EQUATIONS

Response times will be calculated for three systems. The first case is an air-to-air system when the valve is air-filled and suddenly exposed to higher pressure air. The second case is a water-to-air system when the valve is initially air-filled and suddenly exposed to higher pressure water. The last case is the water-to-water system when the valve is water-filled and suddenly exposed to higher pressure water.

Before the analysis can proceed, it is necessary to define what constitutes a severe pressure transient that would be of concern. To do this, we refer to Figure 3, which shows schematically a fully seated hydraulic-assisted, pilot-operated globe valve.

In this seated position, the following relations exist:

$$P_c A_p + F_o > P_i (A_p - A_s) + P_o A_s \quad (1)$$

and

$$P_c = P_i \quad (2)$$

If we neglect P_o and F_o, Equation (1) reduces to:

$$A_p > (A_p - A_s) \quad (3)$$

Equation (3) confirms what we know already, which is that the piston area has to be greater than the difference of the piston and the seat areas to provide hydraulic assistance.

Let us now examine what happens when the valve is suddenly exposed to a pressure rise. Because the refill orifice is generally too small to quickly balance pressures between the inlet and the control chamber, the valve begins to lift. When the valve plug is on the verge of opening, the following conditions exist:

$$P_c A_p + F_o = P_{it} (A_p - A_s) + P_o A_s \quad (4)$$

and

$$P_c < P_{it} \quad (5)$$

Neglecting F_o and P_o, Equation (4) reduces to:

$$P_c A_p = P_{it} (A_p - A_s) \quad (6)$$

or

$$\frac{A_p}{A_p - A_s} = \frac{P_{it}}{P_c} = \frac{P_{it}}{P_i} = \alpha \quad (7)$$

Equation (7) provides the ratio of pressure transient to steady-state inlet pressure that must be evaluated for valve stability. What this means is that step-up pressure transients, which are less than α times the normal steady state pressure need not be considered as posing any concern. If, however, the step-up pressure is equal to, or greater than, α times the steady-state pressure, the valve can open, depending on the fluid medium. The opening process continues until the control chamber pressure reaches P_{it}/α, at which point the valve begins to reclose. The position where the valve plug momentarily stops and begins to reclose is referred to in this paper as the force reversal point.

ANALYSIS

To evaluate the valve stability, the analysis proceeds to calculate the response time required for the valve to reach the force reversal point. If the time is very insignificant or a very small fraction of the normal opening time, the valve will remain closed. If, however, the response time is a significant fraction of, or is even equal to or greater than the normal valve opening time, the valve will be open.

Case 1: Air-to-Air Transient

The valve is air-filled and is suddenly exposed to higher pressure air. Figures 4a, 4b and 4c illustrate what would happen if the valve spuriously opens.

Let V_c be the volume of the control chamber. Therefore, at the force reversal point as shown in Figure 4b,

$$V_c = V_a + V_p \quad (8)$$

where

$$V_a = V_{ai} + V_{at} \quad (9)$$

Assuming isentropic compression of original air in the chamber,

$$V_{ai} = V_c \left(\frac{P_c}{P_f}\right)^{1/n} \tag{10}$$

The flow through the refill orifice is

$$V_{at} = YCA_o \left(\sqrt{\frac{2g\,\Delta P_{cr}}{\rho}}\right)\tau \tag{11}$$

The piston volume displacement is

$$V_p = A_p\,\delta \tag{12}$$

To determine the piston volume displacement we have to perform a force balance at the force reversal point by setting $\Sigma F = 0$

Therefore,

$$F_o + K_s\delta + K_g\delta = P_{ic}\,(A_p - A_s) \tag{13}$$

Neglecting F_o and K_s, Equation (13) reduces to

$$K_g\,\delta = P_{ic}\,(A_p - A_s) \tag{14}$$

or

$$\delta = \frac{P_{ic}\,(A_p - A_s)}{K_g} \tag{15}$$

where K_g is the pneumatic spring constant defined by

$$K_g = \frac{n\,P_f\,A_p^2}{V_a} \tag{16}$$

Substituting Equation (16) into Equation (15), we have

$$\delta = \frac{1}{n}\left(\frac{P_{ic}}{P_f}\right)\left(\frac{A_p - A_s}{A_p}\right)\frac{V_a}{A_p}$$

