NUREG/CR-4302
Volume 1
ORNL-6193/V1

OAK RIDGE
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Aging and Service Wear of Check Valves Used in Engineered Safety-Feature Systems of Nuclear Power Plants

Volume 1. Operating Experience and Failure Identification

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Prepared for the U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Under Interagency Agreement DOE 40-551-75

OPERATED BY
MARTIN MARIETTA-ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

NUREG/CR-4302
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Dist. Category RV

AGING AND SERVICE WEAR OF CHECK VALVES USED IN ENGINEERED SAFETY-FEATURE SYSTEMS OF NUCLEAR POWER PLANTS

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Manuscript Completed — October 25, 1985
Date Published — December 1985

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NRC FIN No. B0828

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

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ACKNOWLEDGMENTS

The authors gratefully acknowledge the continuing support and counsel of the NRC Nuclear Plant Aging Research Program Manager, J. P. Vora, in the planning and implementing of this study.

The preparation of this report required the help of a number of individuals, and the authors acknowledge with gratitude the support given. J. L. Hawley, Walthworth Company; E. J. Majewski, Rockwell International, Flow Control Division; and R. Brennan, Atwood and Morrill Company, Inc., were very helpful in providing needed information as well as answering questions in the initial phases.

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Rockwell International, Flow Control Division (Fig. 2.3)

Jenkins Brothers (Fig. 2.4)

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SUMMARY

Practical and cost-effective methods are to be evaluated and identified for detecting, monitoring, and assessing the severity of time-dependent degradation (aging and service wear) of check valves (CVs) in nuclear plants under the Nuclear Plant Aging Research Program of the Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research. These methods are to provide capabilities for establishing degradation trends prior to failure and developing guidance for effective inspection, surveillance, and maintenance.

This report is the first of three on CVs and addresses failure modes and failure causes resulting from aging and service wear, recommended surveillance and maintenance practices, and measurable parameters for detecting degradation prior to failure. The results presented are based primarily on information from plant operating experience records, plant operators, and equipment manufacturers. The two reports that follow will address, respectively, (1) assessment of inspection, surveillance, and monitoring techniques through testing and (2) recommendation of guidelines for monitoring methods and maintenance to ensure operability under normal and emergency conditions.

This report briefly reviews typical CVs in boiling-water reactor and pressurized-water reactor nuclear power plants in terms of functional requirements, materials of construction, and operational stressors that contribute to aging and service wear under both normal and emergency operating conditions.

Operating experiences reported in data bases for nuclear power plants and in nuclear industry reports were examined. These data bases included the Licensee Event Report (LER) file, Nuclear Plant Reliability Data System (NPRDS), and the In-Plant Reliability Data System (IPRDS).

Information was obtained from component manufacturers by reviewing their literature and in direct discussions with their representatives. The subjects addressed were failure modes, failure causes, and manufacturer-recommended surveillance and maintenance practices. Five failure modes were identified: failure to open, failure to close, plugged, reverse leakage, and external leakage. Failure causes for each failure mode were then identified at the subcomponent or subassembly level.

Manufacturer-recommended surveillance and maintenance practices are general in nature, although detailed instructions for repair of internals are sometimes provided. These practices include obturator movement and external leakage checks, exercising, bonnet (or cap) joint inspection, repair of internal parts, and reverse leakage repair.

Failure modes are examined in this study by identifying methods for detecting failure modes and differentiating between failure causes. The report identifies measurable parameters (including functional indicators) currently used for inspection, surveillance, and monitoring. They consist of force or torque for obturator movement, pressure, temperature, flow rate, reverse leakage rate, fluid level, and noise. The report also identifies parameters potentially useful for enhancing detection of degradation and incipient failure; these parameters include dimensions, bolt torque, noise, appearance, roughness, and cracking. The appropriateness and utility of these and other parameters will be evaluated in subsequent phases of the CV project.

AGING AND SERVICE WEAR OF CHECK VALVES USED IN ENGINEERED SAFETY-FEATURE SYSTEMS OF NUCLEAR POWER PLANTS

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ABSTRACT

This is the first in a series of three reports on check valves (CVs) to be published under the Nuclear Plant Aging Research Program, and it addresses the subject of Detection of Defects and Degradation Monitoring of Nuclear Plant Safety Equipment. The program is concerned with the evaluation and identification of practical and cost-effective methods for detecting, monitoring, and assessing the severity of time-dependent degradation (aging and service wear) of CVs in nuclear plants. These methods will allow degradation trends to be established prior to failure and allow guidance for effective maintenance to be developed.

The topics of interest for this first report are failure modes and causes resulting from aging and service wear, manufacturer-recommended maintenance and surveillance practices, and measurable parameters (including functional indicators) for use in assessing operational readiness, establishing degradation trends, and detecting incipient failure. The results presented are based on information derived from operating experience records, nuclear industry reports, manufacturer-supplied information, and input from plant operators.

Failure modes are identified for CVs. For each failure mode, failure causes are listed by subcomponent or subassembly, and parameters potentially useful for detecting degradation, which could lead to failure, are tabulated.

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1. INTRODUCTION

1.1 Background

The Office of Nuclear Regulatory Research of the Nuclear Regulatory Commission (NRC) has instituted a study aimed at understanding the time-related degradation (aging) of nuclear power plant systems and equipment. It includes assessing the effectiveness of methods of inspection and surveillance that monitor such degradation and establishing guidelines for maintenance. The study is intended to provide technical bases for examining the ongoing operational safety of operating plants. The strategy[1] that will be followed should be useful to others interested in analyses of equipment in nuclear applications.

This report addresses the time-related degradation of check valves (CVs) — the second of eight components to be studied in the Nuclear Plant Aging Research (NPAR) Program list of components. The others on the list are motor-operated valves (MOVs), auxiliary feedwater pumps, diesel generators, snubbers, batteries, chargers, and inverters.

CVs are one of the most common components in a nuclear power plant — they are located in almost all plant fluid systems. The failure of these valves causes a significant amount of plant maintenance and, more importantly, degradation of safety-related systems. In the last few years considerable attention has been given to CVs by the NRC and industry groups.

1.2 Objective

The objective of this NPAR Program element is to review operating experience and manufacturers' information, to identify failure modes and causes resulting from aging and service wear of CVs in nuclear plant service, and to identify measurable parameters. These parameters are to be suitable for detecting and establishing trends in the time-dependent degradation of CV components prior to loss of function.

1.3 Project Scope

This report is Volume 1 of a three-part report to be prepared on CVs. The contents of each of the three parts are summarized below.

Volume 1 — Operating experience, failure modes, and failure causes

1. Background information on CVs — boundary of CVs to be studied, types, uses, requirements, and materials of construction
2. Reviews of regulatory requirements, guides, and standards
3. Summary of operational and environmental stressors
4. Summary of operating experience
5. Manufacturers' input
6. State-of-the-art aging and service wear monitoring and assessment

Volume 2 — Tests and assessments

1. Complete comprehensive aging assessment
    Postservice examination and tests
    In-plant assessments
2. Assessment of advanced monitoring techniques

3. Controlled laboratory testing
    - Aging assessment
    - Monitoring technique evaluation

Volume 3 — Analysis and recommendations

1. Impact analysis
2. Recommendations of guidelines for monitoring methods and maintenance

1.4 Definitions

For the purpose of this report, the following definitions apply:

Failure mode — the way in which a component does not perform a function for which it was designed; that is, fails to actuate or leaks to outside.

Failure cause — degradation (the presence of a defect) in a component that is the proximate cause of its failure; for example, bent shaft, loss of lubricant, and loosening of a bolt.

Failure mechanisms — the phenomena that are responsible for the degradation present in a given component at a given time. Frequently, several failure mechanisms are collectively responsible for degradation (synergistic influences). Where one major failure mechanism is identified, it has been called the "root cause." Generic examples of failure mechanisms (and of root causes) include aging, human error, and seismic events.

Aging — the combined cumulative effects over time of internal and external stressors acting on a component, leading to degradation of the component, which increases with time. Aging degradation may involve changes in chemical, physical, electrical, or metallurgical properties, dimensions, and/or relative positions of individual parts.

Normal aging — aging of a component that has been designed, fabricated, installed, operated, and maintained in accordance with specifications, instructions, and good practice, and that results from exposure to normal stressors for the specific application. Normal aging should be taken into account in component design and specification.

Measurable parameters — physical or chemical characteristics of a component that can be described or measured directly or indirectly and that can be correlated with aging. Useful measurable parameters are those that can be used to establish trends of the magnitude of aging associated with each failure cause, that have well-defined criteria for quantifying the approach to failure, and that are able to discriminate between the degradation that leads to failure and other degradation.

Inspection, surveillance, and condition monitoring (ISCM) — the spectrum of methods and hardware for obtaining qualitative or quantitative values of a measurable parameter of a component. The methods may be periodic or continuous, may be in plant or may require removal and installation in a test stand or disassembly, and may involve dynamic or static measurements.

2. BASIC INFORMATION

2.1 Principal Types and Uses of CVs in BWRs and PWRs

CVs are used extensively within pressurized-water reactor (PWR) and boiling-water reactor (BWR) nuclear power plants for service in safety-related and balance-of-plant (BOP) systems. Sizes vary depending on service requirements and range between 0.5 and 28 in. (nominal pipe diameter).* The most commonly used types are swing, horizontal lift, vertical lift, and ball CVs.

A summary of the usage of CVs in typical BWR and PWR nuclear power plant systems is given in Table 2.1. The table indicates numbers of valves, size ranges, and types used in the various systems. The functions of the listed safety-related system may differ from plant to plant.

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*In conformance with current nuclear power industry practice, English units will be used in this report.

Table 2.1. Summary of CV applications in nuclear power plants

System	Number of CVs	Valve size (in.)
BWR (typical)		
Low-pressure core spray	10–18	2–28
High-pressure coolant injection (HPCI)	10–14	4–24
Low-pressure coolant injection (LPCI) [includes residual heat removal (RHR) and containment spray]	10–21	4–24
BOP systems	200–400	1/2–24
PWR (typical)		
Auxiliary feedwater	4–23	4–8
Containment spray	4–14	6–14
HPCI	12–28	2-1/2–4
LPCI/RHR	5–14	8–10
BOP systems	200–400	2–60

2.2 CV Types

Swing* CVs are the most widely used of all CVs because they offer very little resistance to the flow when in wide-open position. Generally used on all piping where the pressure differential is of prime importance, swing CVs are used for flowing liquids and can be installed in vertical or horizontal position. However, these CVs are not recommended for applications where the reversal of flow is frequent; this causes the valve obturator to fluctuate rapidly and result in "valve chatter." Some swing CVs have an external lever and counterweight balance arrangement to permit adjustments that make the valve obturator more sensitive to flow and allow it to open under a minimum of fluid pressure.

Horizontal-piston-lift CVs (Fig. 2.3) are quite frequently assembled on the same valve bodies as those used for the regular globe valves. They are generally used for such applications where the reversal of flow and pressure fluctuations are very frequent, because they have less tendency to develop "obturator slam" and valve chatter. Horizontal-lift CVs are used for flowing steam, air, and gases on horizontal piping lines, but they are not recommended for installation on vertical piping systems.

Vertical-lift CVs (Fig. 2.4) are similar in construction to horizontal-lift CVs and are especially designed for installation on vertical piping systems. Another modification of the vertical-lift CV is the angle vertical CV, which is used on right-angle turns in the piping systems.

Ball CVs (Fig. 2.5) are designed to handle viscous fluids and for services where scale and sediment are present. These valves, usually made in vertical, horizontal, and angle designs, are particularly recommended for rapidly fluctuating flow because of their quiet operation. During the ball CV operation, the ball rotates constantly, equalizing the wear on the ball and seat, thus prolonging the life of the valve.

Further design variations of the CV include stop-check valves and nonreturn valves.

Stop-check valves, sometimes called "screw-down" CVs, are actually modifications of the globe or angle valves. This modification consists of making a slip stem connection to the valve obturator instead of using the obturator lock nut. In this design, the obturator can be closed by hand, but can be opened only by the CV action; that is, by the fluid pressure under the obturator. Probably the most common application of the stop-check valve is as a safety nonreturn valve. The *ASME Boiler and Pressure Vessel Code* specifies use of these valves for the boiler nozzle of every boiler when two or more boilers are connected to the same header. These valves are also called boiler stop-check valves or boiler "screw-down" checks.

In nuclear power plants, CVs are frequently used as containment isolation valves in lines where, in normal operation, fluid flows into the containment. If the pipe outside the containment should fail or the

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*See Figs. 2.1 and 2.2, which show valves from two manufacturers. The nomenclature used is shown in Fig. 2.2.

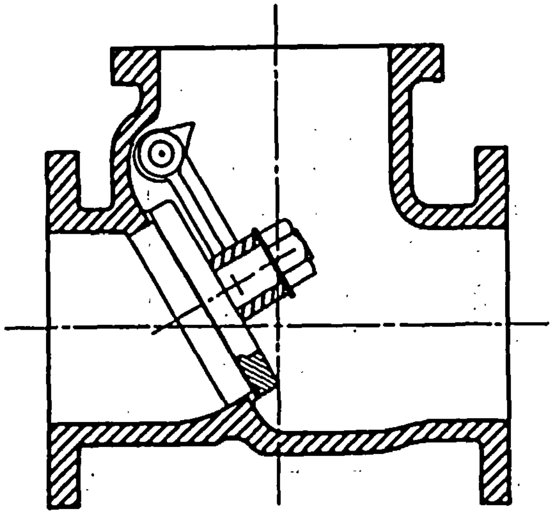
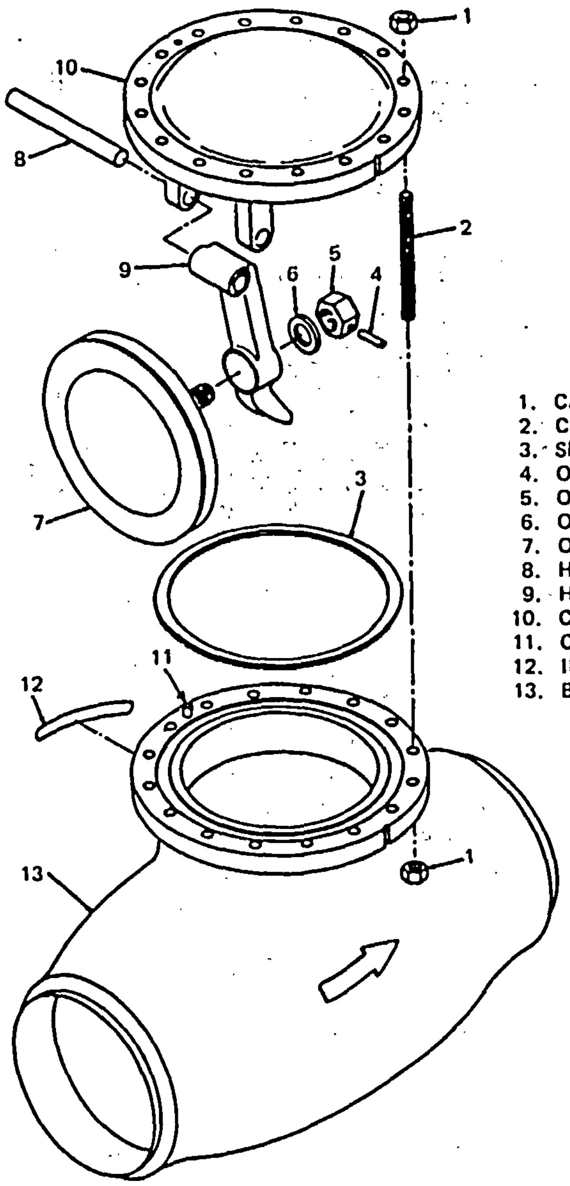


Fig. 2.1. Swing CV.



