FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

ELECTRIC POWER RESEARCH INSTITUTE TECHNICAL REPORT 3002019621

SUSCEPTIBILITY OF VALVE APPLICATIONS TO FAILURE OF THE

STEM-TO-DISK CONNECTION

EPID: L-2021-NTR-0003; DOCKET NO. 99902021

1.0 INTRODUCTION

By letter dated April 28, 2021, the Electric Power Research Institute (EPRI) submitted Technical Report (TR) 3002019621, Revision 0, "Susceptibility of Valve Applications to Failure of the Stem-to-Disk Connection," to the U.S. Nuclear Regulatory Commission (NRC) staff for review (Agencywide Documents Access and Management System (ADAMS) Accession No. ML21126A208 Cover Letter and ADAMS Accession No. ML21126A210 Non-Proprietary version). The purpose of this TR is to provide a methodology and technical basis for operating nuclear power plants to apply American Society of Mechanical Engineers (ASME) *Operation and Maintenance of Nuclear Power Plants*, Division 1, OM Code: Section IST (OM Code) Code Case OMN-28, "Alternative Valve Position Verification Approach to Satisfy ISTC-3700 for Valves Not Susceptible to Stem-Disk Separation."

On November 29, 2021, the NRC sent a draft safety evaluation (SE) that was marked as proprietary to EPRI for its review to identify any proprietary information that was not marked as such. In the November 2021 letter, the NRC staff also informed EPRI that it would exercise its discretion on whether to address any EPRI comments not related to the proprietary review. By letter dated December 23, 2021 (ADAMS Accession No. ML22012A095), EPRI confirmed that the NRC draft SE did not contain any proprietary information and provided comments on the draft SE. On January 21, 2022, the NRC staff held a public meeting with EPRI to discuss the draft SE. This final SE reflects the NRC staff's discretion in the consideration of the comments provided during the public meeting on January 21, 2022.

2.0 REGULATORY EVALUATION

The NRC regulations in Title 10 of the *Code of Federal Regulations* (10 CFR) 50.55a(f)(4), "Inservice testing standards requirement for operating plants," state:

> Throughout the service life of a boiling or pressurized water-cooled nuclear power facility, pumps and valves that are within the scope of the ASME OM Code must meet the inservice test [IST] requirements (except design and access provisions) set forth in the ASME OM Code and addenda that become effective subsequent to editions and addenda specified in [10 CFR 50.55a(f)(2) and (3)] and that are incorporated by reference in [10 CFR 50.55a(a)(1)(iv)], to the extent practical within the limitations of design, geometry, and materials of construction of the components. The [IST] requirements for pumps and valves that are within the scope of the ASME OM Code but are not classified as ASME [*Boiler and Pressure Vessel Code*] BPV Code Class 1, Class 2, or Class 3 may be satisfied as an augmented IST program in accordance with [10 CFR 50.55a(f)(6)(ii)] without requesting relief under [10 CFR 50.55a(f)(5)] or alternatives under

> [10 CFR 50.55a(z)]. This use of an augmented IST program may be acceptable provided the basis for deviations from the ASME OM Code, as incorporated by reference in [10CFR 50.55a], demonstrates an acceptable level of quality and safety, or that implementing the [ASME OM] Code provisions would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety, where documented and available for NRC review.

Valves are nominally exercised in accordance with ASME OM Code, Subsection ISTC, "Inservice Testing of Valves in Water-Cooled Reactor Nuclear Power Plants," paragraph ISTC-3520, "Exercising Requirements." All moving parts of a valve are verified by paragraph ISTC-3530, "Valve Obturator Movement," and paragraph ISTC-3700, "Position Verification Testing." In addition, operating nuclear power plants will be required to perform the condition described in 10 CFR 50.55a(b)(3)(xi), "OM condition: Valve Position Indication," which states:

> When implementing paragraph ISTC-3700, "Position Verification Testing," in the ASME OM Code, 2012 Edition through the latest edition and addenda of the ASME OM Code incorporated by reference in paragraph (a)(1)(iv) of this section [10 CFR 50.55a], licensees shall verify that valve operation is accurately indicated by supplementing valve position indicating lights with other indications, such as flow meters or other suitable instrumentation to provide assurance of proper obturator position for valves with remote position indication within the scope of Subsection ISTC including its mandatory appendices and their verification methods and frequencies.

The NRC regulations in 10 CFR 50.55a(z), "Alternatives to codes and standards requirements," state:

> Alternatives to the requirements of [10 CFR 50.55a(b) through (h)] or portions thereof may be used when authorized by the Director, Office of Nuclear Reactor Regulation. A proposed alternative must be submitted and authorized prior to implementation. The applicant or licensee must demonstrate that:
>
> (1) *Acceptable level of quality and safety.* The proposed alternative would provide an acceptable level of quality and safety; or
>
> (2) *Hardship without a compensating increase in quality and safety.* Compliance with the specified requirements of this section would result in hardship or unusual difficulty without a compensating increase in the level of quality and safety.

3.0 TECHNICAL EVALUATION

3.1 Background

The ASME established a committee in 1911 for the purpose of formulating standard rules for the construction of steam boilers and other pressure vessels. During the early days of nuclear power plant design and construction, it was determined that a special set of rules would be needed. In 1971, ASME published the BPV Code, Section III, "Rules for Construction of Nuclear Power Plant Components," and BPV Code, Section XI, "Rules for Inservice Inspection of Nuclear Reactor Coolant Systems."

ASME BPV Code, Section XI, established the requirements for testing and examination of piping, welds, and repairs. Section XI was later updated in the 1973 summer addenda to include test requirements for pumps designated as Section IWP and valves designated as Section IWV.

Section IWV's objective is to test and verify valve operational readiness on a continuing basis. There are three major tests for Category A (valves with a seat leakage limit) and Category B (valves with no leakage limit):

1) IWV-3410(2)(b), "Valve Exercising Test," which states, "The necessary valve stem or disk movement shall be established by exercising the valve while observing either an appropriate indicator which signals the required change of valve stem or disk position, or indirect evidence, such as changes in system pressure, flowrate or temperature which reflect stem or disk position." (IWV-2104, "Exercising," defines "exercising" as "the demonstration based on direct or indirect visual or other positive indication that the moving parts of a valve function satisfactorily.")

2) IWV-3300, "Check of Valve Position Indicator," which states, "All valves with remote position indicators, which during power operation are inaccessible for direct observation, shall be visually observed at the same (or greater) frequency as scheduled refueling outages but not less than one observation every two years, to confirm that remote valve indications accurately reflect valve operation."

3) IWV-3420, "Valve Leak Rate Test," which states, in part, that "Category A valves shall be leak tested. Tests shall be conducted at the same (or greater) frequency as scheduled outages but not less than once every two years."

As the ASME BPV Code, Section XI, developed, these three requirements remained the same with the exception that the paragraph IWV-3300's title changed to "Valve Position Indicator Verification," and the requirement was simplified to read, "Valves with remote position indicators shall be observed at least once every 2 years to verify that valve operation is accurately indicated."

The ASME BPV Code, Section XI, valve exercise requirements can be summed up as:

1) Valve exercise tests shall demonstrate that the valve functions satisfactorily (all moving parts are working).

2) Once every two years, the licensee must locally observe that the valve and indicating lights are operating correctly and the overall condition and performance of the valve's moving parts are acceptable.

In June 1975, the Committee on Operation and Maintenance of Nuclear Power Plants (Operation and Maintenance (O&M) Committee) was formed when the N45 Committee was disbanded. The N45 Committee was established by the American National Standards Institute (ANSI) and was officially known as, "Committee N45 on Reactor Plants and Their Maintenance." The N45 Committee was chartered to promote the development of standards for the location, design, construction, and maintenance of nuclear reactors and plants embodying nuclear reactors, including equipment, methods, and components. The scope of the O&M Committee was to identify, develop, maintain, and review codes and standards considered necessary for the safe and efficient O&M of nuclear power plants, particularly as they relate to structural and functional adequacy.

By 1981, the O&M Committee had published five standards that were later consolidated into one single publication, ASME/ANSI OM-1987, *Operation and Maintenance of Nuclear Power Plants*, issued on December 15, 1987. The five standards are as follows:

1) OM-1-1981 - Requirements for Inservice Performance Testing of Nuclear Power Plant Pressure Relief Devices (ASME/ANSI OM-1987 Part 1)
2) OM-2-1982 - Requirements for Performance Testing of Nuclear Power Plant Closed Cooling Water Systems (ASME/ANSI OM-1987 Part 2)
3) OM-3-1982 - Requirements for Preoperational and Initial Start-up Vibration Testing of Nuclear Power Plant Piping Systems (ASME/ANSI OM-1987 Part 3)
4) OM-4-1982 - Examination and Performance Testing of Nuclear Power Plant Dynamic Restraints (Snubbers) (ASME/ANSI OM-1987 Part 4)
5) OM-5-1981 - Inservice Monitoring of Core Support Barrel Axial Preload in Pressurized Water Reactors (ASME/ANSI OM-1987 Part 5)

The O&M Committee was given responsibility to review ASME BPV Code, Section XI, to determine where O&M standards could replace then-current ASME BPV Code, Section XI, requirements. It was determined that pumps and valves were major areas in ASME BPV Code, Section XI, requiring O&M standards. The ASME/ANSI OM-1987 first addenda was issued on July 14, 1988, as ASME/ANSI OMa-1988. It added the following standards:

1) Part 6 - Inservice Testing of Pumps in Light-Water Reactor Power Plants
2) Part 7 - Requirements for Thermal Expansion Testing of Nuclear Power Plant Piping Systems
3) Part 8 - Start-up and Periodic Performance Testing of Electric Motor Operators on Valve Assemblies in Nuclear Power Plants (place holder due to in preparation)
4) Part 9 - Requirements for Inservice Performance Testing of Radioactive Material Handling Cranes (place holder due to in preparation)
5) Part 10 - Inservice Testing of Valves in Light-Water Reactor Power Plants

With the development of the ASME/ANSI OMa-1988 addenda, the requirements for valve exercise and position indicator verification were updated. This update led to confusion and opened requirements for interpretation as follows:

1) IWV-2104 was placed in ASME/ANSI OMa-1988, Section 1.3, “Terminology.” - The wording is: “exercising – the demonstration based on direct or indirect visual or other positive indications that the moving parts of a valve function.”