Since $\frac{P_{ic}}{P_f} = \frac{A_p}{A_p - A_s} = a$, then $\delta = \frac{1}{n}\frac{V_a}{A_p}$ (17)

The piston volume displacement becomes

$$V_p = V_a/n \tag{18}$$

Substituting Equations (9), (10), (11), and (18) into Equation (8), we have:

$$V_c = \left(\frac{n+1}{n}\right)\left[V_c\left(\frac{P_c}{P_f}\right)^{1/n} + \left(YCA_o\sqrt{\frac{2g\Delta P_{cr}}{\rho}}\right)\tau\right] \tag{19}$$

Solving for time, τ, we have

$$\tau = \frac{\left[\left(\frac{n}{n+1}\right) - \left(\frac{P_c}{P_f}\right)^{\frac{1}{n}}\right] V_c}{YCA_o\sqrt{\frac{2g\Delta P_{cr}}{\rho}}} \tag{20}$$

<u>Case II: Water-to-Air Transient</u>

In the water-to-air transient, the valve is air-filled and is suddenly exposed to a step-up higher pressure water. Figures 5a, 5b, and 5c illustrate the valve dynamics. As in the air-to-air case, Figure 5b corresponds to the force reversal point. At this point, the following relationships exist:

$$V_c = V_{ai} + V_w + V_p \tag{21}$$

where

$$V_{ai} = V_c\left(\frac{P_c}{P_f}\right)^{\frac{1}{n}} \tag{22}$$

$$V_w = \left(C\,A_o\sqrt{\frac{2g\Delta P_{cr}}{\rho}}\right)\tau \tag{23}$$

and

$$V_p = A_p\,\delta \tag{24}$$

The displacement δ is given for this case as:

$$\delta = \frac{V_{ai}}{n\,A_p} \tag{25}$$

Therefore, the piston volume displacement becomes

$$V_p = \frac{V_c}{n}\left(\frac{P_c}{P_f}\right)^{\frac{1}{n}} \tag{26}$$

Combining Equations (22), (23), and (26)

$$V_c = V_c\left(\frac{P_c}{P_f}\right)^{\frac{1}{n}}\left(\frac{n+1}{n}\right) + \left(C\,A_o\sqrt{\frac{2g\Delta P_{cr}}{\rho}}\right)\tau \tag{27}$$

Solving for time,

$$\tau = \frac{V_c\left[1 - \left(\frac{P_c}{P_f}\right)^{\frac{1}{n}}\left(\frac{n+1}{n}\right)\right]}{C\,A_o\sqrt{\frac{2g\Delta P_{cr}}{\rho}}} \tag{28}$$

Case III: Water-to-Water Transient

In the water-to-water transient case, the valve is initially filled with water and suddenly subjected to higher step-up pressure. This case is considered to be of no concern for the simple fact that water is virtually incompressible with a bulk modulus of 300,000 psi, hence there is no piston displacement. In this case, therefore, the valve remains closed in spite of the pressure changes.

Discussion

In the foregoing analyses, we have developed the equations describing the response times for air-to-air system and water-to-air system. At this time, therefore, it is important to restate the criteria for opening. To do this, we would like to point out that most of these valves normally open fully between 0.1 and 0.5 seconds. Therefore, any valve which responds to a pressure surge in less than 10% of its normal opening time will not open. Using this criterion, we evaluated the response times for an air-to-air case and a water-to-air case for a hypothetical valve using the parameters tabulated in Table 1. The results of the analysis are plotted in Figure 6. As can be seen, the air-to-air system is rather insensitive to pressure surges while in the water-to-air system the valve opens.

TABLE 1
Valve Parameters

Valve Size = 1 inch
$V_c = 4.2 \ in^3$
$A_o = 0.002 \ in^2$
$\alpha = 2$
$C = 0.65$
Normal Opening time 0.5 sec.
$P_c = 15$ psia

Test

To verify the validity of the analysis, a limited test was conducted to demonstrate the phenomenon. Figure 7 illustrates the test setup. Three tests were conducted to simulate each of the three cases. The results of the tests are summarized in Table 2.

