Tennessee Valley Authority, 1101 Market Street, Chattanooga, Tennessee 37402

CNL-20-006

October 2, 2020

10 CFR 50.90

ATTN: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Watts Bar Nuclear Plant, Units 1 and 2
Facility Operating Licenses Nos. NPF-90 and NPF-96
NRC Docket Nos. 50-390 and 50-391

Subject: Application to Modify the Watts Bar Nuclear Plant Unit 1 and Unit 2 Technical Specifications 5.7.2.19 "Containment Leakage Rate Testing Program" (WBN-TS-19-01)

Reference:

1. Nuclear Energy Institute 94-01, Revision 3-A, "Industry Guideline for Implementing Performance-Based Option of 10 CFR Part 50, Appendix J," dated July 2012, (ML12221A202)
2. Electrical Power Research Institute Report, "Risk Impact Assessment of Extended Integrated Leak Rate Testing Intervals, Revision 2-A of 1009325," dated October 2008
3. Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk- Informed Decisions on Plant-Specific Changes to the Licensing Basis," Revision 3, January 2018 (ML17317A256)

In accordance with the provisions of Title 10 of the *Code of Federal Regulations* (10 CFR) 50.90, "Application for amendment of license, construction permit, or early site permit," Tennessee Valley Authority (TVA) is submitting a request for an amendment to Facility Operating License Nos. NPF-90 and NPF-96 for the Watts Bar Nuclear Plant (WBN), Units 1 and 2, respectively.

The proposed changes would revise the WBN Units 1 and 2, Technical Specifications (TS) 5.7.2.19, "Containment Leakage Rate Testing Program," by adopting Nuclear Energy Institute (NEI) 94-01, Revision 3-A, "Industry Guideline for Implementing Performance-Based Option of 10 CFR Part 50, Appendix J," (Reference 1) as the implementation document for the performance-based Option B of 10 CFR Part 50, Appendix J. The proposed changes permanently extend the Type A containment integrated leak rate testing (CILRT) interval from 10 years to 15 years and the Type C local leakage rate testing intervals from 60 months to 75 months. In addition, a clarification of the value of P_a to be used for containment leakage rate testing purposes is incorporated.

The proposed amendment is considered risk-informed. An evaluation has been performed to assess the risk effect of the proposed change. The risk assessment follows the guidelines of Reference 1, and the corresponding Electrical Power Research Institute (EPRI) Report, "Risk Impact Assessment of Extended Integrated Leak Rate Testing Intervals, Revision 2-A of 1009325" (Reference 2), and the guidance of Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis" (Reference 3).

Enclosure 1 to this submittal provides a description of the proposed changes, technical evaluation of the proposed changes, regulatory evaluation, and a discussion of environmental considerations. Attachments 1 and 2 to the enclosure provide the existing TS pages marked-up to show the proposed changes for WBN Unit 1 and Unit 2, respectively. Attachments 3 and 4 to the enclosure provide the WBN Unit 1 and Unit 2 TS pages retyped to show the proposed changes. Attachment 5 to the enclosure provides the existing WBN Unit 1 TS Bases pages marked-up to show the proposed changes. Only the Unit 1 TS Bases pages have been provided, as the Unit 2 changes will be nearly identical except for some editorial differences. Changes to the existing TS Bases are provided for information only and will be implemented under the TS Bases Control Program.

Enclosure 2 to this submittal is a probabilistic risk assessment (PRA) evaluation for permanently extending the containment Type A test interval. Enclosure 2 provides resolutions of the PRA Peer Review Team Facts & Observations and impact on the proposed license amendment.

Enclosure 3 to this submittal is the Kalsi Engineering Report 3960C, “Evaluation of Higher Test Pressure on Leakage for Watts Bar,” in support of the value of P_a to be used for containment leakage rate testing purposes. Enclosure 3 contains information that Kalsi Engineering considers to be proprietary in nature in accordance with 10 CFR Section 2.390. Enclosure 4 contains a non-proprietary version of Enclosure 3. Enclosure 5 provides the affidavit from Kalsi Engineering supporting the proprietary withholding request. The affidavit sets forth the basis on which the information may be withheld from public disclosure by the Nuclear Regulatory Commission (NRC) and addresses with specificity the considerations listed in paragraph (b)(4) of Section 2.390. Accordingly, TVA requests that the information which is proprietary to Kalsi Engineering be withheld from public disclosure in accordance with 10 CFR Section 2.390. Correspondence with respect to the copyright or proprietary aspects of the items listed above or the supporting Kalsi Engineering affidavit should be addressed to Neal Estep, Senior Vice President, Kalsi Engineering, Inc., 745 Park Two Drive, Sugar Land, TX 77478.

TVA has determined that there are no significant hazards considerations associated with the proposed changes and that the TS changes qualify for a categorical exclusion from environmental review pursuant to the provisions of 10 CFR 51.22(c)(9). In accordance with 10 CFR 50.91(b)(1), TVA is sending a copy of this letter and enclosures to the Tennessee State Department of Environment and Conservation.

TVA requests approval of the proposed license amendment within one year from the date of this submittal with implementation within 30 days following NRC approval.

There are no new regulatory commitments associated with this submittal. If you have any questions about this proposed change, please contact Gordon Williams, Senior Manager, Fleet Licensing (Acting) at (423) 751-2687.

I declare under penalty of perjury that the foregoing is true and correct. Executed on this 2nd day of October 2020.

Respectfully,

James Barstow
Vice President, Nuclear Regulatory Affairs & Support Services

Enclosures

1. Evaluation of Proposed Change
2. PRA Evaluation
3. Kalsi Engineering Report 3960C (Proprietary)
4. Kalsi Engineering Report 3960C (Non-Proprietary)
5. Kalsi Engineering Affidavit

cc (Enclosures):

NRC Regional Administrator – Region II
NRC Senior Resident Inspector – Watts Bar Nuclear Plant
NRC Project Manager – Watts Bar Nuclear Plant
Director, Division of Radiological Health – Tennessee State Department of
Environment and Conservation

Enclosure 1

Evaluation of Proposed Change

Subject: Application to Modify the Watts Bar Nuclear Plant Unit 1 and Unit 2 Technical Specifications 5.7.2.19 "Containment Leakage Rate Testing Program" (WBN-TS-19-01)

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Attachments

1. Proposed TS Changes (Mark-Ups) for WBN Unit 1
2. Proposed TS Changes (Mark-Ups) for WBN Unit 2
3. Proposed TS Changes (Final Typed) for WBN Unit 1
4. Proposed TS Changes (Final Typed) for WBN Unit 2
5. Proposed TS Bases Page Changes (Mark-Ups) for WBN Unit 1 (For Information Only)

1.0 SUMMARY DESCRIPTION

In accordance with the provisions of Title 10 of the *Code of Federal Regulations* (10 CFR) 50.90, "Application for amendment of license, construction permit, or early site permit," Tennessee Valley Authority (TVA) is requesting a license amendment to Facility Operating License Nos. NPF-90 and NPF-96 for the Watts Bar Nuclear Plant (WBN), Units 1 and 2.

This evaluation supports a request to revise WBN Units 1 and 2, Technical Specifications (TS) 5.7.2.19, "Containment Leakage Rate Testing Program," by adopting Nuclear Energy Institute (NEI) 94-01, Revision 3-A, "Industry Guideline for Implementing Performance-Based Option of 10 CFR Part 50, Appendix J," (Reference 1) as the implementation document for the performance-based Option B of 10 CFR Part 50, Appendix J. The proposed changes permanently extend the Type A containment integrated leak rate testing (CILRT) interval from 10 years to 15 years and the Type C local leakage rate testing (LLRT) intervals from 60 months to 75 months. In addition, a clarification of the value of P_a to be used for containment leakage rate testing purposes is incorporated.

2.0 DETAILED DESCRIPTION

The following is a detailed description of the proposed TS changes for WBN Unit 1 and Unit 2.

- WBN Unit 1 TS 5.7.2.19 is revised as follows:

  5.7.2.19 Containment Leakage Rate Testing Program

  A program shall be established to implement the leakage rate testing of the containment as required by 10 CFR 50.54(o) and 10 CFR 50 Appendix J, Option B, as modified by approved exemptions. This program shall be in accordance with the guidelines contained in ~~Regulatory Guide (RG) 1.163, "Performance-Based Containment Leak-Test Program," dated September 1995~~ NEI 94-01, "Industry Guideline for Performance-Based Option of 10 CFR 50, Appendix J," Revision 3-A, July 2012, and Section 4.1, "Limitations and Conditions for NEI TR 94-01, Revision 2," of the NRC Safety Evaluation Report in NEI 94-01, Revision 2-A, dated October 2008, as modified below:

  ~~The peak calculated containment internal pressure for the design basis loss of coolant accident, P_a, is 15.0 psig.~~

  For containment leakage rate testing purposes, a value of 15.0 psig, which is equivalent to the maximum allowable internal containment pressure, is utilized for P_a to bound a range of peak calculated containment internal pressures from 9.0 to 15.0 psig for the design basis loss of coolant accident.

- WBN Unit 2 TS 5.7.2.19 is revised as follows:

  5.7.2.19 Containment Leakage Rate Testing Program

  A program shall be established to implement the leakage rate testing of the containment as required by 10 CFR 50.54(o) and 10 CFR 50 Appendix J, Option B, as modified by approved exemptions. This program shall be in accordance with the guidelines contained in ~~Regulatory Guide (RG) 1.163, "Performance-Based Containment Leak-Test Program," dated September 1995.~~ NEI 94-01, "Industry Guideline for Performance-Based Option of 10 CFR 50, Appendix J," Revision 3-A, July 2012, and Section 4.1, "Limitations and Conditions for NEI TR 94-01, Revision 2," of the NRC Safety Evaluation Report in NEI 94-01, Revision 2-A, dated October 2008, as modified below:

  For containment leakage rate testing purposes, a value of 15.0 psig, which is equivalent to the maximum allowable internal containment pressure, is utilized for P_a to bound ~~the~~a range of peak calculated containment internal pressures from 9.0 to 15.0 psig for the design basis loss of coolant accident.

Note that the existing version of TS 5.7.2.19 for WBN Unit 2 already included the language regarding the use of 15.0 pounds per square inch gauge (psig) as Pa for containment leakage rate testing program purposes.

Attachments 1 and 2 to this enclosure provide the existing TS pages marked-up to show the proposed changes for WBN Unit 1 and Unit 2, respectively. Attachments 3 and 4 to this enclosure provide the WBN Unit 1 and Unit 2 TS pages retyped to show the proposed changes. Attachment 5 to this enclosure provides the existing WBN Unit 1 TS Bases pages marked-up to show the proposed changes. Only the Unit 1 TS Bases pages have been provided, as the Unit 2 changes will be nearly identical except for some editorial differences. Changes to the existing TS Bases are provided for information only and will be implemented under the TS Bases Control Program.

3.0 TECHNICAL EVALUATION

3.1 Background

The testing requirements of 10 CFR 50, Appendix J (Reference 2), provide assurance that leakage from the containment, including systems and components that penetrate the containment, does not exceed the allowable leakage values specified in TS 5.7.2.19. The periodic surveillance of containment penetrations and isolation valves ensure that proper maintenance and repairs can be performed on the systems and components penetrating containment during the service life of the containment. The limitation on containment leakage provides assurance that the containment would perform its design function following an accident up to and including the plant design basis accident. Appendix J identifies three types of required tests: (1) Type A tests, intended to measure the containment overall integrated leakage rate; (2) Type B tests, intended to detect local leaks and to measure leakage across pressure-containing or leakage limiting boundaries (other than valves) for containment penetrations; and (3) Type C tests, intended to measure containment isolation valve leakage. Type B and C tests identify the vast majority of potential containment leakage paths. Type A tests identify the overall (integrated) containment leakage rate and serve to ensure continued leakage integrity of the containment structure by evaluating those structural parts of the containment not covered by Type B and Type C testing.

This request modifies the existing Appendix J Type A and Type C testing intervals but does not change the Appendix J Type A or Type C test methods. The CILRT imposes significant expense on the station while the safety benefit of performing this test within 10 years, versus 15 years, is minimal. Increasing the allowable extended testing interval for Type C LLRTs by 15 months will result in a reduction in the amount of testing required, with commensurate reductions in radiation exposure, personnel time in lining up for tests, draining systems, conducting tests, and the risk involved in performing such testing while the safety benefit of performing Type C LLRTs within 60 months, versus 75 months, is minimal. This request represents a cost-beneficial licensing change with minimal effect on safety margin.

In 1995, 10 CFR 50, Appendix J was amended to provide a performance-based Option B for containment leakage testing requirements. Option B requires that test intervals for Type A, Type B, and Type C testing be determined by using a performance-based approach. Performance-based test intervals are based on consideration of the operating history of the component and resulting risk from its failure. The use of the term "performance-based" in 10 CFR 50, Appendix J refers to both the performance history necessary to extend test intervals, as well as to the criteria necessary to meet the requirements of Option B. Also in 1995, NRC Regulatory Guide (RG) 1.163 (Reference 3) was issued. RG 1.163 endorsed NEI 94-01, Revision 0, "Industry Guideline for Implementing Performance-Based Option of 94-01, Appendix J" (Reference 4), with certain modifications and additions. Option B, in concert with RG 1.163 and NEI 94-01, Revision 0, allows licensees with a satisfactory integrated leak rate test (ILRT) performance history (i.e., two consecutive successful Type A tests) to reduce the test frequency from the containment Type A ILRT test from three tests in ten years to one test in ten years. This relaxation was based on an NRC risk program documented in NUREG-1493, "Performance-Based Containment Leak-Test Program" (Reference 5) and Electric Power Research Institute (EPRI) Topical Report (TR)-104285, "Risk Impact Assessment of Revised Containment Leak Rate Testing Intervals" (Reference 6), both of which illustrated that the risk increase associated with extending the ILRT surveillance interval was very small.

NEI 94-01, Revision 2 (Reference 7), describes an approach for implementing the optional performance-based requirements of Option B described in 10 CFR 50, Appendix J, which includes provisions for extending Type A intervals to up to 15 years and incorporates the regulatory positions stated in RG 1.163. NEI 94-01, Revision 2 delineates a performance-based approach for determining Type A, Type B, and Type C containment leakage rate surveillance testing frequencies. This method uses industry performance data, plant-specific performance data, and risk insights in determining the appropriate testing frequency. NEI 94-01, Revision 2, also discusses the performance factors that licensees must consider in determining test intervals. However, NEI 94-01, Revision 2 does not address how to perform the tests because these details are included in existing documents (e.g., American National Standards Institute/American Nuclear Society [ANSI/ANS]-56.8-2002). The NRC final Safety Evaluation (SE), issued by letter dated June 25, 2008 (Reference 8), documents the NRC's evaluation and acceptance of NEI 94-01, Revision 2, subject to the specific limitations and conditions listed in Section 4.1 of the SE. The accepted version of NEI 94-01 was subsequently issued as Revision 2-A dated October 2008 (Reference 9).

EPRI Report 1009325, "Risk Impact Assessment of Extended Integrated Leak Rate Testing Intervals," Revision 2 (Reference 10), provides a risk impact assessment for optimized ILRT intervals of up to 15 years, utilizing current industry performance data and risk-informed guidance. The assessment validates increasing allowable extended LLRT intervals to the 120 months as specified in NEI 94-01, Revision 0. However, the industry requested that the allowable extended interval for Type C LLRTs be increased only to 75 months, to be conservative, with a permissible extension (for non-routine emergent conditions) of nine months (i.e., 84 months total). The NRC's final SE, issued by letter dated June 25, 2008, documents the NRC's evaluation and acceptance of EPRI Report 1009325, Revision 2, and extension of the Type C LLRT interval to 75 months, subject to the specific limitations and conditions listed in Section 4.2 of the SE. An accepted version of EPRI Report 1009325, Revision 2 was subsequently issued as EPRI Report 1018243, "Risk Impact of Extended Integrated Leak Rate Testing Intervals - Revision 2-A of 1009325," dated October 2008 (Reference 12).

NEI 94-01, Revision 3 (Reference 13), describes an approach for implementing the optional performance-based requirements of Option B described in 10 CFR 50, Appendix J, which includes provisions for extending Type A and Type C intervals to up to 15 years and 75 months, respectively, and incorporates the regulatory positions stated in RG 1.163. It delineates a performance-based approach for determining Type A, Type B, and Type C containment leakage rate surveillance testing frequencies. In determining the appropriate testing frequency, this method uses industry performance data, plant-specific performance data, and risk insights, primarily Revision 3 of RG 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Bases" (Reference 11). NEI 94-01, Revision 3, also discusses the performance factors that licensees must consider in determining test intervals. However, it does not address how to perform the tests because these details are included in existing documents (e.g., ANSI/ANS-56.8-2002). The NRC final SE issued by letter dated June 8, 2012 (Reference 14), documents the NRC's acceptance of NEI 94-01, Revision 3, subject to the specific limitations and conditions listed in Section 4.0 of the SE. The accepted version of NEI 94-01 was subsequently issued as Revision 3-A dated July 2012 (Reference 1).

3.2 Description of WBN Containment

The WBN containment consists of a containment vessel and a separate Shield Building enclosing an annulus. The containment vessel is a freestanding, welded steel structure with a vertical cylinder, hemispherical dome, and a flat circular base. The Shield Building is a reinforced concrete structure similar in shape to the containment vessel.

The WBN steel containment vessel (SCV) is a low-leakage, freestanding steel structure consisting of a cylindrical wall, a hemispherical dome, and a bottom liner plate encased in concrete. The structure consists of side walls measuring 114 feet 8-5/8 inches in height from the liner on the base to the spring line of the dome and has an inside diameter of 115 feet. The bottom liner plate is 1/4 inch thick, the cylinder varies from 1-3/8 inch thickness at the bottom to 1-1/2 inch thick at the springline, and the dome varies between 1-3/8 inch thickness and 13/16 inch thickness with 15/16 inch thickness at the apex.

The SCV is provided with both circumferential and vertical stiffeners on the exterior of the shell. These stiffeners are required to satisfy design requirements for expansion and contraction, seismic forces, and pressure transient loads. The circumferential stiffeners were installed on approximately 10-foot centers during erection to ensure stability and alignment of the shell. Vertical stiffeners are spaced at 5° between the two lowest circumferential stiffeners. Other locally stiffened areas are provided at the equipment hatch and two personnel locks.

During the WBN Unit 1 steam generator replacement in Fall 2006, two construction openings were made in the steel containment vessel. These openings were restored by reinstalling the removed steel sections and rewelding them to the remaining structure using full penetration welds. Abandoned-in-place reinforcement and support members to stiffen the SCV during creation and use of the two construction openings are designed to remain attached to the SCV during a seismic event. The integrity of the restored vessel was verified by nondestructive examination (NDE) and leak testing of the welds.

The WBN dual-unit Updated Final Safety Analysis Report (UFSAR) Section 3.8.2.2.2 describes that the SCV maximum internal pressure is 15 psig at 250°F and the design internal pressure is 13.5 psig at 250°F. The difference between the two is explained in the same section by stating, "Paragraph NE-3312(b) of Section III of the ASME Code states that the 'design internal pressure' of the vessel may differ from the 'maximum containment pressure', but in no case shall the design internal pressure be less than 90% of the maximum containment internal pressure."

3.3 Leak Test History

3.3.1 Type A Integrated Leak Rate Test

WBN TS 5.7.2.19 requires the measurement of the containment leakage rate. TS 5.7.2.19 limits as-left Type A leakage to ≤ 0.75 L_a. The results of past Type A tests for WBN are provided in Tables 3.3.1-1 and 3.3.1-2. The method for leakage determination is the mass point 95 percent upper confidence level (UCL) estimate of leakage rate. Previous ILRT testing confirmed that WBN Units 1 and 2, containment structures leakage is acceptable, with considerable margin, with respect to the TS acceptance criteria of 0.25% of containment air weight per day at the design basis loss of coolant accident (LOCA) pressure (P_a). Because the WBN Unit 1 and WBN Unit 2 Type-A results (as shown below) meet the performance leakage rate criteria from NEI 94-01, Revision 3-A, a test frequency of at least once per 15 years would be in accordance with NEI 94-01, Revision 3-A.

Table 3.3.1-1

WBN Unit 1							
Test Date	P_a psig	P_t psig	P_d psig	As Found Leak Rate		Acceptance Limits	
				Method	Result	As-Found	As-Left
10/12/12	15	15.03	13.5	Mass Point UCL leakage with penalties	0.0904135 %/day	0.25 %/day (1.0 La)	0.1875 %/day (0.75 La)
10/10/97	15	14.97	13.5	Mass Point UCL leakage with penalties	0.10613 %/day	0.25 %/day (1.0 La)	0.1875 %/day (0.75 La)
U1 Startup* (06/23/94)	15	14.59	13.5	Mass Point UCL leakage with penalties	0.01683 %/day	0.25 %/day (1.0 La)	0.1875 %/day (0.75 La)

P_a - As defined in WBN U1 TS 5.7.2.19
P_t - Final Test Pressure (psig) - minimum allowable P_t is P_a -1 psig = 14 psig
P_d - Containment Design Pressure
L_a - 0.25% containment air weight per day at P_a
* - value from startup is as-left data

Table 3.3.1-2

WBN Unit 2							
Test Date	P_a psig	P_t psig	P_d psig	As Found Leak Rate		Acceptance Limits	
				Method	Result	As-Found	As-Left
05/09/19	15	15.26	13.5	Mass Point UCL leakage with penalties	0.0590 %/day	0.25 %/day (1.0 La)	0.1875 %/day (0.75 La)
U2 Startup* (08/27/15)	15	15.32	13.5	Mass Point UCL leakage with penalties	0.01399 %/day	0.25 %/day (1.0 La)	0.1875 %/day (0.75 La)

P_a - As defined in WBN U1 TS 5.7.2.19
P_t - Final Test Pressure (psig) - minimum allowable P_t is P_a -1 psig = 14 psig
P_d - Containment Design Pressure
L_a - 0.25% containment air weight per day at P_a
* - value from startup is as-left data

In accordance with NEI 94-01, Revision 3-A (Reference 1), Section 9.1.2, further extensions in test intervals are based upon two consecutive, periodic, successful Type A tests and requirements stated in Section 9.2.3 of this guideline. The results in Tables 3.3.1-1 and 3.3.1-2 show that there has been margin to the maximum allowable leakage rate of 0.25 wt%/day in the last two consecutive successful Type A tests for each unit.

There is no anticipated addition or removal of plant hardware within containment that could affect leak-tightness that would not be challenged by local leak rate testing. There are no known modifications that will require a Type A test to be performed prior to Fall 2027 for Unit 1 and Spring 2034 for Unit 2, when the next Type A tests are due for performance in accordance with this proposed change. TVA plans to replace the WBN Unit 2 Steam Generators during the Unit 2 Cycle refueling outage (U2R5 scheduled for Fall 2023). A local leak inspection of the applicable containment dome welds using bubble solution while the primary containment is pressurized to at least P_a will be performed during U2R5 as post-maintenance testing (PMT) in accordance with the condition on use of NEI 94-01, Revision 2-A. Any unplanned modifications to the containment prior to the next scheduled Type A test would be subject to the testing requirements of NEI 94-01, Revision 3-A, Section 9.2.4, as applicable, and as discussed in condition 4 from the June 25, 2008 safety evaluation (Reference 8) for NEI 94-01, Revision 2 (see Table 3.6.1-1).

3.3.2 Type B and Type C Testing

As discussed in NUREG-1493, Type B and Type C tests can identify the vast majority of all containment leakage paths. This amendment request adopts the guidance in NEI 94-01, Revision 3-A in place of NEI 94-01, Revision 0, but otherwise does not affect the scope, performance or scheduling of Type B or Type C tests. Type B and Type C testing will continue to provide a high degree of assurance that containment leakage rates are maintained well within limits.

The WBN Units 1 and 2, Appendix J, Type B and Type C leakage rate test program requires testing of electrical penetrations, airlocks, hatches, bellows, and valves within the scope of the program as required by 10 CFR 50, Appendix J, Option B and TS 5.7.2.19. The Type B LLRTs for each unit includes; two personnel airlocks, 46 individual bellows, 53 electrical penetrations, 12 resilient seals, and an Equipment Hatch. The Type C LLRTs for Unit 1 include 81 valve penetrations and the Type C LLRTs for Unit 2 include 73 valve penetrations.

Summary of Recent Type B and C Testing

A review of the Type B and Type C test results from the recent WBN Unit 1 and Unit 2 refueling outages in Tables 3.3.2-1 and 3.3.2-2 demonstrates a large margin between the actual as-found and as-left outage summations and the TS leakage rate acceptance criteria (that is, less than $0.6\ L_a$).

Table 3.3.2-1

Unit 1 Type B and Type C LLRT Totals				
Refueling Outage	**As-Found Minimum Pathway**		**As-Left Maximum Pathway**	
	Total Leak Rate	**Percentage of $0.6L_a$ (147.6 scfh)**	**Total Leak Rate**	**Percentage of $0.6L_a$ (147.6 scfh)**
U1R16 05/31/20	8.97 scfh	6.1%	22.44 scfh	15.2%
U1R15 10/18/18	6.78 scfh	4.6%	20.84 scfh	14.1%
U1R14 04/23/17	5.30 scfh	3.6%	15.31 scfh	10.4%
U1R13 10/16/15	5.57 scfh	3.8%	16.60 scfh	11.2%

Table 3.3.2-2

Unit 2 Type B and Type C LLRT Totals				
Refueling Outage	**As-Found Minimum Pathway**		**As-Left Maximum Pathway**	
	Total Leak Rate	**Percentage of $0.6L_a$ (147.6 scfh)**	**Total Leak Rate**	**Percentage of $0.6L_a$ (147.6 scfh)**
U2R2 05/10/19	19.75 scfh	13.4%	31.87 scfh	21.6%
U2R1 11/27/17	12.50 scfh	8.5%	31.02 scfh	21.0%
U2 Startup 03/15/16	n/a	n/a	15.86 scfh	10.7%

Repeat LLRT Failures over the Last Two Refueling Outages

A repeat failure is defined as two consecutive failures of the as-found LLRT administrative limit. There have been three repeat failures in Unit 1 and three repeat failures in Unit 2 over the last two outages. In each case, the failure was a Type C tested valve as described in Tables 3.3.2-3 and 3.3.2-4.

Table 3.3.2-3

Unit 1 Repeat LLRT Failures					
Valve	Outage / Date	As-Found Leak Rate	Admin Limit	As-Left Leak Rate	Discussion
1-FCV-90-116	U1R16	1.25 scfh	1.0 scfh	0.0 scfh	Residual foreign material was observed in the seat area. Valve was cleaned and reworked. New disc and stem internals were installed
	U1R15	3.259 scfh	1.0 scfh	0.034 scfh	Foreign material was observed in the seat area. Seat area was cleaned and new diaphragm and packing installed
1-FCV-63-23	U1R16	1.49 scfh	1.0 scfh	1.49 scfh	No maintenance performed based on no active adverse trend present.
	U1R15	1.38 scfh	1.0 scfh	1.38 scfh	No maintenance performed based on no active adverse trend present.
1-FCV-43-287	U1R16	3.41scfh	1.0 scfh	3.41 scfh	No maintenance performed based on Post Accident Sampling (PAS) valves maintained in the block position with no possibility for adverse trend possible.
	U1R15	5.28 scfh	1.0 scfh	5.28 scfh	No maintenance performed based on PAS valves maintained in the block position with no possibility for adverse trend possible.

Table 3.3.2-4

Unit 2 Repeat LLRT Failures					
Valve	Outage / Date	As-Found Leak Rate	Admin Limit	As-Left Leak Rate	Discussion
2-CKV-31-3392	U2R2	64.50 scfh	1.0 scfh	0.39 scfh	Residual foreign material was observed in the seat area. Valve was cleaned and reworked. New disc and stem internals were installed.
	U2R1	Gross	1.0 scfh	0.005 scfh	Foreign material was observed in the seat area. Valve was disassembled cleaned and inspected.
2-FCV-32-111	U2R2	4.60 scfh	2.0 scfh	4.60 scfh	No maintenance performed based on no active adverse trend present from U2R1 as-left test to U2R2 as-found test.
	U2R1	2.20 scfh	2.0 scfh	4.39 scfh	Attempts at fixing the valve by machining the plug seat were performed with limited success
Electrical penetration X-122E	U2R2	7.968 scfh	0.5 scfh	0.07 scfh	Discovered loose ceramic isolator. Re-torqued isolator to correct leakage.
	U2R1	4.43 scfh	0.5 scfh	4.43 scfh	No maintenance performed. Performed leakage evaluation to allow leakage to remain as-is.

Extension of Type B and C Testing

Extensions of the Type B and Type C testing intervals are governed by NEI 94-01 and the associated regulatory documents that endorse its use. WBN Units 1 and 2 currently comply with NEI 94-01, Revision 0 in accordance with RG 1.163 which allow the Type B and Type C testing intervals for most components to be extended out to 120 months and 60 months, respectively, based on acceptable as-found LLRT performance and other factors. Table 3.3.2-5 provides a breakdown of those components currently on NEI 94-01, Revision 0 or RG 1.163 extended frequency by unit and test type.

Table 3.3.2-5

	Unit 1 Totals		Unit 2 Totals	
	LLRT Components	Extended Frequency	LLRT Components	Extended Frequency
Type B	114	114	114	113
Type C	189	161	184	146

Following each refueling outage (18-month cycle), LLRT results are reviewed, component performance is evaluated, and LLRT frequencies are changed accordingly - reduced for failure to meet administrative limits and extended, if eligible, following two successful as-found tests. Results of these evaluations and frequency changes are summarized in a post-outage report and this information is used for development of future outage scope of periodic as-found LLRTs. Development of outage scope for conditional as-found and as-left LLRTs is based on planned maintenance and modification activities that have potential to affect containment leakage integrity.

There is adequate margin in the percentage of total allowable leak rate to accommodate addition of an understatement for those Type C tested valves extended from 60 months to 75 months as required by the condition on use of NEI 94-01, Revision 3-A.

The number of LLRTs on extended frequency and the low percentage of the total of allowable leak rate used demonstrate the WBN LLRT program will provide continuing assurance that the most likely sources of leakage will be identified and repaired.

3.4 Containment Inspections

3.4.1 Containment Inservice Inspections

The WBN Containment Inservice Inspection (CISI) Program provides the site-specific requirements for implementation of the examinations of the SCV, American Society of Mechanical Engineers (ASME) Code Class MC components, in accordance with ASME Code, Section XI, Subsection IWE, 2013 Edition, as conditioned by 10 CFR 50.55a.

The WBN Unit 2 First Interval CISI Program was developed in accordance with the requirements of 10 CFR 50.55a and the 2007 Edition with the 2008 Addenda of ASME Section XI, subject to the limitations and modifications contained within paragraph (b) of the regulation. With the update to the WBN Unit 1 CISI Program for the Third Interval, the WBN Unit 2 CISI Program was updated to the 2013 Edition of ASME Section XI through use of a request for alternative in accordance with 10 CFR 50.55a(g)(4)(iv). This update allowed WBN to utilize a single CISI Program. The WBN Unit 1 Third Interval is effective from September 9, 2018 through September 8th, 2028. The WBN Unit 2 First Interval is effective October 19th, 2016 through October 18th, 2026.

Component Accessibility

ISI Class MC and CC components subject to examination shall remain accessible for either direct or remote visual examination, from at least one side, per the requirements of ASME Section XI, Paragraph IWE-1230.

Paragraph IWE-1231(a)(3) requires 80% of the pressure-retaining boundary that was accessible after construction to remain accessible for either direct or remote visual examination, from at least one side of the vessel, for the life of the plant.

Portions of components embedded in concrete or otherwise made inaccessible during construction are exempted from examination, provided that the requirements of ASME Section XI, Paragraph IWE-1232 have been fully satisfied.

In addition, inaccessible surface areas exempted from examination include those surface areas where visual access by line of sight with adequate lighting from permanent vantage points is obstructed by permanent plant structures, equipment, or components; provided these surface areas do not require examination in accordance with the inspection plan, or augmented examination in accordance with paragraph IWE-1240. The areas around inaccessible areas, including those inaccessible due to the ice condenser configuration, are examined and, to date, no areas have been identified that would indicate there is an issue that would adversely affect structural integrity or leak tightness of the SCV in inaccessible areas.

Responsible Individual

The qualified primary CISI program owner serves as the Responsible Individual (RI) for containment inspections per IWE-2320. The specific responsibilities of the RI are provided below:

1. Development of plans and procedures for general visual examination of containment surfaces.
2. Instruction, training, and approval of general visual examination personnel.
3. Performance or direction of general visual examinations.
4. Evaluation of general visual examination results and documentation.

The CISI Program owner may delegate performance of these responsibilities to qualified individuals in the Inspection Services Organization, but retains overall responsibility for their implementation.

Owner Elected Examinations

The WBN Unit 1 Steam Generators were replaced during U1R7. The inside surface of the two SCV cut-outs in the top of the containment dome, which were removed for steam generator replacement, remain uncoated and shall be monitored for wall thickness due to potential corrosion activity. These areas do not have the potential for accelerated corrosion activity, and any corrosion is expected to be generally uniform across the uncoated surface. Any degradation is expected to occur in the area surrounding the cut line weld toe. Examinations were initially performed every other outage beginning U1R8. After six cycles of operation, the examination areas have shown no measurable corrosion. Trending of the examination results showed corrosion of the liner equal to 10% wall loss would not occur for approximately 125 years in one grid location and more then 300 years in all other locations. Based on these trending results, the examination frequency has been extended to once every 10 years. Examinations consist of performing a 100% ultrasonic thickness examination to the extent possible (except for weld surface) of three grids per cut line (two cuts). Each grid is to be 12 inches wide (six inches on each side from the center on the weld) by 24 inches long.

There are currently no owner elected examinations for WBN Unit 2 containment.

Table 3.4.1-1

Components Subject to Examination Unit 1

EXAM CAT.	ITEM NO.	DESCRIPTION	EXAM METHOD	NUMBER OF COMPONENTS	INTERVAL REQMN'T. FOR EXAM	NUMBER EXAMS FOR INTERVAL	FREQ. OF EXAM / DEFERRAL	NUMBER OF EXAMS 1st PERIOD	NUMBER OF EXAMS 2nd PERIOD	NUMBER OF EXAMS 3rd PERIOD	DRAWING NO.
E-A	**CONTAINMENT SURFACES**										
E-A	E1.10	**Containment Vessel Pressure Retaining Boundary**									
E-A	E1.11	Accessible Surface Areas	General Visual	1 (Note 1)	300 %	3	Each Inspection Period	1	1	1	ISI-503-C Series
E-A	E1.12	Accessible Surface Areas	Visual VT-3	0	100%	0	End of Interval	0	0	0	
E-A	E1.20	Vent System - Accessible Surface Areas	Visual VT-3	0	100%	0	End of Interval	0	0	0	
E-A	E1.30	Moisture Barriers	General Visual	1 Thermal Barrier 18 LCC Boxes	300%	57	Each Inspection Period	19	19	19	ISI-503-C Series
E-C	**CONTAINMENT SURFACES REQUIRING AUGMENTED EXAMINATION**										
E-C	E4.10	**Containment Surface Areas**									
E-C	E4.11	Visible Surfaces	Visual VT-1	Unit 1 Category E-C Augmented Examinations Schedule (None Currently Identified)							
E-C	E4.12	Surface Area Grid, Minimum. Wall Thickness Location	Volumetric UT	Unit 1 Category E-C Augmented Examinations Schedule (None Currently Identified)							

Components Subject to Examination Unit 1											
EXAM CAT.	**ITEM NO.**	**DESCRIPTION**	**EXAM METHOD**	**NUMBER OF COMPONENTS**	**INTERVAL REQMN'T. FOR EXAM**	**NUMBER EXAMS FOR INTERVAL**	**FREQ. OF EXAM / DEFERRAL**	**NUMBER OF EXAMS 1st PERIOD**	**NUMBER OF EXAMS 2nd PERIOD**	**NUMBER OF EXAMS 3rd PERIOD**	**DRAWING NO.**
E-G	**Pressure Retaining Bolting**										
E-G	E8.10	Bolted Connections	Visual VT-1	34 (Note 2)	100%	34	Each Interval	0	0	34	ISI-503-C Series
APP-D	**Owner Elected Examinations**										
APP-D	2.0	SCV Dome	UT	6	6	6	Each Interval	0	0	6	ISI-503-C Series

Notes:

1. The 1 area, which is the entire SCV, is divided into ten examinations, five on the interior surface and five on the exterior surface of the SCV. The five interior/exterior exams are the four 90-degree quadrants of the vertical cylinder and the dome of the SCV.
2. Examination may be performed with the connection assembled and bolting in place under tension, provided the connection is not disassembled during the interval. If the bolted connection is disassembled for any reason during the interval, the examination shall be performed with the connection disassembled.

Table 3.4.1-2

Components Subject to Examination Unit 2											
EXAM CAT.	**ITEM NO.**	**DESCRIPTION**	**EXAM METHOD**	**NUMBER OF COMPONENTS**	**INTERVAL REQMN'T. FOR EXAM**	**NUMBER EXAMS FOR INTERVAL**	**FREQ. OF EXAM / DEFERRAL**	**NUMBER OF EXAMS 1st PERIOD**	**NUMBER OF EXAMS 2nd PERIOD**	**NUMBER OF EXAMS 3 rd PERIOD**	**DRAWING NO.**
E-A	**CONTAINMENT SURFACES**										
E-A	E1.10	**Containment Vessel Pressure Retaining Boundary**									
E-A	E1.11	Accessible Surface Areas	General Visual	1 (See Note 1)	300 %	3	Each Inspection Period	1	1	1	ISI-20MC-E Series
E-A	E1.12	Accessible Surface Areas	Visual VT-3	0	100%	0	End of Interval	0	0	0	
E-A	E1.20	Vent System - Accessible Surface Areas	Visual VT-3	0	100%	0	End of Interval	0	0	0	
E-A	E1.30	Moisture Barriers	General Visual	1 Thermal Barrier 10 LCC Boxes	300%	33	Each Inspection Period	11	11	11	ISI-20MC-E Series
E-C	**CONTAINMENT SURFACES REQUIRING AUGMENTED EXAMINATION**										
E-C	E4.10	**Containment Surface Areas**									
E-C	E4.11	Visible Surfaces	Visual VT-1	Unit 2 Category E-C Augmented Examinations Schedule (None Currently Identified)							
E-C	E4.12	Surface Area Grid, Minimum Wall Thickness Location	Volumetric UT	Unit 2 Category E-C Augmented Examinations Schedule (None Currently Identified)							

Components Subject to Examination Unit 2											
EXAM CAT.	**ITEM NO.**	**DESCRIPTION**	**EXAM METHOD**	**NUMBER OF COMPONENTS**	**INTERVAL REQMN'T. FOR EXAM**	**NUMBER EXAMS FOR INTERVAL**	**FREQ. OF EXAM / DEFERRAL**	**NUMBER OF EXAMS 1st PERIOD**	**NUMBER OF EXAMS 2nd PERIOD**	**NUMBER OF EXAMS 3 rd PERIOD**	**DRAWING NO.**
E-G	**Pressure Retaining Bolting**										
E-G	E8.10	Bolted Connections	Visual VT-1	38 (See Note 2)	100%	38	Each Interval	0	0	38	ISI-20MC-E Series

Notes:

1. The 1 area, which is the entire SCV, is divided into ten examinations, five on the interior surface and five on the exterior surface of the SCV. The five interior/exterior exams are the four 90-degree quadrants of the vertical cylinder and the dome of the SCV.
2. Examination may be performed with the connection assembled and bolting in place under tension, provided the connection is not disassembled during the interval. If the bolted connection is disassembled for any reason during the interval, the examination shall be performed with the connection disassembled.

General Visual Examinations

A General Visual examination shall be performed once each period per Table IWE-2500-1. Examinations include all accessible interior and exterior surfaces of Class MC components, parts, and appurtenances. The following items are examined during the general visual examinations:

1. Integral attachments and structures that are parts of reinforcing structure, such as stiffening rings, manhole frames, and reinforcement around openings.
2. Surfaces of attachment welds between structural attachments and the pressure retaining boundary or reinforcing structure, except for nonstructural or temporary attachments as defined in NE-4435.
3. Surfaces of containment structural and pressure boundary welds, including longitudinal welds (Category A), circumferential welds (Category B), flange welds (Category C), and nozzle-to-shell welds (Category D) as defined in NE 33511 for Class MC; and surfaces of Flued Head and Bellows Seal Circumferential Welds joined to the Penetration.

General Visual Examination History

Unit 1

The most recent category E-A, Item E1.11 examinations performed on Unit 1 were conducted in accordance with TVA NDE Procedure N-VT-25 during U1R15. There were no relevant indications that required evaluation. The majority of indications documented were chipped or peeling paint and some light surface rust in some areas.

Unit 2

The most recent category E-A, Item E1.11 examinations performed on Unit 2 were conducted in accordance with TVA NDE Procedure N-VT-25 during U2R2. These examinations were completed prior to the performance of the CILRT. The majority of indications documented were chipped or peeling paint and some light surface rust in some areas.

Moisture Barrier Examinations

The moisture barrier examinations include moisture barrier materials intended to prevent intrusion of moisture against inaccessible areas of the pressure retaining metal containment shell or liner at concrete-to-metal interfaces and at metal-to-metal interfaces which are not seal-welded. Containment moisture barrier materials include caulking, flashing, and other sealants used for this application.

Thermal Barrier Flashing

The WBN design does not include a moisture barrier seal as depicted in Figure IWE-2500-1. However, the Thermal Barrier Flashing, which was installed to protect the thermal insulation attached to the SCV for post-accident conditions when high-temperature water may accumulate upon containment floor, inadvertently acts as a moisture barrier. The flashing extends approximately 4’-4” above the containment raceway floor (El. 702’) and is sealed against the SCV with sealant to minimize water intrusion under accident conditions.

Leak Chase Channel Boxes

The WBN design contains Leak Chase Channel (LCC) Boxes in the raceway on El. 702' and the keyway on El. 674'. Each LCC box consists of a closure lid that is sealed with a rubber gasket and/or sealant. The scope of the LCC box moisture barrier examination is limited to the LCC box cover gasket and/or sealant. Inside each LCC box is a pipe stub that leads to the LCC system below. Each pipe stub is equipped with a threaded pipe cap, but is not part of the moisture barrier.

Moisture Barrier Examination History

Thermal Barrier

The Thermal Barrier examinations are normally performed at the end of the refueling outage after the Raceway area has been cleared of outage related equipment and material. The Raceway area experiences high traffic during outages and gouging or denting of the thermal Barrier Flashing is a common observation.

Unit 1

The most recent Thermal Barrier, category E-A, Item E1.30 examinations performed on Unit 1 were conducted in accordance with TVA NDE Procedure N-VT-16 during U1R14.

Observations: Numerous dents and gouges were observed on the metal flashing along the entire circumference. No breach or puncture in the metal flashing was identified. The moisture seal barrier was observed not to be separated or cracked. No leak paths noted.

Unit 2

The most recent Thermal Barrier, category E-A, Item E1.30 examinations performed on Unit 2 were conducted in accordance with TVA NDE Procedure N-VT-25 during U2R2.

Observations: Some rivets were broken/missing on the first horizontal seam from the top. Some vertical seams were loose/bulging. The first horizontal seam from the floor was not sealed. In all occurrences the damage was indicative of damage related to outage activities within the Raceway. The damage was not indicative of service induced flaws nor was there any indication of moisture intrusion. There was no evaluation required as all areas had corrective measures performed to the extent necessary to meet the acceptance standards of IWE-3512. Because no areas of the flashing were indicative of degradation in an inaccessible area, there is no engineering evaluation required in accordance with IWE-2500(d).

Leak Chase Channel Boxes

Unit 1

The most recent LCC Box, category E-A, Item E1.30 examinations performed on Unit 1 were conducted in accordance with TVA NDE Procedure N-VT-16 during U1R14. During performance of these examinations, water was discovered within seven of the LCC Boxes indicating the moisture barrier material had failed. Water samples were removed from the boxes for a chemistry analysis and the remaining water was subsequently removed. Once all of the water was removed a boroscope was used to assess the inaccessible area of the bottom liner plate below the LCC Box. The visual examination concluded there was no accelerated corrosion of the bottom liner plate occurring. Chemical analysis concluded that the water was not ground water intrusion. The source of water had some minor boron concentration present, but was not consistent with the boron concentration of primary water. The moisture barrier materials were replaced and all LCC boxes were re-sealed.