1. CAP STUD FASTENER NUT
2. CAP STUD FASTENER BOLT
3. SPIRAL WOUND GASKET
4. OBTURATOR FASTENER NUT PIN
5. OBTURATOR FASTENER NUT
6. OBTURATOR FASTENER NUT WASHER
7. OBTURATOR
8. HANGER PIN
9. HANGER
10. CAP
11. CAP PIN
12. IDENTIFICATION PLATE
13. BODY

Fig. 2.2. Swing CV, exploded view.

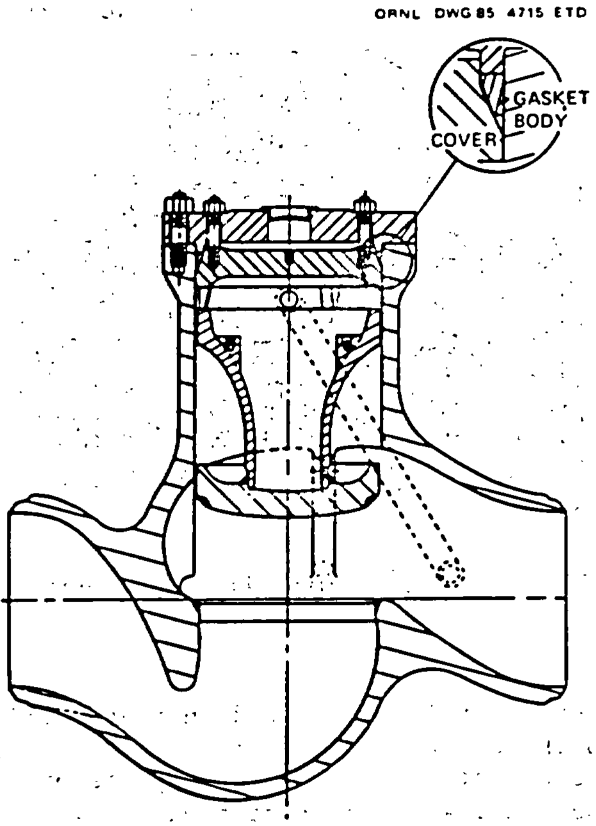
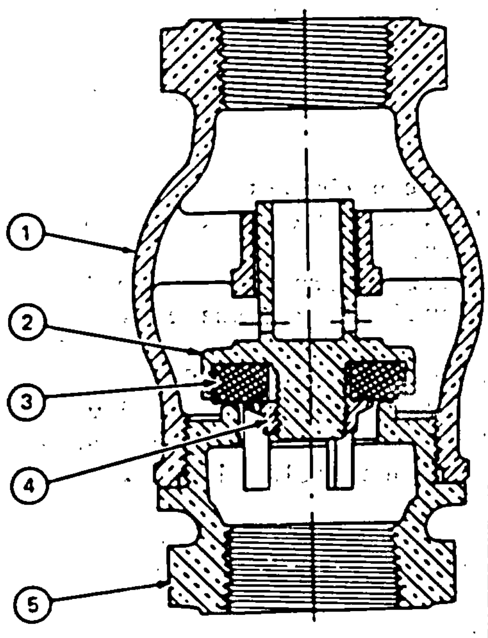


Fig. 2.3. Horizontal-piston-lift CV.



PART	
1	BODY
2	OBTURATOR HOLDER
3	OBTURATOR
4	OBTURATOR GUIDE NUT
5	SCREW-IN HUB

Fig. 2.4. Vertical lift CV.

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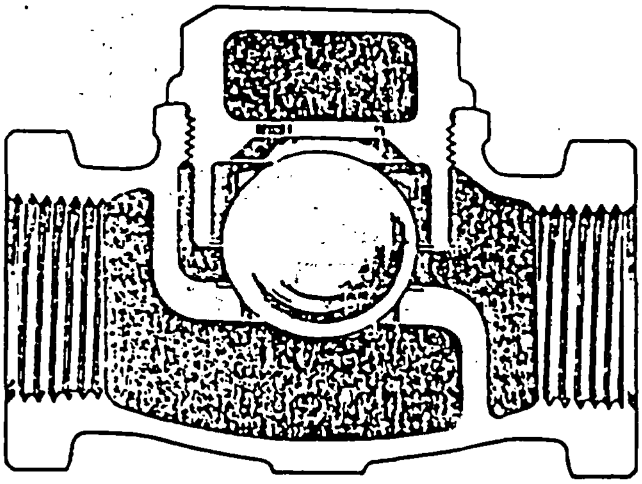

Fig. 2.5. Ball CV, showing ball and seat arrangement.

pressure inside the containment should increase during emergency conditions, flow into the containment ceases and the CV closes, thus preventing flow from the containment to the atmosphere or external systems. Because CVs work automatically to prevent backflow, they are ideal for this situation. However, containment isolation valves are required to have a very low through-seat leak rate, which is sometimes difficult to achieve.

2.3 Equipment Boundaries

For purposes of this report, the CV is defined as follows (see Fig. 2.2).

1. Body assembly — valve body, cap (bonnet), fasteners, and plugs;
2. Internals — seat, obturator, locking devices, hanger pin, hanger, and any other internal parts;
3. Seals — seals and gaskets for external position indicators and/or operators, plus those employed to seal the cap.

The nomenclature for CVs given in Ref. 2 is used.

Remote external position indicator sensors or devices are not considered in this discussion. Their failure would not affect the operation of the CV, and they are therefore not included here.

2.4 Functional Requirements

In the functional grouping of the entire valve family, the CV will be found in the group defined as valves designed to control the direction of flow. Check valves differ considerably in their construction and operation from the other groups of valves, designed either to stop the flow entirely (gate, plug, and quick-opening valves) or throttle the flow to a desired degree (globe, angle, needle, Y, diaphragm, and butterfly valves).

Check valves are entirely automatic in their operation and are activated internally by the flow of fluid that they regulate. Check valves permit the flow of fluids in only one direction; if the flow stops or tries to reverse its direction, the CV closes immediately and prevents backflow. When the operating pressure "direction" in the line is reestablished, the CV opens and the flow is resumed in the same direction as before.

Nuclear power plant CVs typically meet the following requirements.

1. Ambient service conditions: temperatures 32 to 140°F, pressures up to 40 psig, possible vibration from upstream or downstream connected components.
2. Capability: the CV must operate reliably with a minimum of maintenance.
3. Differential pressure (d/p) to close: this depends on the valve service, but in general the valve should close on zero flow, which is zero d/p.
4. Position-sensing device: not often required; may be found on some swing CVs.
5. Minimum pressure drop (ΔP) across the valve when open: ΔP across the valve at the expected maximum flow rate.
6. Process fluid temperature and pressure: operating pressure up to 2600 psig and temperatures up to 650°F.
7. Opening pressure must be less than the pressure drop in the line at the minimum flow.

2.5 Materials of Construction

2.5.1 Body assembly

Body, cap. Cast stainless-steel CVs are manufactured in sizes from 0.25 to 8 in. Working pressure for these types may range from 150 to 2500 psig, with the temperature limit from 500 to 1100°F, by ASTM Standard, depending on the alloy used.

In addition to stainless steel, CVs are also made of bronze, cast iron, Monel, nickel, polyvinyl chloride, and other corrosion-resistant materials to withstand the corrosive action of the fluids in contact. Only stainless-steel valves are considered in this report.

Fasteners. The cap stud bolts used in nuclear service valves are generally of type 304 or 316 stainless steel to be compatible with valve materials in expansion and contraction due to temperature. These materials offer higher strength for a given diameter but, due to their hardness, must be properly lubricated to prevent galling in use.

2.5.2 Internals

Seat. Nuclear service CV seats are generally machined into the forging on smaller valves up to about 3-in. nominal pipe diameter. The seats in larger valves are generally replaceable and are constructed of specially hardened alloys such as Stellite or Hastelloy. Some valve seats are resilient materials (to provide better sealing).

Because the pressure producing the flow in the pipeline must be sufficient to lift the CV obturator from its seat, designers have used various seat angles to aid this lifting action. The most commonly used seat and obturator angles are 0°, 6°, 12-1/2°, and 45° to the vertical.

In the 125-psi class, the obturator of swing CVs usually will be found at an angle of 6° to the vertical. In the 200-psi and up class, the obturators are usually placed at 45° angles, because sufficient pressure is available to lift the obturator and open the flow in the line. Horizontal obturators, placed at 90° angles to the vertical, are found in the lift CVs.

Obturator. Valve obturators are normally of the same material as the valve body to accommodate thermal expansion and contraction. They may have seating surface materials of Stellite or another hard alloy to resist etching or "wire drawing."* Ball CV obturators may be made of Stellite or another hard alloy to resist wear and scratching.

Hanger pin, hanger, and fastener. Swing CV obturators are connected to a hanger that, in turn, hinges on hanger pins; this arrangement permits movement of the obturator out of the flow stream. The hanger and hanger pin in stainless steel CVs are generally stainless steel alloy for strength and corrosion resistance. The obturator fastener nut, washer, and pin (and optional spring) are also stainless steel. If a valve pin is equipped with a special bearing on the hanger, the bearing is usually made of a hardened alloy such as Stellite.

2.5.3 Seals

Gaskets. Nuclear service valves may have (1) welded caps obviating the need for a gasket; (2) pressure-seal construction utilizing a steel sealing ring and bolt configuration that seals the cap; or (3) ordinary machined surfaces for asbestos-type gaskets. Flexitallic®-type gaskets consist of a stainless steel V-shaped strip axially wound with alternating layers of asbestos to form a chevron-like seal cross section. Such gaskets should only be used once because the steel "V" shape is crushed upon tightening — which provides the seal function.

Seals. Only a few CV designs have packing or seals of graphite-asbestos for the hanger pin. (The hanger usually attaches to the cap.) Where there is packing on hanger pin cap seals, the stressors will be identical to those of the cap gasket; therefore, they will not be discussed separately.

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*Wire drawing refers to the case of a minute leak across the seat that, under high differential pressure, causes a straight-line eroded leak path resembling a mark that might occur if a small-diameter wire were drawn across the surface.

3. TECHNICAL SPECIFICATION REQUIREMENTS

In nuclear power plants, periodic surveillance tests are used to ensure operability of safety-related components. Test requirements included in the Technical Specifications for each plant describe, either directly or by reference, the various in-service inspections to be performed on the major components of safety-related systems. In-service inspections of all ASME class 1, 2, and 3 components are specified to be in accordance with Sect. XI of the *ASME Boiler and Pressure Vessel Code*. In addition, the *Code of Federal Regulations* (*CFR*) provides leakage requirements for some components.

Article IWV-3000 in Sect. XI of the *ASME Code* describes in-service inspection requirements for CVs. This requirement consists primarily of exercising the valve to verify obturator travel to or from the full open and closed positions as required to fulfill its safety function. Confirmation of seating or opening may be by visual observation, a position indicator, observation of relevant pressures in the system, or other positive means. Surveillance intervals or frequencies are given in the *ASME Code*. A summary of Article IWV-3000 is provided in Appendix A.

CVs used for containment isolation are also required to be tested in accordance with 10 *CFR* 50 Appendix J (Ref. 3). These tests involve pressurizing the CV locally in the same direction as when the valve is required to perform its safety function and comparing leakage rate with the specified standard. Tests are performed at refueling outages or at least every 2 years.

The purpose of Technical Specifications requirements for surveillance testing is to demonstrate operability of the component within specified limits. The purpose thus does not specifically include monitoring abnormalities in the component that at a later time may lead to loss of operability.

4. SUMMARY OF OPERATIONAL STRESSORS

In this section the CV is divided into subcomponents and parts. The significant stressors acting upon these parts are identified qualitatively and (where possible) quantitatively, under normal and accident (emergency) conditions.

Stressors have been divided into six categories: electrical, mechanical, thermal, chemical, radiation, and environmental. The origins and magnitudes of these stressors depend on the specific valve and include those generated externally to the valve boundary and those generated internally.

Check valves used in nuclear plant safety systems are located inside and outside the containment structure. Under normal conditions the valves inside the containment structure are exposed to the same or slightly more severe external stressors than the valves outside the containment. Under accident conditions, the external environmental stressors inside containment are (depending on location and type of accident) more severe. For some CVs under accident conditions, the internal stressors are also more severe than normal. Therefore, it is impossible to define a unique set of stressors for CVs in safety systems, particularly under accident conditions. Guidance as to possible values of various external stressors can be obtained from valve actuator equipment qualification standards issued by *Institute of Electrical and Electronic Engineers* (IEEE 382) (Ref. 4). Excerpts from that standard are given in Table 4.1 and Fig. 4.1.