TABLE 2
Test Results

System	P_c (psia)	P_{ic} (psia)	Burping
Air-to-air	500	1500	None
	500	1900	None
Water-to-air	15	200	Yes
	15	500	Yes
	15	900	Yes
Water-to-water	15	100	None
	15	500	None
	15	1000	None
	15	2000	None

REMARKS

Based on the results of the analysis and the tests, it appears that this phenomenon is most likely to occur when this type of valve, in a gas or steam application, is suddenly exposed to high-pressure water. There is very little likelihood that this will occur in air-to-air or water-to-water systems.

Although the foregoing analysis is based on step change, fast pressure transients, there are actually very few occasions where such events occur. These types of transients can, however, be produced by water hammer. Also, they can be generated by opening any fast-acting upstream valve in a series double isolation application.

On the basis of the above observations, valve usage should be judiciously made to prevent the valve being exposed to fast transients, thus minimizing the likelihood of a spurious opening. Additionally, valve location should be such that, if the valve happens to open spuriously, the resultant leakage through the main seat would not compromise personnel and plant safety.

ACKNOWLEDGEMENT

The authors wish to thank Mr. A. Jen of Westinghouse Valve Engineering for his assistance in collecting the test data.

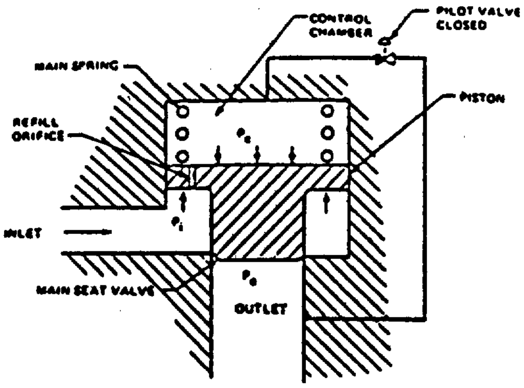


Figure 1a. External Piloted Valve (Closed Position)

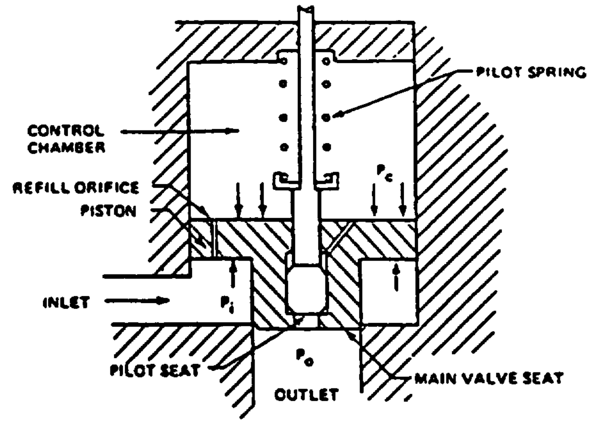


Figure 2a. Internal Piloted Valve (Closed Position)

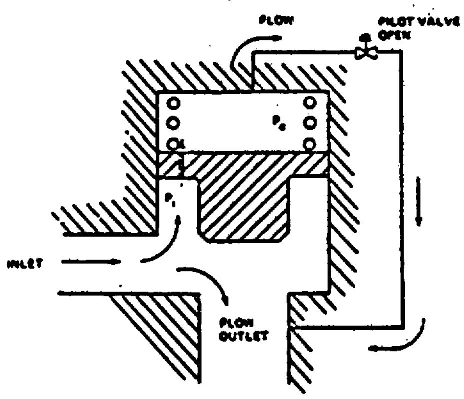


Figure 1b. External Piloted Valve (Open Position)