Unit 2
The most recent category E-A, Item E1.30 examinations performed on Unit 2 were conducted in accordance with TVA NDE Procedure N-VT-25 during U2R2. During performance of these examinations water was discovered within three of the LCC Boxes indicating the moisture barrier material had failed. Water samples were removed from the boxes for a chemistry analysis and the remaining water was subsequently removed. Once all of the water was removed a boroscope was used to assess the inaccessible area of the bottom liner plate below the LCC Box. The visual examination concluded there was no accelerated corrosion of the bottom liner plate occurring. The chemical analysis concluded that the water was not ground water intrusion. The source of water had some minor boron concentration present, but was not consistent with the boron concentration of primary water. The moisture barrier materials were replaced and all LCC boxes were re-sealed.

3.4.2 Containment Coatings Inspections

The WBN Protective Coatings Program is designed to install and maintain all Coating Service Level (CSL) I, II, III, and corrosive environment protective coatings at the quality required to perform their intended function. These inspections assure conformance to the Watts Bar Nuclear Plant response to NRC Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized Water Reactors."

Results of Recent Coatings Inspections

Unit 1
Inspections of the coatings in the Unit 1 reactor containment building were completed in U1R15 in the fall of 2018 and assessed by Engineering. The assessment was compared with a previous containment coating assessment from U1R14 in accordance with license basis requirements and coating program procedures. Overall, no significant findings were identified. The condition of the containment coatings was acceptable and no immediate corrective actions were required to meet design and license basis requirements. Some minor findings were noted and a condition report was generated. The total quantity of unqualified coatings remains within the bounds required by design basis, with considerable margin remaining.

Unit 2
Inspections of the coatings in the Unit 2 reactor containment building were completed in U2R2 (spring of 2019) and assessed by Engineering. The assessment was compared with a previous containment coating assessment from U2R1 in accordance with license basis requirements and coating program procedures. Overall, no significant findings were identified. The condition of the containment coatings was acceptable and no immediate corrective actions were required to meet design and license basis requirements. Some minor findings were noted and a condition report was generated. The total quantity of unqualified coatings remains within the bounds required by design basis, with considerable margin remaining.

3.5 Industry Operating Experience Review

The NRC has issued several information notices and a regulatory issue summary concerning containment corrosion. TVA reviewed these notices to determine the impact on the WBN Unit 1 and Unit 2 containments.

- Information Notice (IN) 1992-20, "Inadequate Local Leak Rate Testing," dated March 3, 1992, stated that problems exist with testing of stainless steel containment penetration bellows. If the plies of the bellows are in contact with each other, the flow of the test medium would be restricted and in-leakage through such bellows may not be readily detectable by LLRTs. The bellows used at WBN contain a full wire mesh between the plies to maintain a uniform gap. Therefore, this problem would not occur at WBN.

- IN 2004-09, “Corrosion of Steel Containment and Containment Liner,” dated April 27, 2004, addresses concerns identified by the NRC for corrosion in freestanding metallic containments and in liner plates of reinforced and pre-stressed concrete containments. Specifically, the integrity of the moisture barrier seal at the floor-to-liner or floor-to-containment junction was noted as important for avoiding conditions favorable to corrosion and thinning of the containment liner plate material. In response to the situations identified in this IN, WBN containment inspection procedures were revised to provide special attention for the SCV to concrete interfaces.

- IN 2010-12, “Containment Liner Corrosion,” dated June 18, 2010, was issued to inform addressees of recent issues involving corrosion of the steel reactor containment building liner. The examples dealt with containment liner corrosion resulting from liner plates in contact with objects and materials that are lodged between or embedded in the containment concrete, including organic materials. WBN containment inspection procedures were reviewed with respect to this issue and were found to be adequate for detecting such situations.

- IN 2011-15, "Steel Containment Degradation and Associated License Renewal Aging Management Issues," dated August 1, 2011, describes mechanisms that can lead to degradation of coatings and pitting of containment liner plates due to long term exposure to water and moisture. IN-2011-15 was reviewed for applicability to WBN. With respect to the mechanisms described in this IN, the WBN SCV is monitored regularly using walkdowns, with input provided to the Maintenance Rule Program.

- IN 2014-07, "Degradation of Leak-Chase Channel Systems for Floor Welds of Metal Containment Shell and Concrete Containment Metallic Liner," dated May 5, 2014, provided examples of operating experience at some plants of water accumulation and corrosion degradation in the leak-chase channel system that has the potential to affect the leak-tight integrity of the containment shell or liner plate. In response to the situations identified in this IN, WBN containment inspection procedures were revised to incorporate moisture barrier examination requirements for the leak chase channel boxes.

- Regulatory Issue Summary 2016-07, “Containment Shell or Liner Moisture Barrier Inspection,” dated May 9, 2016, was issued to reiterate the NRC staff’s position in regard to inservice inspection requirements for moisture barrier materials as discussed in the ASME B&PV Code, Section XI, Subsection IWE. TVA determined that such materials were already included in the containment inspection procedures for WBN Unit 1. WBN Unit 2 inspection procedures were revised to include the thermal barrier flashing as a moisture barrier component under ASME Section XI, Examination Category E-A, E1.30.

3.6 NRC Limitations and Conditions for NEI 94-01

3.6.1 June 25, 2008 NRC Safety Evaluation

The limitations and conditions from the June 25, 2008 safety evaluation (Reference 8) for NEI 94-01, Revision 2 are presented in Table 3.6.1-1 with the TVA response.

Table 3.6.1-1

Item	Limitation/Condition (From Section 4.1 of SE dated June 25, 2008)	TVA Response
1.	For calculating the Type A leakage rate, the licensee should use the definition in the NEI TR 94-01, Revision 2, in lieu of that in ANSI/ANS-56.8-2002.	TVA will utilize the definition in NEI 94-01, Revision 3-A, Section 5.0. This definition has remained unchanged from Revision 2-A to Revision 3-A of NEI 94-01.
2.	The licensee submits a schedule of containment inspections to be performed prior to and between Type A tests.	TVA will perform a general visual inspection of the accessible interior and exterior surfaces of the primary containment and components prior to the Type A test. Inspections performed between Type A tests are described further in Section 3.4 of this enclosure.
3.	The licensee addresses the areas of the containment structure potentially subjected to degradation.	TVA will perform general visual observations of the accessible interior and external surfaces of the containment structure in accordance with containment inspection procedures. Any evidence of structural deterioration is recorded and evaluated or repaired as required. These inspections are described further in Section 3.4 of this enclosure.

Item	Limitation/Condition (From Section 4.1 of SE dated June 25, 2008)	TVA Response
4.	The licensee addresses any tests and inspections performed following major modifications to the containment structure, as applicable.	TVA will implement the staff position with regard to any future post-repair pressure testing following major WBN, Unit 1 and 2, containment repairs and modifications, as explained in Section 3.1.4 of the NRC staff SE for NEI 94-01, Revision 2. Specifically, with regards to major repairs and modifications, TVA recognizes that, since the issuance of the SE for NEI 94-01 Revision 2, the requirement to perform a Type A test has been removed from ASME Section XI, Subsection IWE-5000 and is now NRC condition 10CFR50.55a(b)(2)(ix)(J). Following a major modification, as an alternative to performing a Type A test TVA will perform the following activities. a) Perform all NDE required by the construction code. b) Examine the locally welded areas for essentially zero leakage using a bubble test or equivalent. c) Subject the entire containment to P_a pressure specified in Technical Specifications for a minimum of 10 minutes. d) Perform a general visual examination of the accessible portions of the interior and exterior surfaces of containment in accordance with ASME B&PV Code, Subsection IWE.
5.	The normal Type A test interval should be less than 15 years. If a licensee has to utilize the provision of Section 9.1 of NEI TR 94-01, Revision 2, related to extending the ILRT interval beyond 15 years, the licensee must demonstrate to the NRC staff that it is an unforeseen emergent condition.	TVA will comply with this condition. Extensions of the Type A test frequency beyond 15 years are used only to accommodate unforeseen emergent conditions.

Item	Limitation/Condition (From Section 4.1 of SE dated June 25, 2008)	TVA Response
6.	For plants licensed under 10 CFR Part 52, applications requesting a permanent extension of the ILRT surveillance interval to 15 years should be deferred until after the construction and testing of containments for that design have been completed and applicants have confirmed the applicability of NEI 94-01, Revision 2, and EPRI Report No. 1009325, Revision 2, including the use of past containment ILRT data.	Not applicable. WBN Units 1 and 2 were not licensed pursuant to 10 CFR Part 52.

3.6.2 June 8, 2012 NRC Safety Evaluation

The two conditions from Section 4.0 of the June 8, 2012 safety evaluation (Reference 14) for NEI 94-01, Revision 3 are stated below with the TVA response.

Table 3.6.2-1

Item	Limitation/Condition (From Section 4.0 of SE dated June 8, 2012)	TVA Response
Condition 1 presents three separate items that are required to be addressed.		
1a.	The staff is allowing the extended interval for Type C LLRTs be increased to 75 months with the requirement that a licensee's post-outage report include the margin between the Type B and Type C leakage rate summation and its regulatory limit.	The post-outage report will include the margin between the Type B and Type C Minimum Pathway Leak Rate (MNPLR) summation value, as adjusted to include the estimate of applicable Type C leakage understatement, and its regulatory limit of $0.60L_a$. TVA will establish an administrative limit to provide margin to the regulatory limit of $0.60L_a$.

Item	Limitation/Condition (From Section 4.0 of SE dated June 8, 2012)	TVA Response
1b.	In addition, a corrective action plan shall be developed to restore the margin to an acceptable level.	When the potential leakage understatement adjusted Types B and C MNPLR total is greater than the WBN administrative leakage summation limit, but less than the regulatory limit of $0.60L_a$, then an analysis and determination of a corrective action plan will be prepared to restore the leakage summation margin to less than the WBN leakage limit. This plan will focus on those components which have contributed the most to the increase in the leakage summation value and the manner of timely corrective action that best focuses on the prevention of future component leakage performance issues so as to maintain an acceptable level of margin.
1c.	Use of the allowed 9-month extension for eligible Type C valves is only authorized for non-routine emergent conditions. At no time shall an extension be allowed for Type C valves that are restricted categorically (e.g. BWR MSIVs), and those valves with a history of leakage, or any valves held to either a less than maximum interval or to the base refueling cycle interval.	TVA will apply the 9-month extension period only to eligible Type C components for non-routine emergent conditions. Such occurrences will be documented in the record of tests. This non-routine extension is not allowed for valves specifically restricted to a maximum 30 month interval or any valve held to less than a maximum interval or the base interval (30 months).

<table>
<tr><th>Item</th><th>Limitation/Condition
(From Section 4.0 of SE dated June 8, 2012)</th><th>TVA Response</th></tr>
<tr><td colspan="3">Condition 2 presents two separate items that are required to be addressed.</td></tr>
<tr><td>2a.</td><td>Extending the LLRT intervals beyond 60-months to a 75-month interval should be similarly conservative provided an estimate is made of the potential understatement and its acceptability determined as part of the trending specified in NEI TR 94-01, Revision 3, Section 12.1.</td><td>TVA will apply a potential leakage understatement adjustment factor to the actual As-Left leak rate. This will result in a combined conservative Type C total for all 75-month LLRTs being "carried forward" and will be included when the total leakage summation is required to be updated (either while on line or following an outage).</td></tr>
<tr><td>2b.</td><td>When routinely scheduling any LLRT valve interval beyond 60-months and up to 75-months, the primary containment leakage rate testing program trending or monitoring must include an estimate of the amount of understatement in the Types B and C total and must be included in a licensee's post-outage report. The report must include the reasoning and determination of the acceptability of the extension, demonstrating that the LLRT totals calculated represent the actual leakage potential of the penetrations.</td><td>A post-outage report is prepared with results of the tests performed during that outage. The report will show that the applicable performance criteria are met and serve as a record that continuing performance is acceptable. If an adverse trend in the potential leakage understatement is identified, then a corrective action plan is prepared, focused on those components which have contributed the most to the adverse trend in the leakage summation value.</td></tr>
<tr><td colspan="3">In addition, NEI 94-01, Revision 3-A also has a margin related requirement as contained in Section 12.1, Report Requirements.</td></tr>
<tr><td colspan="2">A post-outage report shall be prepared presenting results of the previous cycle's Type B and Type C tests, and Type A, Type B and Type C tests, if performed during that outage. The technical contents of the report are generally described in ANSI/ANS-56.8-2002 and shall be available on-site for NRC review. The report shall show that the applicable performance criteria are met and serve as a record that continuing performance is acceptable. The report shall also include the combined Type B and Type C leakage summation, and the margin between the Type B and Type C leakage rate summation and its regulatory limit. Adverse trends in the Type B and Type C leakage rate summation shall be identified in the report and a corrective action plan developed to restore the margin to an acceptable level.</td><td>At WBN, in the event an adverse trend in the aforementioned potential leakage understatement adjusted Type B and C summation is identified, then an analysis and determination of a corrective action plan will be prepared to restore the trend and associated margin to an acceptable level. The corrective action plan will focus on those components which have contributed the most to the adverse trend in the leakage summation value and the manner of timely corrective action, as deemed appropriate that best focuses on the prevention of future component leakage performance issues.</td></tr>
</table>

3.7 Plant-Specific Confirmatory Analysis

3.7.1 Methodology

An evaluation has been performed to assess the risk impact of extending the WBN CILRT Type A interval from the current licensing basis (CLB) of once per ten years to a proposed licensing basis (PLB) of once per fifteen years. This evaluation is provided as Enclosure 2 to this LAR.

A simplified bounding analysis consistent with the Electric Power Research Institute (EPRI) approach was used for evaluating the change in risk associated with increasing the test interval to fifteen years. The approach is consistent with that presented in:

- Appendix H of Electric Power Research Institute, "Risk Impact Assessment of Extended Integrated Leak Rate Testing Intervals: Revision 2-A of 1009325," EPRI Topical Report TR-1018243, October 2008 (Reference 12)
- Electric Power Research Institute, "Risk Impact Assessment of Revised Containment Leak Rate Testing Intervals," EPRI Topical Report TR-104285, August 1994 (Reference 6)
- Nuclear Regulatory Commission, "Performance-Based Containment Leak-Test Program," NUREG-1493, September 1995 (Reference 5)
- Calvert Cliffs liner corrosion analysis described in a letter to the NRC dated March 27, 2002 (Reference 16)

The analysis uses results from the WBN analysis of core damage scenarios (Level 1) and subsequent containment responses (Level 2) resulting in various fission product release categories (including intact containment or negligible release). The applicable figures of merit for this risk-informed application include:

- **Total LERF** (Large Early Release Frequency) - Acceptance Criteria from RG 1.174 (Reference 11) <1.0E-05/yr (All Hazards)
- **Change in LERF** - Acceptance Criteria from RG 1.174, <1.0E-06/yr (All hazards)
- **Population Dose Rate** - Acceptance Criteria EPRI 1018243 §2.2 (Reference 12) <1.0 person-rem/yr or,
- **Percent Increase in Population Dose** - Acceptance Criteria EPRI 1018243 §2.2, <1.0% of total dose increase whichever is less restrictive
- **Condition Containment Failure Probability (CCFP)** - Acceptance Criteria EPRI 1018243 §2.2, Less than or equal to 1.5% increase

In the safety evaluation issued by NRC letter dated June 25, 2008 (Reference 8), the NRC concluded that the methodology in EPRI Report No. 1009325, Revision 2 (Reference 10) is acceptable for referencing by licensees proposing to amend their TS to permanently extend the Type A surveillance test interval to 15 years, subject to the conditions noted in Section 4.2 of the safety evaluation.

Table 3.7.1-1 addresses each of the four conditions for the use of EPRI Report No. 1009325, Revision 2 (from Section 4.2 of NRC Safety Evaluation dated June 25, 2008) (Reference 8).

Table 3.7.1-1

Item	**Limitation/Condition (From Section 4.2 of SE dated June 25, 2008)**	**TVA Response**
1.	The licensee submits documentation indicating that the technical adequacy of their PRA (Probabilistic Risk Assessment) is consistent with the requirements of RG 1.200 relevant to the CILRT extension application.	WBN PRA technical adequacy is addressed in Section 4.0 of the PRA Evaluation. (Reference 17)
2a.	The licensee submits documentation indicating that the estimated risk increase associated with permanently extending the CILRT surveillance interval to 15 years is small, and consistent with the clarification provided in Section 3.2.4.5 of this SE.	The containment Type A ILRT does not mitigate or support the mitigation of core damage; however, it does identify potential leakage paths from within containment to the environment. The relevant figure of merit is the large early release frequency (LERF). Using the methodology from the EPRI guidance, the increase in LERF resulting from a change in the Type A ILRT test interval from three tests-in-ten years to one test-in-fifteen years is estimated as 1.90E-07/year for both units (internal events and external events). The total LERF is 1.61E-6/year for Unit 1 and 1.60E-6/year for Unit 2. As such, the estimated change in LERF is determined to be "small" using the acceptance guidelines of RG 1.174.
2b.	Specifically, a small increase in population dose should be defined as an increase in population dose of less than or equal to either 1.0 person-rem per year or 1% of the total population dose, whichever is less restrictive.	The postulated impact on the population dose and dose-rate resulting from changing the Type A test frequency to the proposed licensing basis from the original licensing basis (OLB) of three tests-in-ten years to one test-per-fifteen years is determined using the method discussed in Reference 12. The impact is measured as an increase to the total integrated plant dose for those accident sequences influenced by Type A testing, is 0.058 person-rem/year, or 0.4% (both units). NEI 94-01 states that a small population dose is defined as an increase of ≤ 1.0 person-rem per year, or ≤ 1% of the total population dose, whichever is less restrictive for the risk impact assessment of the extended ILRT

Item	Limitation/Condition (From Section 4.2 of SE dated June 25, 2008)	TVA Response
		intervals. The results of this evaluation meet these criteria. Moreover, the risk impact for the ILRT extension when compared to severe accident risks is negligible. Section 7.3 of the PRA Evaluation in Reference 17 presents the population dose information.
2c.	In addition, a small increase in CCFP should be defined as a value marginally greater than that accepted in a previous one-time 15-year ILRT extension requests. This would require that the increase in CCFP be less than or equal to 1.5 percentage point.	The increase in the conditional containment failure probability (CCFP) from the three tests-in-ten years interval to one test-in-fifteen years interval is 0.908%. NEI 94-01 states that an increase in CCFP of ≤ 1.5% is small. Therefore, this increase is judged to be small. Section 7.4 of the PRA evaluation in Reference 17 presents the conditional containment failure probability information.
3.	The methodology in EPRI Report No. 1009325, Revision 2, is acceptable except for the calculation of the increase in expected population dose (per year of reactor operation). In order to make the methodology acceptable, the average leak rate for the pre-existing containment large leak rate accident case (accident case 3b) used by the licensees shall be 100 L_a instead of 35 L_a.	EPRI Class 3b represents a Large, pre-Existing Leak in the Containment liner. All core damage accident progression bins with a pre-existing leak in the containment structure in excess of normal leakage (L_a) are characterized as >10 L_a. For this evaluation, the representative containment leakage for Class 3b sequences used by WBN is 100 L_a, based on the guidance provided in Reference 12.
4.	A LAR is required in instances where containment over-pressure is relied upon for ECCS performance.	WBN does not credit containment over-pressure for ECCS performance.

3.7.2 Probabilistic Risk Assessment (PRA) Acceptability

The WBN Internal Events, Internal Flood, and Seismic PRA models have been peer reviewed and there are no PRA upgrades that have not been peer reviewed. The PRA models credited in this request are the PRA models used in the TSTF-425 Surveillance Frequency Control Program (SFCP) application (Reference 18), with routine maintenance updates applied. Capability Category (CC) II of the NRC-endorsed ASME/ANS PRA Standard is the target capability level for both of these applications. The acceptability (previously referred to as technical adequacy or quality) of the PRA models was reviewed by the NRC for that application and determined to be acceptable, as discussed in the Safety Evaluation (Reference 19).

The NRC Safety Evaluation also states the assessment of external events can be taken from existing, previously submitted and approved analyses or other alternate method of assessing an order of magnitude estimate for contribution of the external event to the impact of the changed interval. Therefore, the CILRT interval extension risk assessment is allowed to use the existing models and other existing fire and external hazard evaluations.

Section 3.2 of the WBN TSTF-425 submittal (Reference 18) provides a more detailed discussion of the external hazard evaluations. The information in Section 2 of the WBN TSTF-425 submittal demonstrates that the PRA is of sufficient quality and level of detail to support this submittal, and has been subjected to a peer review process assessed against a standard or set of acceptance criteria that is endorsed by the NRC.

3.7.3 Conclusions of the Plant-Specific Risk Assessment Results

The findings of the WBN risk assessment confirm the general findings of previous studies that the risk impact associated with extending the original licensing basis of Type A test intervals from three tests in ten years to one test in 15 years is small. The WBN plant-specific results for extending the Type A test interval from three-in-ten years to one-in-15 years is summarized in Table 3.7.3-1.

The containment liner does not perform a core damage mitigation function; therefore, extending the CILRT interval has no effect on core damage frequency. Furthermore, WBN does not rely on containment overpressure to assure adequate net positive suction head is available for emergency core cooling system pumps taking suction from the containment sump following design basis accidents.

Table 3.7.3-1

Unit 1 PRA Results			
Metric	**Value**	**Acceptance Criteria**	**Acceptable for Application?**
$\text{LERF}_{\text{IE-Total PLB}}$	1.37E-06/yr	<1.0E-05/rx-yr	Yes
$\text{LERF}_{\text{Total(IE \& EE) PLB}}$	1.61E-06/yr		
$\Delta\text{LERF}_{\text{Total(OLB}\rightarrow\text{CLB) EE\&IE}}$	1.11E-07/yr	<1.0E-06/rx-yr	Yes
$\Delta\text{LERF}_{\text{Total(OLB}\rightarrow\text{PLB) EE\&IE}}$	1.90E-07/yr		
$\Delta\text{CCFP}_{\text{(OLB}\rightarrow\text{CLB), Inc. Corrosion}}$	0.529%	≤ 1.5%	Yes
$\Delta\text{CCFP}_{\text{(OLB}\rightarrow\text{PLB), Inc. Corrosion}}$	0.908%		
$\Delta\text{DOSE}_{\text{(OLB}\rightarrow\text{CLB)}}$	3.37E-02 per-rem/yr	<1.0 person-rem/yr or <1% of total dose, whichever is less restrictive.	Yes
$\Delta\text{DOSE}_{\text{(OLB}\rightarrow\text{PLB)}}$	5.75E-02 per-rem/yr		
$\Delta\%\text{DOSE}_{\text{(OLB}\rightarrow\text{CLB)}}$	0.24%		
$\Delta\%\text{DOSE}_{\text{(OLB}\rightarrow\text{PLB)}}$	0.41%		

Unit 2 PRA Results

Metric	Value	Acceptance Criteria	Acceptable for Application?
$\text{LERF}_{\text{IE-Total PLB}}$	1.36E-06	<1.0E-05/rx-yr	Yes
$\text{LERF}_{\text{Total(IE \& EE) PLB}}$	1.60E-06		
$\Delta\text{LERF}_{\text{Total(OLB}\rightarrow\text{CLB) EE\&IE}}$	1.11E-07	<1.0E-06/rx-yr	Yes
$\Delta\text{LERF}_{\text{Total(OLB}\rightarrow\text{PLB) EE\&IE}}$	1.90E-07		
$\Delta\text{CCFP}_{\text{(OLB}\rightarrow\text{CLB), Inc. Corrosion}}$	0.529%	≤ 1.5%	Yes
$\Delta\text{CCFP}_{\text{(OLB}\rightarrow\text{PLB), Inc. Corrosion}}$	0.908%		
$\Delta\text{DOSE}_{\text{(OLB}\rightarrow\text{CLB)}}$	3.34E-02 per-rem/yr	<1.0 person-rem/yr or <1% of total dose, whichever is less restrictive.	Yes
$\Delta\text{DOSE}_{\text{(OLB}\rightarrow\text{PLB)}}$	5.76E-02 per-rem/yr		
$\Delta\%\text{DOSE}_{\text{(OLB}\rightarrow\text{CLB)}}$	0.24%		
$\Delta\%\text{DOSE}_{\text{(OLB}\rightarrow\text{PLB)}}$	0.42%		

Based on the results in Table 3.7.3-1, the proposed 15-year Type A test interval represents a small change in risk and is acceptable as a permanent change. Details of the WBN risk assessments are contained in Enclosure 2 of the LAR.

NEI 94-01, Revision 3-A, describes an NRC-accepted approach for implementing the performance-based requirements of Appendix J, Option B. It incorporates the regulatory positions stated in Regulatory Guide 1.163 and includes provisions for extending Type A test intervals to 15 years and Type C test intervals to 75 months. NEI 94-01, Revision 3-A, delineates a performance-based approach for determining Type A, Type B, and Type C containment leakage rate surveillance test frequencies.

3.8 Basis for the Proposed TS Changes

3.8.1 General basis

The provisions of Option B in Appendix J to 10 CFR Part 50 will continue to be met through compliance with:

- NEI 94-01 Revision 3-A,
- the Limitations & Conditions set forth in the NRC Safety Evaluations for NEI 94-01 Rev 3-A and Rev 2-A, and
- ANSI/ANS 56.8-2002.

The adoption of NEI 94-01, Revision 3-A, is justified by the excellent performance history at WBN for Type A and Type C leakage test results and for containment inspections as described in Sections 3.3 and 3.4 of this LAR, as well as the risk insights provided by the plant-specific confirmatory analysis described in Section 3.7.

TVA response to the Limitations & Conditions set forth in the NRC Safety Evaluations for NEI 94-01 Rev 3-A and Rev 2-A are described in Section 3.6. Compliance with ANSI/ANS 56.8-2002 is maintained through the use of procedures that already address the requirements and processes for implementation of NEI 94-01, Rev 3-A, at other plants within the TVA nuclear fleet.

3.8.2 Use of a bounding value for P_a

TVA is requesting the use of a bounding value of 15.0 psig for P_a instead of the calculated P_a value as defined 10 CFR 50, Appendix J, Option B, Section II Definitions and ANSI/ANS 56.8, Section 2 Definitions. The current calculated P_a value is 9.36 psig for both Unit 1 and Unit 2 as shown in UFSAR Chapter 6.2.1.3.3 Long-Term Containment Pressure Analysis. A lower limit of 9.0 psig for the calculated P_a was used in evaluating acceptability for the bounding P_a of 15.0 psig.

The purpose of requesting a bounding value for P_a is to minimize the impact on related documents when the calculated P_a is changed. For example, if the calculated P_a changes, then revisions of TS 5.2.7.19 and approximately 43 containment leak rate test procedures, among others, would be required. Use of a bounding value for P_a eliminates that burden and provides a similar level of quality and safety as described below.

NEI 94-01, Revision 3-A, Section 8.0, states, in part, “Type A, Type B, and Type C tests should be performed using the technical methods and techniques specified in ANSI/ANS-56.8-2002, or other alternative testing methods that have been approved by the NRC.”

ANSI/ANS 56.8-2002 provides the following definitions and requirements that are sensitive to the use of a higher bounding value for P_a.

> *L_a (wt%/24 h): The maximum allowable Type A test leakage rate at P_a.*
>
> *P_a (psig or kPa): The calculated peak containment internal pressure related to the design-basis loss-of-coolant accident (LOCA).*
>
> *Type B and Type C tests shall be conducted at a differential pressure of greater than or equal to P_a unless otherwise specified in the plant's licensing basis. When a higher differential pressure results in increased sealing, the differential pressure shall not exceed 1.1 P_a.*

In most cases, the use of a higher bounding P_a pressure is more conservative (e.g., results in a higher leak rate for components where higher pressure reduces sealing) than use of a lower calculated P_a pressure. However, there are two cases where use of a bounding value for P_a will result in a potential non-conservative deviation from ANSI/ANS-56.8-2002 as compared to testing using the lower calculated P_a.

3.8.3 Deviation #1 from ANSI/ANS 56.8-2002 related to the use of a bounding P_a

The first case is related to the allowable leakage rate (L_a). ANSI/ANSI 56.8-2002 defines L_a (wt%/24 h) as “the maximum allowable Type A test leakage rate at P_a.” It also defines P_a (psig or kPa) as “the calculated peak containment internal pressure related to the design basis loss-of-coolant accident (LOCA).” L_a is a mass leakage rate and there is a direct correlation with P_a pressure when converted to a volumetric leak rate. Therefore, a bounding P_a of 15.0 psig will result in a higher allowable leakage rate, L_a, than what would be permitted if using the calculated P_a value. The effect of P_a on L_a is illustrated by the simplified formula below. The resulting L_a at three different P_a values is shown in Table 3.8.3-1.

$$\underset{\text{(scfh)}}{\mathbf{L_a}} = \frac{0.0025\ (\%\text{wt/24hr}) \times \text{Containment Volume (ft}^3) \times [\mathbf{P_a}\ (\text{psig}) + \text{P}_{\text{ATM}}\ (\text{psia})]}{\text{P}_{\text{ATM}} \times 24\ (\text{hrs/day})}$$

$$\underset{\text{(scfh)}}{\mathbf{L_a}} = \frac{0.0025 \times 1{,}171{,}012 \times (\mathbf{P_a} + 14.69595)}{14.69595 \times 24}$$

Table 3.8.3-1

Pa	La
9.00 psig	196.68 scfh
9.36 psig	199.67 scfh
15.00 psig	246.48 scfh

Historically, the WBN as-found minimum pathway total containment leak rate for Local Leak Rate Test (LLRT) components has been less than 14% of the 0.6 L_a TS acceptance criteria at 15.0 psig.

The value for L_a at WBN has been based on a P_a value of 15.0 psig since initial startup and commercial operation. As such, the associated dose analysis has also used an L_a based on P_a of 15.0 psig as described in TS Bases B3.6.1, Applicable Safety Analysis, which states in part as follows.

> *The containment was designed with an allowable leakage rate of 0.25% of containment air weight per day. This leakage rate, used in the evaluation of offsite doses resulting from accidents, is defined in 10 CFR 50, Appendix J, Option B, as L_a: the maximum allowable containment leakage rate at the calculated peak containment internal pressure (Pa) related to the design basis LOCA. The allowable leakage rate represented by L_a forms the basis for the acceptance criteria imposed on all containment leakage rate testing. L_a is assumed to be 0.25% per day in the safety analysis at P_a = 15.0 psig which bounds the calculated peak containment internal pressure resulting from the limiting design basis LOCA.*

Thus, no adverse effects are introduced by the use of this bounding P_a of 15.0 psig.

3.8.4 Deviation #2 from ANSI/ANS 56.8-2002 related to the use of a bounding P_a

The second case is related to the maximum test pressure. ANSI/ANS 56.8-2002 limits the maximum Type B and Type C test pressure to 1.1 times P_a for those components where a higher differential pressure results in increased sealing. This restriction is generically worded to apply to a broad range of component designs and is intended to prevent the use of a higher test pressure as a means to reduce the component leakage rate.

To evaluate the effect of this difference in maximum test pressure, TVA reviewed all WBN components that are Type B and Type C tested, to identify the scope of components where a higher differential pressure “may” increase sealing. This subset scope of components was then evaluated in more detail. The purpose of the detailed evaluation was to determine whether an increase in seat leakage is expected when the differential pressure (LLRT test pressure) is reduced from 16.5 psig to 9.0 psig. The maximum LLRT test pressure of 16.5 psig equates to 1.1 times the historical P_a value of 15.0 psig, which is the current and historical maximum LLRT test pressure allowed by WBN specific LLRT procedures. The lower limit of 9.0 psig for the evaluation was chosen to provide some margin below the current calculated P_a of 9.36 psig in case of future changes in the calculations.

TVA contracted with Kalsi Engineering to perform this detailed evaluation. The full report of the Kalsi evaluation methodology, assumptions, and conclusion is provided in Enclosure 3 (Proprietary) and Enclosure 4 (Non-Proprietary).

The detailed evaluation determined that an increase in seat leakage is not expected when the LLRT test pressure is reduced from 16.5 psig to a bounding lower limit of 9.0 psig. TVA plans to perform a confirmatory test, as recommended in the Kalsi Engineering report, during the WBN Unit 2 Cycle 3 Refueling Outage (U2R3) which is scheduled to commence in October 2020.

3.9 Conclusion

NEI 94-01, Revision 3-A, describes an NRC-accepted approach for implementing the performance-based requirements of Appendix J, Option B. It incorporates the regulatory positions stated in Regulatory Guide 1.163 and includes provisions for extending Type A test intervals to 15 years and Type C test intervals to 75 months. NEI 94-01, Revision 3-A, delineates a performance-based approach for determining Type A, Type B, and Type C containment leakage rate surveillance test frequencies.

Based on the previous Type A tests conducted at WBN extension of the containment Type A test interval from ten to fifteen years represents minimal risk to increased leakage. The risk is further minimized by continued Type B and Type C testing performed in accordance with Appendix J, Option B, and the overlapping inspection activities performed as part of the following WBN inspection programs:

- Containment Inservice Inspection Program
- Protective Coatings Program

This experience is supplemented by risk analysis studies, including the WBN risk analysis provided in Enclosure 2. The findings of the risk assessment confirm the general findings of previous industry studies, on a plant-specific basis, that extending the Type A test interval from ten to fifteen years results in a very small and acceptable change to the WBN baseline risk.

4.0 REGULATORY EVALUATION

4.1 Applicable Regulatory Requirements and Criteria

4.1.1 Regulations

10 CFR 50.54(o), “Conditions of licenses,” requires that primary reactor containments for water cooled power reactors, other than facilities for which the certifications required under §§ 50.82(a)(1) or 52.110(a)(1) of this chapter have been submitted, shall be subject to the requirements set forth in appendix J to this part.

10 CFR 50.54 Appendix J, “Primary Reactor Containment Leakage Testing for Water-Cooled Power Reactors,” Option B identifies the performance-based requirements and criteria for preoperational and subsequent periodic leakage-rate testing.

4.1.2 General Design Criteria

General Design Criteria

WBN Units 1 and 2 were designed to meet the intent of the "Proposed General Design Criteria for Nuclear Power Plant Construction Permits" published in July 1967. The WBN construction permit was issued in January 1973. The dual-unit UFSAR, however, addresses the NRC General Design Criteria (GDC) published as Appendix A to 10 CFR 50 in July 1971, including Criterion 4 as amended October 27, 1987.

GDC 16, “Containment design,” requires that reactor containment and associated systems be provided to establish an essentially leak-tight barrier against the uncontrolled release of radioactivity to the environment and to assure that the containment design conditions important to safety are not exceeded for as long as postulated accident conditions require. Compliance with GDC 16 is described in Section 3.1.2.2 of the WBN UFSAR.

GDC 50, “Containment design basis,” requires that the reactor containment structure, including access openings, penetrations, and the containment heat removal system shall be designed so that the containment structure and its internal compartments can accommodate, without exceeding the design leakage rate and with sufficient margin, the calculated pressure and temperature conditions resulting from any loss-of-coolant accident. This margin shall reflect consideration of (1) the effects of potential energy sources which have not been included in the determination of the peak conditions, such as energy in steam generators and as required by § 50.44 energy from metal-water and other chemical reactions that may result from degradation but not total failure of emergency core cooling functioning, (2) the limited experience and experimental data available for defining accident phenomena and containment responses, and (3) the conservatism of the calculational model and input parameters. Compliance with GDC 50 is described in Section 3.1.2.5 of the WBN UFSAR.

GDC 52, “Capability for containment leakage rate testing,” requires that the reactor containment and other equipment which may be subjected to containment test conditions shall be designed so that periodic integrated leakage rate testing can be conducted at containment design pressure. Compliance with GDC 52 is described in Section 3.1.2.5 of the WBN UFSAR.

GDC 53, “Provisions for containment testing and inspection,” requires that the reactor containment shall be designed to permit (1) appropriate periodic inspection of all important areas, such as penetrations, (2) an appropriate surveillance program, and (3) periodic testing at containment design pressure of the leaktightness of penetrations which have resilient seals and expansion bellows. Compliance with GDC 53 is described in Section 3.1.2.5 of the WBN UFSAR.

With the implementation of the proposed changes, WBN Units 1 and 2 continue to meet the applicable regulations and requirements, subject to the previously approved exceptions.

4.2 Precedent

The following precedents are related to the proposed TS change in this submittal.

Containment Leakage Rate Test Pressure
The changes proposed in this LAR relative to Containment Leakage Rate Test Pressure are consistent with similar changes approved by the NRC for other nuclear power plants. These include changes approved for:

- Millstone Power Station, Unit 2, by License Amendment (LA) No. 326 dated March 31, 2016 (ML16068A312)
- Donald C. Cook Nuclear Plant, Units 1 and 2, by LA Nos. 336 and 318, respectively, dated June 7, 2017 (ML17131A277)

Test Intervals
The changes proposed in this LAR relative to Test Intervals are consistent with similar changes approved by the NRC for other nuclear power plants. These include changes approved for:

- Sequoyah Nuclear Plant, Units 1 and 2, by LA Nos. 335 and 328, respectively, dated November 30, 2015 (ML15320A218)
- Browns Ferry Nuclear Plant, Units 1, 2, and 3, by LA Nos. 305, 328, and 288, respectively, dated September 27, 2018 (ML18251A003)
- Cooper Nuclear Station by LA No. 266 dated August 18, 2020 (ML20191A273)
- Davis Besse Nuclear Power Station, Unit 1, by LA No. 300 dated August 24, 2020 (ML20213C726)

4.3 No Significant Hazards Consideration

Tennessee Valley Authority (TVA) is requesting an amendment to Facility Operating Licenses NPF-90 and NPF-96 for the Watts Bar Nuclear Plant (WBN), Units 1 and 2, respectively. The proposed amendment revises WBN Units 1 and 2 Technical Specification (TS) 5.7.2.19, "Containment Leakage Rate Testing Program," by adopting Nuclear Energy Institute (NEI) 94-01, Revision 3-A, "Industry Guideline for Implementing Performance-Based Option of 10 CFR Part 50, Appendix J," (Reference 1) as the implementation document for the performance-based Option B of 10 CFR Part 50, Appendix J. The proposed changes permanently extend the Type A containment integrated leak rate testing (CILRT) interval from 10 years to 15 years and the Type C local leakage rate testing intervals from 60 months to 75 months. In addition, a clarification of the value of P_a to be used for containment leakage rate testing purposes is incorporated.

TVA evaluated whether or not a significant hazards consideration is involved with the proposed amendments by focusing on the three standards set forth in 10 CFR 50.92, "Issuance of Amendment," as discussed below:

1. *Does the proposed amendment involve a significant increase in the probability or consequences of an accident previously evaluated?*

   Response: No.

   The proposed amendment adopts the NRC-accepted guidelines of NEI 94-01, Revision 3-A, "Industry Guideline for Implementing Performance-Based Option of 10 CFR Part 50, Appendix J," for development of the WBN containment leak rate program. NEI 94-01 allows, based on risk and performance, an extension of Type A and Type C containment leak test intervals. Implementation of these guidelines continues to provide adequate assurance that during design basis accidents, the primary containment and its components will limit leakage rates to less than the values assumed in the plant safety analyses.

   The findings of the WBN risk assessment confirm the general findings of previous studies that the risk impact with extending the containment leak rate is small. Per the guidance provided in Regulatory Guide 1.174, an extension of the leak test interval in accordance with NEI 94-01, Revision 3-A results in an estimated change within the very small change region.

   Because the change is implementing a performance-based containment testing program, the proposed amendment does not involve either a physical change to the plant or a change in the manner in which the plant is operated or controlled. The requirement for containment leakage rate acceptance will not be changed by this amendment. Therefore, the containment will continue to perform its design function as a barrier to fission product releases. The clarification of the value of P_a to be used for containment leakage rate testing purposes also does not involve a physical change to the plant nor a change in the manner in which the plant is operated or controlled

   Based on the above, it is concluded that the proposed change does not involve a significant increase in the probability or consequences of an accident previously evaluated.

2. *Does the proposed change create the possibility of a new or different kind of accident from any accident previously evaluated?*

   Response: No.

   The proposed change to implement a performance-based containment testing program, associated with integrated leakage rate test frequency, does not change the design or operation of structures, systems, or components of the plant. The proposed change would continue to ensure containment integrity and would ensure operation within the bounds of existing accident analyses. There are no accident initiators created or affected by this change. The clarification of the value of P_a to be used for containment leakage rate testing purposes also does not change the design or operation of structures, systems, or components of the plant.

Based on the above, it is concluded that the proposed change does not create the possibility of a new or different kind of accident from any previously evaluated.

3. *Does the proposed change involve a significant reduction in a margin of safety?*

   Response: No.

   Margin of safety is related to confidence in the ability of the fission product barriers (fuel cladding, reactor coolant system, and primary containment) to perform their design functions during and following postulated accidents. The proposed change to implement a performance-based containment testing program, associated with integrated leakage rate test and local leak rate testing frequency, does not affect plant operations, design functions, or any analysis that verifies the capability of a structure, system, or component of the plant to perform a design function. In addition, this change does not affect safety limits, limiting safety system setpoints, or limiting conditions for operation. The clarification of the value of P_a to be used for containment leakage rate testing purposes also has no effect on safety limits, limiting safety system setpoints, or limiting conditions for operation.

   The specific requirements and conditions of the TS Containment Leakage Rate Testing Program exist to ensure that the degree of containment structural integrity and leak-tightness that is considered in the plant safety analysis is maintained. The overall containment leak rate limit specified by TS is maintained. This ensures that the margin of safety in the plant safety analysis is maintained. The design, operation, testing methods and acceptance criteria for Type A, B, and C containment leakage tests specified in applicable codes and standards would continue to be met with the acceptance of this proposed change since these are not affected by implementation of a performance-based containment testing program.

   Therefore, the proposed change does not involve a significant reduction in a margin of safety.

Based on the above, it is concluded that the proposed amendment does not involve a significant hazards consideration under the standards set forth in 10 CFR 50.92(c), and, accordingly, a finding of “no significant hazards consideration” is justified.

4.4 Conclusions

In conclusion, based on the considerations discussed above, (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the Commission's regulations, and (3) the issuance of the amendment will not be inimical to the common defense and security or to the health and safety of the public.

5.0 ENVIRONMENTAL CONSIDERATION

A review has determined that the proposed amendment would change a requirement with respect to installation or use of a facility component located within the restricted area, as defined in 10 CFR 20, or would change an inspection or surveillance requirement. However, the proposed amendment does not involve (i) a significant hazards consideration, (ii) a significant change in the types or significant increase in the amounts of any radioactive effluents that may be released offsite, or (iii) a significant increase in individual or cumulative occupational radiation exposure. Accordingly, the proposed amendment meets the eligibility criterion for categorical exclusion set forth in 10 CFR 51.22(c)(9). Therefore, pursuant to 10 CFR 51.22(b), no environmental impact statement or environmental assessment need be prepared in connection with the proposed amendment.