2) IWV-3410(2)(b) changed to ASME/ANSI OMa-1988, Section 4.2.1.3, “Valve Obturator Movement.” - The wording was updated to: “The necessary valve obturator movement shall be determined by exercising the valve while observing an appropriate indicator, such as indicating lights which signal the required change of obturator position, or by observing other evidence, such as changes in system pressure, flow rate, level, or temperature, which reflect change of obturator position.” The purpose of this change was to allow observation of indicating lights, if equipped, as verification of all the valve moving parts because the exercise test was required to be performed nominally every three months. The indicating lights would be verified to accurately reflect proper valve operation by OMa-1988, Section 4.1, “Valve Position Verification,” once every 2 years.
3) IWV-3300, “Check of Valve Position Indicator,” was changed to OMa-1988, Section 4.1, “Valve Position Verification.” – The wording was updated to: “Valves with remote position

indicators shall be observed locally at least once every 2 years to verify that valve operation is accurately indicated. Where practicable, this local observation should be supplemented by other indications such as use of flow meters or other suitable instrumentation to verify obturator position. These observations need not be concurrent. Where local observation is not possible, other indications shall be used for verification of valve operation." The purpose of this change was to locally observe the valve and if practicable supplement the observation of valve operation with other positive means. The two actions need not be concurrent. This was written for valves that couldn't be tested or locally observed during normal operation. Performance of valve exercise and the local observation at shutdown conditions usually has no other supplemental indications (pressure or flow). The purpose was to allow local observation and, when systems returned to normal, verify proper valve operation via changes in supplemental indicators. However, many have interpreted this requirement to mean monitor the valve once every two years by observing the stem go up and down without any supplemental indicator because none were available (impracticable due to no dynamic conditions) at the time of observance.

The ASME Board on Nuclear Codes and Standards recognized that O&M is the appropriate committee to establish IST requirements and voted to proceed with making the O&M Standard stand on its own, with the objective of eventual deletion of IST from Section XI of the BPV Code when appropriate. A transition was implemented in which Part 1 (pressure relief devices), Part 4 (dynamic restraints or snubbers), Part 6 (pumps), and Part 10 (valves) of ASME/ANSI OM-1987 were incorporated into ASME OM Code-1990, "Code for Operation and Maintenance of Nuclear Power Plants." The ASME OM Code, 1990 Edition, was issued on October 15, 1990.

The ASME OM Code, 1990 Edition, was reformatted with only one section, "IST Rules for Inservice Testing of Light-Water Reactor Power Plants." Section IST was divided into four Subsections, a mandatory appendix, and four nonmandatory appendices as noted in the following table:

OM Code 1990	Previous OM-1987	OM Code 1990 Title
ISTA		General Requirements
ISTB	Part 6	Inservice Testing of Pumps in Light-Water Reactor Power Plants
ISTC	Part 10	Inservice Testing of Valves in Light-Water Reactor Power Plants
ISTD	Part 4	Inservice Testing of Dynamic Restraints (Snubbers) in Light-Water Reactor Power Plants
Mandatory Appendix I	Part 1	Inservice Testing of Pressure Relief Devices in Light-Water Reactor Power Plants
Nonmandatory Appendix A		Preparation of Test Plans
Nonmandatory Appendix B		Dynamic Restraint Examination Checklist Items
Nonmandatory Appendix C		Dynamic Restraint Design and Operating Information
Nonmandatory Appendix D		Comparison of Sampling Plans for Inservice Testing of Dynamic Restraints

With the format update to the first ASME OM Code, 1990 Edition, the following changes were made to the valve testing requirements:

1) Section 1.3 of OMa-1988 was changed to ISTC 1.3, “Definitions.” - The wording is: “exercising – the demonstration based on direct visual or indirect positive indications that the moving parts of a valve function.”

2) Section 4.2.1.3 of OMa-1988 was changed to ISTC 4.2.3, “Valve Obturator Movement.” - The wording is: “The necessary valve obturator movement shall be determined by exercising the valve while observing an appropriate indicator, such as indicating lights that signal the required change of obturator position, or by observing other evidence, such as changes in system pressure, flow rate, level, or temperature, that reflects change of obturator position.”

   Section 4.1 of OMa-1988 was changed to ISTC 4.1, “Valve Position Verification.” - The wording is: “Valves with remote position indicators shall be observed locally at least once every 2 years to verify that valve operation is accurately indicated. Where practicable, this local observation should be supplemented by other indications such as use of flow meters or other suitable instrumentation to verify obturator position. These observations need not be concurrent. Where local observation is not possible, other indications shall be used for verification of valve operation.”

The ASME OM Code is a national, voluntary consensus standard. The NRC mandates the use of editions and addenda to the ASME OM Code in 10 CFR 50.55a, “Codes and Standards,” through the rulemaking process of “incorporation by reference.” With respect to the evaluation of EPRI TR 3002019621, Revision 0, the following is a high-level timeline on the need for this report based on the development of the ASME OM Code starting from 1989:

Date	Description
08/03/1989	Generic Letter (GL) 89-04, “Guidance on Developing Acceptable Inservice Testing Programs,” issued to provide clarification on the requirements and reduce alternative request backlog.
10/25/1989	NRC staff issues “Minutes of the Public Meetings on Generic Letter 89-04,” to provide useful information on how to apply the guidance of GL 89-04.
09/08/1992	1989 Edition of Section XI was incorporated by reference into paragraph 50.55a(b).
1995	National Technology Transfer and Advancement Act of 1995 P.L. 104-113 requires Federal agencies to use industry consensus standards to the extent practical.
04/1995	NUREG-1482, Revision 0, “Guidelines for Inservice Testing at Nuclear Power Plants,” is issued to assist industry in eliminating unnecessary alternative requests.
04/1995	NUREG-1482, Revision 0, Section 4.2.5, “Verification of Remote Position Indication for Valves by Methods Other Than Direct Observation,” provides recommendations on how to verify once every 2 years that valve position is accurately indicated emphasizing the point that if the remote valve position cannot be verified by local observation at the valve, an acceptable approach for the licensee is to observe operational parameters such as leakage, pressure, and flow that give positive indication of the valve's actual position(s).

Date	Description
1997	NRC staff publishes meeting minutes questions and answers of Public Workshops discussing Inspection Procedure (IP) 73756, “Inservice Testing of Pumps and Valves.” Question 2.2.8 - For certain types of valves that can be observed locally, but for which valve stem travel does not ensure that the stem is attached to the disk, the local observation must be supplemented by other indications. If this test is not practicable, such as lack of instruments to observe operating parameters, does this Code requirement apply? NRC Response - Yes, when local observation is not possible, the Code requires that other indications must be used. If this is not practical, relief must be requested.
07/31/1998	ASME OM Code, 1998 Edition, completely reformatted. ISTC 1.3, “Definitions,” was changed to ISTC-2000, “Supplemental Definitions.” The definition of “Exercising” remained the same. ISTC 4.2.3, “Valve Obturator Movement,” was changed to ISTC-3530, “Valve Obturator Movement,” and the wording remained the same. ISTC 4.1, “Valve Position Verification,” was changed to ISTC-3700, “Position Verification Testing,” and the wording remained the same.
11/02/2001	ASME OM Code, 2001 Edition - Definition of “Exercising” was removed from ISTC-2000, “Supplemental Definitions,” and was placed in ISTA-2000, “Definitions,” and the wording was changed to read, “Demonstration based on direct visual or indirect positive indications that the moving parts of a component function.” By moving this definition from the valve Subsection ISTC to the General Requirements SubsectionISTA and changing the word “valve” to “component,” this reduced the clarity even more on evaluating the valve moving parts during an exercise test.
02/26/2010	ASME OM Code, 2009 Edition - ISTC-3700, “Position Verification Testing,” was revised to add a sentence to read, “Position verification for active MOVs [motor-operated valves] shall be tested in accordance with Mandatory Appendix III of this Division.” All other wording remained the same.
10/23/2010	An MOV at Browns Ferry experienced a stem-to-disk failure resulting in an NRC inspection finding classified as red. The initial NRC inspection noted that the licensee was mis-applying the requirements of ISTC-3700 for verifying valve operation is accurately indicated at least once every two years (in particular, watching the stem move up and down only). A special NRC independent review team concluded that the ASME OM Code is not clear with respect to the extent to which the ASME OM Code requires certainty in the verification of obturator position during testing.
06/07/2011	ASME OM Interpretation 12-01-Q1(OMI-11-913) and 12-01-A2(OMI-11-913) addressed the clarifications concerning supplemental methods for obturator position verification in ISTC-3700 and ISTC-3530. NRC staff did not agree with these interpretations.
07/18/2017	The NRC staff worked with the ASME consensus process to clarify and improve the wording in ISTC-3700. After many years, consensus could not be reached. The NRC imposed condition 10 CFR 50.55a(b)(3)(xi) to clarify and modify the provisions in ISTC-3700. In particular, 10 CFR 50.55a(b)(3)(xi) states: “When implementing paragraph ISTC-3700, “Position Verification Testing,” in the ASME OM Code, 2012 Edition, through the latest edition and addenda of the ASME OM Code incorporated by reference in paragraph (a)(1)(iv) of this section [10 CFR 50.55a], licensees shall verify that valve operation is accurately