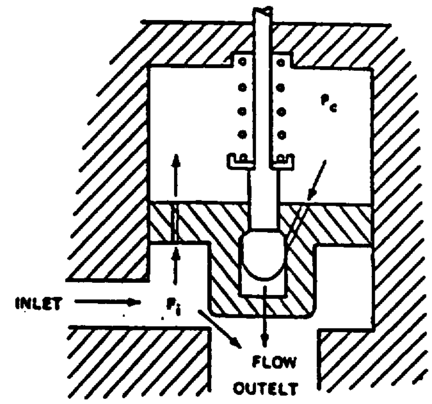


Figure 2b. Internal Piloted Valve (Open Position)

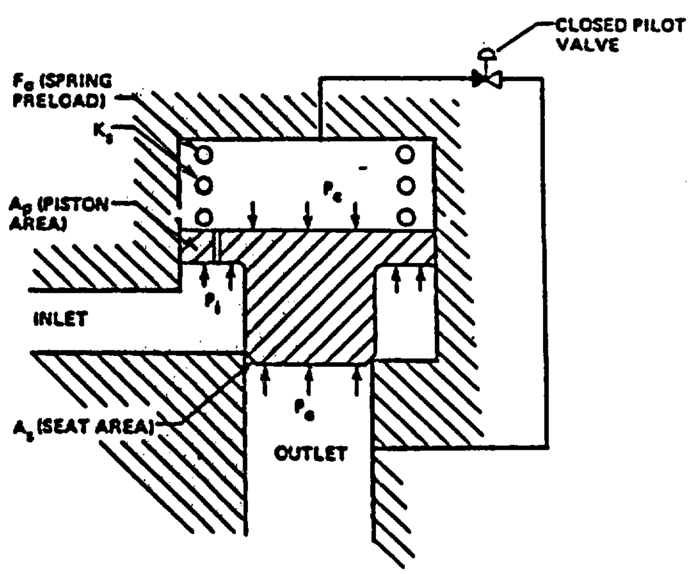


Figure 3. Closed Valve Loadings

5

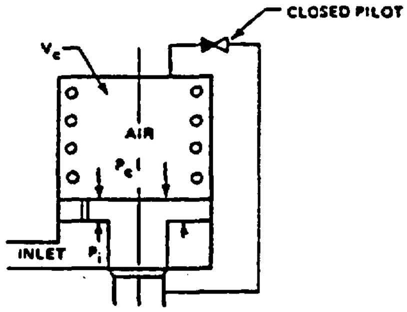


Figure 4a. Valve Closed (Air to Air)

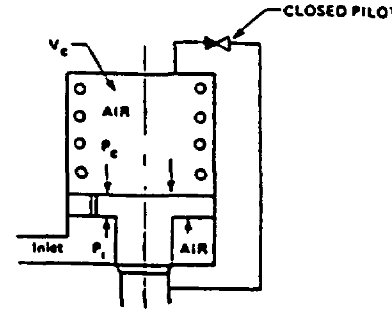


Figure 5a. Valve Closed (Water to Air)

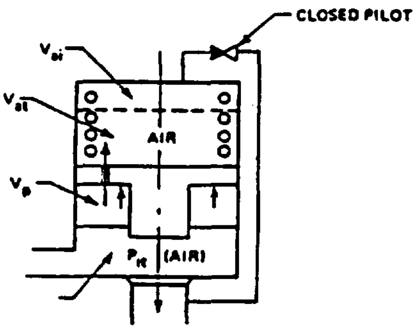


Figure 4b. Valve Opens (Air to Air)

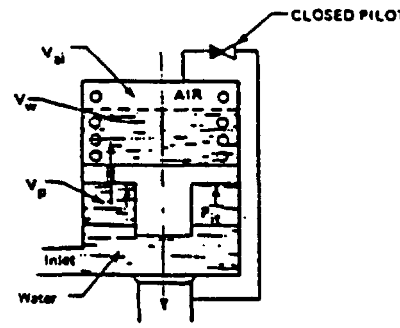


Figure 5b. Valve Open (Water to Air)

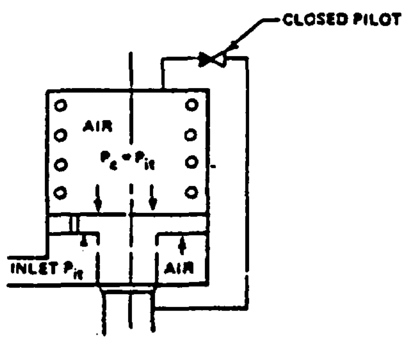


Figure 4c. Valve Recloses (Air to Air)