6.0 REFERENCES

1. Nuclear Energy Institute (NEI) NEI 94-01, "Industry Guideline for Implementing Performance-Based Option of 10 CFR Part 50, Appendix J," Revision 3-A, dated July 2012 (ML12221A202)
2. Title 10, Code of Federal Regulations, Part 50 (10 CFR 50), "Domestic Licensing of Production and Utilization Facilities," Appendix J, "Primary Reactor Containment Leakage Testing for Water-Cooled Reactors."
3. NRC Regulatory Guide 1.163, "Performance-Based Containment Leak-Test Program," dated September 1995 (ML003740058)
4. NEI 94-01, "Industry Guideline for Implementing Performance-Based Option of 10 CFR Part 50, Appendix J," Revision 0, dated July 26, 1995 (ML11327A025)
5. NUREG-1493, "Performance-Based Containment Leak-Test Program," dated September 1995
6. EPRI Report 104285, "Risk Impact Assessment of Revised Containment Leak Rate Testing Intervals," dated August 1994
7. NEI 94-01, "Industry Guideline for Implementing Performance-Based Option of 10 CFR Part 50, Appendix J," Revision 2, dated August 2007 (ML072970206)
8. NRC letter to NEI, "Final Safety Evaluation For Nuclear Energy Institute (NEI) Topical Report (TR) 94-01, Revision 2, "Industry Guideline For Implementing Performance-Based Option of 10 CFR PART 50, Appendix J" and Electric Power Research Institute (EPRI) Report No. 1009325, Revision 2, August 2007, "Risk Impact Assessment of Extended Integrated Leak Rate Testing Intervals" (TAC No. MC9663), dated June 25, 2008 (ML081140105)
9. NEI 94-01, "Industry Guideline for Implementing Performance-Based Option of 10 CFR Part 50, Appendix J," Revision 2-A, dated October 2008 (ML100620847)
10. EPRI Report 1009325, "Risk Impact Assessment of Extended Integrated Leak Rate Testing Intervals," Revision 2, dated August 2007 (ML072970208)

11. NRC Regulatory Guide (RG) 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis," Revision 3, dated January 2018 (ML17317A256)
12. EPRI Report 1018243, "Risk Impact Assessment of Extended Integrated Leak Rate Testing Intervals, Revision 2-A of 1009325," dated October 2008
13. NEI 94-01, "Industry Guideline for Implementing Performance-Based Option of 10 CFR Part 50, Appendix J," Revision 3, dated June 2011 (ML112920567)
14. NRC letter to NEI, "Final Safety Evaluation of Nuclear Energy Institute (NEI) Report, 94-01, Revision 3, "Industry Guideline For Implementing Performance-Based Option of 10 CFR PART 50, Appendix J" (TAC No. ME2164)," dated June 8, 2012 (ML121030286)
15. NRC Regulatory Guide 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities," Revision 2, dated March 2009 (ML090410014)
16. Constellation Nuclear letter to NRC, ”Response to Request for Additional Information Concerning the License Amendment Request for a One-Time Integrated Leakage Rate Test Extension, dated March 27, 2002 (ML020920100)
17. PRA Evaluation WBN-0-19-078, WBN CILRT LAR PRA (provided as Enclosure 2)
18. TVA Letter to NRC, CNL-18-067, “Application for Technical Specifications Change Regarding Risk-Informed Justification for the Relocation of Specific Surveillance Frequency Requirements to a Licensee Controlled Program (WBN-TS-18-14),” dated October 12, 2018 (ML18288A352)
19. NRC letter to TVA, “Watts Bar Nuclear Power Plant, Units 1 and 2 - Issuance of Amendment Nos. 132 and 36 Regarding the Adoption of Technical Specifications Task Force Traveler TSTF-425, Revision 3, dated February 28, 2020 (ML20028F733)

Enclosure 1

Attachment 1

Proposed TS Changes (Mark-Ups) for WBN Unit 1

5.7.2.18 Safety Function Determination Program (SFDP) (continued)

A loss of safety function exists when, assuming no concurrent single failure, a safety function assumed in the accident analysis cannot be performed. For the purpose of this program, a loss of safety function may exist when a support system is inoperable, and:

a. A required system redundant to the system(s) supported by the inoperable support system is also inoperable; or

b. A required system redundant to the system(s) in turn supported by the inoperable supported system is also inoperable; or

c. A required system redundant to the support system(s) for the supported systems (a) and (b) above is also inoperable.

The SFDP identifies where a loss of safety function exists. If a loss of safety function is determined to exist by this program, the appropriate Conditions and Required Actions of the LCO in which the loss of safety function exists are required to be entered.

5.7.2.19 Containment Leakage Rate Testing Program

A program shall be established to implement the leakage rate testing of the containment as required by 10 CFR 50.54(o) and 10 CFR 50 Appendix J, Option B, as modified by approved exemptions. This program shall be in accordance with the guidelines contained in ~~Regulatory Guide (RG) 1.163, "Performance-Based Containment Leak-Test Program," dated September 1995.~~ NEI 94-01, "Industry Guideline for Performance-Based Option of 10 CFR 50, Appendix J," Revision 3-A, July 2012, and Section 4.1, "Limitations and Conditions for NEI TR 94-01, Revision 2," of the NRC Safety Evaluation Report in NEI 94-01, Revision 2-A, dated October 2008, as modified below:

~~The peak calculated containment internal pressure for the design basis loss of coolant accident, P_a, is 15.0 psig.~~

For containment leakage rate testing purposes, a value of 15.0 psig, which is equivalent to the maximum allowable internal containment pressure, is utilized for P_a to bound a range of peak calculated containment internal pressures from 9.0 to 15.0 psig for the design basis loss of coolant accident.

The maximum allowable containment leakage rate, L_a, at P_a, is 0.25% of the primary containment air weight per day.

(continued)

Enclosure 1

Attachment 2

Proposed TS Changes (Mark-Ups) for WBN Unit 2

5.7.2.18 Safety Function Determination Program (SFDP) (continued)

A loss of safety function exists when, assuming no concurrent single failure, a safety function assumed in the accident analysis cannot be performed. For the purpose of this program, a loss of safety function may exist when a support system is inoperable, and:

a. A required system redundant to the system(s) supported by the inoperable support system is also inoperable; or

b. A required system redundant to the system(s) in turn supported by the inoperable supported system is also inoperable; or

c. A required system redundant to the support system(s) for the supported systems (a) and (b) above is also inoperable.

The SFDP identifies where a loss of safety function exists. If a loss of safety function is determined to exist by this program, the appropriate Conditions and Required Actions of the LCO in which the loss of safety function exists are required to be entered.

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For containment leakage rate testing purposes, a value of 15.0 psig, which is equivalent to the maximum allowable internal containment pressure, is utilized for P_a to bound ~~the~~ a range of peak calculated containment internal pressures from 9.0 to 15.0 psig for the design basis loss of coolant accident.

The maximum allowable containment leakage rate, L_a, at P_a, is 0.25% of the primary containment air weight per day.

(continued)

Enclosure 1

Attachment 3

Proposed TS Changes (Final Typed) for WBN Unit 1

5.7 Procedures, Programs, and Manuals

5.7.2.18 Safety Function Determination Program (SFDP) (continued)

A loss of safety function exists when, assuming no concurrent single failure, a safety function assumed in the accident analysis cannot be performed. For the purpose of this program, a loss of safety function may exist when a support system is inoperable, and:

a. A required system redundant to the system(s) supported by the inoperable support system is also inoperable; or

b. A required system redundant to the system(s) in turn supported by the inoperable supported system is also inoperable; or

c. A required system redundant to the support system(s) for the supported systems (a) and (b) above is also inoperable.

The SFDP identifies where a loss of safety function exists. If a loss of safety function is determined to exist by this program, the appropriate Conditions and Required Actions of the LCO in which the loss of safety function exists are required to be entered.

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For containment leakage rate testing purposes, a value of 15.0 psig, which is equivalent to the maximum allowable internal containment pressure, is utilized for P_a to bound a range of peak calculated containment internal pressures from 9.0 to 15.0 psig for the design basis loss of coolant accident.

The maximum allowable containment leakage rate, L_a, at P_a, is 0.25% of the primary containment air weight per day.

(continued)

Enclosure 1

Attachment 4

Proposed TS Changes (Final Typed) for WBN Unit 2

5.7.2.18 Safety Function Determination Program (SFDP) (continued)

A loss of safety function exists when, assuming no concurrent single failure, a safety function assumed in the accident analysis cannot be performed. For the purpose of this program, a loss of safety function may exist when a support system is inoperable, and:

a. A required system redundant to the system(s) supported by the inoperable support system is also inoperable; or

b. A required system redundant to the system(s) in turn supported by the inoperable supported system is also inoperable; or

c. A required system redundant to the support system(s) for the supported systems (a) and (b) above is also inoperable.

The SFDP identifies where a loss of safety function exists. If a loss of safety function is determined to exist by this program, the appropriate Conditions and Required Actions of the LCO in which the loss of safety function exists are required to be entered.

5.7.2.19 Containment Leakage Rate Testing Program

A program shall be established to implement the leakage rate testing of the containment as required by 10 CFR 50.54(o) and 10 CFR 50 Appendix J, Option B, as modified by approved exemptions. This program shall be in accordance with the guidelines contained in NEI 94-01, "Industry Guideline for Performance-Based Option of 10 CFR 50, Appendix J," Revision 3-A, July 2012, and Section 4.1, "Limitations and Conditions for NEI TR 94-01, Revision 2," of the NRC Safety Evaluation Report in NEI 94-01, Revision 2-A, dated October 2008, as modified below:

For containment leakage rate testing purposes, a value of 15.0 psig, which is equivalent to the maximum allowable internal containment pressure, is utilized for P_a to bound a range of peak calculated containment internal pressures from 9.0 to 15.0 psig for the design basis loss of coolant accident.

The maximum allowable containment leakage rate, L_a, at P_a, is 0.25% of the primary containment air weight per day.

(continued)

Enclosure 1

Attachment 5

Proposed TS Bases Page Changes (Mark-Ups) for WBN Unit 1 (For Information Only)

SURVEILLANCE REQUIREMENTS

SR 3.6.1.1

Maintaining the containment OPERABLE requires compliance with the visual examinations and leakage rate test requirements of the Containment Leakage Rate Testing Program. Failure to meet air lock, Shield Building containment bypass leakage path, and purge valve with resilient seal leakage limits specified in LCO 3.6.2 and LCO 3.6.3 does not invalidate the acceptability of these overall leakage determinations unless their contribution to overall Type A, B, and C leakage causes that to exceed limits. As left leakage prior to the first startup after performing a required leakage test is required to be $< 0.6\ L_a$ for combined Type B and C leakage and $\leq 0.75\ L_a$ for overall Type A leakage. At all other times between required leakage rate tests, the acceptance criteria is based on an overall Type A leakage limit of $\leq 1.0\ L_a$. At $\leq 1.0\ L_a$ the offsite dose consequences are bounded by the assumptions of the safety analysis.

SR Frequencies are as required by the Containment Leakage Rate Testing Program. These periodic testing requirements verify that the containment leakage rate does not exceed the leakage rate assumed in the safety analysis.

REFERENCES

1. Title 10, Code of Federal Regulations, Part 50, Appendix J, Option B, "Primary Reactor Containment Leakage Testing for Water-Cooled Power Reactors - Performance-Based Requirements."
2. Watts Bar FSAR, Section 15.0, "Accident Analysis."
3. Watts Bar FSAR, Section 6.2, "Containment Systems."
4. ~~Regulatory Guide 1.163, "Performance-Based Containment Leak-Test Program," September 1995.~~
Nuclear Energy Institute (NEI) NEI 94-01, "Industry Guideline for Implementing Performance-Based Option of 10 CFR Part 50, Appendix J," Revision 3-A, dated July 2012

BASES (continued)

APPLICABLE SAFETY ANALYSES

The DBAs that result in a significant release of radioactive material within containment are a loss of coolant accident and a rod ejection accident (Ref. 2). In the analysis of each of these accidents, it is assumed that containment is OPERABLE such that release of fission products to the environment is controlled by the rate of containment leakage. The containment was designed with an allowable leakage rate (L_a)of 0.25% of containment air weight per day (Ref. 2), at ~~the calculated peak containment pressure of 15.0 psig.~~ Pa = 15.0 psig This allowable leakage rate forms the basis for the acceptance criteria imposed on the SRs associated with the a

The containment air locks satisfy Criterion 3 of the NRC Policy Statement.

LCO

Each containment air lock forms part of the containment pressure boundary. As part of containment pressure boundary, the air lock safety function is related to control of the containment leakage rate resulting from a DBA. Thus, each air lock's structural integrity and leak tightness are essential to the successful mitigation of such an event.

Each air lock is required to be OPERABLE. For the air lock to be considered OPERABLE, the air lock interlock mechanism must be OPERABLE, the air lock must be in compliance with the Type B air lock leakage test, and both air lock doors must be OPERABLE. The interlock allows only one air lock door of an air lock to be opened at one time. This provision ensures that a gross breach of containment does not exist when containment is required to be OPERABLE. Closure of a single door in each air lock is sufficient to provide a leak tight barrier following postulated events. Nevertheless, both doors are kept closed when the air lock is not being used for normal entry into and exit from containment.

(continued)

SURVEILLANCE REQUIREMENTS

SR 3.6.3.3 (continued)

The Note allows valves and blind flanges located in high radiation areas to be verified closed by use of administrative means. Allowing verification by administrative means is considered acceptable, since access to these areas is typically restricted for ALARA reasons. Therefore, the probability of misalignment of these containment isolation valves, once they have been verified to be in their proper position, is small.

SR 3.6.3.4

Verifying that the isolation time of each power operated and automatic containment isolation valve is within limits is required to demonstrate OPERABILITY. The isolation time test ensures the valve will isolate in a time period less than or equal to that assumed in the safety analyses. The isolation time and Frequency of this SR are in accordance with the Inservice Testing Program or in accordance with the Surveillance Frequency Control Program.

SR 3.6.3.5

For containment purge valves with resilient seals, additional leakage rate testing beyond the test requirements of 10 CFR 50, Appendix J, Option B (Ref. 4), is required to ensure OPERABILITY.

Operating experience has demonstrated that this type of seal has the potential to degrade in a shorter time period than do other seal types. Based on this observation and the importance of maintaining this penetration leak tight (due to the direct path between containment and the environment), these valves will not be placed on the maximum extended test interval. Therefore, these valves will be tested in accordance with ~~Regulatory Guide 1.163,~~ which allows a maximum test interval of 30 months. (Ref.3).

NEI 94-01, Revision 3-A,

SR 3.6.3.6

Automatic containment isolation valves close on a containment isolation signal to prevent leakage of radioactive material from containment following a DBA. This SR ensures that each automatic containment isolation valve will actuate to its isolation position on a containment isolation signal. This Surveillance is not required for valves that are locked, sealed, or otherwise secured in the required position under administrative control.

The Surveillance Frequency is controlled under the Surveillance Frequency Control Program.

(continued)

BASES

SURVEILLANCE REQUIREMENTS (continued)

SR 3.6.3.7

Verifying that each 24 inch containment lower compartment purge valve is blocked to restrict opening to ≤ 50°F is required to ensure that the valves can close under DBA conditions within the times assumed in the analyses of References 1 and 2. If a LOCA occurs, the purge valves must close to maintain containment leakage within the values assumed in the accident analysis. At other times when purge valves are required to be capable of closing (e.g., during movement of irradiated fuel assemblies), pressurization concerns are not present, thus the purge valves can be fully open. The Surveillance Frequency is controlled under the Surveillance Frequency Control Program.

SR 3.6.3.8

This SR ensures that the combined leakage rate of all Shield Building bypass leakage paths is less than or equal to the specified leakage rate. This provides assurance that the assumptions in the safety analysis are met. The as-left bypass leakage rate prior to the first startup after performing a leakage test, requires calculation using maximum pathway leakage (leakage through the worse of the two isolation valves). If the penetration is isolated by use of one closed and de-activated automatic valve, closed manual valve, or blind flange, then the leakage rate of the isolated bypass leakage path is assumed to be the actual pathway leakage through the isolation device. If both isolation valves in the penetration are closed, the actual leakage rate is the lesser leakage rate of the two valves. At all other times, the leakage rate will be calculated using minimum pathway leakage.

The frequency is required by Containment Leakage Rate Testing Program. This SR simply imposes additional acceptance criteria. Although not a part of L_a, the Shield Building Bypass leakage path combined leakage rate is determined using the 10 CFR 50, Appendix J, Option B, Type B and C leakage rates for the applicable barriers.

REFERENCES

1. Watts Bar FSAR, Section 15.0, "Accident Analysis."
2. Watts Bar FSAR, Section 6.2.4.2, "Containment Isolation System Design," and Table 6.2.4-1, "Containment Penetrations and Barriers."
3. ~~Regulatory Guide 1.163, "Performance-Based Containment Leak Test Program, September 1995~~.
4. Title 10, Code of Federal Regulations, Part 50 Appendix J, Option B, "Primary Reactor Containment Leakage Testing for Water-Cooled Power Reactors - Performance - Based Requirements."

Nuclear Energy Institute (NEI) NEI 94-01, "Industry Guideline for Implementing Performance-Based Option of 10 CFR Part 50, Appendix J," Revision 3-A, dated July 2012

B 3.6 CONTAINMENT SYSTEMS

B 3.6.4 Containment Pressure

BASES

BACKGROUND

The containment pressure is limited during normal operation to preserve the initial conditions assumed in the accident analyses for a loss of coolant accident (LOCA) or steam line break (SLB). These limits also prevent the containment pressure from exceeding the containment design negative pressure differential (-2.0 psid) with respect to the Shield Building annulus atmosphere in the event of inadvertent actuation of the Containment Spray System or Air Return Fans.

Containment pressure is a process variable that is monitored and controlled. The containment pressure limits are derived from the input conditions used in the containment functional analyses and the containment structure external pressure analysis. Should operation occur outside these limits coincident with a Design Basis Accident (DBA), post accident containment pressures could exceed calculated values.

APPLICABLE SAFETY ANALYSES

Containment internal pressure is an initial condition used in the DBA analyses to establish the maximum peak containment internal pressure. The limiting DBAs considered, relative to containment pressure, are the LOCA and SLB, which are analyzed using computer pressure transients. The worst case LOCA generates larger mass and energy release than the worst case SLB. Thus, the LOCA event bounds the SLB event from the containment peak pressure standpoint (Ref. 1).

The initial pressure condition used in the containment analysis was 15.0 psia. This resulted in a maximum peak pressure from a LOCA of 9.36 psig. The containment analysis (Ref. 1) shows that the maximum allowable internal containment pressure~~, P_a~~ (15.0 psig)~~,~~ bounds the calculated results from the limiting LOCA. The maximum containment pressure resulting from the worst case LOCA, does not exceed the containment design pressure, 13.5 psig.

(continued)

Enclosure 2

PRA Evaluation

B45 200306 001

PRA Evaluation Response	WBN 0-19-078	**Page 1 of 90**
Plant and Unit(s)	WBN 1 & 2	
Department Requesting Evaluation	Licensing	

Type of Evaluation ☐ NOED ☐ DCN

☐ EOOS > 7 days ☐ Unexpected EOOS Results ☐ Missed Surveillance

☐ Plant Trip(s) ☐ Shutdown Evaluation ☒ Other WBN CILRT LAR Input

Evaluate the risk impact of permanently extending the Containment Type A Integrated Leak Rate Test interval from 1 test-in-10 years to 1 test-in-15 years. The risk impact is characterized as the change in the Large Early Release Frequency (LERF), the increase in the Conditional Containment Failure Probability (CCFP) and the increase in the estimated population dose.

Risk Management Actions

Required:

- None

Suggested:

- None

Conclusion/Discussion/Description of Risk Insights

See Attached

Prepared by	Gerry W. Kindred	3/6/2020
	Print Name/Signature/Date	
Reviewed by	Jacob J. Johnson	3/6/2020
	Print Name/Signature/Date	

Contents

List of Tables

1.0 Purpose/Background

In 1995 the NRC amended 10CFR50 Appendix J to include test methods referred to as Option B, a performance-based approach to containment leakage testing which allows licensees with acceptable test performance history to extend surveillance test intervals. At that time, provisions were made for extending the Containment Integrated Leak Rate Test (CILRT) frequency from the original licensing basis (OLB) of 3 tests-in-10 years to 1 test-in-10 years, supported by the NRC's assessment (NUREG-1493) that stated there is an imperceptible increase in risk associated with the increase in CILRT interval..[5 §10.1.2] During the early 2000's most licenses applied for one-time extensions to 1 test-in-15 years, in accordance with NEI 94-01,[3] including Watts Bar.

Integrated leak-rate testing (CILRT) is the only method capable of detecting all existing leaks in the reactor containment system and is only performed during shutdown operations. During the test other activities within or affecting the containment structure cannot be performed; thus, there is an associated cost in terms of critical path, outage duration and lost generation.[5 §1.1] Furthermore, equipment rental to support the test requires several $100Ks, and manpower is also several $100K. Therefore, the overall cost of the test including critical path (~$70,000/hr) is approximately $2,000,000.

Industry analysis has shown that, in general, the risk impact associated with CILRT interval extensions for intervals up to 15 years is small; however, plant-specific confirmatory analysis is required. [1, 3 §9.2.3.1] NEI 94-01 Rev 3-A[3] incorporates by reference the EPRI methodology from report 1018243.[1] NRC's Safety Evaluation endorses NEI 94-01 Rev 3-A and is included as part of the upfront material in the NEI guidance document. The purpose of this analysis is to provide the required plant-specific confirmation of permanently extending the Current Licensing Basis (CLB) allowed Containment Type A Integrated Leak Rate Test (CILRT) interval from 1 test-in-10 years to the Proposed Licensing Basis (PLB) of 1 test-in-15 years and represents an insignificant increase in risk The extension would allow for substantial cost savings as the CILRT could be deferred for additional scheduled refueling outages for the Watts Bar plant, which over the remaining life of the plant would reduce the total required number of Type A CILRTs.

Earlier assessments followed the guidance of EPRI TR-104285 that considered changes in local leak-rate testing and CILRT testing intervals.[2] That report considered the change in risk based only on population dose, whereas EPRI 1018243 guidance considers population dose, large early release frequency (LERF) and the conditional containment failure probability (CCFP).[1] The risk assessment for Watts Bar follows the guidance from NEI 94-01[3], the methodology used in EPRI TR-1018243,[1] NRC regulatory guidance on the use of Probabilistic Risk Assessment (PRA) as stated in RG 1.200,[11] and RG 1.174[10] for risk insights in support of a request for a change to a plant's licensing basis. Additionally, the regulatory endorsed Calvert Cliffs methodology to estimate the likelihood and risk implications of corrosion-induced leakage of steel liners going undetected during the extended test interval is also used for the Watts Bar analysis.[12]

This risk analysis uses the Watts Bar PRA Level 1, Level 2 and Seismic PRA models. The release category and dose (person-rem) information is based on the approach suggested by the EPRI guidance.[1]

The NRC report on performance-based leak testing, NUREG-1493[5] analyzed the effects of containment leakage on the health and safety of the public and the benefits realized from the containment leak rate testing. In the analysis, it was determined that for a representative PWR (i.e., Surry) that containment isolation failures contribute less than 0.1 percent to the latent risk from reactor accidents. This low level of risk contribution is due to the low predicted probability of isolation failure; however, the consequence of containment isolation failure can be substantial. [5,§5.2.2.1] Extending the CILRT interval (Type A test) does not mechanically cause a change in containment isolation leakage, as the Type A test can only identify that there is leakage, if actually present. Furthermore, the increase in the Type A test interval will not cause a significant risk in containment isolation leakage identification because the Type C tests are performed on a more frequent basis than the Type A test.

1.1 References

1. EPRI Report 1018243, Oct 2008, “Risk Impact Assessment of Extended Integrated Leak Rate Testing Intervals, Revision 2-A of EPRI 1009325”
2. EPRI Report 104285, “Risk Impact Assessment of Revised Containment Leak-Rate Testing Intervals”
3. NEI 94-01 Rev. 3-A, “Industry Guideline for Implementation Performance-Based Option of 10CFR Part 50, Appendix J” Reference ML11327A025
4. NUREG-1150, Volumes 1, 2 and 3, “Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants”
5. NUREG-1493, “Performance-Based Containment Leak-Test Program”
6. NUREG/CR-4551 Vol. 3 Rev. 1, Part 1 “Evaluation of Severe Accident Risks: Surry Unit 1”
7. NUREG/CR-4551 Vol. 5, Rev. 1, Part 1 “Evaluation of Severe Accident Risks: Sequoyah, Unit 1”
8. NUREG/CR-4551 Vol. 5, Rev. 1, Part 2 “Evaluation of Severe Accident Risks: Sequoyah, Unit 1”
9. Reg. Guide 1.163 Rev. 0, “Performance-Based Containment Leak-Test Program”
10. Reg. Guide 1.174 Rev. 3, “An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis”
11. Reg. Guide 1.200 Rev. 2, “An Approach For Determining The Technical Adequacy of Probabilistic Risk Assessment Results For Risk-Informed Activities”
12. Response to Request for Additional Information Concerning the License Amendment Request for a One-Time Integrated Leakage Rate Test Extension, Letter from Mr. C.H. Cruse (Calvert Cliffs Nuclear Power Plant) to NRC Document Control Desk, Docket No. 50-317, March 27, 2002. ML 020920100
13. WBN-0-092, WBN ILRT Level 2 Input Data
14. MDN-000-999-2008-0148 Rev 4, “Watts Bar Probabilistic Risk Assessment – Level 2 Analysis”
15. ABS Report R-2361441-1823 “Watts Bar Unit 2 Severe Accident Mitigation Alternatives”
16. Watts Bar Nuclear Plant Individual Plant Evaluation of External Events, April 16, 2015.
17. 1/2-PTI-064-02 , “Containment Integrated Leak Rate Test (CILRT)”
18. IPEEE, Attachment 4, Internal Fires
19. Watts Bar Nuclear Power Plant, Updated Final Safety Analysis Report, Amendment 113
20. Watts Bar Nuclear Plant Unit-2, Individual Plant Evaluation of External Events, April 16, 2015, Attachment 4, “Internal Fires”
21. NUREG-1742, “Perspectives Gained from the IPEEE Program,” USNRC, April 2002

22. EPRI Report 1025287, November 2012, “Seismic Evaluation Guidance”
23. ML100270756, GI-199, Appendix D “Seismic Core-Damage Frequencies”
24. MDN-000-999-2015-000717 Rev 0, “WBN Probabilistic Risk Assessment - Seismic Quantification (SQU) Notebook”
25. Watts Bar Nuclear Plant Unit 1, Individual Plant Evaluation of External Events, February 1998
26. NEI 05-04 Rev. 3, ”Process for Performing Internal Events PRA Peer Reviews Using the ASME/AND PRA Standard”
27. NPG-SPP-09.11 Rev. 3, “Probabilistic Risk Assessment Program”
28. NEDP-26 Rev. 12, “Probabilistic Risk Assessment”
29. MDN-000-999-2008-0151, Rev. 0 “Summary Document”
30. MDN-000-999-2008-0151, Rev. 1 “Summary Document”
31. MDN-000-999-2008-0151, Rev. 2 “Summary Document”
32. MDN-000-999-2008-0151, Rev. 3 “Summary Document”
33. WBN 1-17-075 Rev. 1 B45 170629 001, “Unit 1 Seismic PRA Results”
34. MDN-000-999-2015-000717 Rev. 2 “ Seismic Quantification (SQI) Notebook)
35. WBN-0-18-078, Westinghouse LTR-RAM-II-09-084, “RG 1.200 PRA Peer Review Against the ASME/ANS PRA Standard requirements for the Watts Bar Nuclear Power Plant Probabilistic Risk Assessment”
36. WBN-0-18-079 B45 180614 004, “Watts Bar Units 1 & 2 Internal Events Probabilistic Risk Assessment Peer Review Findings Closure”
37. ASME/ANS RA-Sa-2009, “Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications”
38. ASME/ANS RA-Sb-2013 “Addenda to ASME/ANS RA-S-2008, Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications”
39. WBN-0-18-080, “F&O Closure – Update Versus Upgrade Review”
40. NPG-SPP-09.0.4 Rev. 3, “Conduct of Probabilistic Risk Assessment Engineering”
41. RIMS T42970505066, RIMS Reel E05414, WBN Site Reel 004423915, Problem Evaluation Report WBPER970050, January 22, 1997
42. UFSAR - WBN Updated Final Safety Analysis Report
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44. CNL-19-035 “Response to Request for Additional Information Regarding Application for Technical Specification Change Regarding Risk-Informed Justification for relocating of Specific Surveillance Frequency Requirements to a Licensee Controlled Program”
45. ‘CNL-18-067 “Application for Technical Specifications Change Regarding Risk-Informed Justification for the Relocation of Specific Surveillance Frequency Requirements to a Licensee Controlled Program
46. NEI 12-13, “External Hazards PRA Peer Review Process Guidelines”
47. PWROG-16011-P Rev. 0, “Peer Review of the Watts Bar Seismic Probabilistic Risk Assessment”
48. Jensen Hughes Report 06044-RPT-01, “Watts Bar Nuclear Plant Seismic PRA Finding level F&O Independent Technical Review”

49. MDN-000-999-2015-000717 Rev. 0, “Seismic Quantification (SQU) Notebook”
50. MDN-000-999-2015-000717 Rev. 1, “Seismic Quantification (SQU) Notebook”
51. ML 19210D430 TVA Letter CNL-19-069, “Final Response to NRC Request for Additional Information Regarding Watts Bar Nuclear Plant, Units 1 and 2, Application to Adopt 10 CFR 50.69, ‘Risk-Informed Categorization and Treatment of Structures, Systems, and Components for Nuclear Power Reactors’”
52. CNL-18-068 “Application to Adopt 10 CFR 50.69, ‘Risk-Informed Categorization and Treatment of Structures, systems, and Components for Nuclear Power Reactors’”
53. ML101240992, “Watts Bar Nuclear Plant (WBN) Unit 2 - Individual Plant Examination of External Events Design Report”
54. CNL-19-035, “Response to Request for Additional Information Regarding Application for Technical Specification Change Regarding Risk-Informed Justification for the Relocation of Specific Surveillance Frequency Requirements to a Licensee Controlled Program,” RAI APLB-05

The following acronyms are used in this calculation:

APB - Accident Progression Bin
ARF - Air Return Fans
CCDP - Conditional Core Damage Probability
CCFP - Conditional Containment Failure Probability
CDF - Core Damage Frequency
CET - Containment Event Tree
CILRT - Containment Integrated Leak-Rate Test
CLB - Current Licensing Basis
EPRI - Electric Power Research Institute
F&O - Facts & Observations
HCLPF - High-Confidence of Low-Probability of Failure
CILRT - Integrated Leak Rate Test
ISLOCA - Interfacing System LOCA
La - Leakage (Allowable)
LER - Large Early Release
LERF - Large, Early Release Frequency
MFCR - Mean Fractional Contribution to Risk
MOR - Model of Record
NEI - Nuclear Energy Institute
OLB - Original Licensing Basis
PDR - Population Dose-Rate
PLB - Proposed Licensing Basis
PRA - Probabilistic Risk Assessment
RAI - Request for Additional Information
RCS - Reactor Coolant System
SERF - Small Early Release Frequency

SGTR - Steam Generator Tube Rupture
STG - Source Term Group
WBN - Watts Bar Nuclear Plant

2.0 Assumptions

1. The assumed maximum containment leakage for EPRI Class 1 sequences is 1 La (Type A acceptable leakage) because a new Class 3 has been added to account for increased leakage due to Type A inspections.[1, §5.1.2]
2. The assumed maximum containment leakage (small) for Class 3a sequences is 10 La based on the EPRI guidance. [1, 5.1.2]
3. The assumed maximum containment leakage (large) for Class 3b sequences is 100 La based on the EPRI guidance.[1, 5.1.2]
4. Class 3b is conservatively categorized as LERF based on the NEI guidance and previously approved EPRI methodology.[1, §4.2.1.4]
5. Containment leakage due to EPRI Classes 4 and 5 are considered negligible based on the NEI guidance and the previously approved EPRI methodology, and are not evaluated further by this analysis.[1 , Attachment H, §5.1]
6. Conservatively, it is assumed that EPRI Class 8 sequences (ISLOCA, SGTR) are containment bypass sequences; therefore, potential releases are assumed to go directly to the environment.[1 §4.3]
7. A change in the existing 1 test-in-10 years testing frequency to the proposed 1 test-in-15 years frequency assumes a constant failure rate and that the failures are randomly dispersed during the interval between tests. [1 §3.7]
8. It is assumed that a change in CCFP of up to 1.5% is small. This is because NRC has accepted previous submittals with CCFP increase up to 1.1% for one-time extensions of the CILRT testing interval. In context, it is noted that NRC has approved CCFPs of 10% for evolutionary light water reactor designs.[1, §2.2]
9. The interval between ILRTs at the original licensing basis of 3 tests-in-10 years is taken to be 3 years. This value is consistent with the EPRI guidance report. [1 Table 5-11 Step 3]
10. The likelihood of liner flaw growth over the extended period without benefit of visual inspection is estimated to double every five years. This assumption is generic in nature and does not depend on any plant specific inputs and is used in the EPRI guidance.[1 Table 5-1] As such, the doubling of the liner flaw likelihood in the Watts Bar analysis is judged to be reasonable.
11. A total visual inspection failure likelihood of 10% is assumed for that fraction of the liner that is available for visual inspection. This assumption is consistent with the EPRI methodology[2 §5.1.5.1] which reads: “Five percent failure to identify visual flaws plus 5% likelihood that the flaw is not visible (not through the cylinder but could be detected by CILRT). All industry events have been detected through visual inspection. Five percent visual failure detection is a conservative assumption.[1 Table 5-11 Note 5]
12. It is assumed that the likelihood of leakage escape due to crack formation in the basemat region is considered to be ten times less likely than the cylinder or dome regions consistent with the EPRI guidance.[1 Table 5-11 Step 4]
13. The containment basemat liner is assumed to be un-inspectable consistent with the EPRI methodology. [1 Table 5-11 Step 5]

14. Since a larger assumed Containment CILRT pressure yields a worse result in the corrosion sensitivity analysis, an upper bound for containment pressure during an CILRT is used in the analysis. Based on the Containment Integrated Leak Rate test surveillance instruction [17, §5.B.1] the CILRT containment pressure range is 15.0 – 15.6 psig, which corresponds to 29.7 - 30.3 psia. Accordingly, the upper bound pressure selected will be taken to be slightly larger than the 15.6 psig value. This value is considered reasonable because the test range is limited by procedure.[17]
15. Fire events are considered to be the most limiting external hazard due to their frequency of occurrence and their potential impact on plant operation. Therefore, it is assumed that internal fire events bound the risk contribution from 'other' external hazards.

3.0 Ground Rules

The following ground rules are used in this analysis:

1. The technical adequacy of the Watts Bar PRA is consistent with the requirements of R.G. 1.200 and is relevant to the Containment CILRT interval extension. The technical adequacy is based on peer review and resolution of the previously open facts & observations (F&Os). All F&Os that did not meet capability category 2 or better have been resolved and transmitted to the NRC in other License Amendment Requests, e.g., TSTF-425.[45]
2. The Watts Bar Level 1 and Level 2 internal events and seismic PRA models provide representative results.
3. It is appropriate to use the Watts Bar PRA models as a gauge to effectively describe the risk change attributable to the ILRT extension. It is reasonable to assume that the impact from the CILRT extension (with respect to percent increases in population dose) will not substantially differ if fire events were to be included in the calculations.
4. Dose results for the containment failures modeled in the PRA can be characterized by information provided in NUREG/CR-4551.[7,8] They are estimated by scaling the NUREG/CR-4551 results by population differences for Watts Bar compared to the NUREG/CR-4551 reference plant.
5. Accident classes describing radionuclide release end-states are defined consistent with the EPRI methodology[1] and are summarized in Section 6.0 of this calculation.
6. The representative containment leakage for Class 1 sequences is 1 La. Class 3 accounts for increased leakage due to Type A inspection failures.[1 §5.1.2]
7. The representative containment leakage for Class 3a sequences is 10 La based on the previously approved methodology for Indian Point Unit 3.[1 §5.1.2]
8. The representative containment leakage for Class 3b sequences is 100 La based on the guidance provided in EPRI Report 1009325 R2.[1 §5.1.2]
9. The Class 3b can be conservatively categorized as LERF based on previously approved methodology.[1 §4.2.1.4]
10. The impact on population doses from containment bypass scenarios is not altered by the proposed CILRT extension, but is accounted for in the EPRI methodology as a separate entry for comparison purposes. Since the containment bypass contribution to population dose is fixed, i.e., is not affected by the test interval, no changes on the conclusions from this analysis will result from this separate categorization.

11. The reduction in CILRT frequency does not impact the reliability of containment isolation valves to close in response to a containment isolation signal. Therefore, Class 2 impacts remain static.
12. Where possible, this analysis should include a quantitative assessment of the contribution of external events (e.g., fire and seismic) in the risk impact assessment for extended CILRT intervals. For example, where a licensee possesses a quantitative fire analysis and that analysis is of sufficient quality and detail to assess the impact, the methods used to obtain the impact from internal events should be applied for the external event. If the external event analysis is not of sufficient quality or detail to directly apply the methodology provided in NEI 94-01 R3, the quality or detail will be increased or a suitable estimate of the risk impact from the external events should be performed. This assessment can be taken from existing, previously submitted and approved analyses or other alternate method of assessing an order of magnitude estimate for contribution of the external event to the impact of the changes interval.

4.0 PRA Technical Adequacy for Permanently Extending the Containment CILRT

The Tennessee Valley Authority (TVA) maintains both an Internal Events (IE) PRA Model including Internal Flooding (IF), and a Seismic PRA (SPRA) Model for the Watts Bar Nuclear (WBN) Power Plant. The IE PRA model has been developed in accordance with the requirements of RG 1.200 Rev. 2,[11] subjected to Peer Review[35] and the Appendix X[26] F&O Closure process.[36] The Seismic PRA model (SPRA) was developed and subjected to Peer Review[47] against ASME/PRA Standard RA-Sb-2013,[38 §1.2] which is not endorsed by RG 1.200 Rev. 2, and was subjected to the Appendix X F&O Closure process.[48] See Section 4.5.2 of this analysis for applicability. These models are highly detailed, and include a wide variety of modeled systems, operator actions and common cause events. The TVA PRA uses a multi-faceted, structured approach in establishing and maintaining the technical adequacy and fidelity of the PRA models across its nuclear fleet. This approach includes a proceduralized PRA maintenance and update process [28, §3.2.2], as well as independent peer reviews. The IE with IF PRA quantification process is based on a single top fault tree analysis which is a well-known and accepted methodology in the commercial nuclear power plant industry. The IE with IF model is maintained and quantified using the EPRI Risk & Reliability suite of software programs. The SPRA model is quantified using the widely accepted EPRI FRANX methodology.

4.1 PRA Model Fidelity, Realism and Configuration Control

WBN PRA model fidelity, realism and configuration control is governed by TVA Fleet procedure NPG-SPP-09.11, 'Probabilistic Risk Assessment Program'[27 §3.2.2] which:

- defines PRA model configuration control requirements (e.g., changes to the plant design, operational procedures[1], technical specifications, maintenance and testing, etc.)
- defines data collection sources and requirements
- defines roles and responsibilities of interfacing organizations (e.g., system engineering, operations, maintenance rule, etc.)

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[1] Operating procedures include normal operations, emergency operations, off-normal operations, severe accident mitigation guidelines, and others.

4.2 PRA Maintenance and Update

The PRA maintenance and update process is governed by fleet procedures that are applicable to all TVA nuclear units.[28] The TVA risk management process ensures that the applicable PRA models represent the as-built, as-operated plants. Initial models and model upgrades are required to be subjected to independent peer review against the requirements of the ASME/ANS PRA Standard as endorsed by Regulatory Guide 1.200.

The following information describes this approach as it applies to the Watts Bar PRA.

- NEDP-26, “Probabilistic Risk Assessment”[28]
  - defines the process and management of PRA applications, periodic updates, and model maintenance and review,[28 § 2.0 A]
  - for risk-informed applications, such as TSTF-425, the procedure requires the PRA staff to revise the appropriate risk related calculations following model updates, [28, §3.1.1 F]
  - defines PRA Maintenance and PRA Upgrade,[28 §3.2.2 A and B]
  - updates are required on a routine frequency or by the cumulative impact of plant configuration changes that exceed a threshold value, [28 §3.2.2.D]
  - the decision to update the PRA model ahead of a normal scheduled PRA maintenance cycle should be made commensurate with the overall impact to the model, taking into consideration the impact on risk-informed applications and programs that use the results from model quantification, for example, Mitigating System Performance Index (MSPI), On-Line Risk Management, SFCP, and others, [28 §3.2.2 E]
  - defines information sources to review for model updates,[28 §3.2.2 G and H]
  - defines the ‘living model’ evaluation of plant changes for the cumulative affect on the PRA results, [28 §3.2.2 J]
  - PRA model updates are required to be requantified using truncation limits that ensure preservation of model fidelity and to demonstrate convergence for both CDF and LERF. [28 §3.2.3 A]

There are two types of updates to the PRA models,

1) PRA Maintenance - the update of PRA models to reflect plant changes such as plant modifications, changes to operating procedures, or plant performance data. PRA maintenance focuses on ensuring the model accurately reflects the current plant configuration and performance. This includes identification, review, and evaluation of new plant information and the documentation for that information. This is performed at a minimum of once every five years.[28 3.2.2 A]
2) PRA Upgrade - the incorporation into a PRA model of a new methodology or changes in scope of capability that significantly impacts the results of the significant accident progression sequences. [28 §3.2.2 B]

4.3 PRA Model History

The original Watts Bar IE and IF PRA was developed using the RISKMAN platform. In 2009 the PRA model was completely rebuilt using CAFTA.[29 §3.0] All documentation for the Internal Events and Internal Flooding models were upgraded to meet the requirements of RG 1.200 Rev. 2.[29] The model history shown in section 4.3 begins with

CAFTA model rev. 0, which was subjected to peer review (discussed in section 4.4.1). Section 4.3.2, Table 2 IE With IF PRA Model Update Changes provides the major changes associated with each model revision.

4.3.1 Internal Events PRA with Internal Flooding

Table 1 Internal Events Internal Flooding Model CDF and LERF

Model	Date	U1 CDF/yr	U2 CDF/yr	U1 LERF/yr	U2 LERF/yr
Rev. 0[29]	NOV 2010	1.82E-05	1.71E-05	1.64E-06	1.65E-06
Rev. 1[30]	FEB 2014	1.39E-05	1.43E-05	1.12E-06	1.16E-06
Rev. 2[31]	SEP 2016	1.06E-05	1.03E-05	1.44E-06	1.43E-06
Rev. 3[32]	MAR 2017	9.08E-06	8.98E-06	1.01E-06	1.00E-06

4.3.2 Internal Events PRA With Internal Flooding - Model Updates

Table 2 IE With IF PRA Model Update Changes

Model	% Change In CDF [Table 2]	% Change In LERF [Table 2]	Comments
Rev. 1[30]	-23.5 (U1) -26.4 (U2)	-31.7 (U1) -29.7 (U2)	Changes made in the CAFTA Rev. 0 model include:[30 §6.1.1.3] • added components to fault tree modeling to represent the as-built plant • model refinements of component configurations to represent the as-operated plant • revised the HRA dependency approach to retain individual HEPs (human error probabilities) in cutsets • internal flooding flood frequencies were updated to the EPRI-TR-1021086 values
Rev. 2[31]	-23.7 (U1) -28.0 (U2)	28.6 (U1) 23.3 (U2)	Changes made to the CAFTA Rev. 1 model include: [Level 1 31 §6.1.14.1] [Level 2 31 §6.1.14.2] • model changes to reflect component boundaries described in the Data Analysis Notebook • Common Cause Factors (CCFs) updated from Multiple Greek Letter (MGL) to the Alpha Factor Methodology • Test basic events and Maintenance basic events have been merged to a single basic event, Test & Maintenance (TM) • the component cooling system (CCS) model and the support system initiating event (SSIE) model were revised • FLEX diesel generators were added to the model

Model	% Change In CDF [Table 2]	% Change In LERF [Table 2]	Comments
			• MAAP runs were added or revised to represent the as-built, as-operated plant • hydrogen detonation probabilities were updated • the probabilities of small and large pre-existing containment leaks were updated • the probabilities of pressure-induced and temperature-induced steam generator tube ruptures were updated • Level 2 binning was updated to reflect changes to the Plant Damage States (PDS) for each CDF sequence defined in the Accident Sequence Notebook
Rev. 3[32]	-14.3 (U1) -12.8 (U2)	-29.9 (U1) -30.1 (U2)	Changes made to the CAFTA Rev. 2 model include: • AC power modeling was enhanced to represent the as-built plant to crosstie power across the units in the event of a loss of offsite power

4.3.3 Pending Model Updates Affecting IE With IF PRA

The PRA pending model change database for potential model changes has been reviewed and no potential change meets the criteria for a non-scheduled PRA model update, and no pending changes meet the criteria for a model upgrade.