Date	Description
	indicated by supplementing valve position indicating lights with other indications, such as flow meters or other suitable instrumentation to provide assurance of proper obturator position for valves with remote position indication within the scope of Subsection ISTC including its mandatory appendices and their verification methods and frequencies." This condition goes into effect when licensees update their IST programs to the 2012 or later Editions of the ASME OM Code.
09/2020	EPRI personnel worked with ASME OM Code Committees on the development of Code Case OMN-28. In lieu of having to perform ISTC-3700 and 10 CFR 50.55a(b)(3)(xi) once every 2 years, Code Case OMN-28 allows performance of this verification to be completed once every 12 years for those valves determined to be not susceptible to stem-to-disk separation. EPRI saw the need for a technical report to assist licensees and NRC inspectors in evaluating valve susceptibility to stem-to-disk separation. Thus, TR 3002019621, Revision 0, was created and issued.
03/16/2021	ASME issued ASME OM Code Case OMN-28.
03/26/2021	The NRC issued a proposed rule in the *Federal Register* (86 FR 16087) to incorporate by reference the 2020 Edition of the ASME OM Code into 10 CFR 50.55a. The proposed rule included a revision to 10 CFR 50.55a(b)(3)(xi) for public comment, as follows: "For valves not susceptible to stem-disk separation, the position verification testing specified in paragraph ISTC-3700 may be performed on a 10-year interval where the licensee documents a justification, which is made available for NRC review, demonstrating that the stem-disk connection is not susceptible to separation based on the internal design and evaluation of the stem-disk connection using plant-specific and industry operating experience and vendor recommendations." The NRC staff is currently considering incorporating Code Case OMN-28 directly in the final rule in lieu of the proposed rule language.

3.2 EPRI Technical Report 3002019621, Revision 0, Summary

EPRI Technical Report 3002019621, Revision 0, assesses information to determine whether specific valve designs are susceptible to separation of the stem and disk. In particular, the TR assesses various valve stem-to-disk connection designs and evaluates their performance over 43 years of operating experience (OE) for susceptibility to separation under different operating conditions. It also discusses verification methods that can be used to provide indication that the stem-to-disk connection is intact for various valve types. It does not recommend supplemental verification intervals but does provide information that may be useful in determining an interval. In addition, the TR discusses several NRC generic communications that are associated with valve failures due to stem-to-disk separation.

Key findings of this TR include:

1) A total of 226 stem-to-disk failures were identified over a period of 43 years from 1977 through 2019 for an average failure rate of 5.3 failures per year. This failure rate included safety-related and non-safety-related valves. It is understood that safety-related valves may have more rigor with respect to design and preventive maintenance activities which may yield lower failure rates. However, the purpose of this TR was to examine all failures to better understand the susceptibility of specific stem-to-disk connection

designs to stem-to-disk separation under specific operating conditions. A table listing all the stem-to-disk failures is provided in Attachment A located at the end of the TR.

2) Ten common stem-to-disk connection designs were identified.

3) There are several methods that can be used to provide direct indication that the stem-to-disk connection is intact for various valve types.

4) There are several lessons that the industry has learned over the years related to minimizing the potential for stem-to-disk separation. These lessons should be incorporated into plant processes and procedures as appropriate.

3.3 Ten Common Stem-to-Disk Design Evaluation

3.3.1 Keyed

This design is typically found in butterfly valves where the disk is keyed to the stem. The TR did not identify any failures of this nature, thus considering this design to be not susceptible to stem-to-disk separation. The TR does emphasize the need to have maintenance procedures that provide guidance on key installation and appropriate position retention techniques; for example, staking of the keys.

The NRC staff completed its own review of industry OE events from the Institute of Nuclear Power Operations (INPO) Industry Reporting Information System (IRIS) database and found the following:

INPO Event ID	Event Title	Failure Comments
178025	2/4/1999 - Failure of Essential Service Water System butterfly valve SWN-41-2B	10” Clow butterfly MOV failed to close. Apparent cause was excessive clearances on the disk and keys allowing the shaft to place force on shaft alignment pins. These pins were not designed to absorb the force and they sheared allowing the disk to float on the shaft and eventually hung up when trying to close.
184845	2/23/2000 - Failure of Essential Service Water System butterfly valve SWN-41-4B	10” Clow butterfly MOV failed to close. Apparent cause was excessive clearances on the disk and keys allowing the shaft to place force on shaft alignment pins. These pins were not designed to absorb the force and they sheared allowing the disk to float on the shaft and eventually hung up when trying to close.
148601	10/2/1994 - Failure of Essential Service Water System butterfly valve	Butterfly MOV failed to open. Apparent cause was a sheared key on the shaft due to overtorque or material defect.
149383	11/2/1994 - Failure of Primary Containment Isolation Valve 1VC5	Butterfly air-operated valve (AOV) failed to open. Apparent cause was valve shaft key sheared due to normal aging cyclic fatigue.
169912	12/12/1997 - Failure of Closed/Component Cooling	Butterfly AOV was binding. This was not a key failure. However, it was noted in the failure history

INPO Event ID	Event Title	Failure Comments
	Water System pneumatic valve operator (AOV)	description that this valve was disassembled in 1994 to replace a sheared disk-to-stem key.

The NRC staff identified six other OE events involving a sheared key or pin. However, it was not clear if the sheared component was the part connecting the disk to the shaft or the piece that couples the shaft to the actuator or manual handwheel. Because the INPO data is not sufficient to rule out butterfly valve key stem-to-disk failure, the staff determined that the keyed design should be considered susceptible to such failure in the absence of a documented evaluation of lessons learned from operating experience with such valves; however, the NRC staff agrees with the TR summary that the failure rate for this design is low. Accordingly, the staff has determined that the keyed design may be considered to be not susceptible to stem-to-disk failure provided that lessons learned from past OE concerning key materials, dimensions/tolerances, vendor recommendations, and force being applied are evaluated and documented.

Condition for use of this TR for the keyed design: The staff concludes that it is acceptable to apply the TR to determine that a keyed valve is not susceptible to stem-to-disk separation if a documented engineering evaluation of operating experience justifies the conclusion and is available for NRC inspection and audit. This will be reflected below in a condition on the use of the TR.

3.3.2 Socketed/Splined

The socketed design is typically found in ball valves where the end of the stem has a rectangular cross-section that fits into a rectangular hole in the ball. Ball valves are a type of control valve that features a spherical disk inside. This disk has a hole in it that is called a port. When the port is in line with both ends of the valve, the valve is open and allows medium to flow through it easily. When the port is perpendicular to the ends of the valve, the valve is closed, and the fluid flow stops.

A valve with a splined connection on the stem can be found in eccentric plug valves. A plug valve is named so because it features a conically tapered or cylindrical disk that resembles a plug. The plug features one or more passages going sideways through the plug that allow the fluid to pass through them. When a bored passage is in line with the flow, the valve is open, and fluid can freely flow through the passage. When the plug is no longer aligned with the flow, the solid part of the plug blocks the flow causing the valve to close. Plug valves are similar to the ball valve design in operation. Both are considered a rugged design and as noted in the TR, there have been very few failures.

The NRC staff reviewed the INPO IRIS database for these types of valve failures and found two additional events:

INPO Event ID	Event Title	Failure Comments
192008	4/24/2001 - Delayed power ascension due to failure of stem in HP Heater and	Dump valve 3HD-269 failed closed due to the valve stem separation from the valve causing an actual high level in heater allowing the disk to float

INPO Event ID	Event Title	Failure Comments
	MSR Drains and Vents System ball valve 3HD-269	on the shaft and eventually hung up when trying to close.
216819	7/5/2005 - Failure of pin(s) in Essential Service Water System pneumatic valve operator (AOV) that supports Aux. Bldg. Environmental Control System cooler 2CHE18	Ball valve failed closed due to the actuating pin being broken where it connects to the scotch yoke, a slotted arm that converts the linear action of the actuator piston to rotary motion to turn the valve.

The NRC staff agrees with the TR summary that the socketed/splined design has a very low failure rate, and this design may be considered not susceptible to stem-to-disk failure. The NRC staff believes that the scotch yoke design interface may also be included in a very low failure rate category due to its design to convert linear motion to a quarter turn rotating motion. The scotch yoke design can have a spline, rectangular cross-section, pinned, or keyed connection. Accordingly, the staff determined that the socketed/splined design may be considered to be not susceptible to stem-to-disk separation provided end users evaluate and document lessons learned from past operating experience.