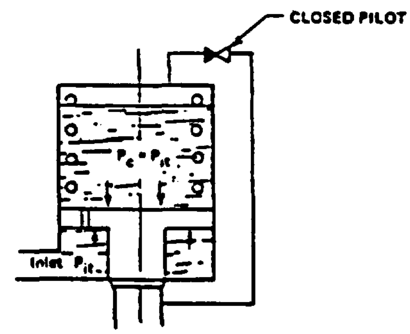


Figure 5c. Valve Reclosed (Water to Air)

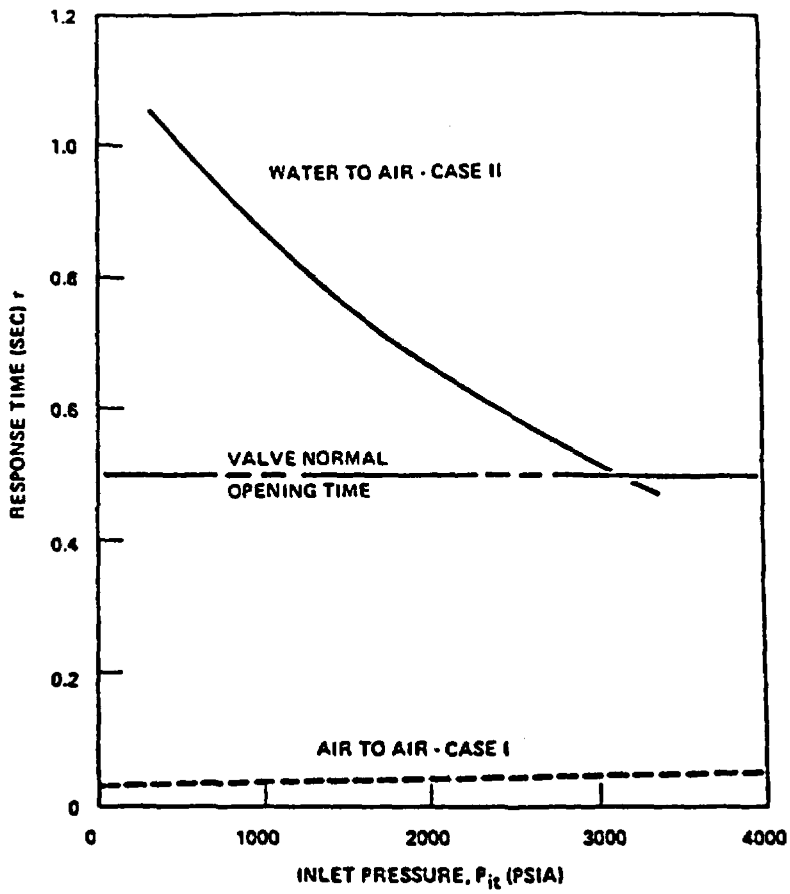


Figure 6. Response Time versus Inlet Pressure (P_c = 15 psia)