4.3.4 Seismic PRA

Table 3 Seismic PRA Model CDF and LERF

Model	Date	U1 CDF/yr	U2 CDF/yr	U1 LERF/yr	U2 LERF/yr
Rev. 0[49]	FEB 2016	N/A	4.31E-06	N/A	2.21E-06
Rev. 1[50]]	APR 2017	N/A	2.69E-06	N/A	1.53E-06
Rev. 2	May 2017 (U2) Jun 2017 (U1)	2.60E-06[33]	2.61E-06[34]	1.70E-06[33]	1.73E-06[34]

4.3.5 Seismic PRA - Model Updates

Table 4 Seismic PRA Model Update Changes

Model	% Change In CDF	% Change In LERF	Comments
Rev. 1[50]	N/A (U1) -37.6% (U2)	N/A (U1) -30.8% (U2)	- Revision 1 reflects changes made in response to resolving F&Os
Rev. 2[33, 34]	N/A (U1) -3.0% (U2)	N/A (U1) +13.1% (U2)	- Revision 2 reflects changes made as part of the closure review process

4.4 Internal Events (With Flooding) PRA Model and Peer Review

4.4.1 Internal Events With Internal Flooding PRA Peer Review Assessment

The Watts Bar Internal Events with Internal Flooding PRA was subjected to a full scope peer review in November 2009,[35 §1.3] in accordance with the requirements of NEI 05-04[26] "Process for Performing Internal Events PRA Peer Reviews Using the ASME/ANS PRA Standard." [35 §1.1] The review covered all technical elements from the ASME/ANS PRA Standard Parts 2 and 3 plus the configuration control element. [37 §3.0]

Table 5 IE With IF PRA Model Peer Review SR Capability Category Distribution

Capability Category	Number[45 §2.4.3 Table 5]	Per-Cent*
Not Met	26	8.0
I	203	62.3
II	19	5.8
III	34	10.4
I/II	5	1.5
II/III	14	4.3
I/II/III	16	4.9
Not Applicable	9	2.8
TOTAL:	326	100%

*Rounded

The conclusion of the peer review team is as follows:[35 §5.0]

- The overall model structure is robust and well-developed, but needs refinement,
- Documentation is very thorough, detailed and well organized such that comparison with the standard is facilitated,
- The processes and tools utilized for the WBN PRA are at the state of technology and generally consistent with Capability Category II,

- The PRA maintenance and update program includes all necessary processes and does a very good job of tracking changes, and
- The qualitative assessment of sources of modeling uncertainty for the Level 1 model is very comprehensive and well documented to support future applications.

The peer review was performed against the RA-Sa-2009 standard which was endorsed by RG 1.200 Rev. 2.[11 App A] The Peer Review Team stated that 'the Watts Bar PRA meets the ASME/ANS PRA Standard. The PRA has issues which have been documented with Facts and Observations (F&Os).[35 §5.0] A total of 50 finding level F&Os were prepared in this review.

4.4.2 Internal Events With Internal Flooding PRA F&O Closure Results

The 50 finding level F&Os identified by the 2009 peer review team were subjected to a Peer Review Closure process in June 2017 over a four day period at the TVA Chattanooga offices. The review was performed in accordance with the process documented in NEI 05-04 Appendix X, as well as the requirements published in the ASME/ANS PRA Standard (RA-Sa-2009) and Regulatory Guide 1.200 Revision 2.[36 §1.1] A team of three independent PRA experts performed the F&O reviews along with consensus sessions consisting of the entire team.[36] The review met the Appendix X requirement that each F&O review include two qualified reviewers. Furthermore, the team examined the changes made to Watts Bar PRA models, data, and documentation to address the findings to determine if the Capability Category II (or better) requirements of the ANS/ASME PRA Standard, including clarifications imposed by Regulatory Guide 1.200, Revision 2 are met.[36 §1.1]

The Closure Peer Review Team had significant PRA experience, and each team member confirmed they were not TVA employees, had no involvement in development of the WBN PRA or performance of risk applications for WBN, and no conflicts of interests, incentives or disincentives.[36 Tables B-1, B-2]

The F&O closure peer review team concluded that 43 F&Os met the requirements for closure, leaving seven open F&Os, which are discussed in Table 6 of this evaluation. The team determined that none of the PRA updates made to address the F&Os were determined to be PRA upgrades and no new PRA methods were utilized. The closed F&Os fell into the following general categories: [36 §3.0]

- Instances in which minor errors in the fault tree modeling were noted, which were corrected,
- Instances in which changes to common cause basic events were needed to address specific issues,
- Instances in which the PRA documentation did not adequately discuss the details of the PRA models and data, hence, resolution involved adding further documentation details,
- Instances in which the method for modeling human error dependency was changed; however, this change primarily affected only how the recovery rules were applied to adjust for dependencies. Numerically, the results are identical to the previous method; only the process used to assign the dependency adjustments was changed,

- Instances in which specific data or modeling details were missing or incorrect in certain parts of the model, but were determined to be appropriate in other parts of the model,
- Instances in which documentation of sources of modeling uncertainty were not included. While the documentation of these sources of uncertainty are important (particularly for applications), the addition of this documentation (which was reviewed by the finding closure review team) is needed for completeness and does not impact the PRA model itself or the risk results,
- Instances where some of the uncertainty parameters for specific basic events were not included. However, the majority of the events had uncertainty parameters and the uncertainty analysis itself was satisfactorily performed.

TVA evaluated each closed F&O against the endorsed ASME/ANS PRA Standard examples for upgrade versus maintenance criteria.[37 Appendix 1-A.3] This review confirmed the peer review closure team's conclusion that no actions taken to close the F&Os met the criteria of an upgrade.[39]

Table 6 provides the F&Os for the Internal Events Model with Internal Flooding that remain open along with the potential impact on the CILRT extension.

Table 6 Open IE With IF PRA Open F&Os

F&O 1-6	MDN-000-999-2008-0145 [Data Analysis] Section 5.3 documents the Bayesian update process used for WBN. Both mean and EF values are produced for each type code. However, it was noted that uncertainty interval data was not entered into the WSBN2.RR file and that extraneous information from previous versions of the database were being applied to the factor (demands or exposure time) field of the BE table.
Associated (SRs) **DA-D3**	**BASIS FOR SIGNIFICANCE** Incorrect entry of uncertainty intervals in the CAFTA database will result in incorrect output from the UNCERT program. **POSSIBLE RESOLUTION** Review the WSBN2.RR file to ensure appropriate uncertainty interval information is entered for each type code and that the uncertainty interval information in the basic event table is removed where it is not applicable. **PLANT RESPONSE** Uncertainty data was added into the *.rr file of the WBN model. Uncertainty error factors confirmed removal from basic event table where not applicable.
Closure Review	**STATUS** OPEN **BASIS** While most of the entries in the .TC and .RR files contain uncertainty information, there still appear to be some entries [that] miss such information. Uncertainty information is not included in the .RR file for

dependent HEP combinations, recovery sequences (e.g., L2FXSBO01 and XSBO01), failure of RHR legs (e.g., RHRCLA-PB), failure of SI piping (e.g., SICL-PB), common cause combinations generated by the CCF tool (e.g., U0_032_ACAS_CMP_FR_CCF_1_2 and U2_EPS_GA_27_FD_CCF_1_2), and ISLOCA basic events (e.g., U2_62-662RV). Uncertainty information is not included in the TC file for operator actions, HXCPL_CC4A3, SLOCA, and SSBO.

Impact on the CILRT Extension

Quantification of the PRA model uses point estimates for the calculation of CDF and LERF; therefore, uncertainty information as described in the closure review would not cause a change to those results. Although it is recognized that some omissions of uncertainty information for some entries is present, they would not be used in the PRA analyses to support the CILRT extension.

F&O 2-28

MDN-000-999-2008-0144 Appendix F addresses identification of dependencies. The criteria are met since the analysts followed common practice. However, the stated rule for application of a lower limit (1E-05) on the combined HEP was not applied in the Qrecover File.

Associated (SRs)

HR-D5

HR-G7

QU-C1

QU-C2

BASIS FOR SIGNIFICANCE

Some of the combined operator action probabilities are below the threshold specified in the notebook.

POSSIBLE RESOLUTION

Redefine the lower threshold for combined HEPs to a value of 1.0E-06 and ensure the combined HEP values are consistent with this threshold. The basis for the lower limit could be that some of the PSFs are global in nature and apply as a sum rather than a product. For any combinations which are retained with a value lower than the specified threshold, a justification should be provided.

PLANT RESPONSE

Appendix F of MDN-000-999-2008-0144 was moved to the Quantification Notebook (MDN-000-999-2008-0147). Combined HEPs were limited to ≥1E-5 in Appendix F of MDN-000-999-2008-0147 revision 5.

Closure Review

STATUS

OPEN

BASIS

Appendix F states: "In order to satisfy this, the recovery rule file was developed to limit the joint probability of each combination to be no less than 1.0E-05." However, review of dependency recovery file U1_CDF_HRA_DEP_MOR_R3.RECV revealed that not all HEP combinations were replaced with a probability no less than 1E-05. A few examples of combinations with probabilities less than 1.0E-05 still exist: COMBINATION_256_U1C 5.499E-07, COMBINATION_257_U1C

	4.195E-08, etc. These same values are reflected in the summary table of Appendix F.
Impact on the CILRT Extension	The CILRT is not affected by HEPs as the calculation determines the change in LERF, Dose, and CCFP. Additionally, use of the JHEP floor values was shown in a sensitivity study (WBN-1-19-075) to result in no change in the CDF or LERF cutsets. Therefore, the impact on the CILRT application is negligible; however, TVA intends to review the recovery rule file and address the JHEPs lower than the acceptable floor value.
F&O 3-6	Section 5.8 of the Quantification Notebook provides a result of the parametric uncertainty analysis. The analysis does not include the uncertainty parameters for the CCF events and ISLOCA events. In addition, the HRADEP* recovery events found in the recovery files are not treated properly in the parametric uncertainty analysis.
Associated (SRs) **QU-A3** **QU-E3**	**BASIS FOR SIGNIFICANCE** The parametric uncertainty assessment is only a partial assessment. The assessment needs to properly account for the CCF events, ISLOCA events and HRA events in the parametric uncertainty assessment, or provide a State-Of-Knowledge Correlation assessment to show that the results are not impacted significantly. **POSSIBLE RESOLUTION** Either include the CCF events, ISLOCA events and HRA events properly in the parametric uncertainty assessment, or provide a State-Of-Knowledge correlation assessment to show that the results are not impacted significantly. The concern with uncertainty assessment of the CCF events is that uncertainty parameters are not defined for the MGL factors. Therefore, the uncertainty analysis only propagates the uncertainty parameters of the independent failures to the CCF events. Consideration should be given to adopting the Alpha method (which does allow definition of uncertainty parameters for each factor) or performance of additional sensitivity analysis to assess the correlated uncertainty of the CCF *events.* **PLANT RESPONSE** The uncertainty analysis is documented in MDN-000-999-2009-0162. ISLOCA uncertainty is discussed in section 5.4.2.6, CCF uncertainty is discussed in Section 5.8, and HRA uncertainty is discussed in section 5.7.
Closure Review	**STATUS** OPEN

	BASIS Discussion of sources of modeling uncertainty for ISLOCA, CCF, and HEP dependent events are included in the current version of the Uncertainty and Sensitivity notebook (MDN-000-999-2009-0162). However, this F&O and the associated SRs pertain to parametric uncertainty. The Uncertainty and Sensitivity notebook specifically notes that the state of knowledge correlation was not applied in the ISLOCA calculation of valve failure probabilities (as required by QUA3). It does not appear that the items identified in this F&O have been addressed. Therefore, this F&O remains open.
Impact on the CILRT Extension	This circumstances of this F&O does not affect the CILRT evaluation as the parameters in question do not affect the delta risk calculated in support of the extension.
F&O 5-8	The operator action failure probabilities considered in the LERF analysis were not correctly estimated. After core damage, the operation steps in the SAMGs would be much different from the steps in the EOPs before core damage.
Associated (SRs) **LE-C2** **LE-C7** **LE-C9** **LE-E1**	**BASIS FOR SIGNIFICANCE** HAPRZ is a key operator action to prevent high pressure accident scenarios. HAPRZ was estimated to be 4.4E-04 while a similar operator action for the level 1 analysis, HAOB1, was estimated to be 1.6E-02. **POSSIBLE RESOLUTION** Describe more specifically how the HEP for action HAPRZ was calculated and how the calculation accounted for conditions after core damage. **PLANT RESPONSE** No changes were made. The F&O comments particularly focused on event HAPRZ and its' HEP relative to event HAOB1. The action HAPRZ is an in-control room action that assumes that the execution stress is 'high' as does action HAOB1. The control room conditions would not be different post-core damage versus pre-core damage (lighting, heat, humidity, radiation and atmosphere). These are not expected to change in EOIs versus SAMG scenarios. The actions associated with HAPRZ are not complex, consisting of opening all pressurizer PORVs and block valves. As to the comparison between HAOB1 and HAPRZ, the system time window (Tsw) and the time available for recovery is shorter for HAOB1 (30 minutes and 12.5 minutes, respectively) than for HAPRZ (1.4 hours and 73 minutes, respectively). The execution steps to perform HAPRZ are not as involved as those required to perform HAOB1 leading to a smaller execution error probability for HAPRZ.

Closure Review	**Status** OPEN **BASIS** Based on actions taken, SR LE-C9 may be considered to be MET at capability category II-III; SR LE-C2 remains met at Cat I because there are several examples of Operator Actions following the onset of core damage that were treated conservatively and not updated to address the F&O (e.g., operator actions to recover equipment were not specifically considered, actions to 'blind' feed the steam generators were not credited, and manual actuation of the nitrogen backup system were not credited). As a result, F&O 5-8 cannot be considered closed.
Impact on the CILRT Extension	This finding addressed over-conservatisms with respect to operator actions that are not credited following the onset of core damage. The CILRT extension risk metrics focus on the delta risk of an additional five year window of containment corrosion, therefore, the absence of the non-credited operator actions is not expected to have an appreciable impact on the delta LERF or population dose. It would be expected to have no impact on the conditional containment failure probability.
F&O 7-10	The analysis in Section 5.4.1 [Internal Flooding Notebook] includes an assessment that evaluates existing human actions. From a cursory review, the main impact seems to be an exclusion of non-MCR actions given a flood event. There appears to be little if any adjustment to the other actions that are performed in the MCR.
Associated (SRs) **IFQU-A6**	**BASIS FOR SIGNIFICANCE** The information in Table 5-15 lists the existing operator actions and defines an impact. No changes are listed for MCR events and those not in the MCR are typically considered to be infeasible. The text indicates that "All actions solely performed from the Main Control Room (MCR) are also expected not to be physically impacted by the flood event." This seems to be in contrast to the SR requirement to adjust PSFs to address additional stress and the work environment following a flood event. This is particularly of interest for events that could include damaged systems such as starting a CCP (HACV2) which could increase flooding rates or results in failure of standby equipment.
	POSSIBLE RESOLUTION Develop a more detailed assessment of why no change would be anticipated for actions or perform a PSF evaluation concentrating on those events that could compound the event (fail equipment due to lack of cooling for instance). **PLANT RESPONSE** MCR actions were considered; generally these were determined not to require changes. Factors such as stress, cues, effect of flood on

Closure Review	response timing etc., were considered and discussed in Section 5.4.1. Scenario specific information was also considered. The detailed assessment provides information why no change is required for some actions, and why other actions are changed. (see Table 5-12 and 5-13). **STATUS** OPEN **BASIS** Confirmed that the discussion in Section 5.4.1 provides the information identified in the F&O response, however, no impacts of these actions were able to be identified. It is noted that the justifications for MCR actions all identify EPRI Guidance items 3.4 & 4.3 as the basis for making no changes to MCR HEPs; however, both items 3.4 & 4.3 state they only apply to HFEs for which there is more than one hour available for the operator action. The MCR actions listed in the table vary from 10 min. to 14.4 hr. For actions that have greater than 1 hour for response or are only in response to IEs that cannot be caused by a flood initiator, items 3.4 & 4.3 are valid justification for no change to the HEP. For the HEPs that are required in less than 1 hour and required to respond to a flood initiator, items 3.4 & 4.3 are not valid and, in these cases, items 4.1 & 4.2 should apply and these require consideration of an increased stress level to account for flood stress levels and consideration of an increased median response time to account for the flood effects, e.g., higher stress and flood distractions. Based on the current documentation, it is not possible to determine whether/how these latter effects were considered to reach the conclusion that there are no numerical effects on the MCR HEPs that are required for a flood initiators in less than 1 hour. As a result, the actions implied by the F&O resolution response cannot be confirmed for these HEPs and the F&O remains open.
Impact on the CILRT Extension	This finding addresses a documentation issue that does not support review in a manner to determine, or to confirm the conclusion of 'no numerical effects.' The CILRT extension analysis is not affected by the issue discussed in this finding because the analysis determines the change in risk for a longer test interval. In addition, it was shown that there is a negligible impact of a flood event on those HFEs which would require less than an hour to either diagnose or perform is presented in the response to RAI APLA-04 in CNL-19-035.
F&O 7-21	The range factors are developed for the flood initiating events, however there is no propagation through the model.
Associated (SRs) **IFEV-B3**	**BASIS FOR SIGNIFICANCE** The current analysis does include uncertainty estimates for the flood initiating events. However, the impact and resultant uncertainty associated with combining the different flooding sources, each with an associated range factor, with regard to the overall study uncertainty is not addressed. Additionally, the sensitivity of assumptions related to propagation and flow rates with regard to consequential failures should

be addressed to ensure that the impact of such simplifications on the overall results are known.

Associated (SRs) IFEV-B3

BASIS FOR SIGNIFICANCE

The current analysis does include uncertainty estimates for the flood initiating events. However, the impact and resultant uncertainty associated with combining the different flooding sources, each with an associated range factor, with regard to the overall study uncertainty is not addressed. Additionally, the sensitivity of assumptions related to propagation and flow rates with regard to consequential failures should be addressed to ensure that the impact of such simplifications on the overall results are known.

POSSIBLE RESOLUTION

Perform a statistical uncertainty assessment for the results and provide additional sensitivity studies assuming various combinations of assumptions related to initiating event grouping and consequences.

PLANT RESPONSE

The current internal flooding notebook includes the parametric uncertainty values developed for the initiating events. The CAFTA basic event database also includes uncertainty parameters for the flooding initiators.

STATUS

OPEN

Closure Review

BASIS

The flooding initiating basic events contained in the current CAFTA .rr file include the error factors and distribution information. The values shown are consistent with the error factors noted in Table 5-16 of the internal flooding notebook. However, it appears that pipes of multiple sizes (and possibly piping from various systems) were lumped together into a single initiating event. It is not clear from the documentation how the selected error factor was calculated in cases where different error factors are shown for various pipe sizes.

SR IFQU-A7 states: "PERFORM internal flood-induced accident sequence quantification in accordance with the requirements described in 2-2.7 as applicable to flood-induced accident sequences." Section 2-2.7 dictates how quantification is to be performed for internal events and includes SR QU-E3 which requires parametric uncertainty be performed. While the WBN IF logic was included in the parametric uncertainty analysis using UNCERT, the absence of error factors for many of the basic events (see F&O 3-6) tends to nullify the validity of the analysis.

Impact on the CILRT Extension

This finding addresses a documentation issue that does not support review of how the selected error factor was calculated in certain cases. The CILRT analysis extending the test interval is not affected by the issue discussed in this finding because the CILRT evaluation determines the change in risk for a longer window of vulnerability. In addition, the response to RAI APLA-05 in CNL-19-035 demonstrates that the impact of the missing error factors does not result in a significant change to the results.

F&O 7-22

The secondary side isolation of a ruptured SG was modeled in the SGTR event tree (top event SL). After core damage, there was no consideration of the secondary side isolation capability in the accident progression sequences.

Associated (SRs)
LE-D5

BASIS FOR SIGNIFICANCE

A cycling SRV allows for the SG to be maintained at a higher pressure which tends to increase holdup time prior to release to the environment and to reduce the rate of release such that the overall source term is lower than for cases with a stuck open SG SRV on the faulted steam generator. Prior analyses have indicated that the resulting reduction is sufficient to reduce the source term from large to small.

Associated (SRs)
LE-D5

POSSIBLE RESOLUTION

The analysis of the SGTR sequences should include credit not only for the ability to maintain covered tubes, but also the impact of the SG SRV cycling instead of failing open. This would provide a sizeable reduction in the release and may result in the reclassification of some LERF sequences to SERF.

PLANT RESPONSE

The SR LE-C4 was considered met Cat II for this element. This action is considered to be an enhancement. Current sequences which may not result in LERF may currently be counted as LERF, possibly resulting in conservative results. Assumption 30 from rev. 5 of the level 2 notebook addresses F&O 7-20 and F&O 7-22: "After core damage, there is no consideration of the secondary side isolation capability in the accident progression sequences.

A cycling SRV allows for the SG to be maintained at a higher pressure which tends to increase holdup time prior to release to the environment and to reduce the Level 2 analysis assumes that all core damage sequences that have feedwater available will result in a small early release. However, a review of the core damage cutsets indicates that the dominant SGTR sequences are due to failure of long term heat removal, which would actually probably all be late releases. The accident binning conservatively bins all SGTR sequences to either small early or large early releases, possibly resulting in conservative results."

	Furthermore, as noted in the response to RAI-08.b.i[51 the intent of this F&O is to question why secondary side isolation was not credited in the LERF analysis. In order to assess the potential for masking SSC risk ranking, a sensitivity study was performed that applied a 0.1 recovery factor to the applicable SGTR sequences to evaluate the impact to LERF. It was determined that this sensitivity study resulted in no change to the LERF cutsets, meaning the importance measures were not affected.
Closure Review	**STATUS** OPEN **BASIS** Confirmed that Level 2 NB includes an assumption that there is no consideration of secondary side isolation capability, even though it is recognized that there is likely source term reduction if SG PORVs / MSSVs are cycling vs stuck-open. Addition of this assumption has no impact on the level of realism used to model secondary side isolation for SGTR sequences, so SR LE-D5 remains MET at Cat I and the F&O resolution is considered to be not closed.
Impact on the CILRT Extension	This finding addresses a conservatism with respect to not crediting secondary side isolation capability. The CILRT analysis for extending the CILRT interval is not affected by the issue discussed in this finding because the evaluation determines the change in risk for the longer window of vulnerability of containment liner corrosion. The change in risk associated with this finding is shown in the response to RAI 8b.i in CNL-19-069 is shown to have a negligible impact to the PRA results. Therefore there is no impact of modeling the aforementioned secondary containment isolation capability.

Closure Review Documentation[36 App A]
F&O Documentation[35 App. C.1]

4.4.3 Pending Model Updates Affecting IE With IF Modeling

TVA Fleet procedure, “Conduct of Probabilistic Risk Assessment Engineering”[40] prescribes the process to ensure the PRA models represent the as-built, as-operated plant configurations in support of integrated decisionmaking and maintaining a high sensitivity for reactor safety in all activities, actions and responses. The requirement for both permanent and temporary changes to the plant design or operation is assessed [40 §3.2.1] by PRA Engineers that monitor changes to the plant design and operating procedures for impact on the PRA model. The PRA Engineer is responsible for ensuring that design changes that impact the PRA model are appropriately incorporated into the PRA model.[40 §3.2.9] Changes in PRA inputs or discovery of new information are required to be evaluated to determine whether such information warrants PRA update (including the cumulative effect of all previously evaluated model changes that are yet to be included in the MOR). Changes causing CDF or LERF to exceed ± 25% requires an off-cycle model update.[28 §3.2.2]

4.5 Seismic PRA Model and Peer Review

4.5.1 Seismic PRA Model and Peer Review

The 2016 Watts Bar Seismic PRA (SPRA) peer review was performed in accordance with NEI 12-13 “External Hazards PRA Peer Review Process Guidelines,”[46 §1.1] The scope of the peer review included all technical elements in Part 5 [Requirements for Seismic Events At-Power PRA] of the ASME/ANS RA-Sb-2013 PRA Standard, “Addenda to ASME/ANS RA-S-2008 Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications.” See 4.5.2 for discussion on the acceptability of using PRA Standard Addendum B.

Part 5 of Addendum b of the PRA standard is referenced in the Electric Power Research Institute (EPRI) report, “Screening, Periodization and Implementations Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic” which the NRC has endorsed as “one acceptable method for responding to the information requested in Enclosure 1 of the 50.54(f) letter” pertaining to Post-Fukushima Near Term Task Force (NTTF) Recommendation 2.1 on seismic re-evaluation.[22 §1.2]

A diverse team of eight experts converged at the TVA offices the week of March 14, 2016. In accordance with the requirement of independence (section 1-6 2.2 of the ASME/ANS PRA Standard), each expert certified they did not participate in the development or participation of any portion of the Watts Bar SPRA that they reviewed. Furthermore, each expert confirmed the Peer Review report reflects the process used by the team, and the element grading, facts, observations and conclusions as agreed to by the review team in its consensus discussions during the review.[48 §1.1] The distribution of F&Os with respect to Capability Category is presented below.

Table 7 SPRA Model Peer Review SR Capability Category Distribution
[47 Table 4-1]

Capability Category	Number[48 Table 4-1]	Per-Cent*
Not Met	10	12%
I	2 (U1) 1 (U2)	2% (U1) 1% (U2)
II to CC-III	18 (U1) 19 (U2)	21% (U1) 22% (U2)
I/II/III	51	59%
Not Applicable	5	6%
TOTAL:	86	100%

*Rounded

As noted in letter CNL-19-035[44] For the WBN TSTF-425 submittal RAI responses, the staff's May 1, 2017 letter providing comments on the F&O Independent Assessment is addressed in Table 1 of the response to RAI ALPB-01.

Furthermore, TVA letter to NRC, CNL-19-035[44] With TVA's RAI ALPB-01 response, on the NRC staff letter from March 7, 2018 on NEI guidance 12-13 with respect to comments on external hazards PRA peer Review process are addressed in Table 1 of the response to RAI ALPB-01.

The conclusion of the peer review was that, in general, the data, methodologies and seismic risk models used for WBN Units 1 & 2 were appropriate and sufficient to meet the majority of the ASME/ANS PRA Standard requirements. All but ten supporting requirements were met. A total of 74 findings were identified by the review team. Based on this peer review, the team concluded the SPRA is judged to be essentially consistent with the PRA Standard and can be used for risk-informed applications. Furthermore, the team stated that the technical adequacy of the WBN SPRA is very good.[48 §5]

4.5.2 Acceptability of Peer Review Against the 2013 Non-Endorsed PRA Standard

RG 1.200, Revision 2 endorses ASME/ANS RA-Sa-2009 (Addendum A) but, as noted in an NRC letter (ML111720067) to ASME, NRC does not endorse PRA Standard ASME/ANS RA-Sb-2013 (Addendum B). As noted in Section 2.5.1 of the WBN License Amendment Request (LAR) to adopt TSTF-425,[45] the SPRA model was subjected to a peer review against the Part 5 (Seismic) supporting requirements of the non-endorsed ASME/ANS RA-Sb-2013 PRA Standard. The SPRA peer review was performed in accordance with NEI 12-13, "External Hazards PRA Peer Review Process Guidelines." No exceptions to use of NEI 12-13 were noted in the peer review report.

As noted in TVA letter CNL-19-035 to NRC which provides the responses to the TSTF-425 PRA application RAIs, the differences between PRA Standard Addendum A and Addendum B are discussed in terms of how the supporting requirements in Addendum B are consistent with the endorsed standard for this application. Where the different criteria are not consistent with the endorsed standard, discussion is provided on how the analogous Addendum A supporting requirements have been met. This information is documented in Table 1 of the response to RAI APLB-02, TVA letter CNL-19-035.[44] Table 1 provides supplemental information to the Vogtle letter for Addendum A supporting requirements not addressed by Addendum B.

4.5.3 Seismic PRA F&O Closure Review

The WBN SPRA Finding Level F&O Technical Review was performed at the Jensen-Hughes offices from April 10 - 13, 2017. The purpose of the review was to perform an independent assessment to review TVA's close out of 'Finding' level F&Os of record from the WBN SPRA peer review against the ASME/ANS PRA Standard, Addenda B. The technical review team consisted of six team members and a dedicated team lead, all of which have extensive qualifications and many years of experience in the pertinent areas of SPRA and peer review. The review met the Appendix X[46] requirement that each F&O review include two qualified reviewers.[48 §2.2.2] All reviewers met the criteria specified NEI 12-13 and the ASME/ANS RA-SA-2009 PRA Standard Section 1-6.2, including independence. [48 §Executive Summary]

The review process was based on the previously completed SPRA peer review. The closure review is intended to support WBN License Amendment Requests (LAR) submittals and other regulatory interactions. Finding level F&O dispositions reviewed and determined to have been adequately addressed through the closure review are considered 'closed; and no longer relevant to the current PRA model, and, therefore, do not need to be carried forward nor discussed in the CILRT LAR submittal.[48 §Executive Summary]

The F&O closure team reviewed the 74 'finding' level F&Os from the SPRA Peer Review and determined that all but one were judged to be resolved, and therefore, closed. The one remaining 'finding' level F&O was technically partially resolved and is discussed in section 4.5.4 for applicability to the proposed risk-informed CILRT application. [48 §Executive Summary]

4.5.4 Applicability of Seismic Open Peer Review Findings (F&O)

According to the Peer Review Closure Team only one F&O, SHA 20-5 remains open.[48 §4.0] The F&O is characterized as 'Technically Resolved;' however, remains open due to documentation. [48, Appendix B]

Table 8 Open Seismic PRA Open F&O

F&O 20-5 **[48, Appendix B]**	Analyses have been performed that indicate that in numerous scenarios involving the seismic-induced failure of earthen and concrete dams upstream of WBN, the resulting flood evaluation at WBN does not exceed 728 ft. However, these analyses are not adequately summarized in the SPRA documentation.
Associated (SRs) **SHA-I1**	**BASIS FOR SIGNIFICANCE** The document entitled "Position Paper on Other Seismic Hazards, Watts Bar Nuclear Plant Unit 2" describes the potential for flooding at WBN due to seismic-induced dam failures upstream of the plant and cites the FSAR as the source of the supporting analyses. The analyses in the FSAR are obsolete and have been replaced by a more comprehensive set of analyses based on current information for seismic hazard, dam stability, and flood routing (Calculation DQ0000002014000024). These newer analyses indicate that in all but the most conservative (and unlikely) scenario, the resulting flood will be less than 728 ft (i.e., plant grade). For the one scenario that yields a flood evaluation above 728 ft, the plant has approximately 30 hours to initiate the appropriate response.
	POSSIBLE RESOLUTION A summary of the recent analyses regarding seismic-induced dam failure should be incorporated into the seismic hazard documentation.
	PLANT RESPONSE A summary of the recent analyses regarding seismic-induced dam failure has been incorporated into CDN000002015000739, Revision 1, Appendix III. [Seismic Induced Dam Failure and Flooding]

Closure Review	**STATUS** Technically Resolved - Open Documentation
	BASIS A revised version of Appendix III [Seismic Induced Dam Failure and Flooding] summarizes the methodology and results of the analyses used to evaluate the potential for flooding at WBN due to the potential seismic failure of upstream dams. The analyses summarized in Appendix III indicate that one scenario (involving the failure of multiple dams upstream of WBN as a result of ground motions equal to ½ of 10^{-4} AFE coincident with a 500-yr flood) results in a flood that exceeds plant grade (728 ft). For this scenario, Appendix III notes that several conservative assumptions were made regarding the timing of the failure of the immediate upstream dam (Watts Bar) and the assumed stability of the downstream dam (Chickamauga Dam). Appendix III also points out that flood protection for the plant is provided to elevation 738.9 feet and that procedures are in place to respond to a flood warning within 27 hours. For the scenario that exceeds plant grade, over 30 hours warning is available. Finally, Appendix III also provides results that indicate if more realistic, less conservative assumptions were made for the scenario that exceeds plant grade, the resulting flood elevation is reduced by nearly 7 feet to elevation 723 feet (5 feet below plant grade). The preponderance of evidence provided in Appendix III and in supporting documentation supports a conclusion that failure of upstream dams during a seismic event is unlikely to lead to flooding that could not be mitigated at the plant and thus can be screened out as a potential seismic hazard. However, the case that is made does not systematically recognize, discuss and address the potential sources of uncertainty in the dam breach process, in the estimation of flooding levels and thus does not present a complete case for screening out this hazard based on the results of the analyses.
	SUGGESTION 1. State clearly the criterion that will be used to screen out seismic induced dam failures. 2. Identify the elevation that will be used to define the plant flood capacity; discuss what plant grade is and what the flood protection level of the plant is. Also discuss what you will use as the basis for the screening analysis and why. 3. Identify the governing dam failure events (combinations) that will be considered in the analysis and the basis for their selection. 4. Systematically identify and describe the sources of aleatory and epistemic uncertainty in the analysis, with particular emphasis on those that will impact the estimate of peak flood elevations at the plant. 5. Ideally, a realistic/best estimate analysis of dam failures would be carried out. Note, the analysis that was presented does not seem

	(though the reviewers are not 100% sure) to be a realistic best estimate analysis. A best estimate would have realistic consideration of the breach characteristics of a dam, realistic timing of dam failures, etc. 6. Identify and evaluate how different sources of aleatory uncertainty could impact the results (possibly estimating the size of these uncertainties). 7. Identify and evaluate how different sources of epistemic uncertainty could impact the results and how these are addressed.
Impact on the CILRT Extension	The F&O Closure Peer Review Team concluded that the issue associated with F&O 20-5 has been technically resolved and pertains only to a suggestion for documentation enhancements. As such, there is no change that the proposed suggestions to the SPRA CDF or LERF. With no change to CDF or LERF, there is no impact on the PRA assessment of evaluating the impact of the CILRT extension.

4.5.5 Pending Model Updates Affecting Seismic PRA

The PRA pending model change database for potential model changes has been reviewed and no potential change meets the criteria for a non-schedule SPRA model update, and no pending changes meet the criteria for a model upgrade.

4.6 Treatment of Non-Modeled Hazards (Internal Fire)

4.6.1 Internal Fires

4.6.1.1 Unit 1 Fire Induced Vulnerability Evaluation (FIVE)

WBN performed a Fire Induced Vulnerability Evaluation (FIVE) in accordance with EPRI TR-100370. This methodology consisted of a progressive screening approach based on quantifying the following:[16 §1.3]

- Fire ignition frequency for specific plant areas
- Availability of automatic suppression systems
- Availability of redundant/alternate safe shutdown systems
- Zone of Influence (ZOI) of ignition sources
- Detailed evaluation of safe shutdown components and their availability

The screening was conducted in 3 phases:

- Fire Area Screening (Qualitative Analysis)
- Critical fire Compartment Screening (Quantitative Analysis)
- Plant Walkdown / Verification and Documentation

The Internal Fire analysis did not uncover any serious fire vulnerabilities and no plant modifications were recommended as a result of the study. In keeping with the requirements of Supplement 4 to Generic Letter 88-20 (NUREG-1407) and the guidance provided by the EPRI FIVE (TR-100370) documentation, this evaluation confirmed that there were no fire-induced vulnerabilities associated with the continued operation of Watts Bar Nuclear plant.[16 §1.4.2]

4.6.1.2 Unit 2 Fire Induced Vulnerability Evaluation (FIVE)

The Unit-2 assessment of fire hazards is an extension of, and used a methodology consistent with, the evaluation performed for Unit-1.[20 §4]

4.7 Treatment of Non-Modeled Hazards (High Winds, External Flooding and Other)

WBN performed the screening described in Supplement 4 to Generic Letter 88-20, and NUREG-1407. Because WBN was designed prior to the 1975 Standard Review Plan (SRP), the approach included review of the design bases and compared them to the 1975 SRP requirements. [16, 25 §1.3] The IPEEE was a one-time review of external hazard risk and was limited in its purpose to the identification of potential plant vulnerabilities and the understanding of associated severe accident risks.

The IPEEE evaluation revealed that the plant meets the 1975 SRP criteria for ‘other’ external hazards and only one recommendation was issued by the team.[25 §1.4.3] The issue was documented and dispositioned by the Corrective Action Program (CAP).[41]

In addition to extreme winds and tornadoes, external flooding including intense local precipitation and transportation and nearby industrial facilities were evaluated,[25 §8.3] and documented in Attachment 5 of the Unit 1 IPEEE. Selection of external events for the IPEEE and the technical approach recommended for evaluation of such external events are discussed in Section 2 and Section 5 of NUREG-1477, respectively. The recommendation was based on those external initiators that have the potential of initiating an accident that may lead to severe reactor core damage or large radioactive release to the environment. The external events required to be evaluated by NRC in the IPEEE response include:[25 Att 5]

- Seismic (replaced by the Seismic PRA)
- Internal Fires
- High Winds and Tornadoes
- External Floods
- Transportation and Nearby Facility Accidents

A review was performed of the external events described in NUREG-1407 and other external events further required each licensee to confirm that no plant-unique external events are excluded from the WBN IPEEE. [25 §5.2]

Table 9 External Hazards IPEEE and Current Applicability

Event	WBN IPEEE Applicability	Current Applicability
Seismic	A modified site specific program was used in the IPEEE. [25 Table 3-1]	Replaced by the Seismic PRA Model

Internal Fires	The EPRI Fire Induced Vulnerability Evaluation (FIVE) approach was used in the WBN IPEEE. It was confirmed that there are no fire-induced vulnerabilities associated with continued operation of WBN[25 Att 4 §6]	The conclusions if the IPEEE FIVE analysis remain valid. Subsequent to the FIVE analysis additional modifications have been made to the plant including fire wrap, cable tray covers, refined fire response procedures, etc.; therefore, the as-built as-operated plant is considered more robust with respect to impacts from internal fires as compared to the plant evaluated in the IPEEE FIVE analysis.
High Winds, Tornadoes	CAT I structures have been designed to resist tornado wind and missile effects equivalent to the 1975 SRP criteria. SSCs important to safety were designed to withstand the design basis tornado and remain functional. There are no unique vulnerabilities for high winds. [25 Att 5 §5.5.3]	The basis for screening High Winds and Tornadoes, remains applicable to the current plant design. 0-AOI-8 provides instruction for actions to be taken in the event of a Tornado Watch or a Tornado Warning issued for Rhea or Meigs County. These actions further mitigate the potential consequences of a tornado event.
External Floods	Design meets the NRC regulatory position 2 of RG 1.59. The new PMP (Probable Maximum Precipitation) criteria was evaluated and WBN was designed to withstand this flood and prevents water from entering safety-related structures.[25 Att 5 §5.6.4]	External flooding due to upstream dam failures and maximum potential precipitation has been re-evaluated since the analysis performed for the IPEEE. Furthermore, enhancements have been made to the upstream dam and other plant modifications to limit the impact on the plant due to external floods.
Transportation and Nearby Facility Accidents	The impact of potential transportation and nearby facility accidents were evaluated and concluded that their contribution to plant risk is negligible. [25 Att 5 §5.7.3]	There are no significant industrial facilities near WBN. The nearest land transportation is State Route 68 about one-mile north of the plant. The nearest main railroad line is about seven miles from the plant. No other significant industrial land use, military facilities, or transportation routes are in the

		vicinity of WBN.[USFAR §2.2.1] An evaluation of potential accidents concluded that no activities are being performed in the vicinity of the plant that could be considered hazardous to the plant. A study of products and materials transported past the site by rail or barge indicates that no potential explosion hazard exists. Postulated accidents resulting in fire or dense smoke will no effect plant safety.[42 §2.2.3]
Other External Hazards	All external other external hazards have been screened based on generic data (e.g., Lightning), site location (e.g., Volcanic Activity), generic bases (e.g., Extraterrestrial Activity), low probability of occurrence (e.g., Turbine Missiles). [25 Table 3-1]	Other external hazards are judged to remain screened based on the same criteria used for screening by the IPEEE.

4.8 Treatment of Non-Modeled Hazards (Shutdown Events)

Shutdown events are not applicable to the CILRT interval extension as events postulated under shutdown operations are not affected by the CILRT, regardless of frequency. Shutdown events do not affect the metrics associated with the CILRT interval extension.

4.9 Treatment of FLEX Equipment in the PRA

4.9.1 Methodology to Assess Failure Probabilities of FLEX Equipment[54]

The Internal events and seismic PRA models credit the permanently installed FLEX Emergency Diesel Generators (EDGs). Use of these EDGs was modeled similarly to other internal event PRA components, including development of fragilities, data, and operator actions.

WBN does not include portable FLEX equipment in the PRA models. WBN includes the permanently installed FLEX Diesel Generators within the PRA model and supporting components including fuel tank, alignment of breakers, buses, and operator actions to align the FLEX Diesel Generators. The failure probabilities for the equipment was assumed to be the same as other components of the same type already included within the model (e.g. the FLEX diesels have the same failure probabilities as the Emergency Diesel Generators).

The NRC memorandum dated May 30, 2017, "Assessment of the Nuclear Energy Institute 16-06, 'Crediting Mitigating Strategies in Risk-Informed Decision Making,' Guidance for Risk-Informed Changes to Plants Licensing Basis" (ADAMS Accession No. ML17031A269), is generally focused on portable FLEX equipment. In regard to data analysis it states the following:

> ASME/ANS PRA Standard Capability Category II (CC-II) for supporting requirement (SR) DA-D1 states that "realistic parameter estimates for significant basic events should be calculated 'based on relevant generic and plant-specific evidence unless it is justified that there are adequate plant-specific data to characterize the parameter value and its uncertainty'." Parameter estimates for the remaining events should be calculated by using generic industry data. Supporting Requirement DA-D2 states that "if neither plant-specific data nor generic parameter estimates are available for the parameter associated with a specific basic event, USE data or estimates for the most similar equipment available, adjusting if necessary to account for differences. Alternatively, USE expert judgment and document the rationale behind the choice of parameter values."

The WBN internal events and seismic PRA models have followed the guidance of the ASME/ANS PRA standard in crediting the permanently installed FLEX DGs. In addition, the FLEX DGs are an uncertainty identified in the PRA model and are subjected to a sensitivity analysis when applicable for the STI extension under consideration.

4.9.2 HRA Approach for FLEX Strategies[54]

WBN used the HRA Calculator to address the human performance shaping factors for each of the FLEX Human Error Probabilities (HEPs). Each type of Diesel Generator has a separate HEP, as the method to start and align the diesels are different. Both of these HEPs were developed in accordance with the corresponding technical elements in the NRC endorsed ASME/ANS PRA Standard.

WBN has procedures governing the initiation into mitigating strategies for use of the permanently installed FLEX diesel generators. The procedures are explicit in what steps must be performed for these actions which are modeled in the PRA in a similar fashion as other human failure events (HFEs)..

4.10 PRA Assessment of Proposed CILRT Interval Extension Methodology

The TVA process for analyzing the proposed extension of the CILRT interval follows the endorsed NEI 94-01 guideline.[3]

4.10.1 Key PRA Attributes

The evaluation allows for a blended approach to assessing the change in risk associated with a change to the CILRT interval extension. This includes approved probabilistic risk models as well as non-PRA methodologies (e.g., FIVE).

Hazards to be evaluated

- Internal Events at Full Power (which includes internal flooding)
- Internal Fire Events
- Seismic Events
- Other External Hazards (e.g., high winds, flooding, etc.)
- Shutdown Events

4.10.2 I

4.11 General Conclusion Regarding PRA Capability

The Watts Bar PRA maintenance and update process and technical capability evaluations (Peer Reviews) described above provide a robust basis for concluding that the PRA is suitable for use in risk-informed licensing actions, including the CILRT interval extension.

4.12 Regulatory Guide 1.174, Revision 3 Defense-In-Depth Evaluation

Regulatory Guide 1.174, Revision 3 (Reference 12), describes an approach that is acceptable for developing risk-informed applications for a licensing basis change that considers engineering issues and applies risk insights. One of the considerations included in Regulatory Guide 1.174, Revision 3, is defense-in-depth. Defense-in-depth is a safety philosophy that employs successive compensatory measures to prevent accidents or mitigate damage if a malfunction, accident, or naturally caused event occurs at a nuclear facility.

The seven considerations presented in Regulatory Guide 1.174, Revision 3, Section 2 1 1 2, "Considerations for Evaluating the Impact of the Proposed Licensing Basis Change on Defense in Depth," are used to evaluate the proposed licensing basis change for overall impact on defense-in-depth. Each of the seven considerations are presented below with a PRA response provided.
Current Technical Specification 5 5 15 indicates that for Type C tests the containment leakage rate testing program shall be in accordance with the guidelines contained in NEI 94-01, Revision 3-A NEI 94-01, Revision 3-A, guidelines allow extension of the containment Type C test interval up to 75 months, based on acceptable performance. The impact of Type C testing in accordance with NEI 94-01, Revision 3-A, was considered in the following defense-in-depth evaluation.