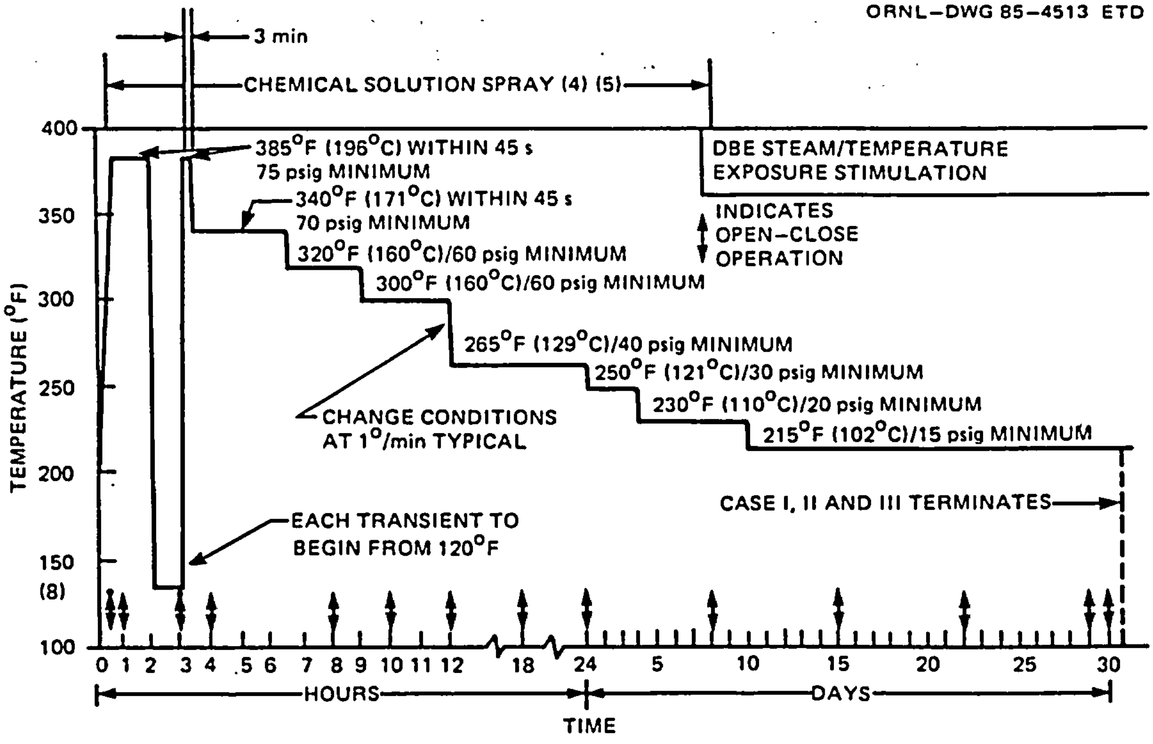

Fig. 4.1. Exposure profile under accident condtions (IEEE 382).

Table 4.1. Equipment qualification tests for valve actuators

a. Environmental aging (parameters derived from Arrhenius formula) — 138°C for 73 days, 400 cycles (all cycles defined as one stroke open and one stroke close against one-third rated load with torque switch operation at rated torque in the close direction).

b. Mechanical wear aging — 2,000 cycles (400 included in environmental aging).

c. Pressurization aging — 15 cycles of 3 min duration at 65 psig.

d. Radiation aging a design basis event (DBE) radiation — 2.04×10^8 rad.

e. Plant-induced vibration aging — Biaxial sinusoidal motion of 0.75 g with a frequency of 10 to 100 to 10 Hz at a rate of two octaves per minute. Ninety minutes of vibration in each orthogonal axis.

f. Resonant search — A low-level (0.2-g) resonant search from 1 to 35 Hz and at one octave per minute.

g. Seismic — A random multifrequency test with a 30-s duration simultaneous horizontal and vertical phase — incoherent inputs of random motion consisting of frequency band widths spaced one-third octave apart over the frequency range of 1 to 40 Hz as necessary to envelope the required response spectra. Five operating basis earthquake (OBE) level tests [three-fourths of safe shutdown earthquake (SSE) level] and one SSE level test in each orientation.

h. DBE environmental test — A steam exposure profile (see Fig. 4.1) for an LOCA simulation representing PWR and BWR in-containment service.

i. Steam impingement test — A steam exposure profile to 492°F (255°C) to simulate a steam-line break in a PWR [inlet steam temperature of 492°F (255°C) obtained in 4 s].

j. Seismic — required input motion test — Two OBE tests with a sinusoidal sweep from 2 to 35 to 2 Hz in each axis at a rate of one octave per minute and a level of two-thirds of the required input motion. One SSE in each axis consisting of a continuous series of single frequency since beat tests at the one-third octave interval test frequencies and test levels indicated in IEEE 382-1980 (see Fig. 4.1).

Source: Ref. 4.

4.1 Electrical Stressors

Check valves do not have electrical operators or position switches, nor are they subject to electrical current. Therefore, there are no electrical stressors associated with them.

4.2 Mechanical Stressors

4.2.1 Body assembly

Body, cap. Mechanical stressors on the valve body consist of (1) pressure of the internal fluid; (2) vibration, including seismic forces; (3) flow-induced forces; and (4) forces resulting from the connections to the piping system. Operating experience has indicated few valve body failures resulting from mechanical stressors during normal conditions except where structural flaws have existed. Water hammer stress is a rapid pressure pulse that momentarily increases the tensile stress in the wall. It tends to cause crack propagation from areas where stress risers exist. In the event of an earthquake, the valve bodies may be subjected to seismic low-frequency, low-magnitude vibrations of a short duration. Emergency conditions, such as an LOCA, may result in flow-induced vibration in the CV and its associated piping, but a vibration of no greater magnitude than that experienced under periodic test conditions. Valves are also subjected to stresses from downstream equipment-induced vibration.

Fasteners. Cap stud bolts are normally under tensile stresses from tightening with moderate-to-high shear forces exerted under potential seismic loads. For stop-check valves there may be moderate shear forces exerted when the valve is closed with the manual operator. Vibration, either flow-induced or other, may cause the cap stud bolt nuts to relax, thus reducing the tensile stress in the bolt and nuts. If the bolts become sufficiently loose, the shear forces may increase considerably because of loss of restraint of the friction forces of the bolted mating surfaces, and fastener failure may result.

4.2.2 Internals

Seat. Valve seats are subject to compressive forces when closed tightly in normal or accident conditions. Such forces are transmitted to the valve body because the seat is often a machined portion of the body or, in the case of replaceable seats, fits into a machined recess. Foreign objects lodged between the seat and obturator can prevent the valve from sealing and can lead to scratches and subsequent erosion of the seat.

Obturator. The portion of the valve that moves to control fluid passage is subjected to hydraulic forces when in the closed position. Additional mechanical stresses arise in stop-check valves if the obturator is forced onto the seat to prevent it from opening. When the valve is open, low-to-moderate stresses occur from operating fluid passing around or over the obturator. The stresses are essentially the same under normal or emergency conditions.

Obturator stress also results from vibration, rapid movement because of flow transients (including water hammer), and pressure differential during potential backflow conditions.

Vibration, both flow-induced and transmitted from nearby equipment, stresses the hanger pin plugs and their bearings and the areas where the obturator attaches to the hanger (see Fig. 2.2). ~~In these two joint locations, vibration can cause excessive wear and high stress concentrations that may result in cracking of the parts.~~

Under conditions of pulsating flow, the CV may cycle with each pulse. Ball checks are not appreciably stressed under these conditions except for the spring, which eventually may fail from fatigue. The swing CV obturator may be heavily stressed; in fact, rapid flow increases may cause the obturator assembly to open suddenly, impacting the stop located on the valve body. This impact can induce stresses throughout the assembly.

When there is a potential for backflow (the closing of the CV prevents actual backflow), a pressure differential across the seating surface occurs. Low stress then develops in the obturator. The seating surface stress may result in (1) distortion of the surfaces, (2) damage to soft-seated seals, or (3) jamming of the obturator in the seat. The forces involved depend on the mating surface angle, as well as the pressure differential.

4.2.3 Seals

Gaskets. Valve gaskets are generally flat or O-ring type. Such devices are compressed to form a pressure-tight seal to prevent fluid leakage. The mechanical (compressive) stresses placed on these parts normally do not degrade the part. Thermal cycling could cause loosening of the bolts, thus decreasing the compressive forces on the gasket. Loosening of the adjacent parts may permit the process fluid to leak through, quickly erode the material, and destroy the sealing ability of the gasket. A gasket properly located between secured mating components can withstand the normal and potential emergency loads.

4.3 Thermal Stressors

4.3.1 Body assembly

Body, cap. Thermal stressors applied to a valve during normal operation originate primarily from the heat of the process fluid. Some stainless steel alloys used in valve forgings or castings may be susceptible to corrosion under certain chemical and temperature conditions [intergranular stress corrosion cracking (IGSCC)]. In some instances, the valve temperature may change very rapidly when the system changes from a no-flow condition to a flow condition. Stress results from the temperature gradient across the valve wall.

During emergency conditions valve parts may be subject to slightly higher process fluid temperatures but still considerably lower than the degradation level.

Fasteners. Fasteners are subject to heat conducted from the valve body but are not adversely affected under normal or emergency conditions, except for possible loosening because of thermal cycling. Under temperature cycling, fasteners may loosen because of differential thermal expansion.

4.3.2 Internals

Seat, obturator. These valve internal parts are generally stainless steel alloys and are subject to the same thermal stresses as the valve body. Such stresses normally do not degrade these components.

4.3.3 Seals

Gasket. Thermally induced degradation of valve gaskets is a significant aging-related effect, even during normal operation. Heat acts on valve gasket materials to cause degradation of sealing capability because of embrittlement.

4.4 Chemical Stressors

4.4.1 Body assembly

Body, cap. Other than chloride stress-corrosion cracking similar to that experienced in piping, the only appreciable chemical stressors on valve bodies result from contacts with borated water.

Under normal conditions most valves are not subject to borated water-induced chemical stressors, the exceptions being those valves that are a part of the boron injection system or are otherwise in contact with primary-system, borated water in PWRs. Under accident or surveillance test conditions, many other systems may be subject to boric acid corrosion either internally or (from sprays or leaks) externally.

Fasteners. Bolts may experience some external chemical stress from borated-water spray or leakage under normal and accident emergency conditions.

4.4.2 Internals

Seat, obturator. Valve seats may be subject to erosion or corrosion stressors from the working fluid and flow velocity. The chemical composition or the presence of particulates (including impurities) in the fluid can affect the corrosion rate.

Most valve obturators are thick enough to resist chemical attack so that seat leakage will occur before obturator failure. Erosion or corrosion of the internal components may, however, cause obturator binding because of the roughness of sliding surfaces, particularly when the valve is not operated frequently.

There is no appreciable difference in chemical stressor levels for normal vs emergency operation.

4.4.3 Seals

Gasket. Most valve gaskets are fabricated from materials that are relatively impervious to the water encountered in nuclear plant systems. Borated water may impose additional chemical stress on gaskets with metallic components (Flexitallic®), but failure would most likely occur when degradation allows the borated water to breech the gasket.

4.5 Radiation Stressors

4.5.1 Body assembly

Ionizing radiation has little effect on the metallic parts of valves used in nuclear power plants. Valves in safety-related service are qualified to about 2 × 10^8 rads for a 40-year integrated dose (inside containment) and 2 × 10^7 rads for outside containment. Few valves are subject to these levels in normal operation so that for aging purposes radiation stress can be considered negligible. Under accident conditions high radiation levels may be present for a short time but would not significantly affect the aging of the body assembly materials.

4.5.2 Internals

Same as body assembly above.

4.5.3 Seals

Valve seals and gasket materials can degrade because of ionizing radiation. The effects of radiation, combined with elevated temperature and humidity, can shorten the life of such nonmetallic materials by a combination of oxidation and free radical reactions that decrease strength and elasticity. The damage increases with increased radiation dose. The effects of radiation, temperature, and humidity appear to be synergistic, and the order of exposure may affect the amount of damage.

The typical integrated radiation dose qualification limits are 2 × 10^8 rads for valves. In normal service inside (or outside) containment, valve gaskets are exposed to levels considerably below this — typically on the order of hundreds of millions. Thus, it is not expected that they will suffer significant degradation because of radiation alone. However, since the combined effects of radiation, temperature, and humidity are not well known, it is possible that damage may occur because of a combination of stressors that includes radiation. Radiation stressors during transient or emergency conditions are not expected to be different from normal except for LOCA conditions. During such conditions, if fuel damage occurs such that there are high-radiation dose rates near valves inside containment, damage due to radiation may occur. Such damage may be exacerbated if elevated temperatures or humidity is also present.

In other transient and emergency conditions not involving the release of radioactive material, any existing elevated temperatures may increase the combined damage, including the radiation effect, but such damage should not be significant.

4.6 Environmental Stressors

The overall atmospheric environment that a valve may be subjected to affects mainly the outside surfaces of the valve. Effects on individual parts are negligible unless the integrity of the valve is degraded; then other stressors (discussed earlier) become dominant.

High humidity may cause unprotected external surfaces to rust or corrode. Outdoor CVs at coastal plants may be subject to chemical stressors from salt spray or mist. In general, however, the effects should not impair the operation of the CV.

In a postulated emergency environment, such as produced by an LOCA, a combination of high temperature, steam (humidity), pressure, and radiation can act synergistically on the valve. This action is in addition to the operational stressors imposed by the altered hydraulic conditions caused by an LOCA.

5. OPERATING EXPERIENCE

The purpose of this section is to identify CV aging information obtained from various sources of nuclear power plant operating experience. Several LER-based valve failure studies were examined for relevant CV operating and failure information. In addition, a number of special reports and studies that addressed valve problems in the nuclear industry were examined. While these documents do not always contain specific CV age-related failure data, the operating experience summaries and failure cause data, included with the overall analysis results, are helpful in understanding the aging degradation of CVs.

There are a number of operating experience data bases for nuclear power plants. The data bases examined for this report include

1. LER file
2. NPRDS
3. IPRDS

Specific information needed for CV failure characterization includes (1) failure modes, causes, and mechanisms; (2) frequencies of failure; (3) methods of failure detection; (4) maintenance actions; and (5) modifications resulting from failures. Each of the above items serves to build a failure "signature" that, when taken totally, can provide a comprehensive assessment of the component failure.

Unfortunately, no single data base provides all of the information desired for each failure. But each data base does possess some useful data elements that can be extracted for CV failure study. Additionally, several studies on valve failures (including CVs) that provide backup information have been conducted by the NRC and industry organizations. Table 5.1 lists the information available from various sources of operating experience and plant-specific documents. A summary of CV failure information available from several data sources and a special study is contained in Appendix B.

5.1 Summary of Failure Modes and Causes

1. Valve seat leakage is a widespread problem in power plant applications. Causes of valve seat leakage include the accumulation of dirt and scale on the surfaces, foreign objects lodging between the surfaces, wear and/or wire cutting, deterioration of elastomers, and insufficient pressure differential for seating.