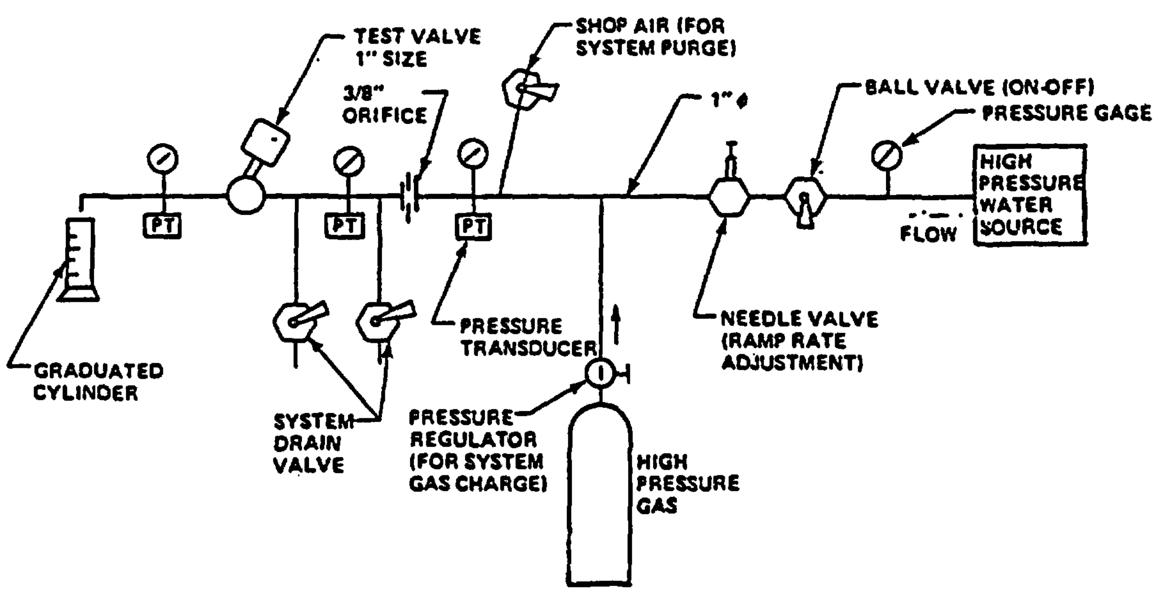


Figure 7. Valve Test Set-Up

7

APPENDIX C

DISPOSITION OF AUTOMATIC SWITCH COMPANY (ASCO) DUAL-COIL 8323 SOLENOID-OPERATED VALVES USED FOR MAIN STEAM ISOLATION VALVE CONTROL

Many plants have experienced problems with dual-coil 8323 solenoid-operated valves (SOVs) manufactured by the Automatic Switch Company (ASCO). These valves have been used as control valves for the main steam isolation valves (MSIVs). Several examples are provided in Section 5 of the case study report. ASCO issued two field notifications (Refs. 110, 111)* addressing NP8323 SOVs. The notifications stated that the NP8323 SOVs have no defects and that their malfunctions were primarily caused by foreign materials, aggravated by adverse service conditions. Furthermore, because ASCO does not envision significant changes in the service conditions that the NP8323 SOVs are subjected to, ASCO is phasing out the sale of those valves. As an alternative, ASCO recommends the use of a pair of single-coil NP8320 SOVs. Two NP8320 SOVs can be configured to perform the function of one NP8323. Because of the single-coil construction of the NP8320 SOVs, ASCO anticipates that they will perform more satisfactorily than the NP8323 SOVs under adverse service conditions.

In anticipation of ASCO's discontinuance of the NP8323 SOVs, the MSIV air pack manufacturer (R. A. Hiller Company) has initiated a program to select a suitable replacement of the ASCO NP8323 SOVs.** The Hiller company has assembled five MSIV air packs for baseline testing. The SOVs to be tested in the MSIV air packs are

- ASCO: NP8320 V (two valves configured as recommended by ASCO in References 110, 111 and two new SOVs (NS series), including one having a low operating coil temperature)
- AVC: A new model SOV manifold
- Valcor: A new model SOV having no dynamic seals and designed especially for MSIV application

It should be noted that the choice of a replacement for the NP8323 SOVs can affect the qualification of the overall MSIV air packs (e.g. seismic/dynamic loading). Final selection of replacements for the NP8323 SOV should address this issue. In the past, GE was actively involved in the qualification testing of MSIV air packs which were used at many plants. GE has indicated that as a result of ASCO's discontinuance of NP8323 SOVs they are trying to interest owners of boiling-water reactors to support a consolidated effort with the Hiller Company to qualify MSIV air packs having suitable replacements for the ASCO NP8323. ***

*References are identified in Section 10 of the report.