1. Preserve a reasonable balance among the layers of defense

A reasonable balance of the layers of defense (that is, minimizing challenges to the plant, preventing any events from progressing to core damage, containing the radioactive source term, and emergency preparedness) helps to ensure an apportionment of the plant's capabilities between limiting disturbances to the plant and mitigating their consequences. The term "reasonable balance" is not meant to imply an equal apportionment of capabilities. The NRC recognizes that aspects of a plant's design or operation might cause one or more of the layers of defense to be adversely affected. For these situations, the balance between the other layers of defense becomes especially important when evaluating the impact of the proposed licensing basis change and its effect on defense-in-depth.

PRA Response

The usage of the risk metrics of large early release frequency (LERF), population dose, and conditional containment failure probability (CCFP) collectively ensures the balance between prevention of core damage, prevention of containment failure, and consequence mitigation is preserved The change in large early release frequency is small per Regulatory Guide 1 17 4, and the change in population dose and conditional containment failure probability are small as defined in Attachment B of this submittal and consistent with NEI 94-01, Revision 3-A.

2. Preserve adequate capability of design features without an overreliance on programmatic activities as compensatory measures

PRA Response

The adequacy of the design feature (the containment boundary subject to Type A testing) is preserved as evidenced by the overall small change in risk associated with the Type A test frequency change.

3 Preserve system redundancy, independence, and diversity commensurate with the expected frequency and consequences of challenges to the system, including consideration of uncertainty.

PRA Response

The redundancy, independence, and diversity of the containment subject to the Type A test is preserved, commensurate with the expected frequency and consequences of challenges to the system, as evidenced by the overall small change in risk associated with the Type A test frequency change

4 Preserve adequate defense against potential common-cause failures

PRA Response

Adequate defense against common-cause failures is preserved. The Type A test detects problems in the containment, which may or may not be the result of a common-cause failure. Such a common-cause failure may affect failure of another portion of containment (that is, local penetrations) due to the same phenomena. Adequate defense against common-cause failures is preserved via the continued performance of the Type B and Type C tests and the performance of inspections. The change to the Type A test, which bounds the risk associated with containment failure modes including those involving common-cause failures, does not degrade adequate defense as evidenced by the overall small change in risk associated with the Type A test frequency change.

5. Maintain multiple fission product barriers

PRA Response

Multiple Fission Product barriers are maintained. The portion of the containment affected by the Type A test extension is still maintained as an independent fission product barrier, albeit with a small change in the reliability of the barrier. Fuel cladding and the reactor coolant system (RCS) are not affected by the proposed change.

6 Preserve sufficient defense against human errors

PRA Response
Sufficient defense against human errors is preserved. The probability of a human error to operate the plant, or to respond to off-normal conditions and accidents is not significantly affected by the change to the Type A testing frequency. Errors committed during test and maintenance may be reduced by the less frequent performance of the Type A test (less opportunity for errors to occur).

7 Continue to meet the intent of the plant's design criteria

PRA Response

The intent of the plant's design criteria continues to be met. The extension of the Type A test does not change the configuration of the plant or the way the plant is operated. As the intent of the plant's design criteria will continue to be met, this consideration for evaluating the impact of the proposed change on defense in depth will not affect the risk associated with the proposed change.

Conclusion

The responses to the seven defense-in-depth questions above conclude that the existing defense-in-depth has not been diminished. Therefore, the proposed change does not comprise a reduction in safety.

5.0 Methodology

The methodology employed is in accordance with NEI 94-01, Revision 3-A[3] and the NRC regulatory guidance on the use of PRA and risk insights in support of a license amendment request (LAR) for changes to a plant's licensing basis, R.G. 1.174[10] This methodology is similar to that presented in the EPRI guidance[1] as specified in NEI 94-01.[3]

A simplified bounding analysis approach is used in the methodology to evaluate the risk impact on increasing the CILRT Type A interval from the current licensing basis of 1 test-in-10 years to the proposed licensing basis of 1 test-in-15 years by examining specific accident sequences in which the containment remains intact or those in which it is impaired. The aspects considered included:

- Accident progression sequences in which the containment remains intact initially and in the long term (Class 1)

  - Class 1 Frequency[2] = $FREQ_{INTACT} – FREQ_{Class\ 3a} - FREQ_{Class\ 3b}$

    where; Class 3a = small containment liner leakage
    Class 3b = large containment liner leakage

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[2] The adjustment to Class 1 is necessary to maintain the sum of the frequencies equal to CDF.

- Accident progression sequences in which containment integrity is impaired due to random isolation failures of plant components other than those associated with Type B[3] or Type C[4] tested components. For example, steam generator manway cover leakage.
- Accident progression sequences in which containment integrity is impaired due to containment isolation failures due to pathways (e.g., misalignment) left open following a plant post-maintenance test.
- Accident progression sequences[5] involving containment failure by any of the following:
  - Large Containment Isolation Failures (Class 2)
  - Small Containment Isolation Failure-to-Seal Events (Class 4 and 5)
  - Containment Isolation Failures – Dependent Failures, Personnel Errors (Class 6)
    - Severe Accident Phenomena Induced Failures (Class 7)
    - Containment Bypass Events (Class 8)

Section 5 contains the following tables and sections.

Table 10	presents detailed information regarding the EPRI accident classes[1, §4.3]
Step 5.1	discussion on how the baseline risk is determined
Step 5.2	discussion on how the baseline population dose/yr is determined
Step 5.3	discussion on how the risk impact (Bin Frequency & Population Dose) is determined
Step 5.4	discussion on the how the change in LERF and CCFP is determined
Step 5.5	discussion on how the sensitivity is determined including CCFP and External Events

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[3] Type B tests measure component leakage across pressure retaining boundaries, e.g., gaskets, expansion bellows and air locks.

[4] Type C tests measure component leakage rates across containment isolation valves.

[5] The sequences of these classes are impacted by changes in Type B and Type C test intervals, and are not affected by changes in the Type A test interval.

Table 10 Detailed Description of EPRI Accident Classes

EPRI Class	Description[1, §4.3]	Frequency	Leakage	Population Dose (person-rem)	Population Dose-Rate (person-rem/rx-yr)
1	CONTAINMENT INTACT – all core damage accident progression bins for which the containment remains intact with negligible leakage. Class 1 sequences arise from those core damage sequences where containment isolation is successful and long-term containment heat removal capability is available. The frequency of an intact containment is established on the individual plant's PRA. For Class 1 sequences, it is assumed that the intact containment end-state is subject to a containment leakage rate less than the containment allowable leakage (La).	Calculated Value $F_{Class\ 1}$ = $CDF_{Intact} – F_{3a} – F_{3b}$	La	Value from NUREG/CR-4551	$DOSE_{Class\ 1} * F_{Class\ 1}$
2	LARGE CONTAINMENT ISOLATION FAILURES – all core damage accident progression bins for which a pre-existing leakage due to failure to isolate the containment occurs. These sequences are dominated by failure-to-close of large (>2" diameter) containment isolation valves.	From Plant PRA $F_{Class\ 2}$ = $P_{LargeCI} * CDF_{Total}$	From Plant PRA	Value from NUREG/CR-4551	$DOSE_{Class\ 2} * F_{Class\ 2}$
3a	SMALL PRE-EXISTING LEAK IN CONTAINMENT - all core damage accident progression bins with a pre-existing leakage in the containment structure in excess of normal leakage. Small leaks are characterized as > 1 La ≤ 10 La.	Calculated Value $F_{Class\ 3a}$ = $P_{Class\ 3a} * CDF$	10 La	(Class 1 dose for La) * 10	$DOSE_{3a} * F_{3a}$
3b	LARGE PRE-EXISTING LEAK IN CONTAINMENT - all core damage accident progression bins with a pre-existing leakage in the containment structure in excess of normal leakage. Large leaks are characterized as > 10 La.	Calculated Value $F_{Class\ 3b}$ = $P_{Class\ 3b}* CDF$	100 La	(Class 1 dose for La) * 100	$DOSE_{3b} * F_{3b}$
4	SMALL ISOLATION FAILURE – FAILURE TO SEAL (TYPE B TEST) - all core damage accident progression bins for which a failure-to-seal containment isolation of Type B test components occurs. Because these failures are detected by Type B tests and their frequency is very low compared with the other classes, this group is not evaluated further. The frequency of Class 4 sequences is subsumed into Class 7, where it contributes insignificantly.	N/A	N/A	N/A	N/A
5	SMALL ISOLATION FAILURE – FAILURE TO SEAL (TYPE C TEST) - all core damage accident progression bins for which a failure-to-seal containment isolation of Type C test components occurs. Because these failures are detected by Type C tests and their frequency is very low compared with the other classes, this group is not evaluated further. The frequency of	N/A	N/A	N/A	N/A

EPRI Class	Description[1, §4.3]	Frequency	Leakage	Population Dose (person-rem)	Population Dose-Rate (person-rem/rx-yr)
	Class 5 sequences is subsumed into Class 7, where it contributes insignificantly.				
6	CONTAINMENT ISOLATION FAILURES (DEPENDENT FAILURES AND PERSONNEL ERRORS) – similar to Class 2. These sequences involve core damage accident progression bins for which failure-to-seal containment leakage, due to failure to isolate the containment occurs. These sequences are dominated by misalignment of containment isolation valves following test/maintenance evolutions. i.e., human error. All other failure modes are bounded by the Class 2 assumption.	N/A	N/A	N/A	N/A
7	SEVERE ACCIDENT PHENOMENA – INDUCED FAILURES - all core damage accident progression bins in which containment failure induced by severe accident phenomena occurs (e.g., hydrogen combustion and direct containment heating).	From Plant PRA $F_{Class\ 7}$ = CDF_{CFL} + CDF_{CFE}	From Plant PRA	Value from NUREG/CR-4551	$DOSE_7$ * F_7
8	CONTAINMENT BYPASS – all core damage accident progression bins in which containment bypass occurs. Each plant's PRA is used to determine the containment bypass contribution. Contributors include ISLOCA and SGTR (unisolated) events.	From Plant PRA $F_{Class\ 8}$ = $CDF_{ISLOCA+}$ CDF_{SGTR}	From Plant PRA	Value from NUREG/CR-4551	$DOSE_8$ * F_8

CDF_{Intact} = core damage frequency for intact containment sequences from the plant-specific PRA
$P_{Large\ CI}$ = random containment large isolation failure probability (i.e., large valves)
CDF_{Total} = total plant-specific core damage frequency
$P_{Class\ 3a}$ = the probability of a small (10 La) pre-existing containment leak
$P_{Class\ 3b}$ = the probability of a large (100 La) pre-existing containment leak
CDF_{CFL} = the core damage frequency resulting from accident sequences that lead to late containment failure
CDF_{CFE} = the core damage frequency resulting from accident sequences that lead to early containment failure

The risk metrics used to evaluate the impact of a proposed change on plant risk include the following figures of merit and acceptance criteria:

The figures of merit (or risk metrics) [1, page 2-4]:

- the change in LERF (∆LERF),
- change in risk as defined by the changes in dose (∆Population Dose [Person-Rem]),
- total LERF,
- and, the change in the conditional containment failure probability (ΔCCFP).

The acceptance criteria:

- ∆LERF and Total LERF, RG 1.174[10]
- ∆ Population Dose<1.0 person-rem or <0.1% Increase – whichever one is less restrictive[1, §1.2]
- ∆CCFP ≤ 1.5% (Assumption 8)[1, §1.2]

The Type A containment test measures the ability of the containment to maintain its function, therefore, the proposed change has no measureable effect on the Level 1 PRA core damage frequency (CDF). The Level 1 PRA CDF remains constant and has no risk significance with respect to the containment CILRT test interval.

The overall methodology[1 , §4.2] used in this analysis followed these steps:

1. Define and quantify the Baseline Risk Determination
2. Develop the Baseline Population Dose
3. Evaluate the Risk Impact (Bin Frequency and Population Dose)
4. Evaluate Change in LERF and CCFP
5. Evaluate Sensitivity of Results

5.1 Step 1 - Baseline Risk Determination

This step[1, §4.2.1] is to define and quantify the baseline risk in terms of core damage frequency (CDF) for each EPRI accident class, excluding classes 4, 5 and 6. According to the EPRI guidance these accident classes are excluded because the circumstances (i.e., CILRT Type B and Type C tests) and types of failures such as simultaneous failure of redundant isolation valves are not impacted by changes in the CILRT Type A frequency.[1] The baseline risk is determined as follows:

- The plant-specific Watts Bar Level 2 PRA release categories [13] are mapped to EPRI accident classes 2, 7 and 8. This is accomplished by linking the release category definitions to the appropriate EPRI accident class.
- The release categories that represent accident Class 1, Containment Intact, are those identified as not having containment failure. The Watts Bar Level 2 analysis refers to these as “INTACT.” The release categories representing INTACT, or no containment failure outcomes may experience leakage due to the increased window of vulnerability of extending the test interval. The increase in leakage contribution is subtracted to obtain the expected no containment failure outcome frequency as follows:

$$FREQ_{Class\ 1} = CDF_{INTACT} - FREQ_{Class\ 3a} – FREQ_{Class\ 3b}$$

To adjust the Class 1 frequency it is necessary to maintain the sum of the frequencies of the accident classes equal to the total CDF.

- Class 3 end-states are developed specifically for this application. These end-states include all core damage accident progression bins with a pre-existing leakage in the containment structure in excess of normal leakage.[1, §4.3] The frequencies for Class 3a and Class 3b are determined as follows:
  $\text{FREQ}_{\text{Class 3a}}$ = CDF * Class 3a leakage probability ($P_{\text{Class\_3a}}$)
  $\text{FREQ}_{\text{Class 3b}}$ = CDF * Class 3b leakage probability ($P_{\text{Class\_3b}}$)

Class 3a represents containment liner leakage characterized as small. The probability is based on industry data. Class 3b represents containment liner leakage that is large which has a probability based on Jeffrey's Non-Informative Prior.[1, §3.5]

According to the EPRI guidance[1] "The methodology employed for determining LERF (Class 3b frequency) involves conservatively multiplying the CDF by the failure probability for this class (3b) accident. This was done for simplicity and to maintain conservatism. However, some plant-specific accident classes leading to core damage are likely to include individual sequences that either may already (independently) cause a LERF or could never cause a LERF, and thus not associated with the postulated Type A containment large leakage path (LERF). The contributors can be removed from class 3b in the evaluation of LERF by multiplying the class 3b probability by only that portion of CDF that may be impacted by Type A leakage.

- An example of the type of sequences that may independently cause LERF is a sequence associated with containment bypass events, such as steam generator tube rupture (SGTR) or interfacing system loss of coolant accidents (ISLOCA). Another example may include those accident sequences associated with anticipated transients without SCRAM (ATWS) events.
- An example of the type of sequences that may never result in LERF is a sequence where containment sprays and containment heat removal are available. In these sequences, containment sprays and cooling reduce the fission products via scrubbing and rapidly reduce containment pressure. The basis for the removal of sequences to reduce conservatism is plant and PRA specific and should be documented by analysis in the risk impact assessment."[1, §4.2.1]

Core damage accident progression end-states are developed for the Watts Bar PRA Level 2 results.[13] which are used to define the representative sequences. Based on the discussion above, determination of the Type A CDF contribution involves identifying two different scenarios. 1) those scenarios corresponding to release categories which include unmitigated containment bypass or pre-existing large isolation failures and 2) those release categories where there is no containment isolation failures prior to core damage combined with effective mitigation of fission product releases. There is no containment isolation failure prior to core damage.

5.2 Step 2 - Develop the Baseline Population Dose Per Year

In step 2[1, §4.2.2] the baseline dose/yr corresponding to the current licensing basis CILRT testing interval (1 test-in-10 years) is estimated. Watts Bar specific estimates of population dose were developed in support of Severe Accident Mitigation Alternatives (SAMAs) for completion and operation of WBN Unit 2 based on 2000 Census data.

SECPOP2000 uses data from the 2000 Census to provide population estimations for input to winMACCS. The population estimates provided for the Severe Accident Mitigation Alternatives calculation were projected for the year 2040 using growth rates from the county population projections. [15, §4.5.2]

The yearly population dose is estimated for each accident class by multiplying the dose estimate for a class by either the frequency estimated in Step 1 or the La factor corresponding to the Class.[1,§4.2.2]

1. From the Watts Bar specific Level 2 results,[13] determine the relationship between offsite dose measured in person-rem and containment leakage rate (the dose in person-rem) for Class 1. Assumed to be equal to 1 La.
2. From the plant Individual Plant Examination of External Events (IPEEE),[16] determine the offsite dose (person-rem) for the accident classes where analysis is available, typically Classes 1, 2, 7 and 8.
3. For those accident classes where analysis is not available in the IPEEE or PRA, determine the dose estimate by determining the class containment leak rate and multiplying by the 1.0 La dose.
4. The offsite dose estimate for EPRI accident Classes 3a and 3b are estimated as following in accordance with the EPRI guidance.

   3a = Class 1 (1 La) * 10

   3b = Class 1 (1 La) * 100
5. Determine the baseline accident class dose-rates (person-rem/yr) by multiplying the dose by the frequency for each of the accident classes. Sum the accident class dose-rates to obtain the total dose-rate.

5.3 Step 3 - Evaluate the Risk Impact (Bin Frequency and Population Dose)

In this step,[1, §4.2.3] the risk impact associated with the change in CILRT intervals is described.

1. Determine the change in probability of leakage detectable only by CILRT (Classes 3a and 3b) for the new surveillance intervals of interest. NUREG 1493[5] states that relaxing the CILRT frequency from 3 tests-in-10 years to one in ten years will increase the average time a leak goes undetected by an CILRT from 18 to 60 months (1/2 the surveillance interval), 60/18 = 3.33 fold increase. Therefore, relaxing the CILRT testing frequency from 3-tests-in-10 years to 1-test-in-15 years will increase the average time a leak goes undetected by an CILRT from 18 to 90 months (1/2 the surveillance interval), 90/18 = 5.0 fold increase.
2. Determine the population dose-rate for the new surveillance intervals of interest by multiplying the dose by the frequency for each of the accident classes. Sum the accident class dose-rates to obtain the total dose-rate.
3. Determine the increase in dose-rate and percentile increase for each extended interval as follows: Increase in dose-rate = (total dose-rate of new interval minus total baseline dose),

and percent increase = [(increase in dose-rate) divided by (total baseline dose-rate)] x 100%.

5.4 Step 4 - Evaluate the Change in LERF and CCFP

In this step,[1, 4.2.4] the changes in LERF and CCFP are described.

Section 5.4.1	Change in LERF is described.
Section 5.4.2	Change in CCFP is described.

5.4.1 Evaluate Risk Impact – Change in LERF

The risk associated with extending the CILRT interval involves a potential that a core damage event that normally would result in only a small radioactive release from containment could result in a large release due to an undetected leak path enlarging during the extended interval. Only Class 3 sequences have the potential to result in early releases if a pre-existing leak were present. Late releases are excluded regardless of the size of the leak because late releases are not, by definition, LERF events. The frequency of class 3b sequences is used as a measure of LERF, and the change in LERF is determined by the change in class 3b frequency. Refer to Regulatory Guide 1.174[10] for LERF acceptance guidelines.

ΔLERF = (frequency class 3b interval x) - (frequency class 3b baseline)

5.4.2 Evaluate Risk Impact – Change in CCFP

Evaluate the change in CCFP. The conditional containment failure probability is defined as the probability of containment failure given the occurrence of a core damage accident, which can be expressed as:

CCFP = [1 - (frequency that results in no containment failure)/CDF] * 100%

CCFP = [1 - (frequency class 1 + frequency class 3a)/CDF] * 100%

CCFP Change (increase) = (CCFP at interval x) – (CCFP at baseline interval), expressed as percentage point change.

5.5 Step 5 - Evaluate the Sensitivity of the Results

In this step,[1, §4.2.5] the sensitivity of the risk impact results to assumptions in liner corrosion are investigated.

- Evaluate the sensitivity of the impact of extended intervals to liner corrosion. The methodology developed for Calvert Cliffs[12] investigates how an age-related degradation mechanism can be factored into the risk impact associated with longer CILRT testing intervals. The instances of through-wall penetration flaws are considered in the development of the risk assessment methodology and are part of the plant-specific analyses performed for assessing the potential for liner corrosion.
- As stated in the Calvert Cliffs analysis,[12] occurrences of through wall liner corrosion related defects had been found between September 1996 implementation of the visual inspection requirements of 10CFR50.55a and the submittal date for that reference. The defects were found in the cylinder region of the liner. No defects were identified in the basemat region.

5.5.1 Containment Overpressure

The Watts Bar plant does not rely on containment overpressure to aid in net-positive suction head (NPSH) for emergency core cooling system (ECCS) injection.

5.5.2 External Events

Where possible, the analysis should include a quantitative assessment of the contribution of external events (for example, fire and seismic) in the risk impact assessment for extended CILRT intervals. For example, where a licensee possesses a quantitative fire analysis and that analysis is of sufficient quality and detail to assess the impact, the methods used to obtain the impact from internal events should be applied for the external event. If the external event analysis is not of sufficient quality or detail to allow direct application of the methodology provided in this document, the quality or detail will be increased or a suitable estimate of the risk impact from the external events should be performed. This assessment can be taken from existing, previously submitted and approved analyses (e.g., FIVE) or another alternate method of assessing an order of magnitude estimate for contribution of the external event to the impact of the changed interval. The EPRI guidance[1,§5] provides an example of the technical approach for the assessment of external events LERF. Watts Bar will use the Seismic PRA for the seismic hazard, and the FIVE evaluation performed for the IPEEE for internal fires.

6.0 Inputs

In this section inputs from the Watts Bar Level 2 PRA are provided and the relationship to the corresponding EPRI accident class is given.

Table 11	presents the EPRI release classifications and the interpretation for assignment to the Watts Bar release categories.
Table 12	presents the Watts Bar release categories, descriptions and mapping to the corresponding EPRI accident class.
Section 6.1	presents the decomposition of the Watts Bar accident sequences and EPRI classification.
Table 13	presents the decomposition of the Watts Bar accident sequences, frequencies and corresponding EPRI classification.
Table 15	presents the EPRI accident class frequencies, the Total CDF and the Baseline CDF (which excludes Class 6).

To determine how the Watts Bar release categories relate to the eight EPRI accident classifications the definitions are interpreted and documented in Table 11.

Table 11 EPRI Release Classes (Containment Failure Classifications)

EPRI Class	Description[1 Table 4-1]	Interpretation for Assigning Watts Bar Release Category
1	Containment remains intact with containment initially isolated	Intact accident sequence bins
2	Large containment isolation failures	Isolation faults that are related to a loss of power or other isolation failure mode that is not a direct failure of an isolation component
3	Independent containment isolation failures due to Type A related failures	Isolation failures identified by Type A testing, Large (3b) or Small (3a)
4	Independent containment isolation failures due to Type B related failures	Isolation failures identified by Type B testing
5	Independent containment isolation failures due to Type C related failures	Isolation failures identified by Type C testing
6	Other penetration failures (dependent failures or personal errors)	Isolation failure with scrubbing or small isolation failures
7	Induced by severe accident phenomena	Early and Late containment failure sequences as a result of hydrogen detonation or other early phenomena
8	Bypass	Bypass sequences, ISLOCA or SGTR

The Watts Bar Level 2 accident sequences are parsed into seven release categories that represent the summation of individual accident categories due to similar characteristics. Table 12 presents the seven release categories, descriptions[14] and mapping to the corresponding EPRI class.[1, §4.3]

Table 12 Watts Bar Release Categories and EPRI Mapping

Release Category	Description	EPRI Class
BLERF	Large Early Release (LER) Via Bypass of Containment	8
HLERF	LER – High Pressure Sequences	7
ILERF	LER – Containment Isolation Failures	2
INTACT	Containment Intact – No Release	1
LATE	Late Release – All Scenarios	7
LLERF	LER – Low Pressure Sequence	7
SERF	Small Early Release	6

6.1 Decomposition of LERF Frequency and EPRI Classification

The decomposition of the Watts Bar accident release categories into the individual Level 2 accident sequences,[13] corresponding EPRI class and the frequency is provided in Table 13.

Table 13 Decomposition of Watts Bar LERF Frequency and EPRI Classification

L2 Accident Sequence	Unit 1 Frequency/yr	Unit 2 Frequency/yr	EPRI Class
BLERF-001	3.82E-09	3.94E-09	8
BLERF-002	2.33E-10	2.72E-10	8
BLERF-003	3.96E-08	3.96E-08	8
BLERF-004	4.53E-07	4.46E-07	8
BLERF-005	1.80E-07	1.78E-07	8
HLERF-001	3.13E-08	3.29E-08	7
HLERF-002	<5.0E-12	<5.0E-12	7
HLERF-003	<5.0E-12	<5.0E-12	7
HLERF-004	<5.0E-12	<5.0E-12	7
HLERF-005	<5.0E-12	<5.0E-12	7
HLERF-006	<5.0E-12	<5.0E-12	7
HLERF-007	<5.0E-12	<5.0E-12	7
HLERF-008	<5.0E-12	<5.0E-12	7
HLERF-009	<5.0E-12	<5.0E-12	7
HLERF-010	<5.0E-12	<5.0E-12	7
HLERF-011	1.18E-09	1.18E-09	7
HLERF-012	<5.0E-12	<5.0E-12	7
HLERF-013	<5.0E-12	<5.0E-12	7
HLERF-014	<5.0E-12	<5.0E-12	7
HLERF-015	<5.0E-12	<5.0E-12	7
HLERF-016	<5.0E-12	<5.0E-12	7
HLERF-017	<5.0E-12	<5.0E-12	7
HLERF-018	<5.0E-12	<5.0E-12	7
HLERF-019	<5.0E-12	<5.0E-12	7
HLERF-020	<5.0E-12	<5.0E-12	7
HLERF-028	3.96E-09	6.47E-09	7
HLERF-029	2.55E-09	4.36E-09	7
HLERF-030	6.94E-12	6.96E-12	7
HLERF-038	1.35E-07	1.33E-07	7
HLERF-039	9.15E-08	9.01E-08	7
ILERF-001	2.21E-08	2.19E-08	2

L2 Accident Sequence	Unit 1 Frequency/yr	Unit 2 Frequency/yr	EPRI Class
INTACT-001	4.26E-07	4.56E-07	1
INTACT-002	2.50E-07	2.51E-07	1
INTACT-003	<5.0E-12	<5.0E-12	1
INTACT-004	<5.0E-12	<5.0E-12	1
INTACT-005	1.50E-06	1.61E-06	1
INTACT-006	1.04E-06	1.04E-06	1
INTACT-007	<5.0E-12	<5.0E-12	1
INTACT-008	<5.0E-12	<5.0E-12	1
INTACT-009	2.36E-08	2.29E-08	1
INTACT-010	<5.0E-12	<5.0E-12	1
INTACT-011	<5.0E-12	<5.0E-12	1
INTACT-012	<5.0E-12	<5.0E-12	1
INTACT-013	8.13E-08	7.86E-08	1
INTACT-014	5.74E-10	5.75E-10	1
INTACT-015	1.13E-10	1.13E-10	1
INTACT-016	<5.0E-12	<5.0E-12	1
INTACT-017	1.12E-07	1.11E-07	1
INTACT-018	6.56E-10	8.85E-10	1
INTACT-019	<5.0E-12	<5.0E-12	1
INTACT-020	<5.0E-12	<5.0E-12	1
INTACT-021	1.62E-06	1.57E-06	1
INTACT-022	4.10E-09	4.08E-09	1
INTACT-023	2.40E-09	2.39E-09	1
INTACT-024	<5.0E-12	<5.0E-12	1
INTACT-028	<5.0E-12	<5.0E-12	1
INTACT-032	<5.0E-12	<5.0E-12	1
INTACT-036	<5.0E-12	<5.0E-12	1
INTACT-040	<5.0E-12	<5.0E-12	1
INTACT-044	<5.0E-12	<5.0E-12	1
INTACT-048	<5.0E-12	<5.0E-12	1

L2 Accident Sequence	Unit 1 Frequency/yr	Unit 2 Frequency/yr	EPRI Class
INTACT-052	<5.0E-12	<5.0E-12	1
INTACT-056	<5.0E-12	<5.0E-12	1
INTACT-060	<5.0E-12	<5.0E-12	1
INTACT-064	<5.0E-12	<5.0E-12	1
INTACT-068	<5.0E-12	<5.0E-12	1
INTACT-072	<5.0E-12	<5.0E-12	1
LATE-001	<5.0E-12	<5.0E-12	7
LATE-002	1.82E-07	1.78E-07	7
LATE-003	<5.0E-12	<5.0E-12	7
LATE-004	<5.0E-12	2.60E-10	7
LATE-005	<5.0E-12	<5.0E-12	7
LATE-006	<5.0E-12	2.56E-10	7
LATE-007	<5.0E-12	<5.0E-12	7
LATE-008	2.15E-11	1.48E-10	7
LATE-009	<5.0E-12	<5.0E-12	7
LATE-010	6.83E-07	6.55E-07	7
LATE-011	<5.0E-12	<5.0E-12	7
LATE-012	2.99E-07	3.00E-07	7
LATE-013	<5.0E-12	<5.0E-12	7
LATE-014	7.28E-12	2.35E-11	7
LATE-015	<5.0E-12	<5.0E-12	7
LATE-016	<5.0E-12	1.13E-10	7
LATE-017	<5.0E-12	<5.0E-12	7
LATE-018	4.86E-10	1.20E-09	7
LATE-019	<5.0E-12	<5.0E-12	7
LATE-020	<5.0E-12	<5.0E-12	7
LATE-021	<5.0E-12	<5.0E-12	7
LATE-022	1.97E-11	<5.0E-12	7
LATE-023	<5.0E-12	<5.0E-12	7
LATE-024	<5.0E-12	<5.0E-12	7
LATE-025	<5.0E-12	<5.0E-12	7

L2 Accident Sequence	Unit 1 Frequency/yr	Unit 2 Frequency/yr	EPRI Class
LATE-026	2.12E-09	4.50E-09	7
LATE-027	<5.0E-12	<5.0E-12	7
LATE-028	<5.0E-12	<5.0E-12	7
LATE-029	<5.0E-12	<5.0E-12	7
LATE-030	2.11E-10	4.86E-11	7
LATE-031	<5.0E-12	<5.0E-12	7
LATE-032	<5.0E-12	<5.0E-12	7
LATE-033	<5.0E-12	<5.0E-12	7
LATE-034	1.56E-09	6.26E-10	7
LATE-035	<5.0E-12	<5.0E-12	7
LATE-036	<5.0E-12	<5.0E-12	7
LATE-037	<5.0E-12	<5.0E-12	7
LATE-038	<5.0E-12	<5.0E-12	7
LATE-039	<5.0E-12	<5.0E-12	7
LATE-040	<5.0E-12	<5.0E-12	7
LATE-041	<5.0E-12	<5.0E-12	7
LATE-042	1.33E-06	1.24E-06	7
LATE-043	<5.0E-12	<5.0E-12	7
LATE-044	1.71E-08	1.67E-08	7
LATE-045	<5.0E-12	<5.0E-12	7
LATE-046	3.39E-09	3.51E-09	7
LATE-047	<5.0E-12	<5.0E-12	7
LATE-048	5.80E-09	5.76E-09	7
LATE-055	<5.0E-12	<5.0E-12	7
LATE-056	3.69E-08	6.40E-08	7
LATE-063	<5.0E-12	<5.0E-12	7
LATE-064	2.93E-08	5.06E-08	7
LATE-071	<5.0E-12	<5.0E-12	7
LATE-072	1.44E-08	2.54E-08	7
LATE-079	1.43E-08	2.49E-08	7
LATE-087	<5.0E-12	<5.0E-12	7
LATE-088	9.87E-07	9.72E-07	7

L2 Accident Sequence	Unit 1 Frequency/yr	Unit 2 Frequency/yr	EPRI Class
LATE-095	<5.0E-12	<5.0E-12	7
LATE-096	8.86E-07	8.73E-07	7
LATE-103	<5.0E-12	<5.0E-12	7
LATE-104	3.13E-06	3.09E-06	7
LATE-111	<5.0E-12	<5.0E-12	7
LATE-112	3.10E-06	3.06E-06	7
LATE-119	<5.0E-12	<5.0E-12	7
LATE-120	7.07E-08	8.48E-08	7
LATE-127	<5.0E-12	<5.0E-12	7
LATE-128	7.13E-08	8.52E-08	7
LATE-135	<5.0E-12	<5.0E-12	7
LATE-136	3.76E-07	3.64E-07	7
LATE-143	<5.0E-12	<5.0E-12	7
LATE-144	3.73E-07	3.62E-07	7
LLERF-001	1.60E-08	1.66E-08	7
LLERF-002	<5.0E-12	<5.0E-12	7
LLERF-003	<5.0E-12	<5.0E-12	7
LLERF-004	<5.0E-12	<5.0E-12	7
LLERF-005	<5.0E-12	<5.0E-12	7
LLERF-006	<5.0E-12	<5.0E-12	7
LLERF-007	5.16E-10	5.18E-10	7
LLERF-008	<5.0E-12	<5.0E-12	7
LLERF-009	<5.0E-12	<5.0E-12	7
LLERF-010	<5.0E-12	<5.0E-12	7
LLERF-011	<5.0E-12	<5.0E-12	7
LLERF-012	<5.0E-12	<5.0E-12	7
LLERF-013	5.56E-10	5.87E-10	7
LLERF-014	<5.0E-12	<5.0E-12	7
LLERF-015	<5.0E-12	<5.0E-12	7
LLERF-016	<5.0E-12	<5.0E-12	7
LLERF-017	<5.0E-12	<5.0E-12	7

L2 Accident Sequence	Unit 1 Frequency/yr	Unit 2 Frequency/yr	EPRI Class
LLERF-018	<5.0E-12	<5.0E-12	7
LLERF-019	2.64E-08	2.57E-08	7
LLERF-020	4.57E-10	4.58E-10	7
LLERF-021	3.28E-10	3.29E-10	7
LLERF-022	1.76E-11	1.77E-11	7
LLERF-023	1.54E-10	1.54E-10	7
LLERF-024	1.08E-10	1.09E-10	7
LLERF-029	1.21E-10	2.05E-10	7
LLERF-030	8.86E-11	1.34E-10	7
LLERF-035	1.79E-07	1.77E-07	7
LLERF-036	1.49E-07	1.47E-07	7
LLERF-041	2.40E-09	2.81E-09	7
LLERF-042	1.84E-09	2.11E-09	7
LLERF-047	1.78E-08	1.77E-08	7
LLERF-048	1.47E-08	1.46E-08	7
SERF-001	9.94E-08	9.94E-08	6
SERF-002	5.64E-10	5.66E-10	6
SERF-007	<5.0E-12	<5.0E-12	6
SERF-008	<5.0E-12	<5.0E-12	6
SERF-013	7.84E-11	1.08E-10	6
SERF-014	<5.0E-12	<5.0E-12	6
SERF-018	4.51E-08	4.46E-08	6
SERF-019	7.59E-08	7.48E-08	6
SERF-025	1.43E-07	1.41E-07	6
SERF-026	<5.0E-12	<5.0E-12	6
SERF-031	1.70E-09	1.97E-09	6
SERF-032	<5.0E-12	<5.0E-12	6
SERF-037	1.41E-08	1.41E-08	6
SERF-038	<5.0E-12	<5.0E-12	6

Table 14 Level 2 Accident Sequence Total Frequency

Accident Sequence Group	EPRI Class	Frequency/yr	
		Unit 1	Unit 2
BLERF	8	6.77E-07	6.68E-07
HLERF	7	2.65E-07	2.68E-07
ILERF	2	2.21E-08	2.19E-08
Intact	1	5.06E-06	5.15E-06
Late	7	1.16E-05	1.15E-05
LLERF	7	4.09E-07	4.06E-07
SERF	6	3.80E-07	3.77E-07

Table 15 presents the EPRI accident class frequencies based on the data from Table 13.

Table 15 EPRI Accident Class Frequencies

EPRI Accident Class Totals[Table 14]		
Classification	Frequency	
	Unit 1	Unit 2
Sum of EPRI Class 1	5.06E-06	5.15E-06
Sum of EPRI Class 2	2.21E-08	2.19E-08
Sum of EPRI Class 6	3.80E-07	3.77E-07
Sum of EPRI Class 7	1.23E-05	1.21E-05
Sum of EPRI Class 8	6.77E-07	6.68E-07
Sum of LERF Sequences	1.37E-06	1.36E-06
Total Level 2 End-States (Total CDF) Including Class 6	1.84E-05	1.83E-05
Total Level 2 End-States (Baseline CDF) Excluding Class 6	1.80E-05	1.80E-05

7.0 Calculation

The section documents the analyses performed for characterizing the effect of containment isolation failures affected by a change in the testing intervals. Section 7 consists of the following sections:

Section 7.1	the baseline (3-year CILRT frequency) risk is quantified in terms of frequency per reactor-year for the EPRI accident classes of interest.
Section 7.2	the baseline population dose (person-rem) is developed for the applicable accident classes.
Section 7.3	the risk impact (in terms of population dose-rate) is evaluated for the EPRI accident classes of interest.
Section 7.4	the risk impact in terms of the change in LERF and the change in CCFP is determined.

7.1 Step 1 - Baseline Risk Determination

Section 7.1 documents the calculations for the quantification of the baseline (3-year CILRT frequency) risk in terms of frequency per reactor year for the EPRI accident classes of interest.[1, §4.2]

Section 7.1.1	presents the calculation for the frequency of Class 2 sequences which consist of large containment isolation failures.

Section 7.1.2	presents the calculation for the frequency of Class 7 sequences which consist of early and late severe accident phenomena.
Section 7.1.3	presents the calculation for the frequency of Class 8 sequences which consist of bypass events such as a steam generator tube rupture (SGTR) or an unisolable interfacing system LOCA (ISLOCA).
Section 7.1.4	presents the calculation for the Type A leakage estimate for the 3a probabilities and frequencies.
Section 7.1.5	presents the calculation for the Type A leakage estimate for the 3b probabilities and frequencies.
Section 7.1.6	presents the calculation for the Class 1 sequences for the intact containment sequences.

7.1.1 Class 2 - Large Containment Isolation Failures

This class represents large containment isolation failures. Class 2 contains LERF contributions related to isolation failures without scrubbing credited. The frequency of Class 2 is the sum of those release categories identified in Table 13 as Class 2 taken from the Watts Bar specific Level 2 analysis, and summed in Table 15.

Equation 1 Calculation of the Class 2 Frequency

Unit 1 $FREQ_{Class\_2} = \Sigma Class\_2 \text{ Accident Sequences}$
$= 2.21E\text{-}08/yr$

Unit 2 $FREQ_{Class\_2} = \Sigma Class\_2 \text{ Accident Sequences}$
$= 2.19E\text{-}08/yr$

7.1.2 Class 7 - Severe Accident Phenomena

Class 7 represents early and late containment failure sequences involving severe accident phenomena related to containment breach and represents contributions to LERF. The frequency of Class 7 is the sum of those release categories identified in Table 13 and summed in Table 15.

Equation 2 Calculation of the Class 7 Frequency

Unit 1 $FREQ_{Class\_7} = \Sigma Class\_7 \text{ Accident Sequences}$
$= 1.23E\text{-}05/yr$

Unit 2 $FREQ_{Class\_7} = \Sigma Class\_7 \text{ Accident Sequences}$
$= 1.21E\text{-}05/yr$

Note: Class 7 events contribute to both early and late releases and are distributed as follows:

Unit 1 $FREQ_{Class\_7\_LERF} = 6.74E\text{-}07/yr$
$FREQ_{Class\_7\_LATE} = 1.16E\text{-}05/yr$

Unit 2

$$FREQ_{Class\_7\_LERF} = 6.74E\text{-}07/yr$$
$$FREQ_{Class\_7\_LATE} = 1.15E\text{-}05/yr$$

7.1.3 Class 8 - Containment Bypass (ISLOCA, SGTR)

The frequency of Class 8 is the sum of those release categories identified in Table 13 and summed in Table 15. Class 8 events include ISLOCA events and non-isolable SGTR events (early or late).

Equation 3 Calculation of the Class 8 Frequency

Unit 1 $FREQ_{Class\_8}$ = ΣClass_8 Accident Sequences
= 6.77E-07/yr

Unit 2 $FREQ_{Class\_8}$ = ΣClass_8 Accident Sequences
= 6.68E-07/yr

7.1.4 Calculation of the 3a Probability and Frequency

Containment Type A leakage is associated with EPRI accident Class 3. Consistent with the EPRI methodology[1] Class 3 has been divided into two subclasses, 3a for small liner breaches, and 3b for large liner breaches. The estimate for Class 3 was redistributed back into Class 1 (INTACT). Therefore each of these classes must be evaluated for applicability to this analysis.

The Class 3 containment failures are due to leaks such as liner breaches that could only be detected by performing a Type A CILRT or for egregious cases, by visual inspection. In order to determine the impact of the extended test interval the probability of Type A leakage must be calculated.

Calculation of the 3a Probability and Frequency Data presented in the EPRI report[1, §4.1] contains two Type A leakage events out of 217 tests. Using the data, a mean estimate for the probability is determined for Class 3a as shown in Equation 4.

Equation 4 Calculation of the Class 3a Probability

$$\begin{aligned} P_{Class\_3a} &= \#Events \div \#Tests \\ &= 2 \div 217 \\ &= 0.0092 \end{aligned}$$

This probability is based on a test interval of 3 tests-in-10 years, as opposed to Watts Bar's current 1 test-in-10 years frequency. The probability must be adjusted to reflect this difference which is performed later in this calculation. P_{Class_3a} can be defined as the probability of small pre-existing containment leakage in excess of design allowable (La) but less than 10 La. Probability of 3a is a function of CILRT test interval.

Multiplying the Internal Events (Level 2) baseline CDF by the probability of a Class 3a leak determines the Class 3a frequency contribution in accordance with guidance provided by EPRI.[1]

Equation 5 Calculation of the Class 3a Failure Frequency

Unit 1

$$\begin{aligned} FREQ_{Class\_3a} &= P_{Class\_3a} \text{ x } CDF_{Baseline} \\ &= 0.0092 \text{ x } 1.80E\text{-}05/yr \\ &= 1.66E\text{-}07/yr \end{aligned}$$

Unit 2

$$\begin{aligned} FREQ_{Class\_3a} &= P_{Class\_3a} \text{ x } CDF_{Baseline} \\ &= 0.0092 \text{ x } 1.80E\text{-}05/yr \\ &= 1.66E\text{-}07/yr \end{aligned}$$

7.1.5 Calculation of the 3b Probability and Frequency

To estimate the failure probability given that no failures have occurred, the EPRI guidance [1, §4.1] suggests the use of a non-informative prior. This approach updates a uniform distribution (no bias) with the available evidence (data) to provide a better estimation of an event.
A beta distribution is typically used for the uniform prior with the parameters α = 0.5 and β = 1. This is combined with the existing data (i.e., no Class 3b events in 217 tests) using

Equation **6** to calculate the 3b failure probability, and by

Equation **7** to calculate the failure frequency.

Equation 6 Calculation of the Class 3b Failure Probability

$$\begin{aligned} P_{Class\_3b} &= (n + \alpha) \div (N + \beta) \\ &= (0 + 0.5) \div (217 + 1) \\ &= 0.5 \div 218 \\ &= 0.0023 \end{aligned}$$

where: n = the number of events of interest (large leakage)

N = the number of tests

α = non-informative prior distribution parameter

β = non-informative prior distribution parameter

P_{Class_3b} can be defined as the probability of large (100 La) pre-existing containment leakage. Probability of 3b is a function of CILRT test interval.

Equation 7 Calculation of the Class 3b Failure Frequency

Unit 1

$$\begin{aligned} FREQ_{Class\_3b} &= P_{Class\_3b} \text{ x } CDF_{Baseline} \\ &= 0.0023 \text{ x } 1.80E\text{-}05/yr \\ &= 4.14E\text{-}08/yr \end{aligned}$$

Unit 2

$$\begin{aligned} FREQ_{Class\_3b} &= P_{Class\_3b} \text{ x } CDF_{Baseline} \\ &= 0.0023 \text{ x } 1.80E\text{-}05/yr \\ &= 4.12E\text{-}08/yr \end{aligned}$$

7.1.6 Class 1 - Intact Containment

The Class 1 frequency is determined by the baseline CDF less Class 2, 7, and 8.