2. Wear or damage to valve internals is the next most frequent problem. Vibration loosens the fastener holding the obturator to the hanger pin, allowing the obturator to move out of position or fall free into the valve body. A rapid start of flow through the valve may cause the obturator to open suddenly, impacting the stop located on the valve body. This impact may cause the obturator to become dislodged so that it does not seal properly. In some cases it has broken free of the hanger, and in other cases the hanger pin or its bushing has broken on one or

Table 5.1. Summary of CV failure information available from operating experience and plant documents

Data source	Operating experience data bases[a]			Plant-specific documents			
	LER	NPRDS	IPRDS	SAR	SD	TS	ISI/IST
Valve type and description		O[b]	X		X	X	
Manufacturer and model No.	O	X				X	
Operating environment		X			X	X	
Failure cause	O	X					
Failure mechanism	O	O					
Discrete failed part	O	X					
Maintenance action	O	O	X				
Modification to prevent recurrence	O	O	X				
Failure trend data						X	X
Incipient failure detection			X			X	X
Specific application					X	X	X

[a] Acronyms

IPRDS = In-Plant Reliability Data System
ISI/IST = In-Service Inspection/In-Service Testing Program
LER = Licensee Event Report
NPRDS = Nuclear Plant Reliability Data System
SAR = Safety Analysis Report
SD = (Plant) System Description
TS = Technical Specification/Surveillance Test Program

[b] O = Occasionally included in failure report
X = Generally available

both sides. A loose obturator can result in restricted flow through the valve.

3. Hanger pins have corroded, causing binding and resulting in the failure of the valve to open. Pins also have failed because of both excessive valve movement during off-design flow rates and fatigue from the impact of the obturator against the body during the off-design flow conditions.

4. Failure of the seal between the valve seat and the valve body occurred in a few cases.

5. Accumulations of dirt and scale in the valve body have caused binding of the valve internals so that the valves do not open.

6. In some stop-check valves, the valve seating angles are such that if excessive pressure is used in seating the valve in the stop mode, the valve will bind and fail to open with the pressure available from normal operation.

7. After installation and initial testing of the CVs, very few problems have occurred with the valve bodies. A few through-wall leaks have occurred. Small structural flaws in the valve body can act as stress risers, resulting in crack propagation through the wall. No record of catastrophic failure of the body was found; only small leaks were found. Most flaws have been found during installation, testing, or routine surveillance.

8. Small leaks through gaskets are also a minor problem. In boric acid systems, such leakage can cause corrosion of the bolts that, if not found, could result in larger leaks.

5.2 Frequency of Failures

Two data bases contain failure frequencies: the NPRDS and the IPRDS. The NPRDS data are contained in the quarterly and annual reports prepared by the Institute of Nuclear Power Operations (INPO). In the *1981 Annual Report*, for CVs up to 4 in., 3.04 failures/10^6 calendar hours were reported during the time period of 7/1/74 to 12/31/81 for leak and failure to stop. For 4- to 12-in. valves, 3.96 failures/10^6 calendar hours were reported for the same period. Data for CVs of 12 in. and larger were insufficient to calculate failure rates.

The IPRDS data base has insufficient data on CVs to arrive at a failure frequency.

5.3 Methods of Detection

The principal method of detecting CV failure is testing. In an LER survey, surveillance testing found 32%, while 10 *CFR* 50 Appendix J (Ref. 3) leakage testing found 27%. (These tests are described in Appendix A.) Another 28% of the failures were detected during normal operation. Only 1% of the failures occurred during an operational demand.

5.4 Maintenance Actions

The IPRDS, which extracts repair information from plant maintenance records, is the only data base that contains detailed information on maintenance actions performed on failed CVs. However, because of insufficient entries for CVs, this data base could not be included.

Maintenance activity is sometimes stated briefly in the LERs. Based on these reports, the valves were repaired 54% of the time and replaced 11%. About 25% of the LERs did not indicate any maintenance activity.

5.5 Modifications Resulting from Failures

The operating experience data bases do not contain detailed descriptions of postfailure modifications. Some IE publications have outlined a few CV modifications, which are summarized below:

1. Improved soft-seated valve seals — Hard seat valves were modified to a combination soft and hard seat configuration. Several types of soft rings were tried before a molded (one-piece) seal provided a satisfactory leaktightness.
2. Obturator attachment — The locking device that secures the obturator to its hanger wore sufficiently to allow the obturator to fall free of the hanger. Modifications to the design reduced this wear to an acceptable level.

6. MANUFACTURER INPUT

This section summarizes CV failure modes and failure causes information, which was determined primarily on the basis of information provided by valve manufacturers. Swing and lift CVs were examined; those in the last category include piston lift and ball. Each valve is assumed to be made up of a body assembly, internals, and seals.

6.1 Failure Modes and Causes

The failure modes associated with the three CV designs are listed in Table 6.1, which gives the modes and clarifying, or defining, remarks. A number of failure causes are associated with each failure mode. The causes of interest in this report are those due to aging and service wear.

Table 6.1. Check valve failure modes[a]

Failure mode	Remarks
Failure to Open	Valve failed to open fully
Failure to Close	Valve failed to close fully
Plugged	This failure mode refers to any event that would stop or limit flow through a normally open valve; valves that fail to open are not considered plugged valves
Reverse Leakage	Valve leaks through (measurable leakage past seat), even though the valve indicates closed
External Leakage	A leak or rupture of the valve that would allow the contained medium to escape from the component boundary

[a] Adapted from Ref. 5.

The following paragraphs describe the procedure used to identify failure modes and causes with the assistance of manufacturers. The resulting modes and related causes are then given in tabular form.

6.2 Failure Cause Analysis

To obtain manufacturer input on failure modes and causes, studies were done on manufacturer-supplied information, and telephone discussions were held with company representatives. Lists of failure causes for each failure mode then were compiled for each valve type.

Visits were made to Rockwell International, Flow Control Division, and to the Walworth Company to discuss failure modes and causes and recommended surveillance and maintenance practices. The compiled lists were used as bases for discussion.

Failure causes are correlated with failure modes for each valve design in Table 6.2. The failure causes listed are self-explanatory. Operating experience indicates that *Foreign material* is an important cause of *Failure to Open* and *Failure to Close* failure modes. *Obturator and seat wear and erosion* are important causes of *Reverse Leakage*. Also prominent are *obturator fastener loosening* and *hanger pin corrosion and fracture*.

Table 6.2. Valve failure causes related to aging and service wear

Subcomponent	Failure cause	Failure modes				
		Failure to Open	Failure to Close		Reverse Leakage	External Leakage
	CV type: Ball lift					
Body assembly	Body guide rib corrosion	X	X			
	Body guide rib wear, erosion, corrosion				X	
	Body wear, erosion, corrosion				X	X
	Body rupture					X
	Fastener loosening, breakage					X
Internals	Obturator corrosion	X	X			
	Obturator wear, erosion, corrosion				X	
	Seat corrosion	X				
	Seat wear, erosion, corrosion		X		X	
	Foreign material	X	X	X		
Seals	Cap or bonnet seal deterioration					X
	CV type: Piston lift					
Body assembly	Obturator guide wear, erosion, corrosion	X	X		X	
	Body wear, erosion, corrosion				X	X
	Body rupture					X
	Equalizer plugged	X				
	Fastener loosening, breakage					X
Internals	Obturator wear, erosion, corrosion	X	X		X	
	Seat corrosion	X				
	Seat wear, erosion, corrosion		X		X	
	Foreign material	X	X	X		
Seals	Cap or bonnet seal deterioration					X

Table 6.2 (continued)

Subcomponent	Failure cause	Failure modes				
		Failure to Open	Failure to Close	Plugged	Reverse Leakage	External Leakage
	CV type: Swing					
Body assembly	Body wear, erosion, corrosion					X
	Body erosion, corrosion				X	
	Body rupture					X
	Fastener loosening, breakage					X
Internals	Hanger pin wear, erosion, corrosion, fracture	X	X		X	X
	Hanger pin fracture			X		
	Hanger pin bearing wear, fracture, corrosion	X	X		X	
	Obturator hanger wear, fracture		X	X		
	Obturator hanger wear				X	
	Obturator fastener loosening, tightening, breakage		X	X	X	
	Obturator wear, erosion, corrosion				X	
	Seat wear, erosion, corrosion				X	
	Foreign material	X	X	X		
Seals	Cap or bonnet seal deterioration					X
	Hanger pin seal wear, deterioration					X

7. MANUFACTURER-RECOMMENDED SURVEILLANCE AND MAINTENANCE PRACTICES

Recommended surveillance and maintenance practices are contained in manufacturer-supplied manuals. Much of the coverage is given only in general terms because the products may be used in a variety of applications and be subjected to a broad spectrum of service conditions. Recommendations given by three manufacturers are outlined in Table 7.1.

Table 7.1. Surveillance and maintenance recommendations

Manufacturer	Valve	Reference	Maintenance and troubleshooting
Atwood and Morrill Co., Inc.	Bleeder check with side-closing cylinder	6	Preventive maintenance Shaft binding check Disk movement check External leakage check General maintenance Inspection, repair, and replacement Exercising of valve
Rockwell International, Flow Control Division	Piston-lift check	7	Troubleshooting Bonnet (or cap) seal leakage Seat leakage Body rupture Body guide rib wear, corrosion Foreign material Maintenance Valve body repair Seat leakage repair
Walworth Company	Swing check	8	Inspection, repair, and replacement Hanger pin Hanger Cap or bonnet Obturator Body Troubleshooting Cap or bonnet seal leakage Reverse leakage

8. AGING AND SERVICE WEAR MONITORING

Failure modes and causes along with associated inspection, surveillance, and monitoring aspects are addressed in this section. The discussion is based on information derived from ASME in-service inspection codes and standards, manufacturers, and this study. The areas covered are failure mode detection, cause determination and identification of parameters for degradation trending, and incipient failure detection.

8.1 Failure Mode and Cause Determination

Failure mode detection is described in terms of currently used parameters and methods. Candidate methods are also identified. Failure cause determination embraces both methods for cause differentiation and use of measurable parameters for detailed evaluation. Methods for differentiation are discussed in this subsection, while measurable parameters are discussed in Subsect. 8.2.

Technical Specification requirements invoke use of the *ASME Boiler and Pressure Vessel Code*, Sect. XI rules for in-service inspection of CVs. These rules employ valve exercising for assessing operational readiness. Exercising is defined as the demonstration, based on direct or indirect visual or other positive indication, that the moving parts of the valve function satisfactorily. For CVs, the exercising tests are to verify that the obturator travels to the full-open and/or full-closed position.

Internal leakage rate testing is required for CVs used for containment isolation. This testing is conducted in accordance with Ref. 3.

The ASME Committee on Operation and Maintenance is preparing a standard, ANSI/ASME OM-10, *Inservice Testing of Valves*, which is expected to supercede Subsect. IWV of Sect. XI. It is expected that exercising will again be used to measure operational readiness.

In conducting the exercising tests in accordance with either *ASME Code* Sect. XI or ANSI/ASME OM-10, a mechanical exerciser can be used to move the obturator. When such an exerciser is used, the applied force or torque is measured. For normally closed valves whose function is to open on reversal of pressure differential, flow rate and pressure differential are parameters that can be used for confirmation of obturator movement under Sect. XI.

The requirements of the *ASME Code* are related to failure modes described in Table 6.1. Measurable parameters, in addition to force or torque, as well as methods for monitoring aging and service wear, can be identified by considering methods for detecting CV failures and ascertaining failure causes. Methods now used for detecting failure modes are listed in Table 8.1; methods for differentiation between failure causes are listed in Table 8.2.

Table 8.1, shows that surveillance testing; process instrumentation measurements of fluid levels, pressure, temperature, and flow-rate changes; and disassembly to verify operability are prominent means for

Table 8.1. Methods currently used to detect CV failure modes

Failure mode	Means of identification
Failure to Open	Surveillance testing in accordance with *ASME Code* Sect. XI (Technical Specification requirement)
Failure to Close	Process instrumentation measurements of fluid level, pressure, temperature, and flow-rate changes or lack thereof Operational abnormality as shown by position indicator (if equipped) Disassembly to verify operability X-ray examination
Plugged	Process instrumentation measurements of fluid level, pressure, temperature, and flow-rate changes or lack thereof Disassembly to verify operability
Reverse Leakage	Surveillance testing in accordance with 10 CFR 50, Appendix J (Ref. 3) (Technical Specification requirement for containment isolation valves) Leakage rate testing Process instrumentation measurements of changes in system pressure, level, or temperature
External Leakage	Environmental changes in vicinity of valve; that is, flooding and high humidity — routine surveillance — incidental observation Area sump monitoring Hydrostatic testing

failure mode identification. Other important means are position indicator signals, leakage rate testing, and X-ray examination. Nondestructive examination (NDE) methods other than X-ray examination that merit consideration[9] are ones based on eddy-current and ultrasonic techniques. Candidate methods for *Reverse Leakage* identification include acoustic monitoring,[10,11] infrared remote detection, and dedicated downstream temperature measurement.

Only piston lift and swing CVs are addressed in Table 8.2. Because compilations for ball valves do not add to the methods for differentiation, they are omitted. The table shows that cause differentiation is heavily dependent on valve disassembly and inspection. Visual examination and inspection during maintenance are applicable to *External Leakage*.