**Telephone discussion between J. Nanci, R. A. Hiller Company, and H. L. Ornstein, NRC, September 10, 1990.

***Telephone discussion between C. Nieh, GE, and H. L. Ornstein, NRC, December 1989.

APPENDIX D

GENERIC COMMUNICATIONS ON SOLENOID-OPERATED VALVES

Document	Date	Title
Bulletin 75–03	March 14, 1975	Incorrect Lower Disc Spring and Clearance Dimension in 8300 and 8302 ASCO Solenoid Valves
Bulletin 78–14	December 19, 1978	Deterioration of Buna-N Components in ASCO Solenoids
Bulletin 79–01A	June 6, 1979	Environmental Qualification of Class 1E Equipment (Deficiencies in the Environmental Qualification of ASCO Solenoid Valves)
Bulletin 80–14	June 12, 1980	Degradation of BWR Scram Discharge Volume Capability
Bulletin 80–17	July 3, 1980	Failure of 76 of 185 Control Rods to Fully Insert During a Scram at a BWR
Bulletin 80–17 Supplement 1	July 18, 1980	Failure of 76 of 185 Control Rods to Fully Insert During a Scram at a BWR
Bulletin 80–17 Supplement 2	July 22, 1980	Failures Revealed by Testing Subsequent Failure to Control Rods to Insert During a Scram at a BWR
Bulletin 80–23	November 14, 1980	Failures of Solenoid Valves Manufactured by Valcor Engineering Corporation
Bulletin 80–25	December 19, 1980	Operating Problems With Target Rock Safety Relief Valves at BWRs
Circular 81–14	November 5, 1981	Main Steam Isolation Valve Failures to Close
Information Notice 80–11	March 14, 1980	Generic Problems with ASCO Valves in Nuclear Applications Including Fire Protection Systems
Information Notice 80–39	October 31, 1980	Malfunction of Solenoid Valves Manufactured by Valcor Engineering Corporation
Information Notice 80–40	November 7, 1980	Excessive Nitrogen Supply Pressure Actuates Safety-Relief Valve Operation to Cause Reactor Depressurization
Information Notice 81–29	September 24, 1981	Equipment Quantification Testing Experience, Equipment Qualification Notice No. 1
Information Notice 81–38	December 17, 1981	Potentially Significant Equipment Failures Resulting From Contamination of Air-Operated Systems
Information Notice 82–52	December 21, 1982	Equipment Environmental Qualification Testing Experience—Updating of Test Summaries Previously Published in IN 81–29
Information Notice 83–57	August 31, 1983	Potential Misassembly Problem With Automatic Switch Company (ASCO) Solenoid Valve Model NP 8316
Information Notice 84–23	April 15, 1984	Results of NRC Sponsored Qualification Methodology Research Test on ASCO Solenoid Valves

Document	Date	Title
Information Notice 84–53	July 5, 1984	Information Concerning the Use of Loctite 242 and Other Anaerobic Adhesive Sealants
Information Notice 84–68	August 21, 1984	Potential Deficiency in Improperly Rated Field Wiring to Solenoid Valves
Information Notice 85–08	January 30, 1985	Industry Experience on Certain Materials Used in Safety-Related Equipment
Information Notice 85–17	March 1, 1985	Possible Sticking of ASCO Solenoid Valves
Information Notice 85–17 Supplement 1	October 1, 1985	Possible Sticking of ASCO Solenoid Valves
Information Notice 85–47	June 18, 1985	Potential Effect of Line-Induced Vibration on Certain Target Rock Solenoid-Operated Valves
Information Notice 85–95	December 23, 1985	Leak of Reactor Building Caused by Scram Solenoid Valve Problem
Information Notice 86–57	July 11, 1986	Operating Problems With Solenoid Operated Valves at Nuclear Power Plants
Information Notice 86–72	August 19, 1986	Failure of 17–7 PH Stainless Steel Springs in Valcor Valves Due to Hydrogen Embrittlement
Information Notice 86–78	September 2, 1986	Scram Solenoid Pilot Valve (SSPV) Rebuild Kit Problems
Information Notice 87–48	October 9, 1987	Information Concerning the Use of Anaerobic Adhesive/ Sealants
Information Notice 88–24	May 13, 1988	Failures of Air-Operated Valves Affecting Safety-Related Systems
Information Notice 88–43	June 23, 1988	Solenoid Valve Problems
Information Notice 88–51	July 21, 1988	Failure of Main Steam Isolation Valves
Information Notice 88–86 Supplement 1	March 31, 1989	Operating With Multiple Grounds in Direct Current Distribution Systems
Information Notice 89–30	March 15, 1989	High Temperature Environments at Nuclear Power Plants
Information Notice 89–66	September 11, 1989	Qualification Life of Solenoid Valves
Information Notice 90–11	February 28, 1990	Maintenance Deficiency Associated With Solenoid Operated Valves
Information Notice 90–64	October 4, 1990	Potential for Common-Mode Failure of High-Pressure Safety Injection Pumps or Release of Reactor Coolant Outside Containment During a Loss-of-Coolant Accident