Equation 8 Calculation of the Class 1 Frequency

Unit 1

$$\begin{aligned} FREQ_{Class\_1} &= CDF_{Baseline} - (FREQ_{Class\ 2} + FREQ_{Class\ 7} + FREQ_{Class\ 8}) \\ &= 1.80E\text{-}05/yr - (2.21E\text{-}08/yr + 1.23E\text{-}05/yr + 6.77E\text{-}07/yr) \\ &= 5.04E\text{-}06/yr \end{aligned}$$

Unit 2

$$\begin{aligned} FREQ_{Class\_1} &= CDF_{Baseline} - (FREQ_{Class\ 2} + FREQ_{Class\ 7} + FREQ_{Class\ 8}) \\ &= 1.80E\text{-}05/yr – (2.19E\text{-}08/yr + 1.21E\text{-}05/yr + 6.68E\text{-}07/yr) \\ &= 5.18E\text{-}06/yr \end{aligned}$$

Although the frequency of this class is not directly impacted by Type A testing, the frequency for Class 1 is reduced by the estimated frequencies in Class 3a and 3b in order to preserve total baseline CDF. The revised Class 1 frequency is therefore determined by Equation 9:

Equation 9 Calculation of the Adjusted Class 1 Frequency

Unit 1

$$\begin{aligned} FREQ_{Class\ 1\ ADJ} &= FREQ_{Class\_1\_BL} - (FREQ_{Class\ 3a\_OLB} + FREQ_{Class\ 3b\_OLB}) \\ &= 5.04E\text{-}06/yr - (1.66E\text{-}07/yr + 4.14E\text{-}08/yr) \\ &= 4.85E\text{-}06/yr \end{aligned}$$

Unit 2

$$\begin{aligned} FREQ_{Class\ 1\ ADJ} &= FREQ_{Class\ 1\_BL} - (FREQ_{Class\ 3a\_OLB} + FREQ_{Class\ 3b\_OLB}) \\ &= 5.18E\text{-}06/yr - (1.66E\text{-}07/yr + 4.12E\text{-}08/yr) \\ &= 4.94E\text{-}06/yr \end{aligned}$$

7.2 Step 2 - Develop the Baseline Population Dose

In this step, the baseline population dose is calculated. The population dose is a function of the accident class frequency and the population within a 50-mile radius of the Watts Bar plant. The following sub-steps and tables are provided in this section.

Section 7.2.1	presents the Watts Bar 50-mile radius population density
Table **16**	presents the estimated 2040 population density in the 50-mile radius surrounding Watts Bar
Table 17	presents the estimates person-rem for Sequoyah source term groups reported from NUREG/CR-4551.[7] This table also assigns each source term group to an EPRI class
Table 18	presents the calculation of the Sequoyah population dose risk at 50-miles by taking the fractional contribution to risk for each collapsed accident progression bin, the population dose risk and the frequency to obtain the estimated dose for each accident progression
Section 7.2.2	presents the Watts Bar off-site consequence (person-rem) estimates
Table 19	presents the Unit-1 Baseline dose calculation without the breakout of Class 3 which is included in the Class 1 values.

Table 20	presents the Unit-2 Baseline dose calculation without the breakout of Class 3 which is included in the Class 1 values.
Table 21	presents the Unit 1 Baseline Dose with the Class 3a and 3b Contribution
Table 22	presents the Unit 2 Baseline Dose with the Class 3a and 3b Contribution

The estimated population within a 50-mile radius of the Watts Bar Plant was taken from calculation R-2361441-1823[15 §4.5.2] which was developed for the Unit 2 Severe Accident Mitigation Alternatives (SAMA) Analysis. The basis for the population projections are described fully in that calculation. The results, in part are provided in Table 16.

Table 16 50-Mile Radius Population Density

	Total Population
2040 Data[15, Table 5]	1,523,390

Per the EPRI guidance[1 §5.1.2], the population dose is calculated by using the data provided in NUREG/CR-4551 Vol 5 Rev 1 Part 1[7] for the Sequoyah plant and adjusting the results for Watts Bar. Specifically each Watts Bar release category is associated with an applicable collapsed accident progression bin of NUREG/CR-4551. Refer to NUREG/CR-4551 for descriptions of the collapsed accident progression bins (APBs) from NUREG/CR-4551[9, §2.4.3].

Table 17 Summary Accident Progression Bin (APB) Descriptions

Summary APB Number	Description
1	VB, Early CF (During CD) Core damage occurs followed by vessel breach, containment fails early during core damage.
2	VB, Alpha, Early CF (at VB) Core damage occurs followed by vessel breach, steam explosion leads to early containment failure at vessel breach.
3	VB, >200 psi, Early CF (at VB) Core damage occurs leading to a high pressure vessel breach resulting in early containment failure during vessel breach.
4	VB, <200 psi, Early CF (at VB) Core damage occurs, followed by vessel breach at low pressure, containment fails early at vessel breach.
5	VB, Late CF Core damage occurs, followed by vessel breach, containments fails late.

6	VB, BMT, Very Late CF Core damage occurs, followed by vessel breach and basemat failure, containments fails very late.
7	Bypass Containment bypass event such as a SGTR.
8	VB, No CF Core damage occurs, followed by vessel breach, pressure is suppressed; therefore, no containment failure.
9	No VB, Early CF (during CD) Core damage occurs; however, the vessel remains intact, containment fails early during core damage.
10	No VB Core damage occurs; however, the vessel remains intact and containment does not fail.

In order to utilize the Sequoyah information from NUREG/CR-4551 it is necessary to convert the data to the form necessary for the CILRT analysis. This involves classification into one of 3 EPRI classes (2, 7 or 8) and then determining the representative person-rem estimates. NUREG/CR-4551 provides guidance with respect to the composition of the source term grouping. Each source term group is a collection of source terms that result in similar consequences. Therefore, the frequency of the source term group is the sum of the frequencies of all the Accident Progression Bins (APB) which make up the group. Using this information the Sequoyah results are grouped into the EPRI classes and presented in **Table 18**.

Table 18 Calculation of the Watts Bar Population Dose Risk at 50-Miles

Collapsed Accident Progression Bin	EPRI Class	Collapsed Accident Progression Bin (APB) [1]	Fractional APB Contributions to Risk[2]	NUREG/CR-4551 Population Dose Risk at 50-Miles (Person-Rem/yr – Mean) [4]	NUREG/CR-4551 Collapsed APB Frequency/ Yr[5]	NUREG/CR-4551 Population Dose at 50-Miles[6]
I	7	VB, Early CF (During CD)	0.039	0.468	2.79E-07	1.68E+06
II	7	VB, Early CF (At VB), Alpha Mode	0.010	0.114	1.12E-07	1.02E+06
III	7	VB >200 psi, Early CF (at VB)	0.159	1.902	1.95E-06	9.74E+05
IV	7	VB <200 psi, Early CF (at VB)	0.125	1.494	1.28E-06	1.16E+06
V	7	VB, Late CF	0.073	0.870	2.12E-06	4.10E+05
VI	7	VB, BMT, Very Late CF	0.140	1.674	9.54E-06	1.75E+05
VII	8	Bypass	0.403	4.830	3.12E-06	1.55E+06
VIII	1	VB, No CF, No Bypass	0.002	0.018	1.50E-05	1.20E+03

Collapsed Accident Progression Bin	EPRI Class	Collapsed Accident Progression Bin (APB)[1]	Fractional APB Contributions to Risk[2]	NUREG/CR-4551 Population Dose Risk at 50-Miles (Person-Rem/yr – Mean)[4]	NUREG/CR-4551 Collapsed APB Frequency/ Yr[5]	NUREG/CR-4551 Population Dose at 50-Miles[6]
IX	7	No VB, Early CF (During CD)	0.051	0.612	6.14E-07	9.97E+05
X	1	No VB, No CF	0.002	0.018	2.07E-05	8.69E+02
		Total Fractional Contribution:	1.000			

1. The accident progression bins used in the EPRI guidance [1 Table 5-5] were taken from Surry data, the corresponding Watts Bar ABP is used for this analysis, including Vessel Breach
2. This is consistent with the EPRI Guidance. [6 Table 5-5 Note 1] the Fractional APB Contributions to risk is represented by the average of the Mean Fractional Contributions to Risk (MFCR) and the Fractional Contribution to Mean Risk taken from NUREG/CR-4551 Vol 5 Rev 1 Part 1. [7, Table 5.1-3]
3. The total population dose risk (PDR) at 50-miles (PDR50) from internal events is 12.0 person-rem/rx-yr, which is provided as the mean of the sample. [7 Table 5.1-1]
4. The contribution for a given APB is the product of the total PDR50 (12.0 person-rem/rx-yr[7 Table 5.1-1]) and the fractional APB contribution to risk. Multiply column 3 by 12.0. Ex. 0.041 * 12 = 0.492
5. NUREG/CR-4551 provides the conditional probabilities of the collapsed APBs.[7, Figure 2.5-3] The weighted averages for these conditional probabilities (6th column in Figure 2.5-3, ex. 0.005 for VB, Early CF (During CD)) are multiplied by the Frequency Weighted Average (5.58E-05), to calculate the collapsed APB frequency.
6. The population dose at 50 miles result in this column is determined by dividing the population dose risk shown in the fourth column (0.492) of this table by the collapsed APB (VB, Alpha, Early CF) frequency (2.79E-08) shown in the fifth column of this table, which equals 1.68E+07 Person-Rem at 50 miles.

7.2.1 Watts Bar Specific Off-Site Consequence (Person-Rem Estimates)

Watts Bar population dose is calculated using the data provided in NUREG/CR-4551 for Sequoyah and adjusting the results for Watts Bar. Sequoyah's population within a 50 mile radius is 1,224,924 people.[5] A ratio of the population between the two plants is given as:

Population of Watts Bar (50 miles) / Population of Sequoyah (50 miles) =
1,523,390 / 1,224,924 = 1.24 Population Dose Factor

To determine the applicable population dose for Watts Bar, the population dose methodology for the Surry collapsed accident progression bins are referenced. This analysis method from the EPRI guidance [1, Table 5-5] was used to estimate the population density within a 50-mile radius of the Watts Bar plant. The corresponding inputs for Watts Bar are inserted into the equations. The results are provided in Table 19 and Table 20 which present the Watts Bar Unit 1 and Unit 2 release category mapping for the eight EPRI accident classes. Dose (person-rem) per year is the product of the baseline frequency (per year) (from Table 15), the population dose factor from above and the person-rem for an accident class.

Equation 10 Baseline Dose Calculation

$$\text{Dose}_{BL}\text{(person-rem/yr)} = \text{Baseline Frequency/yr} * \text{Dose} * \text{Population Dose Factor}$$

Table 19 U1 – Baseline Dose Calculation (Without 3a & 3b)

EPRI Class	EPRI Description	Baseline Frequency/yr	Dose (Person-Rem)	Population Dose Factor	Person-Rem/yr
1	Intact Containment	5.06E-06	2.07E+03	1.24	1.30E-02
2	Large Containment Isol Failures	2.21E-08	9.97E+05	1.24	2.74E-02
3a	Small Isol Failures (Liner Breach)	(1)	(1)	1.24	(1)
3b	Large Isolation failures (Liner Breach)	(1)	(1)	1.24	(1)
4	Small Isolation Failures - Failure-to-Seal (Type B)	(2)	(2)	1.24	(2)
5	Small Isolation Failures - Failure-to-Seal (Type C)	(2)	(2)	1.24	(2)
6	Containment Isolation Failures (Dependent Failure, Personnel Errors)	(2)	(2)	1.24	(2)
7	Severe Accident Phenomena Induced Failure	1.23E-05	2.97E+07	1.24	4.55E+02
8	Containment Bypass (ISLOCA, SGTR)	6.77E-07	1.55E+06	1.24	1.30E+00
	Total:	1.80E-05			4.559E+02

1. The Class 3a and 3b frequencies, dose and dose-rates are subsumed in the associated Class 1 values.
2. Class 4, 5 and 6 containment isolation failures are not affected by the CILRT interval frequency; therefore they are not included in the analysis.

Table 20 U2 – Baseline Dose Calculation (Without 3a & 3b)

EPRI Class	EPRI Description	Frequency/yr	Dose (Person-Rem)	Population Dose Factor	Person-Rem/yr
1	Intact Containment	5.15E-06	2.07E+03	1.24	1.32E-02
2	Large Containment Isolation Failures	2.19E-08	9.97E+05	1.24	2.72E-02
3a	Small Isolation failures (Liner Breach)	(1)	(1)	1.24	(1)
3b	Large Isolation failures (Liner Breach)	(1)	(1)	1.24	(1)
4	Small Isolation Failures - Failure-to-Seal (Type B)	(2)	(2)	1.24	(2)
5	Small Isolation Failures - Failure-to-Seal (Type C)	(2)	(2)	1.24	(2)

EPRI Class	EPRI Description	Frequency/yr	Dose (Person-Rem)	Population Dose Factor	Person-Rem/yr
6	Containment Isolation Failures (Dependent Failure, Personnel Errors)	(2)	(2)	1.24	(2)
7	Severe Accident Phenomena Induced Failure	1.21E-05	2.97E+07	1.24	4.47E+02
8	Containment Bypass (ISLOCA, SGTR)	6.68E-07	1.55E+06	1.24	1.28E+00
	Total:	1.80E-05			4.485E+01

Table 21 and Table 22 account for the Class 3a and 3b data for Unit 1 and Unit 2, respectively. As such, to conserve CDF, the Class 1 frequency is reduced accordingly.

Table 21 U1 – Baseline (Adjusted) Dose Calculation (With 3a & 3b Contribution)

EPRI Class	EPRI Description	Baseline Frequency/yr	Dose (Person-Rem)	Population Dose Factor	Person-Rem/yr
1	Intact Containment(1)	4.85E-06	2.07E+03	1.24	1.25E-02
2	Large Containment Isolation Failures	2.21E-08	7.49E+06	1.24	2.06E-01
3a	Small Isolation failures (Liner Breach)	1.66E-07	2.07E+04	1.24	4.28E-03
3b	Large Isolation failures (Liner Breach)	4.14E-08	2.07E+05	1.24	1.06E-02
7	Severe Accident Phenomena Induced Failure (Early)	1.23E-05	8.63E+05	1.24	1.32E+01
8	Containment Bypass (ISLOCA, SGTR)	6.77E-07	7.14E+05	1.24	6.01E-01
	Total:	1.80E-05			1.404E+01

1. The Class 3a and 3b frequencies, dose and dose-rates were subsumed in the associated Class 1 values. The PRA frequency of Class 1 has been reduced by the frequency of Class 3a and Class 3b in order to preserve CDF.

Table 22 U2 – Baseline (Adjusted) Dose Calculation (With 3a & 3b Contribution)

EPRI Class	EPRI Description	Frequency/yr	Dose (Person-Rem)	Population Dose Factor	Person-Rem/yr
1	Intact Containment(1)	4.94E-06	2.07E+03	1.24	1.27E-02
2	Large Containment Isolation Failures	2.19E-08	7.49E+06	1.24	2.04E-01

EPRI Class	EPRI Description	Frequency/yr	Dose (Person-Rem)	Population Dose Factor	Person-Rem/yr
3a	Small Isolation failures (Liner Breach)	1.66E-07	2.07E+04	1.24	4.26E-03
3b	Large Isolation failures (Liner Breach)	4.12E-08	2.07E+05	1.24	1.06E-02
7	Severe Accident Phenomena Induced Failure (Early)	1.21E-05	8.63E+05	1.24	1.30E+01
8	Containment Bypass (ISLOCA, SGTR)	6.68E-07	7.14E+05	1.24	5.93E-01
	Total:	1.80E-05			1.381E+01

1. The Class 3a and 3b frequencies, dose and dose-rates were subsumed in the associated Class 1 values. The PRA frequency of Class 1 has been reduced by the frequency of Class 3a and Class 3b in order to preserve CDF.

7.3 Step 3 – Risk Impact Evaluation

In this step, the risk associated with the change in CILRT testing intervals is evaluated in terms of change to the accident class frequencies and population doses for classes 1, 3a and 3b. This is accomplished in a 3 step process.

The current surveillance testing requirement of Type A testing and allowed by 10CFR50, Appendix J is at least 1 test-in-10 years based on an acceptable performance history[6] and represents the current licensing basis for Watts Bar. Extending the Type A CILRT interval from 3 tests-in-10 years (original licensing basis) to 1 test-in-10 years (current licensing basis) increased the window of vulnerability for undetected leakage from 18 to 60 months (1/2 the surveillance interval), a factor of 60/18 or a 3.33x increase. Therefore, considering the proposed licensing basis of extending the CILRT Type A test interval from 3 tests-in-10 years to 1 test-in-15 years increases the average time the leaks can be undetected from 18 to 90 months (1/2 the surveillance interval), a factor of 90/18 or a 5x increase.

The following sub-steps are contained within Step 3.

Section 7.3.1	presents the risk impact for a 1 test-in-10 years test interval
Table 23	presents the Unit 1 frequency, dose-rate and dose for a testing interval of 1 test-in-10 years
Table 24	presents the Unit 2 frequency, dose-rate and dose for a testing interval of 1 test-in-10 years

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[6] Defined as two consecutive periodic Type A tests at least 24 months apart in which the calculated performance leakage was less than 1.0 La.

Section 7.3.2	presents the risk impact for a 1 test-in-15 years test interval
Table 25	presents the Unit 1 frequency, dose-rate and dose for a testing interval of 1 test-in-15 years
Table 26	presents the Unit 2 frequency, dose-rate and dose for a testing interval of 1 test-in-15 years
Section 7.3.3	presents the dose-rate increase and percentile increase
Table 27	presents the Unit 1 Class 1 population dose rate increase due to extending the CILRT interval
Table 28	presents the Unit 1 Class 3a population dose rate increase due to extending the CILRT interval
Table 29	presents the Unit 1 Class 3b population dose rate increase due to extending the CILRT interval
Table 30	presents the Unit 1 total population dose rate increase due to extending the CILRT interval
Equation 11	calculates the percent increase in total population dose
Table 31	presents the Unit 2 Class 1 population dose rate increase due to extending the CILRT interval
Table 32	presents the Unit 2 Class 3a population dose rate increase due to extending the CILRT interval
Table 33	presents the Unit 2 Class 3b population dose rate increase due to extending the CILRT interval
Table 34	presents the Unit 2 total population dose rate increase due to extending the CILRT interval

7.3.1 Risk Impact - 1 Test-in-10 Years Test Interval

Based on the approved EPRI methodology and the NEI guidance, the increased probability of not detecting excessive leakage due to Type A tests directly impacts the frequency of the Class 3 sequences.

The risk contribution of 1 test-in-10 years is determined by multiplying the Class 3 accident frequency by a factor of 3.33. Additionally, as the Class 3 sequence are increased, the Class 1 frequency is adjusted downward to maintain the overall core damage frequency constant. The results of this analysis are presented in Table 23 and

Table 24 for Units 1 and 2, respectively.

Table 23 U1 - Testing Once-in-10 Years Risk Profile

EPRI Class	Description	Freq/yr	Dose (Person-Rem)	Population Dose Factor	Person-Rem/yr
1	Intact Containment(1)	4.35E-06	2.07E+03	1.24	1.12E-02

2	Large Cont. Isol. Failures	2.21E-08	7.49E+06	1.24	2.06E-01
3a	Small Isolation Failures (Liner Breach) Assumed 10 La	5.54E-07	2.07E+04	1.24	1.42E-02
3b	Large Isolation Failures (Liner Breach) Assumed 100 La	1.38E-07	2.07E+05	1.24	3.54E-02
7	Severe Accident Phenomena Induced Failure (Early & Late)	1.23E-05	8.63E+05	1.24	1.32E+01
8	Containment Bypass (ISLOCA, SGTR)	6.77E-07	7.14E+05	1.24	6.01E-01
Total:		1.80E-05			1.407E+01

1. The frequency of Class 1 sequences have been reduced by the frequency of Class 3a and Class 3b in order to preserve total CDF constant.

Table 24U2 - Testing Once-in-10 Years Risk Profile

EPRI Class	Description	Freq/yr	Dose (Person-	Population Dose	Person-Rem/yr
1	Intact Containment (1)	4.49E-06	2.07E+03	1.24	1.16E-02
2	Large Cont. Isolation Failures	2.19E-08	7.49E+06	1.24	2.04E-01
3a	Small Isolation failures (Liner Breach)	5.51E-07	2.07E+04	1.24	1.42E-02
3b	Large Isolation failures (Liner Breach)	1.37E-07	2.07E+05	1.24	3.53E-02
7	Severe Accident Phenomena Induced Failure (Early & Late)	1.21E-05	8.63E+05	1.24	1.30E+01
8	Containment Bypass (ISLOCA, SGTR)	6.68E-07	7.14E+05	1.24	5.93E-01
Total:		1.80E-05			1.385E+01

1. The frequency of Class 1 scenarios have been reduced by the frequency of Class 3a and Class 3b in order to preserve CDF.

7.3.2 Risk Impact - Once-in-15 Years Test Interval

The approach for developing the risk contribution for a 15-yr interval is the same as that used for the 10-yr interval. The increase for a 15-yr CILRT interval is the ratio of the average time for a failure to detect for the increased CILRT test interval (from 18-months to 90-months); therefore the baseline data for Class 3 is multiplied by a factor of 5[1, §4.2.3] and Class 1 is adjusted downward to conserve CDF. The results of this calculation are presented in **Table 25** and **Table 26** for Units 1 and 2, respectively.

Table 25 U1 - Testing Once-in-15 Years Risk Profile

EPRI Class	Description	Freq/yr	Dose (Person-Rem)	Population Dose Factor	Person-Rem/yr
1	Intact Containment(1)	4.00E-06	2.07E+03	1.24	1.03E-02

EPRI Class	Description	Freq/yr	Dose (Person-Rem)	Population Dose Factor	Person-Rem/yr
2	Large Containment Isolation Failures	2.21E-08	7.49E+06	1.24	2.06E-01
3a	Small Isolation Failures (Liner Breach)	8.31E-07	2.07E+04	1.24	2.14E-02
3b	Large Isolation Failures (Liner Breach)	2.07E-07	2.07E+05	1.24	5.32E-02
7	Severe Accident Phenomena Induced Failure (Early & Late)	1.23E-05	8.63E+05	1.24	1.32E+01
8	Containment Bypass (ISLOCA, SGTR)	6.77E-07	7.14E+05	1.24	6.01E-01
Total:		1.80E-05			1.410E+01

1. The frequency of Class 1 scenarios have been reduced by the frequency of Class 3a and Class 3b in order to preserve total CDF constant.

Table 26 U2 - Testing Once-in-15 Years Risk Profile

EPRI Class	Description	Freq/yr	Dose (Person-Rem)	Population Dose Factor	Person-Rem/yr
1	Intact Containment(1)	4.14E-06	2.07E+03	1.24	1.07E-02
2	Large Containment Isolation Failures	2.19E-08	7.49E+06	1.24	2.04E-01
3a	Small Isolation Failures (Liner Breach)	8.28E-07	2.07E+04	1.24	2.13E-02
3b	Large Isolation Failures (Liner Breach)	2.06E-07	2.07E+05	1.24	5.30E-02
7	Severe Accident Phenomena Induced Failure (Early & Late)	1.21E-05	8.63E+05	1.24	1.30E+01
8	Containment Bypass (ISLOCA, SGTR)	6.68E-07	7.14E+05	1.24	5.93E-01
Total:		1.80E-05			1.387E+01

1. The frequency of Class 1 scenarios have been reduced by the frequency of Class 3a and Class 3b in order to preserve total CDF constant.

7.3.3 Dose-Rate Increase and Percentile Increase

Given the above estimates, the increases in population dose-rate for each extended interval for EPRI Classes 1, 3a and 3b are estimated as presented in section 7.3.3.1 and 7.3.3.2. Note: The population dose-rate for Class 1 decreases as Class 3b increases to preserve total CDF.

Section 7.3.3.1 presents the Unit-1 population dose-rate data and calculations.

Section 7.3.3.2 presents the Unit-2 population dose-rate data and calculations.

7.3.3.1 Unit 1 Population Dose-Rate Calculations

This section provides the Unit-1 population dose-rate data due to extending the CILRT interval including the OLB comparison with the CLB and PLB intervals, and the difference from CLB and the PLB interval.

Table 27 presents the Class 1 population dose-rate increase due to extending the CILRT interval.

Table 28 presents the Class 3a population dose-rate increase due to extending the CILRT interval.

Table 29 presents the Class 3b population dose-rate increase due to extending the CILRT interval.

Table 30 presents the Total (Class 1, 3a and 3b) population dose-rate increase due to extending the CILRT interval.

Equation 11 provides the percent increase in population dose-rate calculation.

Table 27 U1 - Class 1 PDR Increase Due to Extended Type A CILRT Intervals

CILRT Interval	3-Yrs (Baseline - Adjusted) (person-rem)	10-Yrs (Current) (person-rem)	15-Yrs (Proposed) (person-rem)
Class 1 PDR	1.25E-02	1.12E-02	1.03E-02
ΔClass 1 PDR (OLB→CLB/PLB)		-1.30E-03	-2.19E-03
ΔClass 1 PDR (CLB→PLB)			-8.92E-04

Table 28 U1 - Class 3a PDR Increase Due to Extended Type A CILRT Intervals

CILRT Interval	3-Yrs (Baseline - Adjusted) (person-rem)	10-Yrs (Current) (person-rem)	15-Yrs (Proposed) (person-rem)
Class 3a PDR	4.28E-03	1.42E-02	2.14E-02
ΔClass 3a PDR (OLB→CLB/PLB)		9.97E-03	1.71E-02
ΔClass 3a PDR (CLB→PLB)			7.14E-03

Table 29 U1 - Class 3b PDR Increase Due to Extended Type A CILRT Intervals

CILRT Interval	3-Yrs (Baseline - Adjusted) (person-rem)	10-Yrs (Current) (person-rem)	15-Yrs (Proposed) (person-rem)

Class 3b PDR	1.06E-02	3.54E-02	5.32E-02
ΔClass 3b PDR (OLB→CLB/PLB)		2.48E-02	4.26E-02
ΔClass 3b PDR (CLB→PLB)			1.78E-02

Table 30 U1 –Total PDR Increase Due to Extended Type A CILRT Intervals

CILRT Interval	**3-Yrs (Baseline - Adjusted) (person-rem)**	**10-Yrs (Current) (person-rem)**	**15-Yrs (Proposed) (person-rem)**
ΔPDR_{Total}(OLB→CLB/PLB) Σ ΔClass 1 + ΔClass 3a + ΔClass 3b	2.74E-02	3.35E-02	5.76E-02
ΔPDR_{Total}(CLB→PLB) Σ ΔClass 1 + ΔClass 3a + ΔClass 3b			2.40E-02

Given the above values, the percentile increases in total population dose-rate (PDR) for the each test interval compared to the OLB interval are estimated by dividing the increase in total PDR by the baseline total dose for the OLB. The change from the CLB to the PLB uses the total dose for the CLB PDR.

Equation 11 Percent Increase in Total Population Dose-Rate (PDR)

$$\%INC_{Total\_PDR} = \Delta(PDR_{(Change\ in\ CILRT\ Interval)} / DOSE_{Total(CILRT\ Interval)}) * 100\%$$

Note: $PDR_{(Change\ in\ CILRT\ Interval)}$ taken from Table 30
$DOSE_{Total(CILRT\ Interval)}$ taken from Tables 21 - 26

Unit-1

Percent Increase in Total PDR (OLB→CLB) = (3.35E-02 - 2.74E-02 / 14.04)*100%
= 0.044%

Percentile Increase in Total PDR (CLB→PLB) = (5.75E-02 - 3.35E-02 / 14.07)*100%
= 0.171%

Percentile Increase in Total PDR (OLB→PLB) = (5.75E-02 - 2.74E-02 / 14.10)*100%
= 0.214%

7.3.3.2 Unit 2 Population Dose-Rate Calculations

The following presents the Unit-2 population dose-rate data due to extending the CILRT interval including the OLB comparison with the CLB and PLB intervals, and the CLB and PLB interval.

Table 31 provides the Class 1 population dose-rate increase due to extending the CILRT interval.

Table 32 provides the Class 3a population dose-rate increase due to extending the CILRT interval.

Table 33 provides the Class 3b population dose-rate increase due to extending the CILRT interval.

Table 34 provides the Total (Class 1, 3a and 3b) population dose-rate increase due to extending the CILRT interval.

Table 31U2 – Class 1 PDR Increase Due to Extended Type A CILRT Intervals

CILRT Interval	Baseline - Adjusted (person-rem)	10-Yrs (Current) (person-rem)	15-Yrs (Proposed) (person-rem)
Class 1 PDR Increase	1.27E-02	1.15E-02	1.05E-02
ΔClass 1 PDR (OLB→CLB/PLB)		-1.24E-03	-2.13E-03
ΔClass 1 PDR (CLB→PLB)			-8.89E-04

Table 32U2 – Class 3a PDR Increase Due to Extended Type A CILRT Intervals

CILRT Interval	Baseline - Adjusted (person-rem)	10-Yrs (Current) (person-rem)	15-Yrs (Proposed) (person-rem)
Class 3a PDR Increase	4.26E-03	1.42E-02	2.13E-02
ΔClass 3a PDR (OLB→CLB/PLB)		9.93E-03	1.70E-02
ΔClass 3a PDR (CLB→PLB)			7.12E-03

Table 33U2 – Class 3b PDR Increase Due to Extended Type A CILRT Intervals

CILRT Interval	Baseline - Adjusted (person-rem)	10-Yrs (Current) (person-rem)	15-Yrs (Proposed) (person-rem)
Class 3b PDR Increase	1.06E-02	3.53E-02	5.30E-02
ΔClass 3b PDR (OLB→CLB/PLB)		2.47E-02	4.24E-02
ΔClass 3b PDR (CLB→PLB)			1.77E-02

Table 34U2 Total PDR Increase Due to Extended Type A CILRT Intervals

CILRT Interval	Baseline - Adjusted (person-rem)	10-Yrs (Current) (person-rem)	15-Yrs (Proposed) (person-rem)
ΔPDR$_{Total}$(OLB→CLB/PLB) Σ ΔClass 1 + ΔClass 3a + ΔClass 3b	2.76E-02	3.34E-02	5.73E-02
ΔPDR$_{Total}$(CLB→PLB) Σ ΔClass 1 + ΔClass 3a + ΔClass 3b			2.39E-02

Given the above values, the percentile increases in total population dose-rate (PDR) for the each test interval compared to the OLB interval are estimated by dividing the increase in total PDR by the baseline total dose for the OLB. The change from the CLB to the PLB uses the total dose for the CLB PDR.

Equation 11 Percent Increase in Total Population Dose-Rate (PDR)

$$\%INC_{Total\_PDR} = \Delta(PDR_{(Change\ in\ CILRT\ Interval)} / DOSE_{Total(CILRT\ Interval)}) * 100\%$$

Unit-2

Percent Increase in Total PDR (OLB→CLB) = (3.34E-02 - 2.76E-02 / 13.81)*100%
= 0.042%

Percentile Increase in Total PDR (CLB→PLB) = (5.73E-02 - 3.34E-02 / 13.85)*100%
= 0.172%

Percentile Increase in Total PDR (OLB→PLB) = (5.73E-02 - 2.76E-02/ 13.87)*100%
= 0.214%

7.4 Step 4 – LERF and CCFP Changes

In accordance with the methodology presented above, the potential LERF increase due to a CILRT interval extension is estimated as the difference in the Class 3b frequency value of the original licensing basis of 3 tests-in-10 years, the current licensing basis of 1 test-in-10 years, and the proposed licensing basis of 1 test-in-15 years.

The risk impact associated with extending the CILRT interval involves the potential that a core damage event that normally would result in only a small radioactive release from a containment liner breach could in fact result in a larger release due to the extended window of vulnerability. The additional time between tests could allow for a flaw to continue corroding resulting in a larger containment liner flaw.

In accordance with the EPRI guidance, the Class 3a (Small Liner Leak) dose is assumed to be 10 times the allowable intact containment leakage, 10 La (or 2.07E+04 person-rem) and the Class 3b is assumed to be 100 La (or 2.07E+05 person-rem). The method for defining the dose equivalent for allowable leakage (La) is developed in the EPRI report.[1 §4.2.2] The historical observed average leakage is two times La. Therefore, the estimate is conservative.

Based on the EPRI guidance, the Class 3 sequences represent those leakage paths that have the potential to result in large release if a pre-existing leak path were present. Class 1 sequences are not considered as potential large release pathways because the containment remains intact. Therefore, the containment leak-rate is expected to be small (i.e., less than 2 La). A larger leak-rate would imply an impaired containment, e.g., Classes 2, 3, 6 and 7. Late releases are excluded regardless of the size of the leak because late releases are by definition, not a LERF event.

Therefore, the change in the frequency of Class 3b sequences is used as the increase in LERF for Watts Bar and the change in LERF can be determined by the differences of the 3 test intervals. The EPRI guidance [1 §4.3] states that Class 3b sequences are considered the contributor to LERF associated with the Type A CILRT. Equation **12** for Unit 1 and Unit 2 summarizes the results of the LERF evaluation and the delta LERF for the 3 test intervals.

Regulatory Guide 1.174 provides guidance for determining the risk impact of plant-specific changes to the licensing basis. The EPRI guidance cites RG 1.174 and defines small changes in risk as resulting in increases below 1.0E-05/yr and 1.0E-06/yr, for CDF and LERF, respectively.[10 §2.4] Since the CILRT frequency does not impact CDF, only LERF is relevant. Furthermore, total LERF from all hazards must be less than 1.0E-05/yr.

7.4.1 ΔLERF Determination

Equation 12 ΔLERF Determination for Class 3b

$$\Delta LERF = FREQ_{Class\_3b(CLB\ or\ PLB)} - FREQ_{Class\_3b(OLB)}$$

Unit-1

$\Delta LERF\ (OLB \rightarrow CLB) = FREQ_{Class\_3b\ (CLB)} - FREQ_{Class\_3b(OLB)}$
$= 1.38E\text{-}07/yr - 4.14E\text{-}08/yr$
$= 9.64E\text{-}08/yr$

$\Delta LERF\ (CLB \rightarrow PLB) = FREQ_{Class\_3b(PLB)} - FREQ_{Class\_3b(CLB)}$
$= 2.07E\text{-}07/yr - 1.38E\text{-}07/yr$
$= 6.91E\text{-}08/yr$

$\Delta LERF\ (OLB \rightarrow PLB) = FREQ_{Class\_3b(PLB)} - FREQ_{Class\_3b(OLB)}$
$= 2.07E\text{-}07/yr - 4.14E\text{-}08/yr$
$= 1.66E\text{-}07/yr$

Unit-2

$\Delta LERF\ (OLB \rightarrow CLB) = FREQ_{Class\_3b\ (CLB)} - FREQ_{Class\_3b(OLB)}$
$= 1.37E\text{-}07/yr - 4.12E\text{-}08/yr$
$= 9.60E\text{-}08/yr$

$\Delta LERF\ (CLB \rightarrow PLB) = FREQ_{Class\_3b(PLB)} - FREQ_{Class\_3b(CLB)}$
$= 2.06E\text{-}07/yr - 1.37E\text{-}07/yr$
$= 6.88E\text{-}08/yr$

$\Delta LERF\ (OLB \rightarrow PLB) = FREQ_{Class\_3b(PLB)} - FREQ_{Class\_3b(OLB)}$
$= 2.06E\text{-}07/yr - 4.12E\text{-}08/yr$
$= 1.65E\text{-}07/yr$

7.4.2 Conditional Containment Failure Probability

In accordance with the methodology[1, §5.1.4] presented in Section 5.4.2, the change in the Conditional Containment Failure Probability (CCFP) due to an CILRT interval extension is estimated as the difference in the CCFP values for the original and extended intervals.

Equation 13 Change in CCFP

CCFP = [1 - (FREQClass_1(CILRT Interval) + FREQClass_3a(CILRT Interval) / CDFTotal] *100%

Unit-1

CCFP (OLB) = $[1 – (FREQ_{Class\_1\_U1\_ADJ} + FREQ_{Class\_3a\_U1\_OLB}) / CDF_{Total\_U1}]$ *100%
= [1 – (4.85E-06/yr + 1.66E-07/yr) / 1.84E-05/yr] *100%
= 72.74%

CCFP (CLB) = $[1 – (FREQ_{Class\_1\_U1\_CLB} + FREQ_{Class\_3a\_U1\_CLB}) / CDF_{Total\_U1}]$ *100%
= [1 – (4.35E-06/yr + 5.54E-07/yr) / 1.84E-05/yr] *100%
= 73.38%

CCFP (PLB) = $[1 – (FREQ_{Class\_1\_U1\_PLB} + FREQ_{Class\_3a\_U1\_PLB}) / CDF_{Total\_U1}]$ *100%
= [1 – (4.00E-06/yr + 8.31E-07/yr) / 1.84E-05/yr] *100%
= 73.75%

Unit-2

CCFP (OLB) = $[1 – (FREQ_{Class\_1\_U2\_ADJ} + FREQ_{Class\_3a\_U2\_OLB}) / CDF_{Total\_U2}]$ *100%
= [1 – (4.94E-06/yr + 1.66E-07/yr) / 1.84E-05/yr] *100%
= 72.16%

CCFP (CLB) = $[1 – (FREQ_{Class\_1\_U2\_CLB} + FREQ_{Class\_3a\_U2\_CLB}) / CDF_{Total\_U2}]$ *100%
= [1 – (4.49E-06/yr + 5.51E-07/yr) / 1.84E-05/yr] *100%
= 72.52%

CCFP (PLB) = $[1 – (FREQ_{Class\_1\_U2\_PLB} + FREQ_{Class\_3a\_U2\_PLB}) / CDF_{Total\_U2}]$ *100%
= [1 – (4.14E-06/yr + 8.28E-07/yr) / 1.84E-05/yr] *100%
= 72.89%

Equation 14 %Change CCFP

$$INC_{CCFP(For\ given\ CILRT\ Interval)} = CCFP_{(CILRT\ Interval\ of\ Interest)} - CCFP_{OLB}$$

Unit-1

CCFP Increase (OLB→CLB) = $CCFP_{CLB}– CCFP_{OLB}$
= 73.37% - 72.73%
= 0.638%

CCFP Increase (OLB→PLB) = $CCFP_{PLB}– CCFP_{OLB}$
= 73.75% - 72.73%
= 1.013%

CCFP Increase (CLB→PLB) = $CCFP_{PLB}– CCFP_{CLB}$
= 73.75% - 73.37%
= 0.375%

Unit-2

CCFP Increase (OLB→CLB) = $CCFP_{CLB} – CCFP_{OLB}$
= 72.58% - 72.23%
= 0.354%

CCFP Increase (OLB→PLB) = $CCFP_{PLB} – CCFP_{OLB}$
= 72.96% - 72.23%
= 0.729%

CCFP Increase (CLB→PLB) = $CCFP_{PLB}– CCFP_{CLB}$
= 72.96% - 72.58%
= 0.375%

7.4.3 Summary ΔLERF - ΔCCFP

Table 35 and Table 36 summarize the ΔLERF and ΔCCFP results for Unit-1 and Unit-2, respectively.

Table 35 Unit-1 Summary ΔLERF - ΔCCFP

Risk Metric	CILRT Interval		
	OLB→CLB	OLB→PLB	CLB→PLB
Δ LERF	9.64E-08	1.66E-07	6.91E-08
Δ CCFP (% Change)	0.638	1.013	0.375

Table 36 Unit-2 Summary ΔLERF - ΔCCFP

Risk Metric	CILRT Interval		
	OLB→CLB	OLB→PLB	CLB→PLB
Δ LERF	9.60E-08	1.65E-07	6.88E-08
Δ CCFP (% Change)	0.354	0.729	0.375

8.0 Sensitivity Analyses

The EPRI guidance for the analysis of extending the CILRT interval suggests using the liner corrosion sensitivity analysis performed by Calvert Cliffs.[12] Additionally the contribution of external events will be addressed in this section. It is important to note that the corrosion analysis is a sensitivity case that represents the first 15-year extension. It is possible for some slow corrosion mechanisms, such as embedment of debris in containment during initial containment construction, where the probability of leakage can continue to increase over longer periods. However, these mechanisms are generally very slow and have a very limited potential for the development of large leakage pathways before detection.[1, §5.1.5.1]

8.1 Liner Corrosion

The analysis approach uses the Calvert Cliffs Nuclear Plant (CCNP) methodology[12] as modified by the EPRI guidance.[1] This methodology is an acceptable approach to incorporate the liner corrosion issue into the CILRT interval extension evaluation. The results of the analysis indicate that increasing the interval from the original licensing basis to the proposed licensing basis did not significantly increase plant risk of a large early release (Reference Table 40 and Table 41, Unit 1 and 2, respectively).

The methodology investigates how an age-related degradation mechanism can be factored into the risk impact associated with longer CILRT testing intervals.

The results of the analysis indicate that increasing the interval from 3 years (e.g., 3 tests-in-10 years) to 15 years did not significantly increase plant risk of a large early release.

The metric used in the sensitivity analysis is the conditional containment failure probability (CCFP) which is defined as the probability of containment failure given the occurrence of an accident.

The following approach is used to determine the change in likelihood, due to extending the CILRT interval, of detecting corrosion of the steel liner. This likelihood is used to determine the potential change in risk in the form of the sensitivity analysis. Consistent with the Calvert Cliffs analysis, the following are addressed:

- Differences between the containment basemat and the containment cylinder and dome,
- The historical steel liner flaw likelihood due to corrosion,
- The impact of aging,
- The corrosion leakage dependency on containment pressure,
- The likelihood that visual inspections will be effective at detecting a flaw.

8.1.1 Assumptions Used In the Corrosion Sensitivity Analysis

The assumptions used in this sensitivity study are consistent with the Calvert Cliffs methodology and include the following:

1. A half-failure is assumed (e.g., Jeffrey's non-informative prior) for basemat concealed liner corrosion due to no operational experience with basemat failures. (Table 37 Step 1)
2. Two corrosion events are used to estimate the liner flaw probability. These events, one at North Anna Unit 2 and the other at Brunswick Unit 2, were initiated from the non-visible (backside) of the containment liner.
3. The success data was limited to 5.5 years to reflect the years since September 1996 when 10CFR50.55a started requiring visual inspection and the Calvert Cliffs analysis.[7] (Table 37 Step 1)
4. The likelihood of the containment atmosphere reaching the outside atmosphere given a liner flaw exists was estimated at 1.0% for the cylinder/dome and 0.1% (1/10 of the cylinder failure probability) for the basemat. These values are conservative as the WBN Level 2 analysis has 1.0% leakage probability at 62 psia; whereas the design pressure is 28.2 psia. [19, §6.2.1.2]
5. The likelihood of leakage escape (due to crack formation) in the basemat region is assumed to be ten times less likely than the containment cylinder and dome region. (Table 37, Step 4)
6. A 5% visual inspection detection failure likelihood given the flaw is visible and a total detection failure likelihood of 10% is assumed in the analysis.[6] (Table 37, Step 5)
7. All non-detectable failures are assumed to result in large early releases. This approach is conservative and avoids detailed analysis of containment failure timing and operator recovery actions. That is, the probability of all non-detectable failures from the corrosion sensitivity analysis are added to the EPRI Class 3b (and subtracted from EPRI Class 1).

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[7] Additional success data was not used to limit the aging impact of the corrosion issue, although inspections were being performed prior to the requirement. Furthermore there was no evidence that other liner corrosion issues were identified.

8. The liner flaw likelihood is assumed to double every five years. This is based solely on judgment and was included in the Calvert Cliffs analysis. This is done to address the increased likelihood of corrosion as the liner ages. (Table 37 Steps 2 and 3)

8.1.2 Differences in the Watts Bar Design from Calvert Cliffs

8.1.2.1 Structural Design

The WBN containment design[19, §6.2.1.2] complies with NRC General Design Criteria 16 (Containment Design). The primary reactor containment is a freestanding, continuous welded steel membrane structure with a vertical cylinder, hemispherical dome, and a flat circular base. A reinforced concrete shield building, surrounding the steel vessel, allows for collection of any containment leakage into an annular region which is subsequently processed by the Emergency Gas Treatment System (EGTS) before release to the environment. The shield building protects the containment vessel from external events.