Condition for use of this TR for the socketed, splined, or scotch yoke design: The staff concludes that it is acceptable to apply the TR to determine that a socketed, splined, or scotch yoked valve is not susceptible to stem-to-disk separation if a documented engineering evaluation of operating experience justifies the conclusion and is available for NRC inspection and audit. This will be reflected below in a condition on the use of the TR.

3.3.3 Integral/Single Piece

The integral/single piece design is a stem and disk that are machined from the same bar stock. There is no stem-to-disk connection that can fail. This type of design is typically found in smaller globe and/or plug valves. The TR does identify one stem failure that was due to cycling after a thermal transient. The NRC staff agrees with the TR summary that the integral/single piece design has a very low failure rate. Accordingly, the staff has determined that the integral/single piece design may be considered not susceptible to stem-to-disk failure provided that lessons learned from past OE specific to system conditions, stem materials susceptible to embrittlement, vendor recommendations, and thermal transients are evaluated and documented.

Condition for use of this TR for the integral or single piece design: The staff concludes that it is acceptable to apply the TR to determine that an integral or single piece valve is not susceptible to stem-to-disk separation if a documented engineering evaluation of operating experience justifies the conclusion and is available for NRC inspection and audit. This will be reflected below in a condition on the use of the TR.

3.3.4 Threaded and Welded

This design is typically found in gate or globe valves where the stem is threaded into the disk or plug then welded. The TR identified four events that appear to be isolated issues due to design, manufacturing, or maintenance, and considers this low failure rate to support this valve design as essentially not susceptible to stem-to-disk separation.

The NRC staff reviewed the INPO IRIS database for these types of valve failures and found several additional events using the key words “tack weld”:

INPO Event ID	Event Title	Failure Comments
69978	8/16/1988 - Failure of RHR Supp Pool Full Flow Disch Isol Valve MO-2009	Anchor/Darling globe valve that had the stem and the disk breaking apart due to a failed tack weld.
89572	1/7/1990 - Failure of weld in Condensate System globe valve	Velan globe valve that stem nut and plug had separated from the stem due to a broken tack weld.
99364	9/20/1990 - Failure of weld in Closed/Component Cooling Water System globe valve	Velan globe valve disk separated from the stem due to a broken tack weld.
102576	12/6/1990 - Forced normal Rx shutdown due to failure of RHR/LPCI System (BWR) gate valve HV-051-1F068B	Anchor/Darling gate valve (MOV) that had process water enter the threaded area between the valve disk and disk nut causing threads to weaken. The threads eroded and the tack weld failed separating the disk from the stem.
132723	12/29/1992 - Failure of weld in Essential Service Water System globe valve	Crane globe valve that had vibration causing loss of stem guide retainer and broke the tack weld allowing the stem to unscrew from the disk.
227104	6/7/2007 - Broken Tack Welds on Condensate Pump Recirc/Fill Valve	Broken tack weld on disk plug stem ring allowed the plug to unscrew from the stem.

The data suggest that the failure rate for valves that rely on a tack weld increases the susceptibility to failure. However, the NRC staff agrees with the TR summary that the failure rate for this design is low. Accordingly, the staff has determined that the threaded and welded design may be considered to be not susceptible to stem-to-disk failure provided that lessons learned from past OE concerning 1) system conditions such as vibration, 2) system fluid that could affect the threaded connection (untreated water), 3) verification that the weld is sufficient, and 4) vendor recommendations are evaluated and documented. In particular, the staff considers those valve designs which rely on a weld to secure the stem-to-disk connection and operate under high vibration conditions acceptable provided additional evaluation and documentation justifies dependance on the welded connection. Examples could include a structural analysis (weak link) or disassembly and inspection after several years of service to evaluate the condition of the stem-to-disk connection.

Conditions for use of this TR for the threaded and welded design: The staff concludes that it is acceptable to apply the TR to determine that a valve that is threaded and welded is not susceptible to stem-to-disk separation if (1) a documented engineering evaluation of operating experience justifies the conclusion and is available for NRC inspection and audit, and (2) for those valve designs that rely on a weld to secure the stem-to-disk connection and operate under high vibration conditions, the documented engineering evaluation includes additional justification for relying on the welded connection. This will be reflected below in conditions on the use of the TR.

3.3.5 Captured and Free

The captured and free design has its end of the stem captured by a sleeve that is threaded into the top of the disk and then welded (or otherwise secured) to the disk. There is a clearance between the stem and the sleeve/disk such that the stem has some axial freedom of movement relative to the disk. This design is used primarily in globe valves.

The NRC staff reviewed the INPO IRIS database for the model valves that had stem-to-disk valve failures, which are listed in Appendix A of the TR, and identified three additional events:

INPO Event ID	Event Title	Failure Comments
76821	2/15/1989 - Failure of Essential Service Water System globe valve	When attempting to close this globe valve, the valve was found to have a broken stem. Apparent cause was over torquing the valve on its previous operation.
109431	5/17/1991 - Failure of Feedwater System gate valve	During inspection of a special hydrostatic pressure test, it was discovered that the valve stem was broken. Apparent cause was excessive force applied during closing. The report states that this is a gate valve, but it is the same Crane model 3652 valve as INPO report # 241014, which is a globe valve.
142351	12/21/1993 - Failure of Main Steam Turbine Bypass Valve	During a plant startup, it was discovered that this valve disk was found broken off and laying inside the valve body. Apparent cause unknown.

The NRC staff agrees with the TR summary that this type of valve design does not appear to have any common issues or failure themes with the exception that a few of the failures were caused by excessive force used by maintenance personnel to operate the valve. The failure rate for this valve design is very low. Accordingly, the staff has determined that the captured and free design may be considered to be not susceptible to stem-to-disk separation provided lessons learned on application of excessive force are evaluated and documented when applicable.

Condition for use of this TR for the captured and free design: The staff concludes that it is acceptable to apply the TR to determine that a captured and free valve is not susceptible to stem-to-disk separation if a documented engineering evaluation justifies the conclusion and is available for NRC inspection and audit. This will be reflected below in a condition on the use of the TR.

3.3.6 Bolted

The bolted design has its end of the stem threaded and the disk is rigidly attached to the stem with a clamping nut. There is typically a locking device on the nut, such as a cotter pin, star washer, or weld. This design is used primarily in globe valves.

The NRC staff reviewed the INPO IRIS database for the model valves with stem-to-disk valve failures listed in Appendix A of the TR and found an additional event:

INPO Event ID	Event Title	Failure Comments
207847	12/17/2003 - Auxiliary Feedwater Flow Control Valve Cotter Pin Degradation	4” globe valve had reduced flow. Inspection of valve found missing cotter pin that secures the hex nut, pilot plug spacer, and washer on the valve plug, which became dislodged and was obstructing flow.

The NRC staff has reviewed the OE associated with this type of valve design and agrees with the TR conclusions that the failure rate is low. Accordingly, the staff has determined that the bolted design may be considered to be not susceptible to stem-to-disk separation provided lessons learned are applied from past OE concerning vendor recommendations and the evaluation of vibration impact on internal connection components, and are also evaluated and documented.

Conditions for use of this TR for the bolted design: The staff concludes that it is acceptable to apply the TR to determine that a bolted valve is not susceptible to stem-to-disk separation if (1) a documented engineering evaluation of operating experience justifies the conclusion and is available for NRC inspection and audit, and (2) the documented engineering evaluation includes an assessment of the effect of vibration on internal connection components in bolted valves. This will be reflected below in conditions on the use of the TR.

3.3.7 Captured and Clamped

The captured and clamped design is the same as the captured and free design except that the stem T-head is “clamped” between the sleeve and disk such that the stem T-head is immobile relative to the sleeve/disk in the direction of motion. This design is used primarily in globe valves.

Because there is no axial clearance between the stem and disk (i.e., the stem head is clamped), flow-induced loads imposed on the disk are translated to the stem-to-disk connection. As a result, this design is susceptible to flow-induced failures (e.g., due to vibration).

The NRC staff reviewed the INPO IRIS database for the model valves that had stem-to-disk valve failures listed in Appendix A of the TR and found additional events plus comments:

INPO Event ID	Event Title	Failure Comments
231497	03/25/2008 - Outage impacted due to failure of stem/plug assembly in Primary Containment Isolation Valve 3-FCV-023-0040	Failure of the anti-rotation weld and subsequent fretting failure of the threads. This event is similar to INPO event 231486 listed in the table in Appendix A.
245831	10/23/2010 - AP-913 failure event due to failure of disk and weld in RHR/LPCI System (BWR) globe valve 1-FCV-074-0066	This event was captured in the Appendix A table for valve design that is threaded and welded. However, this actually should be placed in the Captured and Clamped category. This is a 24” Walworth globe valve with a T-head stem captured

INPO Event ID	Event Title	Failure Comments
		via screw in skirt. The skirt is tack welded to the disk.
522	02/01/1975 - Failure of weld in RHR/LPCI System (BWR) globe valve	This failure was discovered as part of an extent of condition investigation due to a stem-to-disk separation that occurred in 1974 which does not appear in the INPO database due to not being in existence at that time. The failure was identified in a 10 CFR Part 21 notification where the recommended fix was to increase the weld holding the skirt. This is the same model valve identified in INPO event 245831 and the recommendation for this event was not applied to the subject valve, subsequently resulting in failure.