APPENDIX E

ABBREVIATIONS

ADS	automatic depressurization system
AEOD	Office for Analysis and Evaluation of Operational Data
ANSI	American National Standards Institute
AOV	air–operated valve
ASCO	Automatic Switch Company
ASME	American Society of Mechanical Engineers
AVC	Automatic Valve Corporation
BWR	boiling-water reactor
CALCON	California Controls Co.
CFR	Code of Federal Regulations
CRD	control rod drive
EDG	emergency diesel generator
EPDM	ethylene propylene diene monomer
EQ	equipment qualification
FRC	Franklin Research Center
FUSS	foreign unidentified sticky substance
GE	General Electric
GM-EMD	General Motors Electro-Motive Division
HPCI	high–pressure cooling injection
IEEE	Institute of Electrical and Electronics Engineers
LWR	light-water reactor
LER	licensee event report
MCH	million cumulative hours
MOV	motor-operated valve
MSIV	main steam isolation valve
MOPD	maximum operating pressure differential
NPRDS	nuclear plant reliability data system
NRC	Nuclear Regulatory Commission
PORV	power–operated relief valve
PRA	probabilistic risk assessment
PWR	pressurized-water reactor
RCM	reliability-centered maintenance
SDV	scram discharge volume
SIL	service information letter
SOV	solenoid-operated valve
SRV	safety relief valve
VEPCO	Virginia Electric and Power Co.

NRC FORM 335 (2-89) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)
NUREG-1275, Vol. 6
AEOD Case Study C90-01

2. TITLE AND SUBTITLE
Operating Experience Feedback Report – Solenoid-Operated Valve Problems
Commercial Power Reactors

3. DATE REPORT PUBLISHED

MONTH	YEAR
February	1991

4. FIN OR GRANT NUMBER

5. AUTHOR(S)
H. L. Ornstein

6. TYPE OF REPORT
Final

7. PERIOD COVERED (Inclusive Dates)
1980 – 1990

8. PERFORMING ORGANIZATION – NAME AND ADDRESS (If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)
Office for Analysis and Evaluation of Operational Data
U.S. Nuclear Regulatory Commission
Washington, DC 20555

9. SPONSORING ORGANIZATION – NAME AND ADDRESS (If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)
Same as 8, above.

10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

This report highlights significant operating events involving observed or potential common-mode failures of solenoid-operated valves (SOVs) in U.S. plants. These events resulted in degradation or malfunction of multiple trains of safety systems as well as of multiple safety systems. On the basis of the evaluation of these events, the Office for Analysis and Evaluation of Operational Data (AEOD) of the U.S. Nuclear Regulatory Commission (NRC) concludes that the problems with solenoid-operated valves are an important issue that needs additional NRC and industry attention. This report also provides AEOD's recommendations for actions to reduce the occurrence of SOV common-mode failures.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)
solenoid-operated valves, SOV, solenoid, common-mode failure, common cause failure, safety system failure, cross train failures, cross system failures, AEOD case study C90-01

13. AVAILABILITY STATEMENT
Unlimited

14. SECURITY CLASSIFICATION
(This Page)
Unclassified
(This Report)
Unclassified

15. NUMBER OF PAGES

16. PRICE

NRC FORM 335 (2-89)

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

FIRST CLASS MAIL
POSTAGE & FEES PAID
USNRC

PERMIT No. G-67