The double enclosure concept affords minimal interaction between the containment vessel (leakage barrier) and the reactor building (protected structure); a margin of conservatism in leakage rate from the use of two structures and the EGTS; and a reduction of gaseous and particulate radioactive release due to mixing and holdup prior to filtering and release.

- Containment Design – General Information
  The following information is from Reference [19, §6.2.1.2]
    - Design Pressure, psig 13.5
    - Design Temperature 250°F
    - Design & Maximum Allowable Leakage Rate, 0.25%/day
    - Free Volume 1,171,012 ft^{3} [19 Table 6.2.1-13]

- Testing

  The WBN reactor containments meets NRC General Design Criteria (GDC) Criterion 52 and 53 with respect to integrated leak rate testing and inspections.[19, §3.1]
- Foundation & Bottom Liner Plate

  The primary containment foundation consists of a 9-foot thick circular reinforced concrete structural slab. The outer 5 - 13 feet where adjacent to other structures is thickened from 12 - 16 feet. [19, §3.8.5.1.1] The containment bottom liner plate is encased in concrete and is not visible. [19, §3.8.2.2.2]
- Visual Accessibility

  Visual inspections of the containment steel liner to satisfy the applicable requirements of the Technical Specifications and ASME Section XI are governed by procedure.[5]] The purpose of the general visual examination is to detect evidence of abnormal degradation or evidence of structural deterioration that may affect either structural integrity or leak tightness.

  The general visual examination is currently performed prior to the ten-year containment CILRT, and during two subsequent outages preceding the next required CILRT.[5]]

The containment liner has areas where visual inspection is impossible to perform. These areas include the containment floor liner which is incased in concrete, the area adjacent to the ice condensers, the fuel transfer tube areas and others.[19, §6.2.1.2]

8.1.3 Base Case Risk Assessment

Table 37 summarizes the results obtained from the CCNP methodology using plant-specific data for Watts Bar.

Table 37 WBN Liner Corrosion Base-Case Risk Assessment

Step	Description	Containment Cylinder and Dome (85%)		Containment Basemat (15%)	
1	Historical Liner Flaw Likelihood[8] **Failure Data:** Containment Location Specific	Events: 2 (Brunswick & North Anna) 2 / (70 * 5.5) = **5.19E-03**		Events: 0 Assume a ½ Failure 0.5 / (70 * 5.5) = **1.30E-03**	
2	Aged Adjusted Liner Flaw Likelihood[9]	**Year**	**Failure Rate**	**Year**	**Failure Rate**
		1	2.1E-03	1	5.0E-04
		5-10 (ave)	5.2E-03	5-10 (ave)	1.3E-03
		15	1.4E-02	15	3.5E-03
		15 Year Ave = **6.27E-03**		15 Year Ave = **1.57E-03**	
3	Flaw Likelihood at 3, 10 and 15 years.[10]	**Range**	**% Increase**	**Range**	**% Increase**
		1 – 3 yrs	0.71	1 – 3 yrs	0.18
		1 – 10 yrs	4.06	1 – 10 yrs	1.02
		1 – 15 yrs[11]	9.40	1 – 15 yrs[12]	2.35

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[8] Containment location specific (consistent with the Calvert Cliffs analysis)[12]

[9] During the 15-year interval, assume the failure rate doubles every five years (14.9% increase per year). The average for the fifth to tenth year set to the historical failure rate. (Consistent with the Calvert Cliffs analysis)

[10] Uses age-adjusted liner flaw likelihood (Step 2), assuming failure rate doubles every five years (consistent with Calvert Cliffs)

[11] The Calvert Cliffs analysis presents the delta between 3 and 15 years of 8.7% to utilize in the estimation of the delta LERF value. For this analysis however, the values are calculated based on 3, 10 and 15 year intervals, consistent with the desired presentation of the results.[1, §5.2.5.1]

[12] The Calvert Cliffs analysis presents the delta between 3 and 15 years of 2.2% to utilize in the estimation of the delta-LERF value. For this analysis however, the values are calculated based on 3, 10 and 15 year intervals, consistent with the desired presentation of the results.[1, §5.2.5.1]

Step	Description	Containment Cylinder and Dome (85%)	Containment Basemat (15%)
4	Likelihood of Breach in Containment Given Liner Flaw[13]	1.0%	0.1%
5	Visual Inspection Detection Failure Likelihood	10% [14]	100% [15]
6	Likelihood of Non-Detected Containment Leakage (Steps 3 x 4 x 5)	**3-Year (Ave) Interval (OLB)** 0.71% x 1.0% x 10% 0.00071%	**3-Year (Ave) Interval (OLB)** 0.18% x 0.1% x 100% 0.00018%
		10-Year Test Interval (CLB) 4.06% x 1.0% x 10% 0.00406%	**10-Year Test Interval (CLB)** 1.02% x 0.1% x 100% 0.00102%
		15-Year Test Interval (PLB) 9.4% x 1.0% x 10% 0.0094%	**15-Year Test Interval (PLB)** 2.35% x 0.1% x 100% 0.00235%
	Total Likelihood of Non-Detected Containment Leakage (Cylinder, Dome and Basemat)	OLB: 0.00071% + 0.00018% = 0.00000089% or 8.90E-07 CLB: 0.00406% + 0.00102% = 0.00000508% or 5.62E-06 PRB: 0.0094% + 0.00235% = 0.0000094% or 1.18E-05	

8.1.4 Likelihood of Non-Detected Containment Leakage and LERF Impact

The total likelihood of non-detected containment leakage is the sum of Step 6 for the containment cylinder and dome and the containment basemat. The results from Equation 15 apply to both Watts Bar units.

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[13] The failure probability of the cylinder and dome is assumed to be 1%, and basemat is 0.1% as compared to 1.1% and 0.11% in the Calvert Cliffs analysis.

[14] 5% failure to identify visual flaws plus 5% likelihood that the flaw is not visible (not through-cylinder but could be detected by CILRT). All events have been detected through visual inspection. 5% visible failure detection is a conservative assumption.

[15] The containment basemat liner cannot be visually inspected.

Equation 15 Total Likelihood of Non-Detected Containment Leakage

Total Likelihood of Non-Detected Containment Leakage

Non-Det Cont $\text{Leakage}_{\text{Total}}$ = Step $6_{\text{(Cylinder \& Dome)}}$ + Step $6_{\text{(Basemat)}}$

(OLB) = 0.00071% + 0.00018% = 0.00089% or 8.90E-06
(CLB) = 0.00406% + 0.00102% = 0.00508% or 5.62E-05
(PLB) = 0.00940% + 0.00235% = 0.01175% or 1.18E-04

Equation 16 Liner Corrosion Non-LERF Frequency

$$\mathbf{FREQ_{Non\text{-}LERF} = CDF_{BL} - FREQ_{Class\ 2} - FREQ_{Class\ 3b(OLB)} - FREQ_{Class\ 7\_Early} - FREQ_{Class\ 8}}$$

Example (U1): = 1.80E-05/yr – 2.21E-08/yr – 4.14E-08/yr – 6.74E-07/yr - 6.77E-07/yr
= 1.66E-05/yr

The above factors are applied to those core damage accidents that are not already independently LERF or that could never result in LERF. The following explains how this data is used in

Table 38 and Table 39 Unit-2 Increase in LERF/yr for Unit 1 and 2, respectively.

- Per Table 21, the Unit-1 EPRI Class 3b frequency is 4.14E-08/yr.
- As shown in Table 15, the Watts Bar CDF associated with accidents that are not independently LERF or could never result in LERF (i.e., SERF, Class 6) is 1.84E-05/yr – 3.80E-07/yr = 1.80E-05/yr
- The OLB test interval data determined by Equation 15 (8.90E-06) is multiplied by the non-LERF probability determined by the example in Equation 16 (1.73E-05/yr), which results in an increase in LERF of 1.46E-10/yr (
-
- Table 38) The value represents the increase in the baseline Class 3b frequency due to the corrosion-induced concealed flaw issue.

The term “Case” denotes the following abbreviations, OLB – Original Licensing Basis, or 1 test every 3 years, CLB – Current Licensing Basis, or 1 test in 10 years, and PLB – Proposed Licensing Basis, or 1 test in 15 years.

Equation 17 Liner Corrosion – Increase in LERF

$$\mathbf{Increase\ In\ LERF = FREQ_{Non\text{-}LERF} * P_{Non\text{-}Detected\ leakage}}$$

Table 38 Unit-1 Increase in LERF/yr

Case	CDF/yr Baseline	Class 2/yr	Class 3b/yr	Class 8/yr	Non-LERF Frequency (Eq. 16)	Non-Detected Leakage (Eq. 15)	Increase In LERF/yr (Eq. 17)

OLB	1.80E-05	2.21E-08	4.14E-08	6.77E-07	1.66E-05	8.90E-06	1.48E-10
CLB	1.80E-05	2.21E-08	1.38E-07	6.77E-07	1.66E-05	5.62E-05	9.34E-10
PLB	1.80E-05	2.21E-08	2.07E-07	6.77E-07	1.66E-05	1.18E-04	1.95E-09

Table 39 Unit-2 Increase in LERF/yr

Case	CDF/yr Baseline	Class 2/yr	Class 3b/yr	Class 8/yr	Non-LERF Frequency (Eq. 16)	Non-Detected Leakage (Eq. 15)	Increase In LERF/yr (Eq. 17)
OLB	1.80E-05	2.19E-08	4.12E-08	6.68E-07	1.66E-05	8.90E-06	1.47E-10
CLB	1.80E-05	2.19E-08	1.37E-07	6.68E-07	1.66E-05	5.62E-05	9.31E-10
PLB	1.80E-05	2.19E-08	2.06E-07	6.68E-07	1.66E-05	1.18E-04	1.95E-09

8.1.5 Corrosion Impact on CCFP

This section uses the likelihood of the containment atmosphere reaching the outside atmosphere given a liner flaw exists which was estimated at 1.0% for the cylinder/dome and 0.1% (1/10 of the cylinder failure probability) for the basemat. These values are conservative as the WBN Level 2 analysis has 1.0% leakage probability at 62 psia; whereas the design pressure is just 28.2 psia. This methodology is consistent with the Calvert Cliffs methodology.[5]

In Equation 18 the increase in the CCFP (From Equation 13) due to assumed corrosion is calculated.

Equation 18 Increase in CCFP Due to Increase in Flaw Likelihood

$$\mathbf{INC_{CCFP(CILRT\ Interval)} = CCFP_{(CILRT\ Interval)} * 1.10\% + CCFP_{(CILRT\ Interval)}}$$

Unit-1

$$\begin{aligned} INC_{CCFP\_OLB} &= CCFP_{OLB} * 1.1\% + CCFP_{OLB} \\ &= 0.7273 * 1.1\% + 0.7274 \\ &= 0.7354 \\ INC_{CCFP\_CLB} &= CCFP_{CLB} * 1.1\% + CCFP_{CLB} \\ &= 0.7337 * 1.1\% + 0.7338 \\ &= 0.7419 \\ INC_{CCFP\_PLB} &= CCFP_{PLB} * 1.1\% + CCFP_{PLB} \\ &= 0.7375 *1.1\% + 0.7375 \\ &= 0.7457 \end{aligned}$$

Unit 2

$$\begin{aligned} INC_{CCFP\_OLB} &= CCFP_{OLB} * 1.1\% + CCFP_{OLB} \\ &= 0.7223 * 1.1\% + 0.7216 \\ &= 0.7296 \\ INC_{CCFP\_CLB} &= CCFP_{CLB} * 1.1\% + CCFP_{CLB} \\ &= 0.7258 * 1.1\% + 0.7252 \\ &= 0.7332 \\ INC_{CCFP\_PLB} &= CCFP_{PLB} * 1.1\% + CCFP_{PLB} \\ &= 0.7296 * 1.1\% + 0.7289 \end{aligned}$$

$= 0.7370$

Equation 19 uses the CCFP calculated in Equation 13 and subtracts the Corrosion-Induced CCFP from Equation 18 to determine the increase in the CCFP due to corrosion.

Equation 19 ΔCCFP Increase Due to Corrosion

$$\mathbf{INC_{\Delta CCFP(CILRT\ Interval)} = CCFP(_{With\ Corrosion)} - CCFP(_{Without\ Corrosion)}}$$

Unit-1

$$\begin{aligned} INC_{\Delta CCFP\_OLB} &= CCFP_{OLB(With)} - CCFP_{OLB(Without)} \\ &= 0.7354 - 0.7274 \\ &= 0.00800 \\ INC_{\Delta CCFP\_OLB} &= CCFP_{CLB(With)} - CCFP_{CLB(Without)} \\ &= 0.7419 - 0.7338 \\ &= 0.00807 \\ INC_{\Delta CCFP\_OLB} &= CCFP_{PLB(With)} - CCFP_{PLB(Without)} \\ &= 0.7457 - 0.7375 \\ &= 0.00811 \end{aligned}$$

Unit 2

$$\begin{aligned} INC_{\Delta CCFP\_OLB} &= CCFP_{OLB(With)} - CCFP_{OLB(Without)} \\ &= 0.7296 - 0.7216 \\ &= 0.00794 \\ INC_{\Delta CCFP\_OLB} &= CCFP_{OLB(With)} - CCFP_{OLB(Without)} \\ &= 0.7332 - 0.7252 \\ &= 0.00798 \\ INC_{\Delta CCFP\_OLB} &= CCFP_{OLB(With)} - CCFP_{OLB(Without)} \\ &= 0.7370 - 0.7289 \\ &= 0.00802 \end{aligned}$$

8.1.6 Summary of Base Case and Corrosion Sensitivity Cases

The contribution of corrosion-induced LERF likelihood (determined in section 8.1.4) is added to the Class 3b LERF cases and a sensitivity analysis is performed. Table 40 and

Table 41 for Unit 1 and Unit 2, respectively, provide a summary of the base case as well as the corrosion sensitivity case. The table is divided into three main columns representing the frequency of the CILRT interval:

- Base Case, which represents the Original Licensing Basis (OLB) of 3 tests-in-10 years.
- Current Licensing Basis (CLB), 1 test-in-10 years.
- Proposed Licensing Basis (PLB), 1 test-in-15 years.

Each of the three columns is sub-divided further into corrosion and non-corrosion cases. For both the corrosion and non-corrosion cases, the frequencies of the EPRI accident classes are provided. In the non-corrosion cases, an additional column titled ‘Δ Person-Rem/Yr’ is provided. The ‘Δ Person-Rem/Yr’ column provides the change in person-rem/yr between the corrosion and non-corrosion cases. Negative values in the ‘Δ Person-Rem/Yr’ column indicate a reduction in the person-rem/yr for the selected accident class. This occurs only in accident Class 1 and is a result of the reduction in the frequency of the accident class 1 and an increase in Class 3b.

Rows for the totals, both frequency and dose-rate, are provided in the table. Additional summary rows are also provided, including:

- The change in dose-rate, expressed as person-rem/yr and percentage of the total baseline dose is provided in the row below the ‘baseline’ row.
- The Conditional Containment Failure Probability (CCFP) is provided in the next row, followed by the change in the CCFP as a percentage.
- Class 3b LERF is provided and the accident Class 3b frequency as well as the change in the Class 3b frequency below.
- The row titled ‘ΔLERF Class 3b & Non-Corrosion LERF’ provides the difference between the non-corrosion and corrosion cases.
- The row titled ‘ΔLERF (from base case of 3 per 10 years)’ provides the change in LERF as a function of CILRT frequency from the OLB. The difference between the non-corrosion and corrosion-cases is provided.
- The row titled ‘ΔLERF from 1 per 10 years’ provides the change in LERF as a function of CILRT frequency from the CLB. The difference between the non-corrosion and corrosion-cases is provided.

Table 40 Unit-1 Summary of Base Case and Corrosion Sensitivity Cases

EPRI Class	Original Licensing Basis Base Case (3 per 10 years)					Current Licensing Basis (1 per 10 years)					Proposed Licensing Basis (1 per 15 years)				
	Without Corrosion		With Corrosion			Without Corrosion		With Corrosion			Without Corrosion		With Corrosion		
	Frequency	Person-Rem Per Year	Frequency	Person-Rem Per Year	ΔPer-Rem Per Year	Frequency	Person-Rem Per Year	Frequency	Person-Rem Per Year	ΔPer-Rem Per Year	Frequency	Person-Rem Per Year	Frequency	Person-Rem Per Year	ΔPer-Rem Per Year
1	4.85E-06	1.25E-02	4.85E-06	1.25E-02	-3.81E-07	4.37E-06	1.12E-02	4.37E-06	1.12E-02	-2.40E-06	4.02E-06	1.04E-02	4.02E-06	1.03E-02	-5.03E-06
2	2.21E-08	2.05E-01	2.21E-08	2.05E-01	N/A	2.21E-08	2.05E-01	2.21E-08	2.05E-01	N/A	2.21E-08	2.05E-01	2.21E-08	2.05E-01	N/A
3a	1.66E-07	4.28E-03	1.66E-07	4.28E-03	N/A	5.54E-07	1.42E-02	5.54E-07	1.42E-02	N/A	8.31E-07	2.14E-02	8.31E-07	2.14E-02	N/A
3b	4.14E-08	1.06E-02	4.15E-08	1.07E-02	3.81E-05	1.38E-07	3.54E-02	1.39E-07	3.57E-02	2.40E-04	2.07E-07	5.32E-02	2.09E-07	5.37E-02	5.03E-04
7	1.23E-05	1.32E+01	1.23E-05	1.32E+01	N/A	1.23E-05	1.32E+01	1.23E-05	1.32E+01	N/A	1.23E-05	1.32E+01	1.23E-05	1.32E+01	N/A
8	6.77E-07	6.01E-01	6.77E-07	6.01E-01	N/A	6.77E-07	6.01E-01	6.77E-07	6.01E-01	N/A	6.77E-07	6.01E-01	6.77E-07	6.01E-01	N/A
CDF/ Total Dose	1.80E-05	1.40E+01	1.80E-05	1.40E+01	3.77E-05	1.80E-05	1.40E+01	1.80E-05	1.40E+01	2.38E-04	1.80E-05	1.41E+01	1.80E-05	1.41E+01	4.98E-04
ΔDose Rate	N/A		N/A			ΔDose (per-rem/yr)	3.35E-02	ΔDose (per-rem/yr)	3.37E-02		ΔDose (per-rem/yr)	5.76E-02	ΔDose (per-rem/yr)	5.75E-02	
						%Inc	0.239%	%Inc	0.241%		%Inc	0.411%	%Inc	0.410%	
CCFP	72.74%		73.54%			73.26%		74.07%			73.64%		74.45%		
ΔCCFP	N/A		N/A			0.523%		0.529%			0.899%		0.908%		
Class 3b LERF	4.14E-08		4.15E-08			1.38E-07		1.39E-07			2.07E-07		2.09E-07		
ΔLERF Class 3b & Non-Corrosion LERF			1.48E-10			N/A		9.34E-10			N/A		1.95E-09		
ΔLERF (from base case of 3 per 10 years)						9.64E-08		9.72E-08			1.66E-07		1.67E-07		
ΔLERF from 1 per 10 years						N/A					6.91E-08		7.01E-08		

Table 41 Unit-2 Summary of Base Case and Corrosion Sensitivity Cases

EPRI Class	**Original Licensing Basis Base Case (3 per 10 years)**					**Current Licensing Basis (1 per 10 years)**					**Proposed Licensing Basis (1 per 15 years)**				
	Without Corrosion		**With Corrosion**			**Without Corrosion**		**With Corrosion**			**Without Corrosion**		**With Corrosion**		
	Frequency	**Person-Rem Per Year**	**Frequency**	**Person-Rem Per Year**	**ΔPer-Rem Per Year**	**Frequency**	**Person-Rem Per Year**	**Frequency**	**Person-Rem Per Year**	**ΔPer-Rem Per Year**	**Frequency**	**Person-Rem Per Year**	**Frequency**	**Person-Rem Per Year**	**ΔPer-Rem Per Year**
1	4.94E-06	1.27E-02	4.94E-06	1.27E-02	-3.79E-07	4.46E-06	1.15E-02	4.46E-06	1.12E-02	-2.39E-06	4.11E-06	1.06E-02	4.11E-06	1.03E-02	-5.01E-06
2	2.19E-08	2.04E-01	2.19E-08	2.04E-01	N/A	2.19E-08	2.04E-01	2.19E-08	2.04E-01	N/A	2.19E-08	2.04E-01	2.19E-08	2.04E-01	N/A
3a	1.66E-07	4.26E-03	1.66E-07	4.26E-03	N/A	5.51E-07	1.42E-02	5.51E-07	1.42E-02	N/A	8.28E-07	2.13E-02	8.28E-07	2.13E-02	N/A
3b	4.12E-08	1.06E-02	4.14E-08	1.06E-02	3.79E-05	1.37E-07	3.53E-02	1.38E-07	3.55E-02	2.39E-04	2.06E-07	5.30E-02	2.08E-07	5.35E-02	5.01E-04
7	1.21E-05	1.30E+01	1.21E-05	1.30E+01	N/A	1.21E-05	1.30E+01	1.21E-05	1.30E+01	N/A	1.21E-05	1.30E+01	1.21E-05	1.30E+01	N/A
8	6.68E-07	5.93E-01	6.68E-07	5.93E-01	N/A	6.68E-07	5.93E-01	6.68E-07	5.93E-01	N/A	6.68E-07	5.93E-01	6.68E-07	5.93E-01	N/A
CDF/ Total Dose	1.80E-05	1.38E+01	1.80E-05	1.38E+01	3.75E-05	1.80E-05	1.39E+01	1.80E-05	1.39E+01	2.37E-04	1.80E-05	1.39E+01	1.80E-05	1.39E+01	4.96E-04
ΔDose Rate	N/A		N/A			ΔDose (per-rem/yr)	3.34E-02	ΔDose (per-rem/yr)	3.34E-02		ΔDose (per-rem/yr)	5.73E-02	ΔDose (per-rem/yr)	5.76E-02	
						%Inc	0.241%	%Inc	0.241%		%Inc	0.414%	%Inc	0.416%	
CCFP	72.16%		72.96%			72.692%		73.49%			73.06%		73.87%		
ΔCCFP	N/A		N/A			0.523%		0.529%			0.899%		0.908%		
Class 3b LERF	4.12E-08		4.14E-08			1.37E-07		1.38E-07			2.06E-07		2.08E-07		
ΔLERF Class 3b & Non-Corrosion LERF			1.47E-10			N/A		9.31E-10			N/A		1.95E-09		
ΔLERF (from base case of 3 per 10 years)						9.60E-08		9.68E-08			1.65E-07		1.67E-07		
ΔLERF from 1 per 10 years						N/A					6.88E-08		6.98E-08		

8.1.7 Liner Corrosion Sensitivity Conclusion

As shown in Table 40 and Table 41 for Unit 1 and Unit 2, respectively, the inclusion of corrosion does not result in an increase in LERF sufficient to invalidate the baseline analysis and the overall potential impact is negligible.

8.2 Seismic CDF

The WBN seismic model has been peer reviewed and the Findings and Observations (F&Os) have been subjected to the Appendix X closure review process, discussed in section 4.5.
The seismic PRA CDF value is 2.60E-06/yr and 2.61E-06/yr, for Unit 1 and 2, respectively.[33]

9.0 Evaluation of External Events

In this step, the potential contribution from external events is estimated as a result of increasing the CILRT interval. Due to lack of detailed Level 2 PRA modeling availability for external events, their potential contribution is limited to a conservative estimate of the change in LERF associated with the CILRT interval extension. External events were evaluated in the Watts Bar 10CFR 50.69 License Amendment Request (LAR) where justification for screening of all other external hazards from further consideration was performed with exception of seismic, internal flooding and internal fires. Both seismic and internal flooding hazards are evaluated with a plant specific PRA model. Internal fires were subjected to the Fire Induced Vulnerability Evaluation (FIVE) in support of the IPEEE submitted to NRC.[5

Fire events were considered to be the most limiting due to their frequency of occurrence and their potential impact on plant operation. Therefore, it is assumed that internal fire events bound the risk contribution from other external events.

External events were evaluated in the Watts Bar 10CFR 50.69 License Amendment Request (LAR)[52] where justification for screening of all ‘other’ external hazards from further consideration was performed with exception of seismic, internal flooding and internal fires. Both seismic and internal flooding hazards are evaluated with plant specific PRA models. Internal fires were subjected to the Fire Induced Vulnerability Evaluation (FIVE) in support of the IPEEE submitted to NRC.[18]

9.1 Internal Fires Analysis

The findings contained in NUREG-1742[21] indicate that the fire CDF is primarily determined by plant transient type of events such as those from assessed plant transients. The judgment is made based on this observation that it is reasonable to assume that the ratio of intact to impaired containments will be similar for fire as for the internal events such that the total CDF and the breakdown by EPRI Class will be equivalent to that presented for the internal events.

The Watts Bar internal fire analysis was originally performed in 1998 for WBN Unit 1 and updated in 2014 for WBN Unit 2,[53] in accordance with the Fire Induced Vulnerability Evaluation (FIVE) approach to meet the requirements for the IPEEE. FIVE is fundamentally a prescriptive fire PRA-based screening approach, which uses progressively more detailed phases of screening. All of the WBN fire areas were screened being lower than 1.0E-06 in Phase II of the analysis.[20]

The fire-induced core damage frequencies calculated in Part II of the IPEEE FIVE analysis were not summed to give a total fire-induced core damage frequency because, since all fire areas screened there was not a determination made of the core damage frequency from internal fires. For this analysis, a bounding frequency of 1.0E-06/yr is used.[16, 20] Subsequent to FIVE, the Watts Bar plant has performed modifications to reduce the risk from fire events. These modifications include hot-short probability mitigation and Appendix R modifications (cable routing, cable wrapping, cable tray covers, and others).

9.2 Seismic Hazards Analysis

Addressed in Section 4.3.4.

9.3 Other External Events Analysis

The contribution from 'other' external hazards such as high winds, transportation, etc., are relatively insignificant in comparison to the consequences of seismic and internal fire events. Watts Bar screen 'other external hazards' from further consideration as part of the required information for the 10 CFR 50.69 License Amendment Request (LAR).[52] The IPEEE assessment of internal fires concluded that the risk (CDF) is less than 1.0E-06/yr; therefore, 1.0E-06 yr is used in this analysis which bounds internal fire risk. Seismic risk is determined by the SPRA model quantification.

9.3.1 External Events Contribution to CDF

The following calculation and results are applicable for both Watts Bar units.

Equation 20 External Events Contribution to CDF

$$\begin{aligned}
\mathbf{CDF_{EE\text{-}U1}} &= \mathbf{CDF_{Fire\_Ux} + CDF_{Seismic\_U1}} \\
&= 1.0E\text{-}06/yr + 2.60E\text{-}06/yr \\
&= 3.60E\text{-}06/yr
\end{aligned}$$

$$\begin{aligned}
\mathbf{CDF_{EE\text{-}U2}} &= \mathbf{CDF_{Fire} + CDF_{Seismic\_U2}} \\
&= 1.0E\text{-}06/yr + 2.61E\text{-}06/yr \\
&= 3.61E\text{-}06/yr
\end{aligned}$$

Note:

9.3.2 External Events Contribution to LERF

In Equation 21 the CDF due to external hazards (internal fire and seismic) risk is multiplied by the probability of a Class 3b event. The product is the external events frequency contribution for Class 3b. This calculation applies to both Unit 1 and Unit 2. The LERF contribution for seismic hazards is taken directly from the SPRA model quantification.

Equation 21 External Events Impact on the Class 3b Frequency

$$\begin{aligned}
\mathbf{FREQ_{Class\ 3b(OLB\text{-}EE)U1}} &= \mathbf{(CDF_{Fire} * P_{Class\ 3b}) + (LERF_{Seismic\_U1} * P_{Class\ 3b})} \\
&= (1.0E\text{-}06/yr * 0.002294) + (1.70E\text{-}06 * 002294)
\end{aligned}$$

$$= 6.19\text{E-09/yr}$$

$$\mathbf{FREQ_{Class\ 3b(OLB\text{-}EE)U2} = (CDF_{Fire} * P_{Class\ 3b}) + (LERF_{Seismic\_U2} * P_{Class\ 3b})}$$
$$= (1.0\text{E-06/yr} * 0.002294) + 1.73\text{E-06} * 002294)$$
$$= 6.26\text{E-09/yr}$$

9.3.3 External Events Contribution to LERF for CILRT Interval Extension

This section characterizes the change in risk associated with external events. The following tables are provided in this section.

Equation 22	presents the external events impact on the Class 3b frequency for the extended CILRT test intervals
Equation 23	presents the external events impact on the change in LERF (3b only) from extended CILRT test intervals
Table 42	presents the results for external events contribution to the CILRT interval extensions
Equation 24	presents the total external events impact on LERF from extending CILRT test interval
Table 43	presents the Unit 1 upper bound on the external events ΔLERF to the CILRT interval extensions
Table 44	presents the Unit 2 upper bound on the external events ΔLERF to the CILRT interval extensions

In Equation 22 the Class 3b frequency determined by multiplying by the CILRT interval factor, 3.33x for 1 test-in-10 years, and 5.0x for 1 test-in-15 years.

Equation 22 EE Impact on the Class 3b Frequencies for Extended CILRT Intervals

$$\mathbf{FREQ_{EE\text{-}Class\ 3b(xx\text{-}yr)} = FREQ_{Class\ 3b(OLB\text{-}EE)} * MULT_{CLB}\ (or\ MULT_{PLB})}$$

Unit 1

$$FREQ_{Class\ 3b(CLB\text{-}EE)} = 6.19\text{E-09/yr} * 3.33$$
$$= 2.06\text{E-08/yr}$$
$$FREQ_{Class\ 3b(PLB\text{-}EE)} = 6.19\text{E-09/yr} * 5.0$$
$$= 3.10\text{E-08/yr}$$

Unit 2

$$FREQ_{Class\ 3b(CLB\text{-}EE)} = 6.26\text{E-09/yr} * 3.33$$
$$= 2.09\text{E-08/yr}$$
$$FREQ_{Class\ 3b(PLB\text{-}EE)} = 6.26\text{E-09/yr} * 5.0$$
$$= 3.13\text{E-08/yr}$$

Given the values calculated by Equation 22, the LERF increases for the extended CILRT intervals due to the external events contribution is determined by Equation 23.

Equation 23 External Events Contribution to a Change in LERF

$$
\begin{aligned}
\text{Unit 1 } \mathbf{\Delta LERF_{EE(OLB \to CLB)}} &= \mathbf{FREQ_{Class\ 3b(CLB\text{-}EE)} - FREQ_{Class\ 3b(OLB\text{-}EE)}} \\
&= 2.06E\text{-}08/yr - 6.19E\text{-}09/yr \\
&= 1.44E\text{-}08/yr \\
\mathbf{\Delta LERF_{EE(OLB \to PLB)}} &= \mathbf{FREQ_{Class\ 3b(PLB\text{-}EE)} - FREQ_{Class\ 3b(OLB\text{-}EE)}} \\
&= 3.10E\text{-}08/yr - 6.19E\text{-}09/yr \\
&= 2.48E\text{-}08/yr
\end{aligned}
$$

$$
\begin{aligned}
\text{Unit 2 } \mathbf{\Delta LERF_{EE(OLB \to CLB)}} &= \mathbf{FREQ_{Class\ 3b(CLB\text{-}EE)} - FREQ_{Class\ 3b(OLB\text{-}EE)}} \\
&= 2.09E\text{-}08/yr - 6.26E\text{-}09/yr \\
&= 1.46E\text{-}08/yr \\
\mathbf{\Delta LERF_{EE(OLB \to PLB)}} &= \mathbf{FREQ_{Class\ 3b(PLB\text{-}EE)} - FREQ_{Class\ 3b(OLB\text{-}EE)}} \\
&= 3.13E\text{-}08/yr - 6.26E\text{-}09/yr \\
&= 2.51E\text{-}08/yr
\end{aligned}
$$

Table 42 External Events Contribution to Risk for CILRT Interval Extension

Unit	$FREQ_{EE\text{-}LERF/yr}$			LERF Increase/yr	
	OLB-EE	CLB-EE	PLB-EE	OLB-EE →CLB-EE	OLB-EE →PLB-EE
1	6.19E-09	2.06E-08	3.10E-08	1.44E-08	2.48E-08
2	6.26E-09	2.09E-08	3.13E-08	1.46E-08	2.51E-08

Only the Class 3b events are affected by an increase in the CILRT interval. The internal event results are also provided to allow a composite value to be defined. When both the internal and external event contributions are combined the total change in LERF does not exceed the guidance for a small change in risk and does not exceed the 1.0E-6/rx-yr change in LERF. [10, §2.4]

Table 43 U1 - Upper Bound on Class 3b LERF

Hazard	EPRI Accident Classes FREQ/yr			LERF Increase/yr	
	OLB	CLB	PLB	OLB →CLB	OLB →PLB
External[16] Events	6.19E-09	2.06E-08	3.10E-08	1.44E-08	2.48E-08
Internal Events	1.41E-06	1.51E-06	1.58E-06	9.64E-08	1.66E-07
Combined	1.42E-06	1.53E-06	1.61E-06	1.11E-07	1.90E-07

---

[16] External Events LERF is determined by adding the contribution from Class 3b for the 3 test intervals, and adding the values to the Class 2 and Class 8 values. Only Class 3b is affected by the CILRT interval, therefore, the values for Class 2 and 8 remain static across the 3 test intervals.

Table 44 U2 - Upper Bound on Class 3b LERF

Hazard	EPRI Accident Classes FREQ/yr			LERF Increase/yr	
	OLB	CLB	PLB	OLB →CLB	OLB →PLB
External Events	6.26E-09	2.09E-08	3.13E-08	1.46E-08	2.50E-08
Internal Events	1.40E-06	1.50E-06	1.57E-06	9.60E-08	1.65E-07
Combined	1.41E-06	1.52E-06	1.60E-06	1.11E-07	1.90E-07

10.0 Results/Conclusion

NEI 94-01, Revision 3-A,[3] describes an NRC-accepted approach for implementing the performance-based requirements of 10CFR50, Appendix J, Option B. It incorporates the regulatory positions stated in R.G. 1.163[9] and includes provisions for permanently extending Type A intervals to 15 years. Based on the results of this analysis, sensitivity studies, and conclusions based on calculations that characterize the change in risk are provided for the extended test intervals in this section. A permanent CILRT Type A extension to 1 test-in-15 years presents an insignificant increase in risk to the general public and plant staff as indicated by the results documented in Table 46.

Table 45	presents the figures of merit and acceptance criteria
Section 10.1	discussion for the change in LERF
Section 10.2	discussion for the change in CCFP
Section 10.3	discussion for the change in population dose
Table 46	presents the results of the calculations and the applicability to this application

Table 45 Acceptance Criteria

Figure of Merit	Acceptance Criteria (Increase Above Baseline)	Source
LERF	<1.0E-05/rx-yr	RG 1.174 §2.4[10]
ΔLERF	<1.0E-06/rx-yr	RG 1.174 §2.4[10]
ΔCCFP[17]	≤ 1.5%	NEI 94-01 R3-a §2.2[3]
ΔDose (person-rem)	Dose increase ≤1.0 person-rem/yr or 1% of the total baseline dose, whichever is less restrictive	EPRI 1018243 APP H[1]

In the discussions that follow the maximum results for Unit 1 and Unit 2 are provided for LERF, CCFP, and Dose. Unit 2 bounds Unit 1 test all 3 figures of merit, therefore only that value is presented in the discussions. However, Table 46 provides the data for both units.

10.1 Results Discussion – LERF

Regulatory Guide 1.174[10] provides guidance for determining the risk impact of plant specific changes to the licensing basis. Leakage characterized by the Type A test does not affect the Core

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[17] It should be noted that a CCFP of 1/10 (10%) has been approved for application to evolutionary light water reactor designs. Given these perspectives, a change in the CCFP of up to 1.5% is assumed to be small.[1 §1.2]

Damage Frequency (CDF). Therefore, there is no change to the plant CDF as a result of implementing this proposed change to the licensing basis. The guidance describes a small change in risk for LERF as less than 1.0E-06/rx-yr, If it can be reasonably shown that the total LERF is less than 1.0E-05/rx-yr. For Watts Bar, the analysis included the estimated contribution from external events in addition to the internal events analysis. Table 43 and Table 44 summarizes the maximum ΔLERF for Watts Bar which is estimated to be 1.66E-07/yr, AND the maximum upper bound total LERF (Including External Events) of 1.90E-07/yr. Both results are within the acceptable bands for a small change in risk according to R.G. 1.174.[10 Figure 4] Table 46 provides the results for Unit 1 and Unit 2 for the internal events LERF, combined external events (EE) and internal events (IE) LERF, and the delta LERF for combined EE and IE results for the change from the original licensing basis (OLB) of 3 tests-in-10 years as compared to the current licensing basis (CLB) of 1 test-in-10 years, and the proposed licensing basis (PLB) of 1 test-in-15 years.

10.2 Results Discussion – CCFP

In accordance with the methodology in EPRI Report 1018243[1] a maximum conditional containment failure probability (CCFP) increase for Watts Bar from the OLB to the PLB is 0.908% which includes the increased contribution due to aging and corrosion affects. EPRI 1018243 characterizes an increase in the CCFP of ≤1.5% as very small.[1, §2.2] This is consistent with the NRC Final Safety Evaluation for NEI 94-01 Rev 3-A[3]and EPRI Report 1018243.[1] Therefore, this increase is judged to be small. Table 46 provides the detailed results for Unit 1 and Unit 2 for the CCFP change for the CLB and PLB compared to the OLB.

10.3 Results Discussion – Population Dose

The proposed licensing change in the Type A CILRT interval to 1 test-in-15 years as measured in terms of an increase on the total integrated plant risk for those accident sequences influenced by Type A testing results in a maximum of 5.76E-02 person-rem/yr which corresponds to increase of 0.41% is calculated for Watts Bar. This value is based on internal events only. EPRI Report 1018243[1] states that a small increase in population dose is defined as ≤1.0 person-rem/yr or ≤1% of the total population dose, whichever is less restrictive for the risk impact of the CILRT interval extension to 15 years. Therefore, Watts Bar meets both metrics. This is consistent with the NRC Final Safety Evaluation for NEI 94-01 Rev 3-A[3] and EPRI Report 1018243.[1] Table 46 provides the detailed results for Unit 1 and Unit 2 for the total change in dose and the % change for the CLB and PLB compared to the OLB. All values presented in Table 46 include the increased risk from corrosion.

Table 46 Results Table and Applicability Determination

Metric	Value	Acceptance Criteria	Acceptable for Application?
Unit 1			
LERF$_{\text{IE-Total PLB}}$	1.37E-06/yr	<1.0E-05/rx-yr	Yes
LERF$_{\text{Total(IE \& EE) PLB}}$	1.61E-06/yr		
ΔLERF$_{\text{Total(OLB}\rightarrow\text{CLB) EE\&IE}}$	1.11E-07/yr	<1.0E-06/rx-yr	Yes
ΔLERF$_{\text{Total(OLB}\rightarrow\text{PLB) EE\&IE}}$	1.90E-07/yr		
ΔCCFP$_{\text{(OLB}\rightarrow\text{CLB), Inc. Corrosion}}$	0.529%	≤ 1.5%	Yes
ΔCCFP$_{\text{(OLB}\rightarrow\text{PLB), Inc. Corrosion}}$	0.908%		
ΔDOSE$_{\text{(OLB}\rightarrow\text{CLB)}}$	3.37E-02 per-rem/yr	<1.0 person-rem/yr or <1% of total dose, whichever is less restrictive.	Yes
ΔDOSE$_{\text{(OLB}\rightarrow\text{PLB)}}$	5.75E-02 per-rem/yr		
Δ%DOSE$_{\text{(OLB}\rightarrow\text{CLB)}}$	0.24%		
Δ%DOSE$_{\text{(OLB}\rightarrow\text{PLB)}}$	0.41%		
Unit 2			
LERF$_{\text{IE-Total PLB}}$	1.36E-06	<1.0E-05/rx-yr	Yes
LERF$_{\text{Total(IE \& EE) PLB}}$	1.60E-06		
ΔLERF$_{\text{Total(OLB}\rightarrow\text{CLB) EE\&IE}}$	1.11E-07	<1.0E-06/rx-yr	Yes
ΔLERF$_{\text{Total(OLB}\rightarrow\text{PLB) EE\&IE}}$	1.90E-07		
ΔCCFP$_{\text{(OLB}\rightarrow\text{CLB), Inc. Corrosion}}$	0.529%	≤ 1.5%	Yes
ΔCCFP$_{\text{(OLB}\rightarrow\text{PLB), Inc. Corrosion}}$	0.908%		
ΔDOSE$_{\text{(OLB}\rightarrow\text{CLB)}}$	3.34E-02 per-rem/yr	<1.0 person-rem/yr or <1% of total dose, whichever is less restrictive.	Yes
ΔDOSE$_{\text{(OLB}\rightarrow\text{PLB)}}$	5.76E-02 per-rem/yr		
Δ%DOSE$_{\text{(OLB}\rightarrow\text{CLB)}}$	0.24%		
Δ%DOSE$_{\text{(OLB}\rightarrow\text{PLB)}}$	0.42%		

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Evaluation of Higher Test Pressure on Leakage for Watts Bar

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Revisions

Rev. No.	DCR/N No.	Description of Changes	Pages Affected
0	N/A	Initial release	All

Description	Pages
Main Text	24
Attachment 1	32
Attachment 2	19
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STATEMENT OF CALCULATION PURPOSE

1.1 PURPOSE

Local leak rate testing (LLRT) is performed to satisfy U.S. Nuclear Regulatory Commission (NRC) regulation 10CFR50 Appendix J [4][1] requirements and is conducted according to ANSI/ANS 56.8, Containment System Leakage Testing Requirements [16].

The purpose of this report is to evaluate whether an increase in valve seat leakage is expected for this scope of valves if the Type C LLRT differential pressure were reduced from current levels to a lower level.

1.2 SCOPE

For this evaluation, the applicable scope are valves where a higher differential pressure results in increased sealing, such as a check valve [16], in the Watts Bar LLRT program. The list of applicable valves and groups is shown in Table 1-1, below.

Valves listed as Exclude-A, Exclude-B, and Exclude-C were originally screened in as having an LLRT configuration where test pressure tends to increase seat force. Upon closer examination of these valves, certain design features and operating principles were identified that cause test pressure to provide minimum or compensating seat force. Explanations are provided in Section 3.1.

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[1] Numbers in brackets [ ] are references in Section 8 of this document.