The TR notes that about half of the valve failures were due to generic issues with design and/or application. The other half of the OE events involved vibration that affected valve internal anti-rotation measures or tack welds and staking of components to keep the stem-to-disk intact. The NRC staff agrees with the TR summary that the failure rate for this design is low. Accordingly, the NRC has determined that the captured and clamped design may be considered not susceptible to stem-to-disk separation if lessons learned from past OE concerning system conditions such as vibration, system fluid that could affect the threaded connection (untreated water), verification that the weld is sufficient, and vendor recommendations, are evaluated and documented.

Condition for use of this TR for the captured and clamped design: The staff concludes that it is acceptable to apply the TR to determine that a captured and clamped valve is not susceptible to stem-to-disk separation if a documented engineering evaluation of operating experience justifies the conclusion and is available for NRC inspection and audit. This will be reflected below in a condition on the use of the TR.

3.3.8 Pinned

The pinned design, which is used in many butterfly designs, has its disk pinned to the stem at the top and a stub shaft or trunnion at the bottom. This design is potentially susceptible to the following important failures:

1) Pin shear failure due to vibration
2) Pin movement (backing out) due to vibration or inadequate pin locking (in some cases, one pin may back out and cause the remaining pin or pins to fail in shear)

The TR details that there were 44 failures of this design. The NRC staff reviewed the INPO IRIS database for this design and found several events that were considered failures but not necessarily complete failure of the stem-to-disk connection:

INPO Event ID	Event Title	Failure Comments
9582	09/19/1982 - Failure of Essential Service Water System butterfly valve	Found the valve shaft broken and the valve bushings and pins were severely worn.
15155	03/02/1984 - Failure of Essential Service Water System butterfly valve	Valve was discovered leaking by due to worn seal ring and pins.
15765	03/27/1984 - Failure of Containment Leakage Control System butterfly valve	Valve failed leak test. The seat and seal were found damaged with the cause being a dowel pin backing out of the shaft.
26508	04/18/1985 - Failure of Containment Leakage Control System butterfly valve	Valve failed leak test. Disk-to-stem pin found to be loose.
34117	11/27/1985 - Failure of Closed/Component Cooling Water System butterfly valve ACCMVAAA126-A	Valve was not operating correctly and was slamming. Disassembly revealed the shaft pins were missing.
41073	06/02/1986 - Failure of Essential Service Water System butterfly valve	Valve was leaking due to worn seats and stem pins.
42125	6/27/1986 - Failure of Containment Spray Discharge to Header Isolation Valve	Valve was leaking. The valve liner was worn out and the valve disk to shaft taper pin holes were elongated causing the disk to wobble.
42875	07/18/1986 - Failure of Condensate Demin Bypass Valve 2-CP-AOV-3B-VALVE	Valve was leaking. The cause was due to loose taper pins on the disk and worn bearings.
44695	09/11/1986 - Failure of Essential Service Water System butterfly valve 11SW58	Valve disk was found loose on the shaft caused by worn pins due to high silt content of the service water.
52185	04/14/1987 - Failure of Closed/Component Cooling Water System butterfly valve	Valve was leaking caused by a loose taper pin.
79497	04/21/1989 - Failure of Essential Service Water System butterfly valve 2CV14272	Valve was leaking caused by corroded carbon steel dowel pins resulting in a rough surface causing the disk to cock.
85244	09/20/1989 - Failure of Condensate Demin Bypass Valve 2-CP-AOV-3B-VALVE	Valve was leaking caused by loose disk-to-stem dowel pins that were worn.
85948	10/06/1989 - Failure of Essential Service Water	Valve would not fully close due to roll pins on the disk backing out causing the disk to drop down and misalign.

INPO Event ID	Event Title	Failure Comments
	System butterfly valve 2CV14251	
86035	10/09/1989 - Failure of Essential Service Water System butterfly valve 2CV14222	Valve was leaking past its seat. The seat was damaged due to foreign material. It was later discovered that the foreign material was the dowel pins had dropped out from corrosion.
86489	10/19/1989 - Failure of Primary Containment Isolation Valve 3JCPAUV0002B	Valve had excessive leakage. The cause of the failure was a sheared thrust collar pin causing the disk to be out of alignment.
105976	03/02/1991 - Failure of Essential Service Water System butterfly valve.	Valve leaking past the seat. The cause was corroded pins that hold the valve disk in place.
115087	10/22/1991 - Failure of Primary Containment Isolation Valve EFHV0032	Valve leaking past the seat. The cause was erosion and corrosion of the valve disk.
120628	03/04/1992 - Failure of Primary Containment Isolation Valve 2-SW-MOV-204B-VALVE	Valve leaking past the seat. Apparent cause was wear of the groove pins that hold the disk to the valve stem allowing the disk to move slightly.
131853	11/27/1992 - Failure of Aux/Emergency Feedwater Pump Alt Source Suction Valve ALHV0031	Valve leaking past the seat. The cause of the leakage was erosion and corrosion of the valve disk and body.
135491	03/31/1993 - Failure of Essential Service Water System butterfly valve 13SW58	Valve failed to open. The cause was the valve disk and pins were worn out from normal wear being in an untreated service water system.
135553	04/02/1993 - Failure of Essential Service Water System butterfly valve	Valve leaking past the seat. The valve leaked by due to worn bushing guide, valve liner, and shaft pin.
178025	02/04/1999 - Failure of Essential Service Water System butterfly valve SWN-41-2B	Valve would not fully close. The cause was due to excessive clearances between the disk and shaft, and the pins that align the disk were found sheared and missing allowing the disk to move along the shaft.
184845	02/23/2000 - Failure of Essential Service Water System butterfly valve SWN-41-4B.	Valve would not fully close. The cause was due to excessive clearances between the disk and shaft, and the pins that align the disk were found sheared and missing allowing the disk to move along the shaft.
188776	10/07/2000 - Failure of Essential Service Water System butterfly valve 24SW72	Valve failed to close. Apparent cause was the taper pins that hold the disk to the stem were found eroded.
229886	12/09/2007 - AP-913 high critical component failure and MSPI monitored	Valve failed to open due to failure of the pins.

INPO Event ID	Event Title	Failure Comments
	component failure due to failure of pin(s) in Closed/Component Cooling Water System butterfly valve 2-SW-8.1C	
234455	10/15/2008 - Failure of pin(s) in Primary Containment Isolation Valve 3CDS*CTV38A	Valve failed to close due to failure of the pins.
308142	07/06/2013 - Power Reduced Due to a Loss of a 500 KV Line on the Distribution Grid	Valve failed to open during power reduction due to pins that hold the valve disk were found broken.
313185	09/21/2014 - Service Water Valve Fails to Stroke Open	Valve failed to open during surveillance. Apparent cause was the shaft had decoupled from the actuator due to a lack of procedural guidance for shaft installation.
407707	03/16/2017 - Secondary Containment Isolation Valve Failed to Isolate Reactor Building Ventilation Penetration	The valve failed to isolate due to connection pin between valve disk stem and the valve actuator became detached.
453735	03/31/2019 - Essential Service Water Ultimate Heat Sink Cooling Tower Bypass Valve Decoupling Results in Inoperable Essential Service Water System	Valve discovered to be 90 degrees closed when indication showed it was open. The cause was flow induced vibration caused the actuator to become disconnected from the valve shaft. Investigation noted that two of the valve's three disk pins were missing.
466015	09/26/2019 - Local Leak Rate Test Failed Acceptance Criteria	Valve failed its leak rate test. Apparent cause was the leakage path was through one of the taper pins that holds the disk to the shaft.

In addition, the NRC has issued several generic communications over the years related to pin or key issues in butterfly valves. For example, see the following NRC communications:

NRC Inspection and Enforcement Circular 80-12, "Valve-Shaft-to-Actuator Key May Fall out of Place When Mounted Below Horizontal Axis" (ADAMS Legacy Accession No. 8005050052)

NRC Information Notice (IN) 1994-67, "Problem with Henry Pratt Motor-Operated Butterfly Valves" (ADAMS Legacy Accession No. 9409200069)

IN 2005-23, "Vibration-Induced Degradation of Butterfly Valves" (ADAMS Accession No. ML051740299)

As noted in the TR and the follow-up NRC staff review of additional OE events found in the INPO IRIS database, most of the valve failures involved disk-to-stem pin failures for reasons of

normal wear, erosion, corrosion, improper assembly, lack of staking the pins, vibration, etc. The TR suggests that by applying recommended guidance on maintaining pin integrity (e.g., staking or securing the pin) and by incorporating into processes and procedures, that this type of valve design can be considered not susceptible to stem-to-disk separation. However, many of the valve failures noted by NRC staff could be considered “near misses” in that failure of leak rate tests found many of the valve internals were a pin or two from complete loss of function.