Table 8.2. Methods for differentiating between failure causes

Failure mode	Subcomponent	Failure causes	Methods for differentiation
		CV type: Piston lift	
Failure to Open	Body assembly	Obturator guide wear, erosion, corrosion	Disassembly and inspection
		Equalizer plugged	Disassembly and inspection
	Internals	Obturator wear, erosion, corrosion	Disassembly and inspection
		Seat corrosion	Disassembly and inspection
		Foreign material	Disassembly and inspection
Failure to Close	Body assembly	Obturator guide wear, erosion, corrosion	Disassembly and inspection
	Internals	Obturator wear, erosion, corrosion	Disassembly and inspection
		Seat wear, erosion, corrosion	Disassembly and inspection
		Foreign material	Disassembly and inspection
Plugged	Internals	Foreign material	Disassembly and inspection
Reverse Leakage	Body assembly	Obturator guide wear, erosion, corrosion	Disassembly and inspection
		Body wear, erosion, corrosion	Disassembly and inspection
	Internals	Obturator wear, erosion, corrosion	Disassembly and inspection
		Seat wear, erosion, corrosion	Disassembly and inspection
External Leakage	Body assembly	Body wear, erosion, corrosion	Disassembly and inspection
		Body rupture	Visual examination, inspection during maintenance
		Fastener loosening, breakage	Visual examination, inspection during maintenance
	Seals	Cap or bonnet seal deterioration	Visual examination, inspection during maintenance

Table 8.2 (continued)

Failure mode	Subcomponent	Failure causes	Methods for differentiation
		CV type: Swing	
Failure to Open	Internals	Hanger pin wear, corrosion, fracture	Disassembly and inspection
		Hanger pin bearing wear, fracture, corrosion	Disassembly and inspection
		Foreign material	Disassembly and inspection
Failure to Close	Internals	Hanger pin wear, corrosion, fracture	Disassembly and inspection
		Hanger pin bearing wear, fracture, corrosion	Disassembly and inspection
		Obturator hanger wear, fracture	Disassembly and inspection
		Obturator fastener loosening, breakage	Disassembly and inspection
		Foreign material	Disassembly and inspection
Plugged	Internals	Hanger pin fracture	Disassembly and inspection
		Obturator hanger wear, fracture	Disassembly and inspection
		Obturator fastener loosening, breakage	Disassembly and inspection
		Foreign material	Disassembly and inspection
Reverse Leakage	Body assembly	Body erosion, corrosion	Disassembly and inspection
	Internals	Hanger pin wear, erosion, corrosion, fracture	Disassembly and inspection
		Hanger pin bearing wear, fracture, corrosion	Disassembly and inspection
		Obturator hanger wear	Disassembly and inspection
		Obturator fastener loosening, tightening, breakage	Disassembly and inspection
		Obturator wear, erosion, corrosion	Disassembly and inspection
		Seat wear, erosion, corrosion	Disassembly and inspection

Table 8.2 (continued)

Failure mode	Subcomponent	Failure causes	Methods for differentiation
		CV type: Swing (continued)	
External Leakage	Body assembly	Body wear, erosion, corrosion	Disassembly and inspection
		Body rupture	Visual examination, inspection during maintenance
		Fastener loosening, breakage	Visual examination, inspection during maintenance
	Internals	Hanger pin wear, corrosion, fracture	Disassembly and inspection
	Seals	Cap or bonnet seal deterioration	Visual examination, inspection during maintenance
		Hanger pin seal wear, deterioration	Visual examination, inspection during maintenance, acoustic monitoring for packing tightness, measurement of applied force or torque for obturator movement

8.2 Measurable Parameters for Establishing Degradation Trends

In the preceding subsection, failure mode determination and failure cause differentiation were considered. Measurable parameter use was also discussed. As stated in the NPAR strategy, the objective of this subsection is to enlarge on that use by introducing measurable parameters that have the potential for being combined with those already identified to enhance capabilities for examining degradation trends and detecting incipient failure.

Measurable parameters identifiable for evaluating operational readiness include force or torque applied to move the obturator; fluid level, temperature, pressure, pressure differential, and flow rate; reverse leakage rate; humidity; and noise. Additional parameters are necessary both for positive failure cause identification and enhancement of capabilities for degradation tracking and incipient failure detection. Suggested parameters for fulfilling these needs, dimensions, appearance, roughness, cracking, packing gland position, and bolt torque, are given in Table 8.3; these parameters require further investigation. Leakage rate, noise, and applied force or torque are included in the table as well as in the list given previously. Although appearance is not clearly a measurable parameter and is a term whose meaning depends on the application, it is included because it can be used to fulfill a major requirement of monitoring, that is, imparting useful information for establishing trends and assessing aging and service wear.

A summary of valve part failure assessments as addressed in this report is given in Table 8.4., which illustrates relationships between materials, stressors, failure causes, and measurable parameters.

The utility of the parameters identified in this report will be evaluated, and other parameters may be introduced in subsequent phases of the CV investigation. A companion need to that of measurable parameter identification and evaluation for inspection, maintenance, and monitoring use is the development of criteria for accepting or rejecting components or assemblies for further service. The decision criteria will ensure that the component performs its function during system normal operating transients and emergency conditions. Development of such criteria will be an evolutionary process requiring cooperative efforts with users and, thus, is beyond the scope of the NPAR Program.

Table 8.3. Measurable parameters

Failure mode	Subcomponent	Failure causes	Measurable parameters[a]
		CV type: Piston lift	
Failure to Open	Body assembly	Obturator guide wear, erosion, corrosion,	Dimensions, appearance, roughness
		Equalizer plugged	Pressure differential, flow rate
	Internals	Obturator wear, erosion, corrosion	Dimensions, appearance, roughness
		Seat corrosion	Dimensions, appearance
		Foreign material	Appearance
Failure to Close	Body assembly	Obturator guide wear, erosion, corrosion	Dimensions, appearance, roughness
	Internals	Obturator wear, erosion, corrosion	Dimensions, appearance, roughness
		Seat wear, erosion, corrosion	Dimensions, appearance, roughness
		Foreign material	Appearance
Plugged	Internals	Foreign material	Appearance
Reverse Leakage	Body assembly	Obturator guide wear, erosion, corrosion	Dimensions, appearance, cracking
		Body wear, erosion, corrosion	Dimensions, appearance, cracking
	Internals	Obturator wear, erosion, corrosion	Leakage rate, dimensions, appearance, cracking
		Seat wear, erosion, corrosion	Leakage rate, dimensions, appearance, cracking
External Leakage	Body assembly	Body wear, erosion, corrosion	Dimensions, appearance, cracking
		Body rupture	Dimensions, appearance
		Fastener loosening, breakage	Torque, appearance
	Seals	Cap or bonnet seal deterioration	Appearance

Table 8.3 (continued)

Failure mode	Subcomponent	Failure causes	Measurable parameters[a]
		CV type: Swing	
Failure to Open	Internals	Hanger pin wear, corrosion, fracture	Dimensions, appearance, roughness
		Hanger pin bearing wear, fracture, corrosion	Dimensions, appearance
		Foreign material	Appearance
Failure to Close	Internals	Hanger pin wear, corrosion, fracture	Dimensions, appearance, roughness
		Hanger pin bearing wear, fracture, corrosion	Dimensions, appearance
		Obturator hanger wear, fracture	Dimensions, appearance, roughness
		Obturator fastener loosening, breakage	Torque, appearance
		Foreign material	Appearance
Plugged	Internals	Hanger pin fracture	Appearance
		Obturator hanger wear, fracture	Appearance
		Obturator fastener loosening, breakage	Torque, appearance
		Foreign material	Appearance
Reverse Leakage	Body assembly	Body erosion, corrosion	Dimensions, appearance, cracking
	Internals	Hanger pin wear, erosion, corrosion, fracture	Dimensions, appearance
		Hanger pin bearing wear, fracture, corrosion	Dimensions, appearance
		Obturator hanger wear	Dimensions, appearance
		Obturator fastener loosening, tightening, breakage	Torque, appearance
		Obturator wear, erosion, corrosion	Leakage rate, dimensions, appearance, cracking
		Seat wear, erosion, corrosion	Leakage rate, dimensions, appearance, cracking

Table 8.3 (continued)

Failure mode	Subcomponent	Failure causes	Measurable parameters[a]
		CV type: Swing (continued)	
External Leakage	Body assembly	Body wear, erosion, corrosion	Dimensions, appearance, cracking
		Body rupture	Dimensions, appearance
		Fastener loosening, breakage	Torque, appearance
	Internals	Hanger pin wear, corrosion, fracture	Dimensions, appearance
	Seals	Cap or bonnet seal deterioration	Appearance
		Hanger pin seal wear, deterioration	Appearance, noise, force or torque applied for obturator movement, packing gland position

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[a] The measureable parameters listed in this table reflect primarily the methods for differentiation given in Table 8.2.

Table 8.4. Summary of valve part failure assessments

Part	Materials	Significant stressors and failure causes	Measurable parameters
Body, cap (bonnet)	Stainless steel	Mechanical: obturator guide wear, galling, body wear, rupture Chemical: corrosion, erosion	Dimensions, appearance, roughness, cracking
Fasteners	Stainless steel	Mechanical: loosening, breakage Chemical: corrosion	Torque, appearance
Seat	Stainless steel or hardened alloy Resilient material	Mechanical: wear Chemical: erosion, corrosion	Leakage rate, dimensions, appearance, cracking
Obturator	Stainless steel with hardened alloy seating surface	Mechanical: wear Chemical: erosion, corrosion	Leakage rate, dimensions, appearance, cracking
Obturator hanger	Stainless steel	Mechanical: wear, fracture Chemical: erosion, corrosion	Dimensions, appearance, roughness
Hanger pin	Stainless steel	Mechanical: wear, fracture Chemical: erosion, corrosion	Dimensions, appearance, roughness
Hanger pin bearing	Hardened alloy	Mechanical: wear, fracture Chemical: erosion, corrosion	Dimensions, appearance
Seals, gaskets	Asbestos type Stainless steel Resilient material	Mechanical: distortion, comprespression Thermal: hardening, embrittlement (nonmetals) Chemical: corrosion	External leakage, appearance, noise, torque or force applied for obturator movement, packing gland position

9. SUMMARY AND RECOMMENDATIONS

The objective of this study was to identify failure modes and causes resulting from aging and service wear of CVs in nuclear plant service and to identify measurable parameters that are suitable for detecting and establishing time-dependent degradation trends prior to failure, as well as giving input for effective maintenance. To this end, operating experience information, nuclear industry reports, manufacturer-supplied information, and results from discussions with manufacturers and plant operators have been used.

The dominant failure mode shown by operating experience records is *Reverse Leakage* past the seating surfaces. These records also show that *Failure to Close* and *Plugged* are frequent failure modes. These results were not unexpected, and many possible failure causes can be identified with the three modes. It is these causes and those associated with other failure modes that were the focus of this study. Having identified failure causes, potentially useful parameters for degradation tracking and incipient failure detection were listed. The effectiveness and acceptability of these parameters will be evaluated in subsequent phases of the CV project.

The major methods used for failure cause identification are valve disassembly and inspection, visual examination, and inspection during maintenance. Thus, periodic inspection and surveillance are expected to continue for CVs.

Beyond cause determination and degradation monitoring are assessments of the extent of aging and service wear. These assessments will be made in terms of acceptance or rejection criteria for further service, with synergistic effect influences factored in. Decisions will be based on criteria that will ensure that the component performs its function during normal system operating transients and emergency conditions. This broader perspective will be addressed in subsequent phases of the CV study, and it is recommended that review and development of acceptance criteria (in cooperation with users) be given attention in keeping with the prominent roles these play.

The relationship of the first-phase study reported here to the NPAR Program strategy is illustrated by the cross-hatched portions of the diagram in Fig. 9.1.

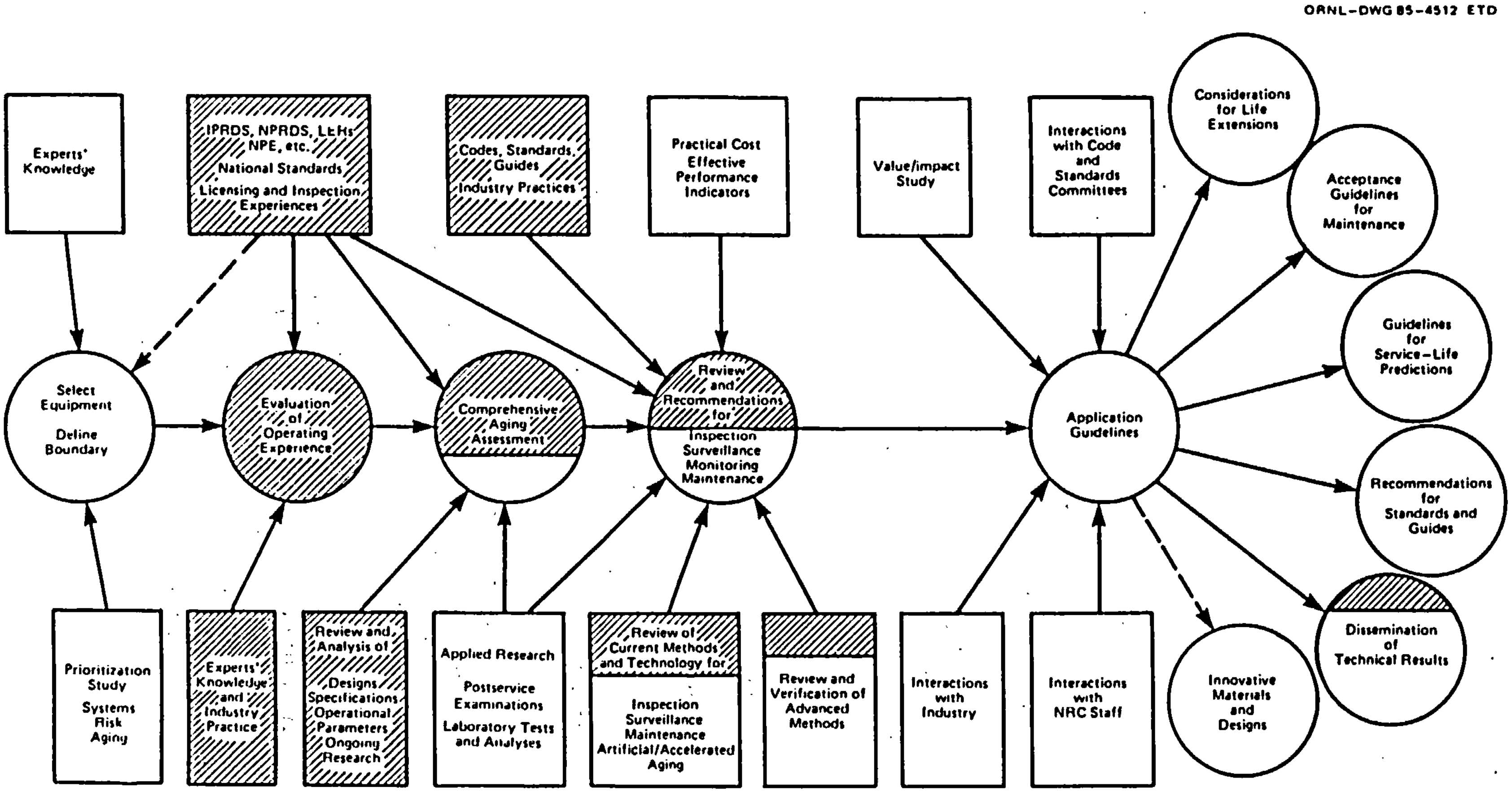

Fig. 9.1. NPAR Program strategy.