For butterfly valves that have a pinned connection, the TR makes a statement that if end users apply lessons learned detailed in vendor and NRC information notices, then this design type may be considered to be not susceptible to stem-to-disk separation. The NRC staff agrees with this assessment in general, but has determined that specific actions are needed to support treatment of a valve with a pinned design as not susceptible to stem-to-disk separation, as discussed in the condition below. In short, the staff determined that the pinned design may be considered to be not susceptible to stem-to-disk separation provided end users evaluate and document lessons learned from past OE concerning system conditions, such as vibration and valve operation, and apply preventive maintenance measures, such as disassembly, inspection, and refurbishment.

Condition for use of this TR for the pinned design: The staff concludes that it is acceptable to apply the TR to determine that a pinned valve is not susceptible to stem-to-disk separation if (1) a documented engineering evaluation of operating experience justifies the conclusion and is available for NRC inspection and audit, and (2) the documented engineering evaluation assesses lessons learned from operating experience for such valves concerning system conditions, including but not limited to vibration and valve operation, and justifies reliance on any preventive maintenance measures, including but not limited to disassembly, inspection, and refurbishment, to demonstrate that the valve is not susceptible to stem-to-disk separation. This will be reflected below in conditions on the use of the TR.

3.3.9 T-Head/T-Slot

The T-head/T-slot designs have a T-head on the end of the stem that fits into a T-slot at the top of the disk. This design is used primarily in solid and flexible wedge gate valves. This design is relatively rugged, there are no connection devices (such as pins or keys) to fail, and the “loose” connection between the stem and disk makes it unlikely to be susceptible to vibration-related failures. However, Appendix A of the TR identifies 45 failures of this valve design. Many of the failures of this design are attributed to:

1) Corrosion of the material due to being in a raw untreated water system, thus reducing the strength
2) Pressure locking or thermal binding (PL/TB)
3) Intergranular stress corrosion cracking, hydrogen embrittlement, forging flaws, backseating, improper heat treatment, excessive closing force yielding excessive unwedging force, manufacturing defects, steam erosion, and wear/out flow erosion.

The NRC staff reviewed the INPO IRIS database for this design and found several additional failure events:

INPO Event ID	Event Title	Failure Comments
135378	03/28/1993 - Failure of Essential Service Water System gate valve	During disassembly of the valve during preventive maintenance activity, it was discovered that the disk had separated from the stem. Apparent cause was dissimilar metals coupled with operation in a raw untreated water system.
142368	12/22/1993 - Forced power reduction due to failure of Main Steam Turbine Bypass Valve SP13A3	The valve was not able to fully close. Apparent cause was a poorly designed T-slot which had a very tight fit of the stem T-head eventually leading to a corner of the T-slot to break off and obstructing the valve for full closure.
174968	08/27/1998 - Failure of disk in Essential Service Water System check valve that supports Emergency Power Generator 034-011	The valve stem separated from the disk because the wedge ears were worn off due to corrosion.
236979	04/08/2009 - RHR Shutdown Cooling Suction Valve Stem Found Broken	Manual valve operation noted that the disk was remaining closed. Disassembly of the valve found the stem was broken at a reduced cross-sectional area that forms a “T” at the end of the stem that connects to the valve disk.
301298	10/08/2012 - Two Main Steam Isolation Valve Stem Failures Resulting in a Manual Reactor Shutdown	During power ascension, two main steam isolation valves experienced a stem-to-disk failure due to thermal embrittlement. The stems were sheared above the T-head.
302566	11/26/2012 - Failure of Steam Generator Main Feedwater Inlet Isolation Valve Impacted Outage Schedule	During plant start-up, a main feedwater inlet isolation valve failed closed due to the wedge had separated from the stem at the T-head.

As described below, the NRC staff agrees with the TR review of the T-head/T-slot valve design. Many of the failures were attributed to those valves operating in an untreated raw water system. The TR recommends that this valve design used in untreated raw water systems be considered susceptible to stem-to-disk failure unless the stem and disk materials can be verified to be not subject to corrosion in a raw water environment. For the other valve failures not involving operation in an untreated raw water system, the failure rate over a long period of time was relatively low. Accordingly, the staff has determined that the T-head/T-slot design for valves used in untreated raw water systems is considered to be susceptible to stem-to-disk separation unless the end user verifies that the stem and disk materials are not subject to corrosion in a raw water environment. Further, the staff has determined that for applications not involving operation in an untreated raw water system, this valve design may be considered not susceptible to stem-to-disk separation provided that the other variables such as conditions that could lead to PL/TB, stress corrosion cracking, or embrittlement are monitored, evaluated, and documented.

Condition for use of this TR for the T-head/T-slot design: The staff concludes that it is acceptable to apply the TR to determine that a T-head/T-slot valve is not susceptible to stem-to-disk separation if a documented engineering evaluation of operating experience justifies the

conclusion and is available for NRC inspection and audit. This will be reflected below in a condition on the use of the TR.

3.3.10 Threaded and Pinned

In the threaded and pinned design, the stem is screwed into the valve disk or plug, and then pinned to the disk/plug. This design is used in many globe valves and in some gate valves. The pin is typically intended only as a locking device and is not designed to withstand the maximum load applied to the valve stem. To ensure the pin is not overloaded, the stem must be properly torqued into the disk, with a preload that exceeds the maximum expected stem load, before installing the pin.

This design is potentially susceptible to the following failures:

1) Pin failure due to inadequate joint preload and subsequent unscrewing of the valve stem from the disk/plug
2) Pin failure due to inadequate joint preload and subsequent wear of the valve stem threads

The NRC staff reviewed the INPO IRIS database for this design and found several additional failure events:

INPO Event ID	Event Title	Failure Comments
15983	04/04/1984 - Forced power reduction due to failure of Feedwater Regulating Valve FCV-1FW-498	Main Feedwater Regulating valve was noisy, and actuator was twisting. The cause was the stem was separated from its plug.
20755	10/14/1984 - Failure of Aux/Emergency Feedwater Discharge To S/G Isolation Valve MV-09-10, VALVE	Valve failed to open. The stem was separated from the disk. Apparent cause was an overtorque event.
30225	08/10/1985 - Failure of Feedwater Regulating Valve FCV-478	Valve appears to be not closed fully. Discovered the valve stem to be broken.
107339	04/02/1991 - Failure of Main Steam Turbine Bypass Valve MS-1-PCV-7	During startup, valve was leaking. Inspection found the stem was separated from the disk.
158719	03/19/1996 - Manual reactor scram due to failure of Feedwater Regulating Valve	Plant auto trip due to stem separating from the disk. Apparent cause was torsional stress fracture.
217064	07/23/2005 - Failure of stem in Closed/Component Cooling Water System plug valve 2-3904-A (2A RBCCW heat exchanger outlet TCV)	Temperature control valve was no longer controlling. Inspection found the stem had separated from the disk.

INPO Event ID	Event Title	Failure Comments
300893	05/28/2012 - Unit 2 Turbine Control Valve #3 Failed to Open	Valve failed to open due to stem separated from the crosshead.
486066	08/12/2020 - Stem Disk Separation of Reactor Building Closed Cooling Water Temperature Control Valve	Temperature control valve failed to control due to a stem-to-disk separation.

In addition to the events listed in the table for the threaded and pinned design, the NRC staff noted several “near misses” whereby the pin had sheared, but the valve stem had not completely unthreaded itself. These near misses were identified during routine preventive maintenance activities or investigations of erratic behavior. It was noted in the TR that many of the listed failures of this design were due to Anchor/Darling double disk gate valves, which were associated with a 10 CFR Part 21 notification.

In addition, the TR indicated that many of the failures were associated with valves that were active and controlling a process during normal operation. Failure of this type of valve is identified immediately. Subtracting the number of Anchor/Darling valves and the valve failures of active controlling valves, the failure rate is relatively small, and the valve design may be considered to be not susceptible to stem-to-disk failure. Accordingly, the staff has determined that the threaded and pinned design may be considered not susceptible to stem-to-disk separation provided the end users evaluate and document lessons learned from past operating experience and establish preventive maintenance measures based on vendor recommendations, system conditions, stem material susceptible to embrittlement, and thermal transients.

Condition for the use of this TR for the threaded and pinned design: The staff concludes that it is acceptable to apply the TR to determine that a threaded and pinned valve is not susceptible to stem-to-disk separation if a documented engineering evaluation of operating experience justifies the conclusion and is available for NRC inspection and audit. This will be reflected below in a condition on the use of the TR.

3.3.11 Hermetically Sealed

In a typical hermetically sealed valve design, the valve disk is not connected to the stem; a diaphragm is used to provide a pressure boundary; and the stem pushes on the diaphragm to move the disk toward the closed position. A spring moves the disk in the open direction when the stem is raised. For these designs, there is no stem-to-disk connection to fail; however, there are other potential failure modes that could cause the valve disk to fail to move for an opening stroke, such as failure of the spring and binding of the disk in the valve body. The TR reviewed the INPO IRIS database for one model valve and found no failures.

The NRC staff performed an independent review of the INPO IRIS database and found no failures of hermetically sealed valves. The TR recommended that the valve design be reviewed for failure modes that could cause the valve disk to fail to move with the valve stem, and an operating experience review be performed to determine the number of such failures that have occurred. Based on the results of these reviews, the valve design might be classified as either susceptible or not susceptible to stem-disk separation depending on the specific valve and OE

history. The NRC staff agrees with the approach recommended by the TR for the hermetically sealed design where the results are justified and documented. Accordingly, the staff has determined that for valves without extensive OE information, the valve design might be classified as either susceptible or not susceptible to stem-disk separation depending on the specific valve and OE evaluation. Such a valve may be considered not susceptible to stem-disk separation if a documented engineering evaluation considers each specific valve design for susceptibility to stem-disk separation and justifies its conclusion.

Condition for use of this TR for the hermetically sealed design: The staff concludes that it is acceptable to apply the TR to determine that a hermetically sealed valve is not susceptible to stem-to-disk separation if (1) a documented engineering evaluation of operating experience justifies the conclusion and is available for NRC inspection and audit, and (2) the documented engineering evaluation of the valve assesses the specific valve design's susceptibility to stem-disk separation. This will be reflected below in conditions on the use of the TR.

4.0 USE OF TR WITH ASME OM CODE CASE OMN-28

The EPRI TR used the INPO IRIS database to identify valve stem-to-disk failures over a period of 43 years from 1977 through 2019. A total of 226 failures were identified by searching key words:

- Stem failure
- Stem separation
- Stem-to-disk failure
- Valves

The NRC staff reviewed the EPRI TR and searched the INPO IRIS database for additional valve failures, which yielded many more failures and/or "near-miss" events. The NRC staff concluded that the failure rate is much higher than noted in the TR for the following reasons:

1) The early years of data input into the INPO database yielded inconsistent event entries. Some events had very little content with no details on the cause of the event.
2) Some event narratives were captured in attached documents which could lead to being passed over by key word searches.
3) Not all non-safety-related valve failures are entered into the database.
4) The rules for data entry changed many times over the years.
5) Many events capture the failure and state that additional information will be entered at a later date, but it does not appear the additional information was entered.
6) Many valve failures were attributed to the de-coupling of the actuator to the valve stem. For this TR, it does not seem that these were counted as failures.
7) Valves that are found in the failed mode or fail when preventive maintenance is performed may not be entered into the database.
8) The NRC staff search on other key words yielded several additional failure events. Some events could be missed due to misspelling of a word. Sometimes a partial key word search is effective.

The EPRI TR was developed to support ASME OM Code Case OMN-28, which allows the test interval of ISTC-3700 to be extended from 2 years to once every 12 years for those valves that have been determined to be not susceptible to stem-to-disk separation. The Code Case defines a valve not susceptible to stem-disk separation as a valve with a documented justification that

the stem-disk connection has been determined to not be susceptible to separation based on the internal design, service conditions, applications and evaluation of the stem-disk connection using plant-specific and industry operating experience, and vendor recommendations. Code Case OMN-28 applies to valves that are not susceptible to stem-disk separation but provides only general provisions for determining whether a valve is susceptible to stem-disk separation or not. The EPRI TR provides a more detailed methodology for making this determination for eleven different valve designs. In particular, the EPRI TR states methods for evaluating valve operating experience for the purpose of compliance with Code Case OMN-28.

The NRC staff finds the use of EPRI TR 3002019621 to be acceptable to implement the operating experience provisions of ASME OM Code Case OMN-28 with the specific conditions discussed in this safety evaluation as summarized below:

1) Application of the TR is acceptable to determine that a valve is not susceptible to stem-to-disk separation if a documented engineering evaluation of operating experience justifies the conclusion, in accordance with the NRC staff evaluation of each valve design in sections 3.3.1 through 3.3.11 of this safety evaluation, and is available for NRC inspection and audit, with the additional conditions below.

2) For a valve design that relies on a weld to secure the stem-to-disk connection and operates under high vibration conditions, application of the TR is acceptable to determine that the valve is not susceptible to stem-to-disk separation if the documented engineering evaluation called for by Condition 1 includes additional justification for relying on the welded connection.

3) Application of the TR is acceptable to determine that a bolted valve is not susceptible to stem-to-disk separation if the documented engineering evaluation called for by Condition 1 includes an assessment of the effects of vibration on internal connection components.

4) Application of the TR is acceptable to determine that a butterfly valve that has a pinned connection is not susceptible to stem-to-disk separation if the documented engineering evaluation called for by Condition 1 assesses lessons learned from operating experience for such valves concerning system conditions, including but not limited to vibration and valve operation, and justifies reliance on any preventive maintenance measures, including but not limited to disassembly, inspection, and refurbishment, to demonstrate that the valve is not susceptible to stem-to-disk separation.

5) For each valve without extensive operating experience information (e.g., a hermetically sealed valve), the valve may be classified as not susceptible to stem-disk separation if the documented engineering evaluation of the valve called for by Condition 1 assesses the specific valve design's susceptibility to stem-disk separation.

5.0 CONCLUSION

EPRI TR 3002019621 represents a comprehensive study on the failure rate of various valve designs in operating nuclear power plants over a 43-year period. The study provides many lessons learned and recommended actions to preclude future valve failures. Based on its evaluation, the NRC staff finds the use of EPRI TR 3002019621, with the conditions discussed in this safety evaluation, to be acceptable as part of the implementation of ASME OM Code Case OMN-28.

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Attachment: Comment Resolution Table

Date: May 4, 2022

COMMENT RESOLUTION TABLE

Staff Response to Electric Power Research Institute Comments
on the Staff's Draft SE for Technical Report 3002019621, Revision 0,
"Susceptibility of Valve Applications to Failure of the Stem-to-Disk Connection"
(EPID: L-2021-NTR-0003)

Comment #	Comment	Comment page/Line	Reason for Comment	NRC Response
1	Revise text to include "technical". "The purpose of this TR is to provide a methodology and technical basis….".	Pg 1, line 16	Editorial; Clarification	Recommended change made on Page 1, first paragraph, in the final SE in response to this comment.
2	Revise text from "object" to "objective". "Section IWV stated that its objective was to…."	Pg 2, line 35	Editorial; Grammatical Correction	The word "objective" is used in this sentence on Page 3, Section 3.1, third paragraph, in the final SE in response to this comment.
3	Revise text to remove "this way". "This was written ~~this way~~ for valves that…"	Pg 4, line 37	Editorial; Grammatical Correction	The phrase "this way" has been deleted from Item 3 on Page 5 of the final SE in response to this comment.
4	Revise table (row added) to include ASME OM Interpretations. "6/11/2007" and "ASME OM Interpretation 12-01-Q1(OMI-11-913) and 12-01-A2(OMI-11-913) addressed the clarifications concerning supplemental methods for obturator position verification in ISTC-3700 and ISTC-3530."	Pg 7, row 2 in the table	Editorial; Clarification	These ASME OM Interpretations included in the table with a statement that the NRC staff does not agree with these ASME interpretations.
5	Last row in table concerning "9/2020" entry, suggest it being moved up in the table so dates are in order to avoid confusion	Pg 7, last table row entry	Editorial; Grammatical Correction	The 9/2020 item has been moved earlier in the table on Page 8 of the final SE in response to this comment.

Comment #	Comment	Comment page/Line	Reason for Comment	NRC Response
6	Clarification added. "However, it was not clear if the sheared component was the part connecting the disk to the shaft or the piece that couples the shaft to the actuator or manual handwheel, therefore these were not considered as part of this review."	Pg 9, lines 4-5	Editorial; Clarification	Disagree with this comment. These failures need to be considered as part of the review as discussed in Section 3.3.1 after the table on Page 10 of the final SE.
7	Revise text to remove "~~The keyed design is not totally non-susceptible to failure. However, with proper attention to detail such as key material, dimensions, force being applied, vendor recommendations, and periodic preventive maintenance, this design can be considered not susceptible to disk-to-stem failure.~~" Replace with "Therefore, the NRC staff agrees with the TR summary that the failure rate for this design is low and can be considered to be non-susceptible to stem-to-disk failure. Lessons learned from past OE concerning key materials, dimensions/tolerances, and force being applied should be considered when applicable."	Pg 9, lines 5-11	With only 5 failures in 46 years, the last failure being in 2002, and considering all failures were immediately known, the value of these statements is questionable. The proposed text captures intent without being prescriptive.	Disagree with this comment. These failures need to be considered as part of the review. However, the text has been revised for clarity on Page 10 of the final SE.
8	Revise text and insert "with the TR summary". "The NRC staff agrees with the TR summary that the…"	Pg 10, line 10	Editorial; Clarification for consistency	This recommended change has been made in Section 3.3.2 after the table on Page 10 of the final SE.

Comment #	Comment	Comment page/Line	Reason for Comment	NRC Response
9	Revise text to include "with TR summary" and "stem-to-disk". "The NRC staff agrees with the TR summary that the integral/single piece design has a very low failure rate and can be considered to be non-susceptible to stem-to-disk failure.	Pg 10, lines 21-23.	Editorial; Clarification for consistency	This recommended change has been made in the first paragraph of Section 3.3.3 on Page 11 of the final SE.
10	Revise text to remove "~~Precautionary considerations include periodic preventive maintenance, vendor recommendations, system conditions, stem material susceptible to embrittlement, and thermal transients~~". Replace with "Lessons learned from past OE specific to system conditions, stem materials susceptible to embrittlement, and thermal transients should be considered when appropriate."	Pg 10, lines 23-27	The data shows 1 failure in 43 years and the last one was in 2001. The proposed text captures intent without being prescriptive and is consistent with other responses.	The last sentence of the first paragraph of Section 3.3.3 on Page 11 of the final SE has been clarified in response to this comment.
11	Revise text to remove "~~In addition to the six additional OE involving a gate or globe valve, eleven OE involving check valves that experienced a broken tack weld occurred. It is noted that the TR did not address check valves or relief valves. Check and relief valve failures typically are self-revealing at the time of failure and they rarely have remote position indication which would not require testing per ASME OM Code, Subsection ISTC, paragraph ISTC-3700.~~"	Pg 11, lines 5-9	Because this is not pertinent to the EPRI report, it does not seem appropriate to include in the SE.	Agree with this comment and have removed this discussion from the paragraph after the table in Section 3.3.4 on Page 12 of the final SE.