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Appendix A

SUMMARY OF *ASME BOILER AND PRESSURE VESSEL CODE* SECT. XI REQUIREMENTS FOR CHECK VALVES

The *ASME Code* Sect. XI requirements for valves are given in Subsect. IWV, *Inservice Testing of Valves in Nuclear Power Plants*. This subsection discusses in-service testing of Nuclear Class 1, 2, and 3 valves, including their activating and position-indicating systems, which are required to perform a specific function in bringing a reactor to the cold shutdown condition or in mitigating the consequences of an accident. Although some valves, such as manual vent, drain, instrument, maintenance, and test valves, are excluded from test requirements, they do not comprise a significant percentage of those valves that fall within the categories requiring testing.

A.1 Valve Categories

The valves selected for in-service testing are placed in one or more of the following categories. When one or more distinguishing category characteristic is applicable, all requirements of each of the individual categories are applicable, although duplication or repetition of common requirements is not done.

1. Category A — valves for which seat leakage is limited to a specific maximum amount in the closed position for fulfillment of their functions.
2. Category B — valves for which seat leakage in the closed position is inconsequential for fulfillment of their function.
3. Category C — valves that are self-actuating in response to some system characteristics, such as pressure (relief valves) or flow direction (check valves).
4. Category D — valves that are actuated by an energy source capable of only one operation, such as rupture disks or explosive-actuated valves.

In addition to these categories, the valves are further classified as being active or passive. Active valves are those requiring a change in position to accomplish their functions, while passive valves do not require a change in position to accomplish their functions.

The requirements applied to CVs (Category C) are discussed below.

A.2 Testing of Category C Valves

CVs, safety valves, and relief valves which, by design, must change position for fulfillment of their function, are Category C valves. Distinction is important between valves that serve a safety-related function and valves that are employed only for overpressure protection under system functional test conditions or for control of flow distribution within interconnected systems undergoing tests. The latter valves are not subject to tests. The intent of Category C tests is to confirm the freedom of obturators in CVs to prevent reverse flow where such reverse flow would impair the fulfillment of a safety function. (Safety and relief valves are tested in accordance with ASME PTC-25.3.) In either case, these valves must be tested on a regular schedule as directed in Subsect. IWV with each valve tested at least once in 5 years.

When a valve fails to function properly during a regular test, all valves in the system in that particular category must be tested. Additional valves are determined by an arbitrary assumption that a 12-month operating period has passed to another refueling period and the additional valves to be tested will make the cumulative total at least N/60 times the total valves in this category.

For example, if there are 10 valves in this category and it is the twelfth month after startup:

$$N/60 \times \text{number of valves to be tested} = (12/60) \times 10 =$$

$$(1/5) \times 10 = 2 \text{ valves} ,$$

where N = 12 months. After one valve has been tested, the second valve fails the test. N now becomes 24, therefore, $(24/60) \times 10 = (2/5) \times 10 =$ 4 valves total or 2 additional valves. If either of these two additional valves fail the test, then all ten valves in this category have to be tested. The exercising tests for CVs are identical to those stated for Category A and B valves; that is, they are simply to show that the valve can obtain the position required to fulfill its function. If the full-stroke position is not practical during plant operation, then the valve will be part-stroke exercised, followed up by a full-stroke exercise during cold shutdown. If a valve cannot be exercised at all during plant operation, then it will also receive a full-stroke exercise during cold shutdown.

Check valves that are normally closed during plant operation and whose function is to open on reversal of pressure differential will be tested by proving that the obturator moves promptly away from the seat when the closing pressure differential is removed and flow through the valve is initiated or when a mechanical opening force is applied to the obturator. This test can be made with or without flow through the valve; however, a mechanical exerciser shall be used to move the obturator if a no-flow test is conducted.

Confirmation that the CV obturator is either on its seat or has moved away from its seat will be by (1) visual observation, (2) an electrical signal indicated by a position-indicating device, (3) observation of appropriate pressure indications in the system, or (4) other positive means.

The corrective action for CVs is also identical to Category A and B valves in that, if the CV fails to exhibit the required change of obturator position, corrective action is to be taken immediately. If the condition is not corrected within 24 h, the valve is declared inoperative. If this occurs during a cold shutdown, the valve's condition shall be corrected prior to startup.

A typical in-service testing program outline for selected valves is shown in Table A.1. The following information is given:

1. Valve Number lists the valve identification number as shown on the piping and instrument drawing (P&ID). The first digit of the valve number usually indicates the appropriate power plant unit.
2. Coordinates references the P&ID on which the valve appears and its coordinates.
3. Class is the In-service Inspection (ISI) classification of the valve. All primary containment valves are included in the program, even though some do not have an ISI classification. These valves are designated as Class NC (not classified).
4. Valve Category indicates the category assigned to the valve based on the definitions given previously.
5. Valve Size lists the nominal pipe size of the valve in inches.
6. Valve Type lists the valve design as indicated by the following abbreviations: Gate — GA, Globe — GL, and Check — CK.
7. Actuator Type lists the type of valve actuator as indicated by the following abbreviations: Motor Operator — MO and Self-Actuated — SA.
8. Normal Position indicates the normal position of the valve during plant operation; either normally open (O) or normally closed (C).
9. Stroke Direction indicates the direction that an active valve must stroke to perform its safety function. Also, the direction in which the valve will be stroked to satisfy the ISI exercising requirements. This may be specified as open (O), closed (C), or both (O&C).
10. Test lists the test or tests that will be performed for each valve to fulfill the requirements of Subsect. IWV. The following tests and abbreviations are used:
    Seat Leak Test (AT)
    Valve will be seat leak tested at the appropriate functional differential pressure.
    Full-Stroke Exercise Test (BT)
    Valve will be full-stroke exercised for operability in the direction necessary to fulfill its safety function.
    Check Valve Exercise Test (CT-1)
    Check valve will be exercised fully open, closed, or both, depending on the safety function of the valve.
    Position Indication Check (PIT)
    All valves with remote position indicators that are inaccessible for direct observation during normal plant operation must be checked to verify that remote valve indications accurately reflect valve operation.
11. Test Mode indicates the frequency at which the above-mentioned tests will be performed. The following abbreviations are used:
    Normal Operation (OP)
    Valve tests with this designation will be performed once every 3 months.

Table A.1. In-service testing program for Class 1, 2, and 3 valves

(Nuclear Power Station Unit-1, System: Residual Heat Removal, P&ID: M-29, Sht. 1)

Valve No.	Coordinates	Class	Valve category	Valve size	Valve type	Actuator type	Normal position	Stroke direction	Test	Test mode	Maximum stroke time (s)	Relief request	Remarks
2-1001-29A	A-5	1	A	16	GA	MO	C	O	AT BT	RR OP	25		
2-1001-29B	A-7	1	A	16	GA	MO	C	O	AT BT	RR OP	25		
2-1001-47	C-5	1	A	20	GA	MO	C	O&C	AT BT	RR CS	40	VR-9	Group 2 isolation
2-1001-50	B-5	1	A	20	GA	MO	C	O&C	AT BT	RR CS	40	VR-9	Group 2 isolation
2-1001-60	A-7	1	A	4	GA	MO	C	O&C	AT BT	RR CS	25	VR-9	Group 2 isolation
2-1001-63	A-6	1	A	4	GA	MO	C	O&C	AT BT	RR CS	25	VR-9	Group 2 isolation
2-1001-68A	A-5	1	C	16	CK	SA	C	O	PIT CT-1	RR CS	NA	VR-7	
2-1001-68B	A-6	1	C	16	CK	SA	C	O	PIT CT-1	RR CS	NA	VR-7	
2-1001-16A	D-2	2	B	18	GL	MO	O&C	O	BT	OP	125		
2-1001-16B	D-10	2	B	18	GL	MO	O&C	O	BT	OP	125		
2-1001-18A	B-4	2	B	3	GA	MO	O	C	BT	OP	30	VR-8	

Cold Shutdown* (CS)
Valve testing at cold shutdown is testing that commences not later than 72 h after cold shutdown and continues until required testing is completed or plant startup, whichever occurs first. Completion of all required valve testing is not a requisite to plant startup. Valve testing that is not completed during a cold shutdown will be performed during subsequent cold shutdowns to meet the *ASME Code*-specified testing requirements. No valve needs to be tested more often than once every 90 d.

Reactor Refueling (RR)
Valve tests with this designation will be conducted at reactor refueling outages only.

12. Maximum Stroke Time lists the maximum allowed full-stroke time in seconds for valves requiring a BT test.
13. Relief Request references the relief request that applies to the particular valve.
14. Remarks lists clarification remarks or indicates that a valve receives an automatic isolation signal.

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*NOTE: Most required valve testing is normally completed in 96 h following cold shutdown. However, completion of all valve testing during cold shutdown is not required if plant operating conditions will not permit the testing of specific valves.

Appendix B

OPERATING EXPERIENCE DATA BASES AND REPORTS

B.1 ORNL Nuclear Operations Analysis Center LER Survey

B.1.1 Introduction

Abstracts of all Licensee Event Reports (LERs) (and event reports issued prior to the LERs) that were issued by U.S. utilities are stored on the Department of Energy (DOE) RECON data base or the NRC's Sequence Coding and Search System (SCSS). Both data bases can be accessed at the Oak Ridge National Laboratory (ORNL) Nuclear Operations Analysis Center. A search was made of these data bases for all events indexed as check valves (CVs), excluding main steam isolation valves (MSIV). Each event abstract was reviewed to determine (1) mode of failure, (2) mode of detection, (3) maintenance activity, and (4) cause of failure.

This review found 472 events that span the time frame from 1969 through 1983 (1981—1983 events were obtained via the SCSS). Results are summarized in Table B.1. Of the events, 51% occurred at pressurized-water reactors (PWRs), 47% at boiling water reactors (BWRs), and 2% at advanced or research reactors. The reactor type should have little or no effect on CV operation. During the review, certain types of events were not included in this study of the 472 events. The types not included are:

1. failure to test the CV,
2. foreign reactor events,
3. design errors of including or omitting CVs,
4. incorrect seismic analysis,
5. ventilation system check dampers,
6. BWR torus vacuum relief valves, and
7. valve body defects found during construction or initial testing.

Each report might include failure of more than one CV or multiple failures of the same valve. Thus, the count does not reflect the total number of CV failures but is the number of reports sent to the Nuclear Regulatory Commission (NRC). Also, the utilities are not required to report all failures but only those that meet conditions as specified in 10 CFR 50. Some failures are not reported as LERs and, therefore, are not included in this review.

B.1.2 Discussion of Results

B.1.2.1 Mode of failure. As would be expected, leakage past the seating surfaces of the CVs was the dominant failure mode (52%). The description of the event would state that leakage through the CV caused certain conditions to occur. The most reported event was leakage into accumulators resulting in high fluid level and/or low boron concentration. In most of these reports the failure cause and description of the

Table B.1 Check valve failures reported in LERs for period 1969–1983

		Percent
I.	Mode of Failure	
	Leakage	
	Seating surfaces	52
	Gasket	4
	Seat-to-body	3
	Internals	32
	Body	2
	Slow response time	1
	Operational error	2
	Other/unknown	4
II.	Mode of Detection	
	Surveillance testing	32
	Leak rate testing	27
	Normal operation	28
	Maintenance	9
	Demand[a]	1
	Other/unknown	3
III.	Maintenance Activity	
	Repair	54
	Replace	
	In-kind	8
	Different	3
	Modification	9
	Other	1
	Unknown	25
IV.	Cause	
	Wear	8
	Crud	15
	Corrosion/erosion	5
	Failure to seat	4
	Design error	6
	Crack/fatigue	2
	Installation/fabrication	9
	Binding	3
	Other/unknown	48

[a] Resulting from emergency or accident condition.

maintenance activity to repair were not included — most CV failures were listed as being detected during normal operation. Level alarms notified the operators of high levels, while routine sampling found low concentrations. Gasket leaks (pressure boundary leaks) occurred in 4% of the report, with seat-to-body leaks (internal leaks) accounting for only 3%.

Problems with the valve internals were reported in 32% of the events. Failure of parts often allows the valve obturator of the swing CVs (see Fig. 2.1) to move out of position, thus preventing seating or allowing it to fall free. The free obturator could move so as to throttle or block flow through the line.

Only a few (2%) valve body problems were reported and only a part of these resulted in pressure boundary leakage. No catastrophic failure was reported.

Slow valve response time (1%) and errors in operating the valves (2%) account for the other identified modes of failure. A few reports (4%) did not describe the failure mode or give a mode not fitting the above-discussed categories.

B.1.2.2 Mode of detection. In 59% of the events, failures were found during testing. Leak rate testing (10 CFR 50, App. J) was involved in 27% of the events, while regular surveillance testing of various systems found 32% of the events. Surveillance testing of diesel generators found CVs that leaked through the seat, allowing the fuel to drain out of the fuel line. This resulted in excessive starting times for the diesel generators.

The next most frequent mode of detection was normal operation (28%). Pumps failed to start because of CVs sticking closed. Accumulator problems were found during routine sampling or reading of instruments.

Only 9% of the events were discovered during maintenance activities where, while repairing equipment, a CV failure was discovered. Some loose obturators were found this way.

In only a very few cases (1%) was a system called on to function in an emergency condition, and a CV failed to operate properly. Thus, the present test programs and maintenance activities have found most of the problems before the emergency demand occurred.

B.1.2.3 Maintenance activity. The major stated maintenance activity was repair of the valve (54%), including cleaning, lubricating, and replacing defective parts. In 11% of the cases the CV was replaced, with 8% of the replacements being the same model, while 3% were replaced with a different type of CV. To solve the failure problem, modifications were made in 9% of the events. This includes change of materials, change of sizes, and a different way of securing the part. Repair procedure was not stated 25% of the time.

B.1.3 Cause

Foreign material (rust scale, sand, weld slug, etc.) accumulating in the valve body caused 15% of the events. This crud prevented seating surfaces from sealing or caused binding of the valve internals. Installation and fabrication errors caused 9% of the failures. Valves were installed backwards or in vertical piping instead of horizontal runs. Proper dimensional tolerances were not met.

Wear of internal components resulted in 8% of the failures. These were mainly the obturator stud and the hanger pin failures that resulted in loose or mispositioned obturators. Design errors were the cause of failure 6% of the time, while corrosion/erosion caused 5%. Some reports (4%) only recorded that the valve failed to seat. Binding of internals caused another 3%, while 2% were caused by cracks or fatigue. However, 48% of the time no cause was given.