Comment #	Comment	Comment page/Line	Reason for Comment	NRC Response
12	Revise text to delete "~~However, the failure rate for valves that rely on a tack weld increases the susceptibility to failure. The NRC staff agrees that this type of valve connection design can be considered to be non susceptible to failure provided that a preventive maintenance measure be in place that reviews system conditions for vibration, system fluid that could affect the threaded connection (untreated water), verification that the weld (if applied) is sufficient, and follow vendor recommendations."~~ Replace with "The NRC staff agrees with the TR summary that the failure rate for this design is low and essentially not susceptible to stem-to-disk failure. Lessons learned from past OE concerning system conditions such as vibration, system fluid that could affect the threaded connection (untreated water), verification that the weld is sufficient, and vendor recommendations should be considered when appropriate."	Pg 11, lines 11-20	The data shows 10 failures in 43 years with the larger amount being found during normal operation with no unit impact. No failures have been reported since 2011 and this is more common on non-safety related valves. The proposed text captures intent without being prescriptive and is consistent with other responses.	The discussion in the paragraph after the table in Section 3.3.4 on Page 12 of the final SE has been clarified based in part on this comment.
13	Revise text to add "when applicable". "Lessons learned on application of excessive force should be considered when applicable."	Pg 12, line 17	Clarification. This is a specific operating condition that is not always applicable.	In response to this comment, the first paragraph after the table in Section 3.3.5 on Page 13 of the final SE has been clarified.

Comment #	Comment	Comment page/Line	Reason for Comment	NRC Response
14	Revise text to delete "~~…provided that attention and precautions are made with…".~~ Replace with "The NRC staff has reviewed the OE with this type of valve design and agrees with the TR conclusions that the failure rate is low and that it can be essentially considered to be not susceptible to stem-to-disk separation. Lessons learned from past OE concerning vendor recommendations and evaluation of system vibration impact on internal connection components should be considered when appropriate."	Pg 13, lines 4-6	The data shows 8 failures in 43 years with only 4 of those being related to safety related applications. The proposed text captures intent without being prescriptive and is consistent with other responses.	The first paragraph after the table in Section 3.3.6 on Page 14 of the final SE has been clarified based in part on this comment.

Comment #	Comment	Comment page/Line	Reason for Comment	NRC Response
15	Revise text to delete "~~The NRC staff agrees that this type of valve connection design can be considered to be non susceptible to failure provided that a preventive maintenance measure be in place that reviews system conditions for vibration, system fluid that could affect the threaded connection (untreated water), verification that the weld (if applied) is sufficient, and follow vendor recommendations~~." Replace with "The NRC staff agrees with the TR summary that the failure rate for this design is low and essentially not susceptible to stem-to-disk failure. Lessons learned from past OE concerning system conditions such as vibration, system fluid that could affect the threaded connection (untreated water), verification that the weld is sufficient, and vendor recommendations should be considered when appropriate."	Pg 14, lines 1-5	The data shows 28 failures in 43 years and most common on manual valves in safety related applications. The proposed text captures intent without being prescriptive and is consistent with other responses.	The first paragraph after the table in Section 3.3.7 on Page 15 of the final SE has been clarified based in part on this comment.

Comment #	Comment	Comment page/Line	Reason for Comment	NRC Response
16	Revise text to delete "The NRC staff agrees with this assessment however end users should also evaluate ~~and establish preventive maintenance measures such as disassembly, inspect, and refurbish internals until system vibration levels, valve operation, and internal wear rates of components are fully understood.~~" Replace with "The NRC staff agrees with this assessment however end users should also evaluate lessons learned from past OE concerning system conditions such as vibration and valve operation and apply preventive maintenance measures such as disassembly, inspection, and refurbishment when appropriate."	Pg 17, lines 18-2	Many sites have applied the recommended industry guidance on this design and it shows in the decrease of failures since 1989. The proposed text captures intent without being prescriptive and is consistent with other responses.	The second full paragraph on Page 19 in Section 3.3.8 in the final SE has been clarified based in part on this comment.

Comment #	Comment	Comment page/Line	Reason for Comment	NRC Response
17	Revise text to move last sentence of paragraph to the front of the paragraph. "The NRC staff agrees with ~~T~~the TR review of the T-head/T-slot design. ~~yielded that m~~Many of the failures were attributed to those valves operating in an untreated raw water system. The TR recommends that this design of valve in untreated raw water systems should be considered susceptible to stem-to-disk failure unless the stem and disk materials can be verified to be not subject to corrosion in a raw water environment. For the other valve failures not involving operation in an untreated raw water system, the failure rate over a long period of time is relatively low and that they may be considered non-susceptible to failure provided that the other variables such as conditions that could lead to PL/TB, stress corrosion cracking, or embrittlement are monitored and addressed appropriately. ~~The NRC staff is in agreement on this assessment.~~	Pg 18, lines 12-19 and pg 19, lines 1-2	Moved last sentence to the beginning of paragraph to be consistent.	The first paragraph after the table in Section 3.3.9 on Page 20 of the final SE has been clarified as suggested in this comment.

Comment #	Comment	Comment page/Line	Reason for Comment	NRC Response
18	Revise text from "The NRC staff agrees with this assessment however end users should evaluate and establish preventive maintenance measures based on vendor recommendations, system conditions, stem material susceptible to embrittlement, and thermal transients" to read "The NRC staff agrees with ~~this~~ the TR assessment however end users should evaluate lessons learned from past OE and consider establishing preventive maintenance measures based on vendor recommendations, system conditions, stem material susceptible to embrittlement, and thermal transients when appropriate"	Pg 20, lines 10-13	The proposed text captures intent without being prescriptive and is consistent with other responses.	The second paragraph after the table in Section 3.3.10 on Page 22 of the final SE has been clarified based in part on this comment.
19	Revise text to delete "~~Each valve that has been determined to be not susceptible to stem-to-disk separation shall have a documented justification entered in their IST Program Plan~~"	Pg 21, lines 34-35	This is a condition for applying OMN-28 but is not relevant to the EPRI TR SE review.	Disagree with this comment. This TR was developed to support the use of OM Code Case OMN-28. Nonetheless, the text has been revised for clarity in Item 1 on Page 24 of the final SE.

Comment #	Comment	Comment page/Line	Reason for Comment	NRC Response
20	Revise text to add "in safety related applications", "known flow induced" and "considered when applicable" to first sentence. Delete "high" and "system" from first sentence. "For those valve designs in safety related applications that rely on a weld to secure the stem-to-disk connection and operate under ~~high~~ known flow induced ~~system~~ vibration conditions, additional justification for relying on the welded connection shall be considered when applicable." Delete "~~This may be in the form of~~ …" and replace with "Examples could include..". "Examples could include~~This may be in the form of~~ a structural analysis (weak link) or disassembly and inspection after a number of years of service that evaluates the connection condition."	Pg 21, lines 36-42	Clarification to focus on safety related applications that operate with known flow induced vibration conditions and consideration for an additional justification when applicable with examples.	The suggested changes are unnecessary because the introduction indicates that the applicable valves are those within the scope of Code Case OMN-28.

Comment #	Comment	Comment page/Line	Reason for Comment	NRC Response
21	Revise text to delete "However, end users shall also evaluate ~~and establish preventive maintenance measures such as disassembly, inspection, and refurbish internals until system vibration levels, valve operation, and internal wear rates of components are fully understood.~~" Replace with "However, end users shall also evaluate lessons learned from past OE concerning system conditions such as vibration and valve operation and potentially apply preventive maintenance measures such as disassembly, inspection, and refurbishment when appropriate."	Pg 21, lines 47-50 and pg 22, lines 1-2	The number of pinned failures has dropped significantly since 1989. The data does not support a need for routine PM measures if industry guidance has been applied. The proposed text captures intent without being overly prescriptive.	Item 4 on Page 23 of the final SE has been clarified based in part on this comment.
22	Revise text to delete "~~For valves that are high failure rate valve types (Captured and Clamped, Pinned, T Head/T-Slot, Threaded and Pinned) and have been determined to be not susceptible to stem-to-disk separation, local observation during the required valve exercise shall be completed at least once every 2 years looking for any abnormal operation of the actuator to valve stem interface. Valve position indication testing as described in ASME OM Code Case OMN-28 may remain at the 12-year interval.~~"	Pg 22, lines 3-8	The value of a 2 yr local observation requirement is unclear when the valve position indication testing is pushed to 12 years. This comment is more specific to the adoption and use of code case OMN-28 and not relevant to the use of the EPRI TR.	Section 4.0 on Pages 23 and 24 of the final SE has been revised to remove this discussion. It should be noted that OMN-28 specifies verification of the valve position indicators at the 12-year interval.