B.2 IE Bulletins, IE Circulars, and IE Information Notices

When an incident occurs at a nuclear facility or several similar incidences occur at one or more than one nuclear facility that might have a similar effect on other facilities, the NRC Office of Inspection and Enforcement may issue an IE Bulletin, IE Circular, or IE Information Notice to those facilities that might be similarly affected. (IE Circulars have not been issued since 1981.) These notifications briefly describe the incident(s) with emphasis on the cause of failure. A solution to correct the failure(s) and/or prevent recurrence may be given. IE Bulletins require the licensees to take certain specified action and to provide written response to IE concerning the results of such actions. IE Information Notices may suggest action(s) to be taken, but no written response is required. A review of all of these IE publications found 3 IE Bulletins (IEBs), 2 IE Circulars (IECs), and 12 IE Information Notices (INs) that concern CV failures. Each of these publications is summarized below.

B.2.1 IEB 83-03, *Check Valve Failures in Raw Water Cooling Systems of Diesel Generators*, issued March 10, 1983

A review of available operating experience data and LERs shows that numerous CV failures have occurred in systems important to safety in nuclear power plants. A series of IE generic communications has been issued that describes a broad range of CV failures involving various designs, causes, and applications. The NRC has evaluated CV failures in consideration of the need to request generic action by licensees. The focus of this bulletin is directed primarily at the failure mode of disassembly or partial disassembly of CV internals; for example, the CV disk becomes separated from the hinge.

Although most CVs in systems important to safety are included in current in-service testing (IST) program reviews, most are not required to be reverse-flow tested or disassembled to detect gross internal failure because licensees have identified each of these valves as having a single safety function: the open position. However, forward-flow tests to verify the open position are inadequate for detecting internal disassembly. Effective CV testing techniques are necessary to the development of a more meaningful and productive IST program. Operating experience provides a basis for determination of what areas of IST CV surveillance need to be improved.

The specific requirements of this bulletin stem from analysis of CV failures in the raw cooling water supply to the diesel generators at the Dresden and Quad Cities nuclear power stations and other events. At Dresden and Quad Cities, it was found that six of six CVs in the raw cooling water systems for the diesel generators had failed, with the disk becoming detached from the pivot arm.

For all valves, the most dominant failure mode was caused by a combination of abrasive and corrosive wear of valve internals. In particular, the valve disk was held to the pivot arm by a stud with washer and nut. Apparently, flow conditions at the valves were such that the disks vibrated (fluttered), causing local abrasive wear at the arm bore of the hinge where it joins the disk. This same action also resulted in severe degradation of the washer used to retain the disk on the hinge, and, once the degree of degradation at the hinge bore and washer was sufficient, the two components separated. The stud and nut wore such that the stud and nut assembly pulled through the enlarged hole in the pivot arm and became detached.

B.2.2 IEB 80-01, *Operability of ADS Valve Pneumatic Supply*, issued January 14, 1980

Engineering evaluation for Peach Bottom 2 and 3 has disclosed that the Automatic Depressurization System (ADS) pneumatic supply (either nitrogen or air) may not be operable for all possible events because of a combination of misapplication of CV, a lack of leak testing of the accumulator system backing up each ADS valve operator, and questions about the continued operability of the pneumatic supply in a seismic event. The CV nearest the accumulator is a PAL, 3/4-in., stainless steel, socket-welded CV with a hard seat.

B.2.3 IEB 79-04, *Incorrect Weights for Swing Check Valves Manufactured by Velan Engineering Corporation*, issued March 30, 1979

North Anna No. 1, Beaver Valley No. 1, and Salem No. 1 have reported to the NRC that they had been provided incorrect weights for the 6-in. swing CVs provided by Velan Engineering Corporation. The 6-in. valve weight provided on the drawing was 225 lb, whereas the actual weight has been determined to be 450 lb. In addition to the 6-in. valves, drawings for 3-in. valves have specified 60-lb weight, while the measured weight by the manufacturer was 85 lb, and drawings for 4-in. valves have specified 100-lb weight, while the measured weight was 135 lb. In some cases, incorrect valve weights derived from engineering drawings were used in piping stress analyses.

B.2.4 IEC 78-15, *Tilting Disc Check Valves Fail to Close With Gravity in Vertical Position*, issued July 20, 1978

At the San Onofre Nuclear Plant, an 8-in., 1500-lb tilting disk CV failed to close with gravity because it was installed in a vertical rather than a horizontal pipeline. The valve disk was counter-weighted to close with the force of gravity when installed in a horizontal pipe. The manufacturer did not determine the reverse flow necessary to close the improperly installed valve. The CV is located in the Low Pressure Safety Injection System as the first valve inside the containment and may not have closed as required to maintain the containment integrity.

Tilting disk CVs can be designed for either horizontal or vertical piping but not for both. Improperly installed tilting disk CVs will not function properly.

B.2.5 IEC 77-08, *Failure of Feedwater Sample Probe*, issued April 15, 1977

During surveillance testing at the Cooper station on January 21, 1977, a high-pressure coolant injection (HPCI) system CV was found to be nonfunctional. Inspection of the valve revealed a length of feedwater sample probe lodged in the valve preventing the CV from fully closing, which allowed feedwater to flow backward into the HPCI system injection line. However, the blocked CV would not have prevented the HPCI system from supplying coolant to the feedwater system in the event it was required at the time.

B.2.6 IN 84-12, *Failure of Soft Seat Valve Seals*, issued February 27, 1984

This information notice is provided as a notification of the failure of soft seat valve seals to meet the leakage limits of Appendix J of 10 CFR 50.

On September 29, 1983, the Commonwealth Edison Company reported (LER 83-107) that the inboard feedwater CVs at LaSalle Unit 1 had failed to meet the leakage limits of Appendix J of 10 CFR 50. When the CVs were opened for inspection, the soft seat showed damage around the pressure-relieving vent grooves, some wear on the soft seat face, and slight wear on the body seat.

These CVs had been modified before initial plant operation from a hard seat valve to a combination soft and hard seat configuration. This was accomplished by modifying the valve disks to allow the installation of the soft seat seals. The seals were of molded ethylene-propylene rubber obtained through the valve manufacturer, Anchor/Darling Valve Company, from the Stillman Rubber Company.

The reason these soft seat valve seals failed has not been definitely determined at this time, but failure is believed to be due to one or more of the following.

1. Sharp edges around the pressure-equalizing ports located in the disks had cut the soft seal material in many locations. The sharp edges apparently had not been properly removed when the valve disks were modified. It is possible that air bypassed the seal through these cuts.
2. The machining of the soft seals for proper fit may have affected their sealing capability.
3. The service conditions encountered by the valves during plant startup and shutdown may have damaged the soft seals.

The damaged molded seals were replaced in September with new soft seals of an extruded-vulcanized design obtained through the valve manufacturer from Stevens Associates. The licensee reported (LER 83-146) that, following approximately one month of operation, the inboard feedwater CVs again failed to pass the local leak rate tests. It was determined that the excessive leakage was a result of gaps on the perimeter of the disk seal material, one about 1/2 in. long and the other about 1-1/2 in. in length. These gaps appeared at the seam, or "vulcanized," points of the seal. The utility has replaced the vulcanized seals with molded (one piece) seals similar to those in the original design.

B.2.7 IN 84-06, *Steam Binding of Auxiliary Feedwater Pumps*, issued January 25, 1984

This information notice provides notification of a problem pertaining to steam binding in the auxiliary feedwater (AFW) pumps due to leakage from the main feedwater system.

The discharge piping from the motor-driven AFW train is connected to the main feedwater piping near the steam generator. Hot water, about 425°F, from the main feedwater system leaked back through the first CV, the motor-operated valve, and the second CV to the pump and flashed to steam because of the lower pressure in the AFW system. (A significant amount of steam was vented from the pump casing during the testing to determine the cause of the trip.) When the motor-driven pumps started, the instrumentation sensed a low discharge pressure. The steam binding reduced flow and prevented discharge pressure from increasing above the low pressure set point in the 30 s before the instrumentation tripped the pump. Condensation could have further lowered the pressure to the sensors.

Leakage into the AFW from the feedwater system constitutes a common mode failure that can lead to the loss of all AFW capability. Further, there is the potential for water hammer damage if an AFW pump discharges relatively cold water into a region of the piping system that contains steam.

B.2.8 IN 83-06, *Nonidentical Replacement Parts*, issued February 24, 1983

In October 1980, Beaver Valley 1 filed an LER reporting the failure of a pump discharge CV to seat properly when the pump was shut down. The licensee attributed the problem to binding between an antirotation device on the valve disk and the disk swing arm. Because this was the third time the licensee had experienced similar problems with this style of Velan valves, additional efforts were directed toward longer term resolution after correcting the immediate problem. The licensee found that replacement disks, installed as part of leakage correction maintenance, differed enough from the original disks to cause the problem. A total of 24 valves of this make and type are installed at the facility.

B.2.9 IN 82-35, *Failure of Three Check Valves on High Pressure Injection Lines to Pass Flow*, issued August 25, 1982

At Davis-Besse Unit 1 on June 4, 1982, a stop-check valve (HP-57) in the normal makeup system failed to pass flow although 120 psid was applied across the valve. Normal opening pressure is about 5 psid. The problem was discovered while filling the reactor coolant system (RCS) using a small low-head pump following a refueling and maintenance outage. Normal makeup at Davis-Besse is via one of the four 2-1/2-in. high-pressure injection (HPI) lines. Upon further investigation, HPI valves HP-48 and HP-56 also failed to pass flow at 120 psid. Each HPI line has a stop CV and a swing CV in series.

According to the manufacturer, all Velan 2-1/2-in. stop-check valves are of the same basic design. The internals consist of a disk that is lightly spring-loaded against the valve seat. The disk opens to allow flow at pressures sufficient to overcome spring tension. A valve stem, which is not connected to the disk, can be turned down on the disk via a handwheel to block it against the seat. In this mode, the valve provides an isolating function.

The causes for valve failure are thought to be a combination of overtorquing by operators and a steep valve seat angle. Wear may have also been a contributing factor; however, no obvious signs of wear have been detected by visual inspection.

Because the stem packing of the valves was so tight, the operators used a 1-1/2-ft valve wrench rather than the handwheel to close the valves. The valve manufacturer recommends that no more than 150 ft-lb of torque be used to close the valve. With the valve wrench, the operator could have easily overtorqued the valve.

B.2.10 IN 82-26, *RCIC and HPCI Turbine Exhaust Check Valve Failures*, issued July 22, 1982

A number of reactor core isolation cooling (RCIC) turbine exhaust CV failures have occurred during the past 20 months.

On December 10, 1980, Carolina Power and Light Company reported (LER 80-101/03L) an RCIC system turbine trip at Brunswick Steam Electric Plant Unit 2 while conducting an RCIC system test. The turbine tripped on high turbine exhaust pressure due to the turbine exhaust swing CV failing in the closed position. Inspection revealed the CV disk stem had broken off where it connects to the valve hinge assembly, allowing the disk to fall into the discharge part of the valve and isolate flow.

On May 29, 1981, Pennsylvania Power and Light Company reported (LERs 100450/100508) the failure of the RCIC turbine exhaust swing CV at Susquehanna Steam Electric Station Unit 1 while conducting an RCIC system test. The stud (integrally cast with the disk) that attached the disk to the valve hinge broke off. In a subsequent report on February 5, 1982, they indicated that turbine exhaust steam flow conditions experienced during testing caused the valve disk to cycle violently open and close.

On December 10, 1981, Georgia Power Company reported (LER 81-112/03L) an RCIC isolation at Edwin I. Hatch Nuclear Plant Unit 2 while conducting an RCIC rated flow test. An investigation revealed that the turbine exhaust CV had internal damage, creating a block in the line causing the rupture diaphram to fail.

General Electric identified the possible causes of failure as improper system operation, improper CV sizing, inadequate CV design, or inadequate exhaust line design.

B.2.11 IN 82-20, *Check Valve Problems*, issued June 28, 1982

During required modifications of the low-pressure coolant injection system at the Palisades Nuclear Plant, Consumers Power Co. of Michigan reported that two of the four LPSI swing CVs were found to have internal damage. In both valves the disk nut washer and the disk nut pin were missing, and the valve body, clapper arm, disk clapper arm shaft, and clapper arm support were severely worn. The disks were still attached to their clapper arms; however, valve seat and disk sealing surfaces were damaged, and leaks from the valves could have been excessive.

During start-up testing at the Susquehanna Steam Electric Station Unit 1, Pennsylvania Power and Light reported three problems with Pacific check valves: (1) disk assembly-to-body interference and excessive packing friction, (2) excessive wear at hinge arm/disk stud interface, and (3) disk stud breakage. The Pacific check valves are used in many nonsafety systems as well as the residual heat removal, reactor core isolation cooling, and core spray systems.

B.2.12 IN 82-09, *Cracking in Piping of Makeup Coolant Lines at B&W Plants*, issued March 31, 1982

A visual inspection inside the reactor building revealed a leak associated with a 2-1/2-in. CV (MOV-43) in the makeup line to the 26-in. reactor coolant loop A inlet line. This line is used for normal makeup of reactor coolant but is also part of the redundant HPCI system. After the insulation was removed from the affected valve, a 140° circumferential crack in the CV body near the valve-to-safe-end weld (i.e., valve end toward RC inlet nozzle) was found. The leak was nonisolatable.

A metallurgical investigation of the affected valve body indicated two crack initiation sites. One was inside on the valve body at a machine mark (i.e., weld counterbore area) and one was on the outside diameter (OD) at the valve-to-weld transition (geometrical discontinuity). The cracks progressed through the wall on a slightly different plane and merged about midwall of the valve body. Scanning electron microscope examination of the fracture features disclosed the cracks propagated transgranularly and exhibited clearly defined grain structure striations characteristic of cyclic fatigue failure.

B.2.13 IN 82-08, *Check Valve Failures on Diesel Generator Engine Cooling Systems*, issued March 26, 1982

During a monthly diesel generator surveillance test, the diesel generator was started normally from the control room but soon tripped on high engine temperature. Cooling water flow to the diesel generator heat exchanger was found to be inadequate. A surveillance test was then commenced on a second diesel generator where indications of insufficient cooling water flow were also observed. A broken CV on the discharge of the second diesel generator was found and replaced. The valve disk had broken free of the pivot arm and was lodged in the discharge side of the valve, restricting nearly all flow. The licensee inspected the discharge CV on the first diesel generator pump and found it was broken also. As was the case with the second pump CV, the disk had broken free of the pivot arm.

These failures were not adequately characterized by operator observations and instrument readings during diesel generator surveillance tests but were discovered by direct inspection of the internals of the CV. It is not known how long these CVs were broken before their condition was detected because the broken valve disks were free to move within the valve bodies.

B.2.14 IN 81-35, *Check Valve Failures*, issued December 2, 1981

Metropolitan Edison Company reported loose valve internals in the high-pressure injection pump discharge CVs. The valves are Crane 3-in. 1500-lb tilting obturator CVs. The initial cause of the loose valve internals was traced to the corrosion of the seat holddown devices of the valves.

Metropolitan Edison also found many fabrication inconsistencies that may have initiated and/or contributed to these failures. These inconsistencies ranged from the use of materials, other than those specified in procurement documents, to poor workmanship, particularly in the case of welds. Thus, the CV failures can be attributed to two main causes: (1) poor retaining device design and (2) poor quality control on the assembly of the valve internals.

B.2.15 IN 81-30, *Velan Swing Check Valves*, issued September 28, 1981

While a CV leakage test at the Point Beach Nuclear Plant Unit 1 was being performed, the CVs closest to the reactor coolant system in the low-head safety injection lines were found to be leaking more than allowed by the leakage acceptance criteria. The valves are Velan 6-in. 1500-psig ASA swing CVs (Velan Drawing No. 78704).

The valves were disassembled and the disks were found to be stuck in the full-open position due to interference between the disk nut lockwire (disk wire) and the valve body. The disk nut and its shaft can rotate freely, and, in certain random rotational positions, this interference is likely to occur.

While a leak in the bonnet of a swing CV in the steam supply to the turbine-driven auxiliary feedwater pump at Salem Generating Station Unit 2 was being repaired, the valve was found to be internally damaged. The valve is a Velan 6-in. swing CV (Type B14-2114 B-2TS).

The valve disk stud had broken and the valve disk was in the bottom of the valve body. The valve also had cracks in the disk, cracked bushings, and a warped hinge pin, and all hinge pin holes were elongated.

The licensee inspected the corresponding swing CV in the other steam supply line and discovered similar damage.

B.2.16 IN 80-41, *Failure of Swing Check Valve in the Decay Heat Removal System at Davis-Besse Unit No. 1*, issued November 10, 1981

The licensee performed leak rate tests and identified excessive leakage through decay heat removal system CV CF-30. Valve CF-30 is the inboard one of two in-series CVs that is used to isolate the RCS from the low-pressure decay heat removal system. On further investigation, the licensee found that the valve disk and arm had separated from the valve body and was lodged just under the valve cover plate. The two 2-5/8 by 5/8-in. bolts and locking mechanism for the bolts that holds the arm to the valve body were missing and have not been located. The CF-30 valve is a 14-in. swing CV manufactured by Velan Valve Corporation. The cause of the failure has not been identified.

B.2.17 IN 79-08, *Interconnection of Contaminated Systems with Service Systems Used as the Source of Breathing Air*, issued March 29, 1979

One of the functions of the service air system at Peach Bottom is to provide a source of breathing air for personnel using supplied air respiratory protective equipment. By means of an interconnection to the radwaste system, the facility also uses the service air system to provide a source of compressed air during the backwash cycle of the demineralizer filter element. The compressed air provides the motive force for reverse-water flow through the filter element and was being used to perform this function when two incidents occurred wherein liquid from the radwaste system leaked past a CV and a process valve.

The examinations revealed the presence of dirt deposits in the CV and air-operated ball valve. The specific cause of the leakage was attributed to these dirt deposits, which prevented the proper seating of the valves.

B.3 ALO-75, *Pilot Program to Identify Valve Failures Which Impact the Safety and Operation of LWR Nuclear Power Plants*, published April 1980

This paper presents the results of a pilot program initiated by Sandia Laboratories under the Department of Energy, Light Water Reactor Safety Research and Development Program. The program was conceived as a result of earlier LWR safety and reliability studies that indicated that a substantial number of plant trip incidents were caused by failure of system components such as valves. The specific objectives of this program were to (1) identify the principal types and causes of failures in valves, valve operators, and their controls and associated hardware that lead to or could lead to plant trip and (2) suggest possible remedies for the prevention of these failures and recommend future research and development programs that could lead to reducing these valve failures or to mitigating their effect on plant operation.

The data surveyed cover incidents reported over the 6-year period, beginning 1973 through the end of 1978. Three sources of information on valve failures were consulted: (1) failure data centers, (2) participating organizations in the nuclear industry, and (3) technical documents.

The results of this study indicate that frequent failure modes in valves include lack of leaktightness in both stem packing seals and valve seats and operational malfunction resulting from problems with actuators, their power controls, and instrumentation. Specifically for CVs, the study concluded that main seat leaktightness in main steam isolation and feedwater CVs was reported as a major source of maintenance work. These hard seat valves require long periods of work onsite and may involve removal of bonnets and welding, grinding, and lapping of seat surfaces.

Valve seat leakage is a universal problem in electric power generation. In nuclear applications, this problem becomes more acute because of the severe restrictions imposed on permissible leakage rates. Utility personnel report that this problem occurs most during off-power testing, when pressure differentials across the disk are low. Therefore, it is not a major disruptive factor during plant power operation, but it is a major source of maintenance activity during outages. Opinions of utility personnel attribute this problem primarily to the severity of leakage limitations and changing leak test requirements, coupled with the difficulty in obtaining leaktight repeatability in valves. In addition, leakage indicated in a gaseous test medium, such as nitrogen, is not considered to necessarily indicate excessive leakage under the LWR operating medium.

This study found 5 CV failures out of a total of 138 valve failures. Two of these were in PWRs and three in BWRs. Failure modes were one seat leakage, one packing leakage, one stuck valve, and two procedures. A program to address seat leakage has been recommended in a previous study of this problem. MPR Associates in a report entitled *Assessment of Industry Valve Problem*, EPRI NP-241, November 1976, recommends, in summary, the following.

1. Find improved methods of achieving seat tightness for MSIV and feedwater CVs in BWRs and containment isolation valves in PWRs and BWRs.
2. Develop leak testing methods and techniques that are directly applicable to nuclear stations.
3. Sponsor a long-range program to develop technology for achieving leaktight seating designs in steam, gas, and high-pressure, high-temperature water applications. This program would address material combinations, seat geometry, surface wear, corrosion, radiation damage, and alignment of moving parts.
4. Develop maintenance procedures, tooling, and techniques for restoring seat tightness while keeping radiation exposure to maintenance personnel at a minimum.

B.4 SAND 80-1887, Proceedings EPRI/DOE Workshop, *Nuclear Industry Valve Problems*, Washington, D.C., May 20–21, 1980

A workshop on nuclear industry valve problems was held at the Electric Power Research Institute (EPRI) offices in Washington, D.C. The following recommendations were developed in working sessions on key valves and on valve stem and seat leakage: (1) establish a small permanent expert staff to collect, analyze, and disseminate information about nuclear valve problems; (2) perform generic "key" valve programs for PWRs and BWRs and several plant-specific "key" valve programs, the latter to demonstrate the cost effectiveness of such studies; (3) confirm the identity of, define, and initiate needed longer-term research and development programs dealing with seat and stem leakage; and (4) establish an industry working group to review and advise on these efforts.

Valve problems are discussed in general terms with no data given. Concern is focused on valve problems that resulted in reactor trips or shutdowns. Four other reports are included as appendices. Parts of one of these that concern CVs is as follows.

EPRI Report NP-241, *Assessment of Industry Valve Problems*, November 1976 (prepared by MPR Associates, Inc.).

Maintenance burdens associated with CVs include renewal of pivot pin seals and relapping or replacing disk-to-body seating surfaces. One of the problems is misapplication of specific valve type in using CVs where leaktightness of the seat is demanded. Leaktightness of valve seat to flapper is a generic technical problem. Another problem is awarding of purchase to the lowest bidder. The misapplication can result in excessive maintenance requirements and/or high radiation exposures to qualified maintenance personnel.

B.5 R. L. Scott and R. B. Gallaher, *Summary and Bibliography of Operating Experience With Valves in Light-Water-Reactor Nuclear Power Plants for the Period 1965-1978*, NUREG/CR-0848 (July 1979)

Operating experience with all types of valves in LWRs is summarized for the period 1965–1978. Tables are presented giving the causes of valve failures, time of occurrence, systems involved, and the equipment in which the valve failures occurred. Check valves are included as part of the whole but are not tabulated separately.

B.6 W. H. Hubble and C F. Miller, *Licensee Event Report Analysis for Selected Safety System Valves*, IDO-1570-Ts (1979)

This analysis utilized the NRC LER file to estimate LER-based failure rates for selected safety-system valves in operating nuclear power plants. In general, the selected safety systems included PWR and BWR emergency core cooling system (ECCS) valves, AFW valves, and primary safety/relief valves. LER rates were calculated for reverse leakage of check valves in both the ECCS and AFW systems as well as other types of valve rates. The time frame used for this analysis was January 1976–October 1978.

B.7 W. H. Schmidt, *An Analysis of Nuclear Power Plant Valve Failure From Licensee Event Reports 1975–1978*, SAND80-0743, (April 1980)

A computer analysis of the NRC data file, compiled from LER data sheets, has been performed to characterize and highlight valve failures in LWR nuclear power plants and provide guidance for valve improvement programs. The analysis is based on data from 1975 through 1978. For PWRs, the second most important identified component failure category is one-way flow; for BWRs the third category is one-way flow.

B.8 In-Plant Reliability Data System (IPRDS)

A search was made of the IPRDS for CVs. Two plants were included in the search, one PWR and one BWR. The data available were insufficient to include in this review.

B.9 Nuclear Plant Reliability Data System (NPRDS)

The NPRDS, operated by the Institute for Nuclear Power Operations (INPO), contains component engineering and failure data that can be obtained upon special request. Such data do have some limitations — no plant identification or failure-event reference is permitted, preventing correlation with other data bases such as LERs. But generic population failure data can be obtained by utilizing a specified sort strategy. For a failure event, certain information can be obtained from the data base if computer searching techniques are applied, such as

1. severity — incipient, degraded, immediate;
2. failure symptom;
3. failure detection;
4. cause description;
5. environment — internal and external;
6. manufacturer and model number of failed component;
7. material;
8. size; and
9. narrative of failure cause, description, and corrective action.

Because of a lack of computer searching capability in response to a special request, INPO provided hard copy of a data search, which yielded

585 CV failure events. The event data had to be manually reviewed and sorted to extract actual aging-related check valve failures. The following types of failure reports were eliminated:

1. main steam check valves,
2. vacuum relief valves,
3. design errors,
4. maintenance errors that were immediately identified,
5. nonaging events,
6. operational errors,
7. instruments attached to the check valve,
8. installation errors, and
9. Fort St. Vrain reports.

After elimination of the above event types, 382 check valve failures remainded. Each event was reviewed and data were collected as to failure mode, method of detection, maintenance activity, and identified failure cause. Tables B.2.—B.5 summarize the results of this effort. The NPRDS annual reports contain data on cumulative component reliability. Copies of NPRDS annual reports are available from INPO to NPRDS participating members only.

Summary tables follow of 382 events involving NPRDS component VALVE, component engineering code C (check valves).

Table B.2.--Failure mode distribution

Failure mode	Percent
Seat leakage	70
External leakage	16
Failed to close	8
Failed to open	2
Damaged internals	4

Table B.3. Method of detection

Detection	Percent
In-service and surveillance test	67
Incidental observation	4
Routine observation	14
Operational abnormality	11
Maintenance	2
Special inspection	2

Table B.4. Maintenance activity

Activity	Percent
Repair/replace	93
Modify/substitute	4
Temporary measure	3

Table B.5. Identified failure cause

Failure cause	Percent
Aging/cyclic fatigue	7
Normal/abnormal wear	50
Binding/mechanical damage	6
Lubrication problem	2
Previous repair/installation	2
Corrosion	4
Weld related	2
Dirty	14
Particulate contamination	1
Out of adjustment	3
Foreign/incorrect material	3
Unknown	1
Connection defect/loose part	3
Material defect	2

NUREG/CR-4302
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NUREG/CR-4302, Vol. 1
ORNL-6193/V1
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2 TITLE AND SUBTITLE
Aging and Service Wear of Check Valves Used in Engineered Safety-Feature Systems of Nuclear Power Plants

3 LEAVE BLANK

4 DATE REPORT COMPLETED

MONTH	YEAR
October	1985

5 AUTHOR(S)

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6 DATE REPORT ISSUED

MONTH	YEAR
December	1985

7 PERFORMING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
Oak Ridge National Laboratory
P.O. Box Y
Oak Ridge, TN 37831

8. PROJECT/TASK/WORK UNIT NUMBER

9 FIN OR GRANT NUMBER
B0828

10 SPONSORING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

11a TYPE OF REPORT
Topical

b PERIOD COVERED *(Inclusive dates)*

12 SUPPLEMENTARY NOTES

13 ABSTRACT *(200 words or less)*

This is the first in a series of three reports on check valves (CVs) to be produced under the U.S. Nuclear Regulatory Commission's Nuclear Plant Aging Research program. This program addresses the evaluation and identification of practical and cost-effective methods for detecting, monitoring, and assessing the severity of time-dependent degradation (aging and service wear) of CVs in nuclear plants. These methods are to provide capabilities for establishing degradation trends prior to failure and developing guidance for effective maintenance.

This report examines failure modes and causes resulting from aging and service wear, manufacturer-recommended maintenance and surveillance practices, and measurable parameters (including functional indicators) for use in assessing operational readiness, establishing degradation trends, and detecting incipient failure. The results presented are based on information derived from operating experience records, nuclear industry reports, manufacturer-supplied information, and input from plant operators.

14 DOCUMENT ANALYSIS – a KEYWORDS DESCRIPTORS
Valves, check valves, aging, service wear, maintenance, degradation, failure mode, failure cause, measurable parameter, incipient failure, inspection, surveillance, monitoring, functional indicators, operating experience.

b IDENTIFIERS OPEN ENDED TERMS

15 AVAILABILITY STATEMENT
Unlimited

16 SECURITY CLASSIFICATION
(This page)
Unclassified
(This report)
Unclassified

17 NUMBER OF PAGES

18 PRICE