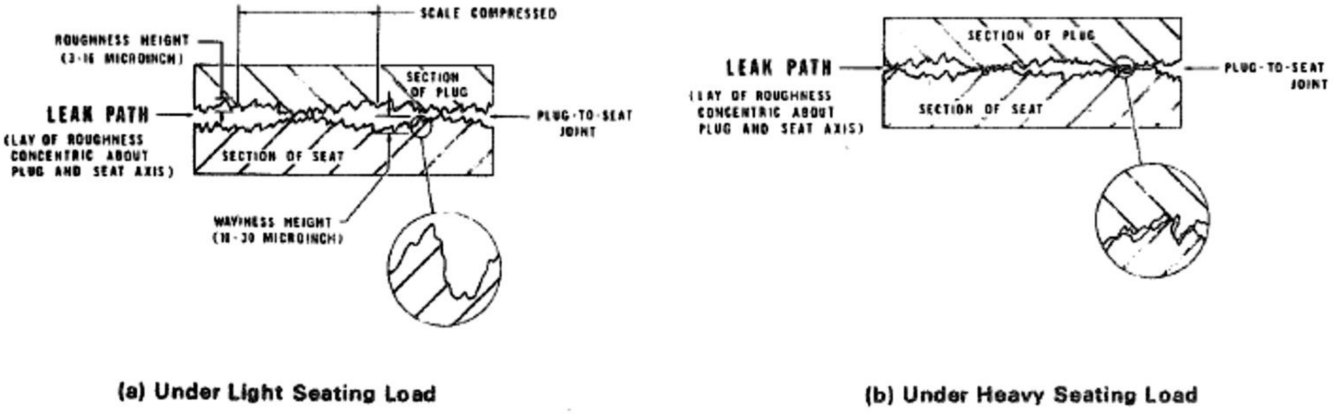
Table 1-1: Scope of Valves for Evaluation

Attachment	Description	Valve IDs	
1	MOV Wedge Gate Valves	1(2)-FCV-26-240	1(2)-FCV-70-134
	Groups 26-2, 62-3, 70-3, 70-4, 70-5, and 70-6	1(2)-FCV-26-243	1(2)-FCV-70-87
		1(2)-FCV-62-61	1(2)-FCV-70-90
		1(2)-FCV-62-63	
2	AOV and MOV Plug Valves	2-FCV-31-305	1(2)-FCV-67-134
	Groups 31-2, 67-5, 67-6, and 77-2	2-FCV-31-306	1(2)-FCV-67-138
		2-FCV-31-308	1(2)-FCV-67-139
		2-FCV-31-309	1(2)-FCV-67-141
		2-FCV-31-326	1(2)-FCV-67-142
		2-FCV-31-327	1(2)-FCV-67-295
		2-FCV-31-329	1(2)-FCV-67-296
		2-FCV-31-330	1(2)-FCV-67-297
		1(2)-FCV-67-130	1(2)-FCV-67-298
		1(2)-FCV-67-131	1(2)-FCV-77-127
		1(2)-FCV-67-133	1(2)-FCV-77-128
3	Swing Check Valves	1(2)-CKV-26-1260	1(2)-CKV-67-580C
	Groups 26-1, 67-2, 70-1, and 81-1	1(2)-CKV-26-1296	1(2)-CKV-67-580D
		1(2)-CKV-67-580A	1(2)-CKV-70-679
		1(2)-CKV-67-580B	1(2)-CKV-81-502
4	Lift/Piston Check Valves	2-CKV-31-3378	1(2)-CKV-61-680
	Groups 31-1, 32-2, 43-1, 61-1, 62-4, 63-1, 67-1, 67-3, and 68-1	2-CKV-31-3392	1(2)-CKV-61-692
		2-CKV-31-3407	1(2)-CKV-61-745
		2-CKV-31-3421	1(2)-CKV-62-639
		1-CKV-32-293	1(2)-CKV-63-868
		1-CKV-32-303	1(2)-CKV-67-575A
		1-CKV-32-313	1(2)-CKV-67-575B
		2-CKV-32-323	1(2)-CKV-67-575C
		2-CKV-32-333	1(2)-CKV-67-575D
		2-CKV-32-343	1(2)-CKV-67-585A
		1-CKV-43-834	1(2)-CKV-67-585B
		1-CKV-43-841	1(2)-CKV-67-585C
		1-CKV-43-883	1(2)-CKV-67-585D
		1-CKV-43-884	1(2)-CKV-68-849
		1(2)-CKV-61-533	

Attachment	Description	Valve IDs	
5	AOV Globe Valves Groups 32-3, 63-2, 63-3, 63-4, 63-5, and 68-3	1-FCV-32-102 1-FCV-32-110 1-FCV-32-80 2-FCV-32-103 2-FCV-32-111 2-FCV-32-81	1(2)-FCV-63-64 1(2)-FCV-63-23 1(2)-FCV-63-71 1(2)-FCV-63-84 1(2)-FCV-68-307 1(2)-FCV-68-308
Exclude-A See Section 3.1.5 for details	Manual and AOV Kerotest Diaphragm Globe Valves Groups 32-1 and 90-1	1-BYV-32-288 1-BYV-32-298 1-BYV-32-308 2-BYV-32-318 2-BYV-32-328	2-BYV-32-338 1(2)-FCV-90-110 1(2)-FCV-90-111 1(2)-FCV-90-116 1(2)-FCV-90-117
Exclude-B See Section 3.1.5 for details	Manual Dragon Diaphragm Globe Valves Group 52-1	1(2)-ISV-52-500 1(2)-ISV-52-501 1(2)-ISV-52-502 1(2)-ISV-52-503	1(2)-ISV-52-504 1(2)-ISV-52-505 1(2)-ISV-52-506 1(2)-ISV-52-507
Exclude-C See Section 3.1.7 for details	Target Rock Solenoid Valve Group 43-3	1(2)-FCV-43-202 1-FCV-43-208 1(2)-FCV-43-434	1-FCV-43-436 1-FSV-43-307 1-FSV-43-325

1.3 BACKGROUND

Leakage depends on many variables, including seating surface finish (waviness and roughness), seat materials, seat contact width, and seating load. Higher seat loads would tend to decrease the size of microscopic flow passages at the seating interface and diminish the size of the leak passage as shown in the Figure 1-1.



(a) Under Light Seating Load

(b) Under Heavy Seating Load

Figure 1-1: Microscopic Flow Path Under Light and Heavy Seating Load [5]

2

QUALITY ASSURANCE

This project is performed in accordance with TVA Purchase Order No. 6232543 [2], and the Kalsi Engineering, Inc. (KEI) Quality Assurance Program [1], which meets the intent of 10CFR50 Appendix B.

The valves within the scope of this evaluation perform a containment isolation function and are safety related.

3

DESIGN METHOD USED

The approach used for gate and globe valves is to evaluate the decrease in seat load resulting from the decrease in LLRT differential pressure to determine if the size of the leak path is increased to such an extent to increase the measured leakage. For tapered plug valves the total sealing force (sum of upstream and downstream seat load) is evaluated within the range of LLRT test pressures. Swing and piston (lift) check valves the approach is to determine the reduction in seating stress for soft-seated designs and the increase in leak path area for metal seated designs. A combination of analysis, industry data, and supporting test data (if available) are used.

3.1 DESIGN METHOD DESCRIPTION

Valves within the scope of this evaluation were divided into groups based on the analysis approach and are described more fully in Attachments 1 to 5. A summary of the approach for each group is presented in this section.

3.1.1 MOV Gate Valves

During LLRT, sealing load is applied by mechanical wedging and differential pressure (DP). Mechanical wedging load is a function of the applied force acting on top of the gate (or wedge), the wedge angle, and friction at the disk-to-seat surfaces. A higher applied stem force increases the mechanical wedging load. DP load is proportional to the DP and the area over which the DP acts. A higher DP results in a higher DP applied seat load. For MOVs, the seat load due to mechanical wedging is much greater than that due to the LLRT DP as illustrated in Figure 3-1.

The approach for this analysis is to evaluate the reduction in total sealing load due to changing the LLRT test DP from 16.5 psig to 9.0 psig to determine if this reduction is expected to increase the measured leakage.

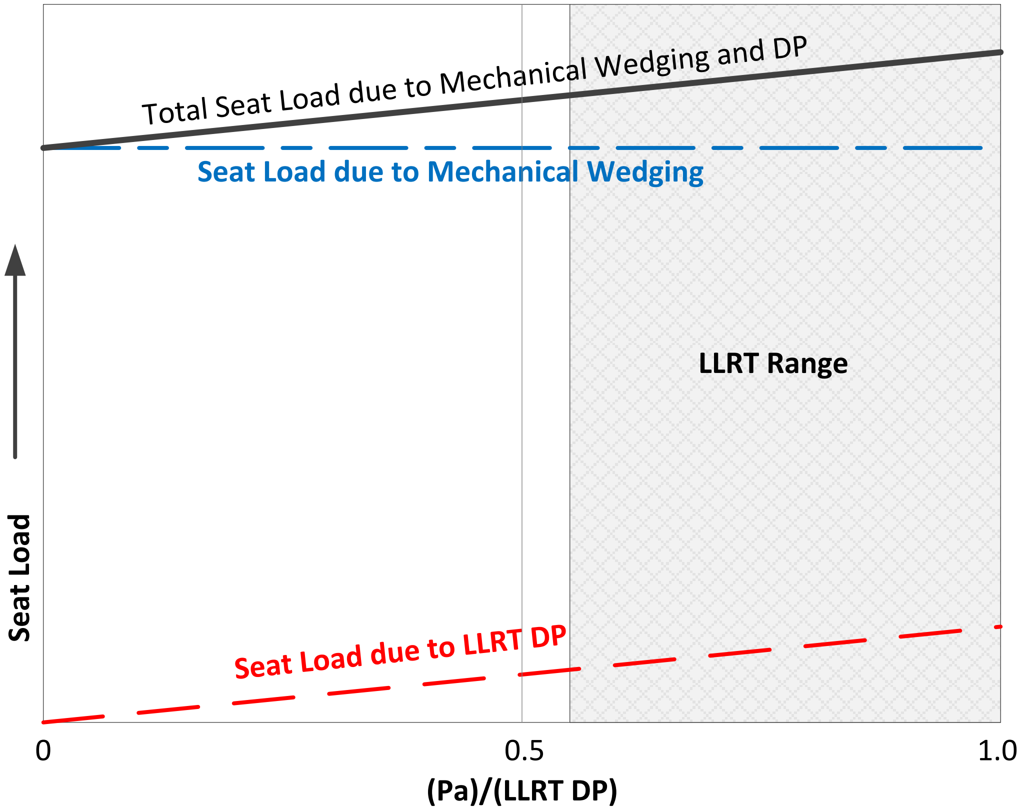


Figure 3-1: Illustration of Total Seat Load for MOV Wedge Gate Valves
LLRT DP + Mechanical Wedging Seat load = Total Seat Load

3.1.2 Plug Valves

Tapered plug valves have a conical metal plug inserted into a polymer body sleeve with an interference fit to form a seal. As the plug rotates 90° from close to open the plug port aligns with the body sleeve port to form a rectangular flow passage. As the plug rotates 90° back from open to close, the plug port rotates away from the sleeve port leaving the solid portion of the plug wall in contact with the rectangular body sleeve port. Differential pressure applied to the valve increases the seat load on the downstream seat and reduces the upstream seat load, although very slightly over the LLRT test DP range as illustrated in Figure 3-2. However, for the low LLRT test DP the net sealing load between the two seats remains the same such that overall leakage is not expected to increase from the higher to lower LLRT DP conditions.

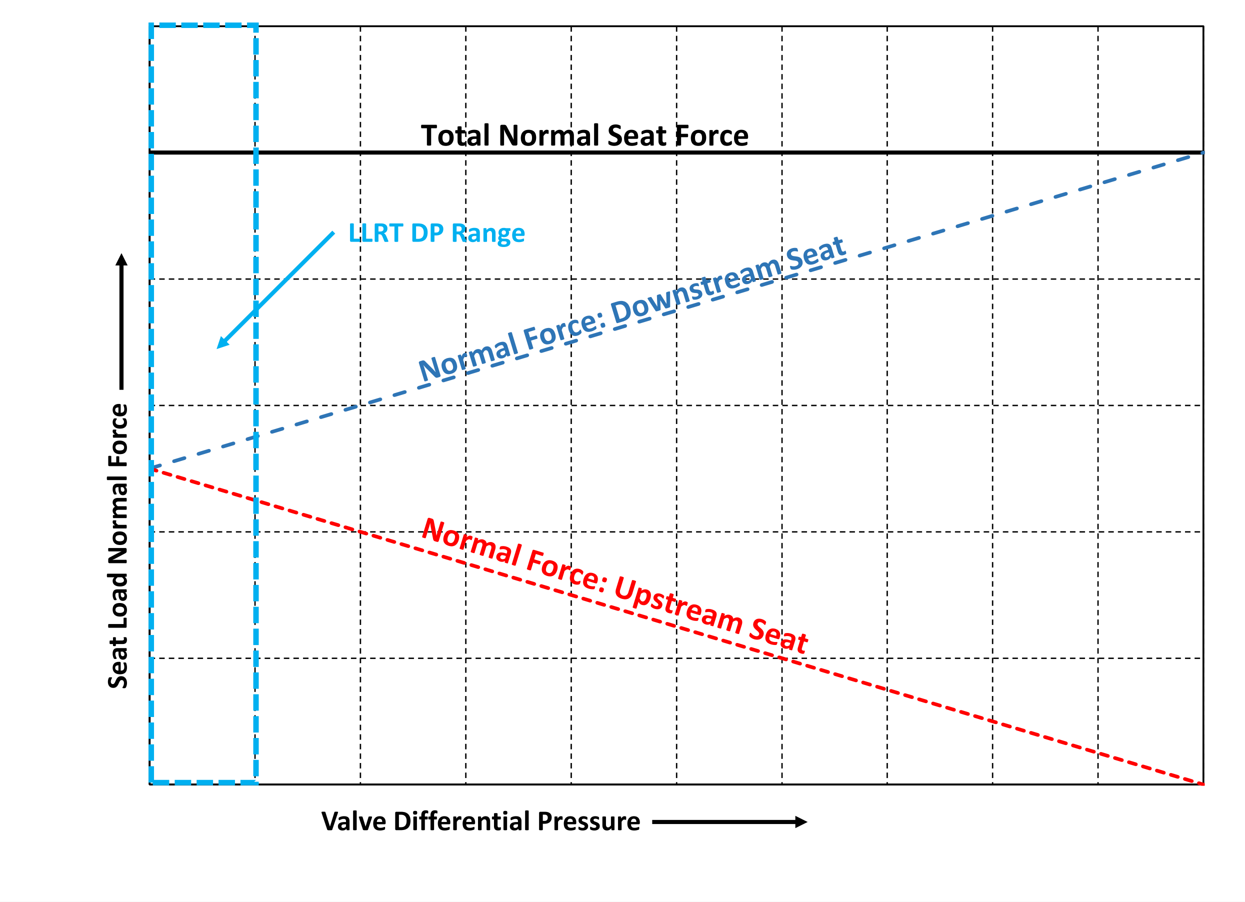


Figure 3-2: Tapered Plug Valve Seat Force vs DP

Downstream Normal Seat Force = Upstream Normal Seat Force = Total Normal Seat Force

3.1.3 Swing Check Valves

There are both soft-seated and metal (or hard)-seated swing check valves within the applicable population for evaluation. Swing check valves rely primarily on differential pressure to form a seal along with some weight (or gravity) force. The approach for soft-seated and metal-seated valves is described below.

For the soft-seated swing check valves, the approach is as follows:

1. Determine the peak and average seat contact stresses based on the seat load at the higher and lower LLRT pressures. Verify that the peak seat contact stress is higher than the differential pressure to ensure a positive sealing margin at that pressure.
2. Determine the percent O-ring or soft seal compression. Verify that the sealing load at the higher and lower LLRT pressures provide adequate O-ring compression to ensure sealing.

For the metal-seated valves, the approach is as follows:

1. Determine the percentage increase in the leakage flow area with the decrease in the seat

load due to the reduction from the higher to lower LLRT test pressure.

2. A negligible change in the leakage flow area shows that the leakage flow resistance (and corresponding leakage flow coefficient, C_L) change is well below 35%. Per Section 3.2, the leakage flow coefficient needs to change greater than 35% to have higher measured leakage at the lower LLRT test pressure.

3.1.4 Lift/Piston Check Valves

Lift/Piston check valves have a plug with seat load applied by an internal spring. The spring is sized to provide a certain cracking pressure in the under-seat flow direction. In the opposite flow direction, the spring and differential pressure close the valve and provide a sealing load. Except for Groups 62-4, all lift/piston check valves within the scope of this evaluation have soft seats. Low modulus soft seats require less seat load to form a seal than high modulus metal seats since the material more easily fills small surface asperities that form leak passages. The approach for lift/piston check valves is similar to that used for the swing check valves as described in paragraph 3.1.3.

3.1.5 Manual and AOV Globe Valves with Metal Diaphragms

All manual globe valves and the System 90 AOVs (Group 90-1) in the scope of this evaluation have dish-shaped metal diaphragms sealing the internal line pressure. Stem packing, if present, acts as a secondary seal. Based on examination of the drawing, pressure applied over-the-seat with the valve in the closed position will act equal and opposite on the plug and diaphragm seal such that the test pressure is effectively balanced and there is no significant change in seat load as a function of LLRT test DP (see Figure 3-3). Based on scaling of the manufacturer's drawings [14, 17, 18], the Group 32-1 manual Kerotest and Group 90-1 Kerotest air-operated valves have a metal diaphragm diameter that are 12% to 16% larger than the seat diameter, and the Group 52-1 manual valves metal diaphragm diameter is 28% larger than. Therefore, additional evaluation is not required since higher test pressure will not increase the seat load for these valves.

Figure 3-3: Metal Sealed Diaphragm Valve Pressure Balance [14]

Metal Diaphragm DP Force Balances Plug DP Force

3.1.6 AOV Globe Valves

Like gate valves, sealing load for AOV globe valves is applied by mechanical wedging and differential pressure (DP). Mechanical wedging load is a function of the applied force acting on top of the plug, the plug angle, and friction at the disk-to-seat surfaces. DP load is a function of the DP and the area over which the DP acts. For AOVs, the seat load due to mechanical wedging is much greater than that due to the LLRT differential pressure.

The approach for this analysis is to evaluate the reduction in total sealing load due to decreasing the LLRT test DP to determine if an increase in the measured leakage is expected.

3.1.7 Solenoid-Operated Globe Valves

Group 43-3 solenoid-operated Target Rock valves are 3/8-inch direct-acting, bi-directional energized-to-open. Per the information provided by TVA, Unit 1 and Unit 2 valves are of welded-bonnet and bolted-bonnet construction, respectively. Since the disc assembly part number in the valve drawings for Unit 1 [12, 13] and Unit 2 [11] is the same (202665-1), the discs between the two Units are identical. The valve drawings show a pressure equalizing port in the disc that connects the under-seat side of the disc to the valve bonnet as shown in Figure 3-4. Using the scaled dimensions from more-legible Unit 2 drawing [11], the scaled seat diameter (0.37”) is estimated to be equal to the scaled disc stem diameter (0.37”). The scaling accuracy was verified through two independent dimensions on the drawing [11]. This results in a zero unbalanced area for the disc making the seat load independent of the differential pressure (DP) load in either direction (flow under-the-seat or flow over-the-seat). In the valve closed condition, the seat load is applied by the spring preload and the plug weight. Therefore, the seat load will remain the same under the reduced LLRT pressure.

Figure 3-4: Balanced Disk Solenoid Valve Showing Upstream and Downstream Pressure [11]

3.2 GENERIC LEAKAGE EVALUATION

Leakage depends on many variables, including seating surface finish (waviness and roughness), seat materials, seat contact width, and seating load. Fortunately, LLRT valves are proven to meet acceptable leakage criteria under the tested conditions which provides assurance that the seating surfaces are in good condition and that minimum seat loads (lb/in) required to achieve sealing have been obtained.

For valves where "…service pressure will tend to diminish the overall leakage channel opening, as by pressing the disk into or onto the seat with greater force,", ASME OM Code ISTC-3630 [3] allows use of the following formula to estimate the leakage. L_{test}, is the measured leakage at a test differential pressure of DP_{test}, L_{max}, is the calculated leakage at DP_{max}, where DP_{max} is higher than DP_{test}.

$$\frac{L_{max}}{L_{test}} = \sqrt{\frac{DP_{max}}{DP_{test}}} \tag{3-1}$$

This equation conservatively assumes the microscopic leak flow passages at the seating interface providing the flow resistance remain constant in size with increasing seal load due to a higher-differential pressure condition. It also assumes the leakage is proportional to the square root of the test differential pressure. Higher pressure would tend to decrease the size of microscopic flow passages at the seating interface as shown in Figure 1-1.

In this analysis, the seat load <u>decreases</u> with <u>decreasing</u> test differential pressure. The amount of seat load decrease is limited to the portion of seat load produced by differential pressure.

For a given leak flow path, the leakage, L, is proportional to the square root of the differential pressure according to ISTC-3630. A leakage coefficient proportionality constant, C_L, is given to relate the square root of the pressure differential to the leakage flow rate.

$$L = C_L \cdot \sqrt{DP} \tag{3-2}$$

Over the small change in test air pressure, any physical properties of the air test fluid associated with C_L would be relatively constant (air density, etc.) such that only the change in leak flow passage size is important. Therefore, leakage at Condition 1 and Condition 2 can be determined as follows:

$$L_1 = C_{L1} \cdot \sqrt{DP1}$$

$$L_2 = C_{L2} \cdot \sqrt{DP2}$$

To maintain the same leakage (i.e. L1 = L2) at test DP condition 1 (DP1) and test DP condition 2 (DP2), the following relationship between the leakage coefficient, C_L, and DP is obtained:

$$\frac{C_{L2}}{C_{L1}} = \sqrt{\frac{DP1}{DP2}} \tag{3-3}$$

Using Equation 3-3, if the LLRT test DP changed from 16.5 psi to 9.0 psi then the leakage coefficient can increase by 35% before the measured leakage at the lower DP2 would increase from the measured leakage at the higher DP1. If the relationship between leakage flow rate and DP were linear or squared (DP^2), as suggested by some references [5] for compressible fluid, the predicted allowed change in leakage coefficient would be larger. Therefore, it is conservative to assume a square root relationship.

4

DESIGN INPUTS

4.1 INPUTS

Design inputs specific to each grouping of valves are contained in Attachments 1 to 5. Generic inputs are shown in Table 4-1, below.

Table 4-1: Generic Inputs for LLRT Evaluation

Parameter	**Value**	**Reference**
Maximum LLRT Test Pressure, psig 15 psig is the maximum containment internal pressure for Watts Bar	=15 x 1.1 = 16.5	15, 16
Calculated peak containment internal pressure related to the design basis loss-of-cooling accident (LOCA), Pa, psig	9.36 (9.0 used in assessment)	15

4.2 LEAKAGE HISTORY SUMMARY

Leakage summary for all valves within the scope of this evaluation are provided in the individual Attachments. Some valves show unacceptable leakage history, but it is assumed that corrective actions are performed to restore leakage to acceptable levels (see Assumption 5.2).

5

ASSUMPTIONS

5.1. Assumptions applicable to each group of valves included in this analysis are identified in Attachments 1 to 5.

5.2. For all valves it is assumed that the tested leakage at normal LLRT DP is acceptable. This assumption is reasonable since corrective actions are required if leakage exceeds acceptance criteria and does not require verification.

6

RESULTS

This section provides the analysis results showing that increased measured leakage is not expected from changing LLRT test conditions from 16.5 psig to 9.0 psig.

A results summary for each attachment is provided below.

6.1 ATTACHMENT 1: MOV GATE VALVES

Groups 26-2, 62-3, 70-3, 70-4, 70-5, and 70-6

Seating load reduction due to a decrease in LLRT test pressure from 16.5 psig to 9.0 psig is shown in Table 6-1. As can be seen, all values are bounded by a 6% reduction in seat load and the seat contact force values all exceed 100 lb/in, which is the minimum recommended value for metal seats per References 5 and 6. Also, the corresponding leakage coefficient, C_L, is not expected to increase seat leakage at the lower test pressure of 9.0 psig unless the seat contact force decreases by more than 35%.

Table 6-1: Seat Load Reduction for MOV Gate Valves

Tag Number	Seat Contact Force at DPtest, lb/in	Reduction in Seat Contact Force at Pa, lb/in	Pct (%) Reduction
1-FCV-26-240	246.6	7.6	3.1
2-FCV-26-240	133.1	7.4	5.6
1-FCV-26-243	224.7	7.6	3.4
2-FCV-26-243	127.3	7.4	5.8
1-FCV-62-61	155.2	7.2	4.6
2-FCV-62-61	205.4	7.2	3.5
1-FCV-62-63	137.3	7.1	5.2
2-FCV-62-63	175.1	7.1	4.1
1-FCV-70-87	1107.7	4.4	0.4
2-FCV-70-87	1234.4	4.4	0.4
1-FCV-70-134	143.7	6.1	4.3
2-FCV-70-134	143.4	6.2	4.3
1-FCV-70-90	1136.8	4.4	0.4
2-FCV-70-90	1001.5	4.3	0.4

KEI test results for two wedge gate valves show that [redacted] is a “best available” bounding reduction in seat load, above which seat leakage can possibly increase for wedge gate valves. Table 6-1 shows that the total reduction in seat load for all MOVs is less than 6% such that an increase in seat leakage is not expected if the LLRT test pressure were to decrease from 16.5 psi to 9.0 psi.

Based on these results, seat leakage for all MOV Gate valves within the scope of this assessment is not expected to increase if tested at a lower differential pressure of 9.0 psig.

6.2 ATTACHMENT 2: MOV/AOV PLUG VALVES

Groups 31-2, 67-5, 67-6, and 77-2

Total seating torque reduction for MOV plug valves due to a decrease in LLRT test pressure from 16.5 psig to 9.0 psig is 0% due to the seat load sharing between the upstream and downstream seating surfaces.

Even though the data to calculate the seat load reduction for the all AOV plug valves is not available, the seat torques for all the plug valves would be independent of the DP load for the range of LLRT test pressures. Therefore, the seat leakage is not expected to increase withing the range of LLRT test pressure.

6.3 ATTACHMENT 3: SOFT-SEATED AND HARD-SEATED SWING CHECK VALVES

Groups 26-1, 67-2, 70-1, and 81-1

6.3.1 Soft-Seated Swing Check Valves

The disk of the valves in Groups 67-2 (Unit 1 and Unit 2) and 70-1 (Unit1) has an O-ring that provides a soft sealing. The percent reduction in the sealing load is 45.5% when the pressure is reduced from 16.5 psig to 9.0 psig. However, the peak and average seat contact stresses are well above the LLRT test pressures. A peak contact stress well above the differential pressure being sealed will ensure a proper sealing. Therefore, the leakage is not expected to increase when the LLRT test pressure is reduced.

The valves in Group 70-1 Unit 2 have a resilient seat to provide a sealing at low pressures and a Stellite-6 hard-faced metal seat to provide sealing at higher pressures. The calculation shows that the maximum seal compression occurs at a seat load of approximately 30 lb and develops a corresponding peak seat contact stress of approximately 114 psi. Since the peak seat contact stress of 114 psi is higher than the LLRT test pressures, a good seal is ensured. Also, to reach full seal compression, a seat load of 30 lb is required. However, a seat load of approximately 61 lb is obtained at 9.0 psig pressures which ensures the seal will stay fully compressed to ensure proper sealing. Therefore, the leakage is not expected to increase when the LLRT test pressure is reduced.

6.3.2 Metal-Seated Swing Check Valves

The valves in Groups 26-1 and 81-1 have a metal-seated disc. The percent reduction in the sealing load is 45.5% when the pressure is reduced from 16.5 psig to 9.0 psig. The reduction in the seat load may increase the leakage coefficient, C_L, by increasing the leakage flow area. A model assuming elastic behavior of the surface asperities along the seat contact band is used to predict the change in leakage flow channel area due to a decrease in test pressure. The calculated increase in the leakage flow channel area is less than [redacted] and is therefore not expected to increase the seat leakage when the LLRT test pressure is reduced.

6.4 ATTACHMENT 4: LIFT/PISTON CHECK VALVES

For soft-seated valves Groups 31-1, 32-1, 61-1, 63-1, 67-1, 67-3, and 68-1, the total seat load reduction due to change in the differential pressure from 16.5 psig to 9.0 psig varies between 34% to 46%. The spring force does not significantly contribute towards the sealing force. Although there is reduction in seat load, the seat contact stress is higher than the LLRT test pressures, which ensures sealing and no expected increase in leakage when the LLRT test pressure is reduced.

For the inline check valves in group 43-1, the initial peak contact stress developed between the O-ring and the gland wall will ensure sealing. The differential fluid pressure acting on the O-ring will only increase this contact pressure further. Therefore, the inline check valve will seal with no expected increase in leakage when the LLRT test pressure is reduced.

For metal-seated valves in Group 62-4, the calculated increase in leakage channel flow area from 16.5 psig to 9.0 psig is less than [redacted]. Therefore, this small change in leakage channel flow area is not expected to change the leakage coefficient, C_L, by more than 35% and leakage is not expected to increase when the LLRT test pressure is reduced.

6.5 ATTACHMENT 5: AOV GLOBE VALVES

Groups 32-3, 63-2, 63-3, 63-4, 63-5, and 68-3

The sealing load per linear inch for the applicable AOV Globe valves are shown in Table 6-2. The minimum recommended seat contact force value for metal seats is 100 lb/in per Reference 5. The seat contact force values exceed 100 lb/in except for Group 32-3 valves at 16.5 psig and 9.0 psig.

Table 6-2: Seat Contact Force Results for AOV Globe Valves

Group ID	Component ID	Seat Contact Force, lb/in		
		At 16.5 psig	At 9.0 psig	Reduction at 9.0 psig from 16.5 psig
32-3	1-FCV-32-80 2-FCV-32-81	23.10	18.80	4.30
	1-FCV-32-102 2-FCV-32-103	23.10	18.80	4.30
	1-FCV-32-110 2-FCV-32-111	23.10	18.80	4.30
63-2	1-FCV-63-64 2-FCV-63-64	374.16	372.65	1.51
63-3	1-FCV-63-23 2-FCV-63-23	390.20	388.69	1.51
63-4	1-FCV-63-71 2-FCV-63-71	614.57	613.73	0.84
63-5	1-FCV-63-84 2-FCV-63-84	537.24	536.40	0.84
68-3	1-FCV-68-307 2-FCV-68-307	146.98	146.75	0.23
	1-FCV-68-308 2-FCV-68-308	146.98	146.75	0.23

The seat contact force is reduced to 18.61% for Group 32-3 at 9.0 psig. Per Section 3.2, the reduction in seat contact force needs to change the leak path leakage coefficient, C_L, by 35% to increase seat leakage at the lower test pressure of 9.0 psig.

Based on the simplified but conservative calculation performed in Section 5.3 of Attachment 5, it is expected that the change in the leakage flow area will be less than [redacted] (Table 5-3 in Attachment 5) with the reduction in seat load. Therefore, it is expected that the leakage coefficient, C_L, will not increase by 35% which is a threshold for the measured leakage at the lower pressure to increase from the measured leakage at the higher pressure. Therefore, the seat load reduction of 18.61% for Group 32-3 valves is not expected to increase the leakage at pressure P_a. Based on these results, seat leakage for all AOV Globe valves within the scope of this assessment is not expected to increase when the LLRT test pressure is reduced.

7

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

The analysis results show that increased measured leakage is not expected when the LLRT test pressure is reduced to 9.0 psig.

7.2 RECOMMENDATIONS

Hard-seated check valves in Groups 62-4 (lift/piston) and 26-1, 81-1 (swing) have low seating stresses and a significant decrease in seat load from 16.5 psig to 9 psig test pressures. Although the results based on calculations and engineering judgment show that leakage is not expected to increase for these valves, it is recommended to test one check valve from each group to support the calculation-based conclusions.

8

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10. TVA Engineering Work Request No. EWR20MEC088032, Generate List of U1 Containment Isolation Valves for Kalsi Engineering Pa impact evaluation, Approval date: 06/09/2020.
11. Target Rock Drawing No. 82KK-003BB, Rev. C, *Valve Solenoid Operated Bi-directional Flow Energize to Open 3/8 inch*.
12. Target Rock Drawing No. 1015005-3, Rev. B, *Sol Oper Valve Assy Bi-Directional Flow Energize to Open Size ¼" to 1"*.
13. Target Rock Drawing No. 82KK-003-1, Rev. G, *Project Control Drawing Solenoid Oper. Valve 3/8" Tube Energize to Open*.

14. Kerotest Drawing TV-D-9909X01S-(2) Rev. A, 2*” 600 Y-Type Globe Valve w/Soft Seat*.

15. Watts Bar UFSAR 6.2, *Containment Systems*.

16. ANSI/ANS-56.8-1994, *American National Standard for Containment System Leakage Testing Requirements*.

17. Dragon Valves, Dwg 13824, Rev. C2, *Valve, Globe, Packless & Secondary Packing ¾ Socket Weld, ASME Section III CL 2 ANSI 2500 LB*.

18. Flowserve Drawing 10-59621-01, Rev. 0, *Y-Type Globe Valve Socket Ends, Stainless Steel Soft Seat w/Air Cylinder, Size: 1.5 Class: 600*.

19. TVA Engineering Work Request No. EWR20MEC026076, Generate U2 Containment Isolation Valves List and Design Inputs for Kalsi Engineering Pa impact evaluation, Approval date: 08/19/2020.

Local Leak Rate Test Leakage Evaluation at Watts Bar for MOV Gate Valves

Document No. 3960C, Rev. 0, Attachment 1

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Revisions

Rev. No.	**DCR/N No.**	**Description of Changes**	**Pages Affected**
0	N/A	Initial release	All

Description	**Pages**
Main Text	26
Appendix A	6
Total Pages	32

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1

OBJECTIVE AND SCOPE

1.1 OBJECTIVE

Kalsi Engineering, Inc. (KEI) has been contracted by Tennessee Valley Authority (TVA) to provide engineering services to evaluate the impact of local leak rate test (LLRT) pressures, DP_{test}, higher than the calculated peak pressure, Pa, for cases where greater test pressure tends to increase the sealing. This work is being done in accordance with Purchase Order No. 6232543 [2][1].

The objective of this report is to determine the impact of the reduced LLRT pressure from the test LLRT DP to Pa on the seat leakage. All work performed under this project was done in accordance with the requirements of the KEI Quality Assurance Program [1], which meets the intent of 10CFR50 Appendix B requirements.

1.2 SCOPE

The scope of this attachment is LLRT motor-operated gate valves. Valve IDs and basic information are shown below in Table 1-1.

Table 1-1: Analysis Scope [3, 17]

Group	Component Id	Comp Description	Manufacturer
26-2	1,2-FCV-26-240	Reactor Bldg Standpipe Isol	Anchor-Darling
26-2	1,2-FCV-26-243	Reactor Coolant Pump Sprinkler Hdr Isol	Anchor-Darling
62-3	1,2-FCV-62-61	CVCS Seal Water Return Header Isol	W120/Westinghouse Elec
62-3	1,2-FCV-62-63	CVCS Seal Water Return Header Isol	W120/Westinghouse Elec
70-3 70-4	1-FCV-70-87 2-FCV-70-87	Thermal Barrier CCS Return	Walworth
70-3 70-5	1-FCV-70-134 2-FCV-70-134	Thermal Barrier CCS Supply	Walworth
70-4 70-6	1-FCV-70-90 2-FCV-70-90	Thermal Barrier CCS Return	Walworth: Unit 1 Flowserve: Unit 2

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[1] Numbers in brackets [ ] are references in Section 6.

1.3 HISTORICAL LEAKAGE

Reference 3 provides the LLRT history for the Unit 1 MOVs. Table 1-2, below, summarizes the results.

Table 1-2: Unit 1 and 2 LLRT Leakage History [3, 17]

Component Id	Leakage Results	Notes
1-FCV-26-240 2-FCV-26-240	Favorable history Favorable history	None
1-FCV-26-243 2-FCV-26-243	Favorable history Favorable history	Unit 2 had high leakage for U2R1, but excellent results for U2R2.
1-FCV-62-61 2-FCV-62-61	Unfavorable history Favorable History	Containment isolation barrier is combined with CKV-62-639
1-FCV-62-63 2-FCV-62-63	Favorable history Favorable history	None
1-FCV-70-87 2-FCV-70-87	Favorable history Favorable history	Containment isolation barrier is combined with CKV-67-575A. U1C2 outage had high leakage but has been 0 since
1-FCV-70-134 2-FCV-70-134	Unfavorable history Favorable history	Unit 1 unfavorable since U1C10 outage
1-FCV-70-90 2-FCV-70-90	Favorable history Favorable history	High leakage for U1C9, but favorable leakage before and after

2

METHODOLOGY

2.1 VARIABLES

Variable	Description	Units
A_o	Area based on mean seat diameter $= \frac{\pi}{4} \cdot d_m^2$	in^2
As	Stem area at packing $= \frac{\pi}{4} \cdot d_s^2$	in^2
dm	Mean body seat ring diameter [13]	in
DP	Valve differential pressure	psi
DP_{test}	Differential pressure used for LLRT	psi
$DP_{test\_10\%}$	Test differential that will result in a 10% reduction in sealing load at Pa	psi
ds	Stem diameter at packing [13]	in
FC	Minimum required thrust from MOV set-up sheet or calculation [13]	lb
FI	Inertia overshoot thrust from diagnostic test	lb
FP	Stem rejection force due to internal line pressure	lb
F_{pack}	Packing friction force from MOV set-up sheet or calculation [13]	lb
Fs	Force applied to the top of the disk by the stem	lb
$Fs_{\_DP}$	Sealing load due to differential pressure	lb
$Fs_{\_reduction}$	Reduction in seat load due to the difference between DP_{test} and Pa	lb
$Fs_{\_Total}$	Total sealing load	lb
FST	Static sealing thrust = C16(max thrust) – C11(thrust at seat contact)	lb
FTR	Friction force due to torque reaction surface	lb
Pa	Calculated peak containment internal pressure related to the design-basis loss-of-coolant accident (LOCA)	psig
Pup	Valve upstream pressure	psig
Rr	Sealing force	lb
r_t	Torque reaction radius = external torque arm radius or mean seat radius per Reference 5.	ft
SF	Stem factor, taken from MOV set-up calculation	ft
U_{meas}	Thrust measurement uncertainty (percent of reading)	%
R	Reduction in sealing load due to Pa vs. test DP	%
μ	Disk-to-seat friction coefficient, close stroke direction [13]	--
μ_t	Friction coefficient at torque reaction surface = 0.5 per Reference 5	--
θ	Half wedge angle [13]	deg.

2.2 WEDGE GATE VALVE SEALING LOAD

During LLRT, sealing load is applied by 1) mechanical wedging and 2) differential pressure (DP). Mechanical wedging load is proportional to the applied force acting on top of the gate (or wedge), the wedge angle, and friction at the disc-to-seat contact surfaces. DP load is proportional to the DP and the area over which the DP acts. For MOVs, the seat load due to mechanical wedging is much greater than that due to the LLRT differential pressure.

The approach for this analysis is to:

1. Determine the reduction in total sealing load due to changing the test DP from the current value, P_{test}, to the design basis containment pressure, Pa.
2. Determine the value of P_{test} required to achieve a 10% reduction in sealing force at Pa. The 10% criterion is based on leak testing and is discussed in Section 2.4.

2.3 MECHANICAL WEDGING

Per References 4 and 5, the sealing force, R_r, due to the applied stem force, F_s, on the wedge is determined by Equation 1.

The free-body diagram for Equation 1 is shown in Figure 2-1.

Figure 2-1: Sealing Force due to Mechanical Wedging

Solving for forces in the stem axis direction:

(1)

Solving for the sealing force, R_r:

(2)

During motor-operated valve (MOV) diagnostic testing, stem force is typically measured by stem-mounted strain gauges. The force applied to the top of the disk is reduced from the measured stem force by the friction force absorbed by the packing (packing force), the stem blow-out force due to internal valve pressure (stem rejection force), and the stem friction force at the torque reaction surface. Weight terms are small and ignored. Therefore, to determine the force applied to the top of the disk when the valve body is pressurized, the packing force, stem rejection force, and torque reaction force must be subtracted from the total closing stem force, Fc, as follows:

[redacted] (3)

Since $F_p = P_{up} \cdot \frac{\pi}{4} \cdot d_s^2 = P_{up} \cdot A_s$, and

[redacted]

Since the minimum closing force, FC, contains the packing load, Fpack, the subtracted packing load term should also contain the torque reaction factor.

Therefore,

[redacted] (4)

The torque reaction factor (TRF) is determined using the following equation per Reference 5:

[redacted] (5)

For LLRT conditions, the downstream pressure will be atmospheric. Therefore, the upstream pressure is equal to the test differential pressure: P_{up} = DP

The minimum closing force, Fc, is taken from the minimum required thrust (Fmin) shown on the MOV set-up sheet [12]. This minimum thrust value must be provided by the actuator for the MOV to perform its design function. 75% of the inertia overshoot load (FI) from diagnostic testing [14] is added since this load will be present regardless of the minimum thrust setting. Even with variations in FI, this is a conservative approach since MOVs are seldom set to the minimum thrust value.

Fc = Fmin + 0.75(FI)

The maximum packing force, F_{pack}, is taken as the maximum packing load shown on the MOV set-up sheet or the MOV calculation. This value cannot be exceeded without evaluation.

Three Unit 2 MOVs, 2-FCV-62-061, 2-FCV-62-063, and 2-FCV-70-134 were found to be set below the minimum required thrust values. For these three MOVs, the thrust at switch trip and packing loads are taken from CR-1604752 [9] instead of the set-up sheets or calculations.

The disk-to-seat friction coefficient used in the mechanical wedging equation, μ, is taken from the MOV calculation [13]. These are threshold or bounding coefficients which provide conservative results (i.e. higher friction coefficient results in less sealing force, Rr, for a given Fs).

The final equation for the sealing force due to mechanical wedging is:

[redacted] (6)

2.4 SEALING FORCE DUE TO DIFFERENTIAL PRESSURE

Differential pressure acts normal to the valve disk surface and produces a sealing force equal to the product of the pressure difference and area over which the DP acts. The area defined by the mean seat ring diameter is used for the area over which the DP acts and the resulting sealing force due to differential pressure is shown in Equation 7.

$$F_{s\_DP} = A_o \cdot DP \qquad (7)$$

2.5 TOTAL SEALING FORCE AND SEAL FORCE REDUCTION

The total sealing force due to mechanical wedging and test differential pressure (DP_{test}) is:

[redacted] (8)

Separating static (independent of DP) and dynamic (DP dependent) components:

[redacted] (9)

The reduction in sealing force at the maximum containment accident pressure, Pa, that is lower than an LLRT test DP is determined as follows:

[redacted] (10)

Therefore, the percentage reduction in sealing force due to testing at DP_{test} which is higher than Pa is determined as follows:

$$R = 100 \cdot \left(\frac{F_{s\_reduction}}{F_{s\_total} @ DP_{test}} \right) \qquad (11)$$

Solving Equation 11 to determine the maximum allowable LLRT DP_{test} such that there is no greater than a 10% reduction in sealing force is determined by the following equation:

[redacted] (12)

Where:

[redacted]

Where $F_C = F_{ST} + F_{pack}$

[redacted]

For each MOV in the scope of this analysis, the percent reduction, R, in sealing force is determined using Equation 11 and the maximum LLRT test DP that results in a 10% reduction in sealing force is determined using Equation 12.

To help Watts Bar establish minimum seating thrust values for static MOV testing, F_{ST}, the static seating thrust required to achieve no less than a 10% reduction in sealing force and a minimum seat contact force of 100 lb/in is determined. The maximum static seating thrust from these two calculations becomes the minimum required static seating thrust. Static seating thrust is typically determined from MOV diagnostic testing as the difference between maximum close thrust (C16) and thrust at seat contact (C11) which is essentially F1, shown above.

Solving Equation 11 to determine the minimum static seat thrust, F_{ST}, required to achieve no greater than a 10% reduction in sealing force is determined by the following equation:

[redacted] (13)

Solving Equation 9 to determine the minimum seat load, F1, required to achieve no less than 100 lb/in of seat contact force is determined by the following equation.

[redacted] (14)

The maximum value from Equation 13 and 14 is presented in Table 5-3 since this represents the limiting static seating thrust required to achieve no greater than a 10% reduction in seat load and at least 100 lb/in of seating contact force.

2.6 CHANGE IN SEAT LEAKAGE

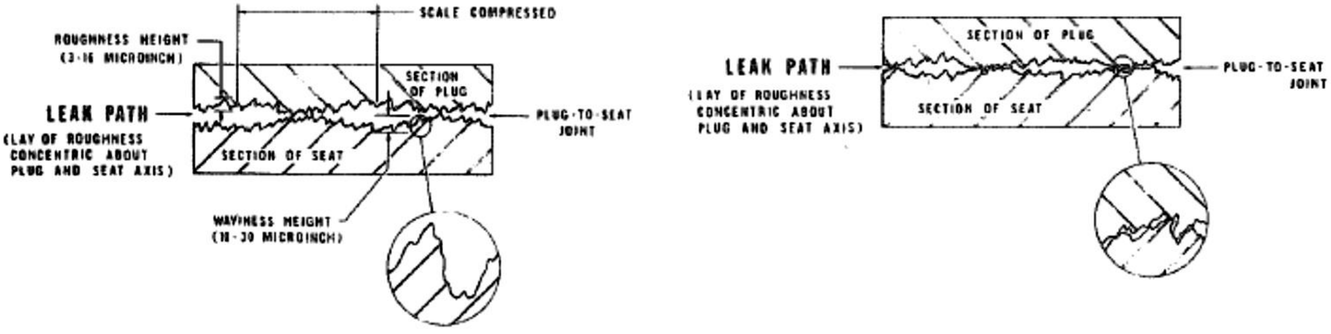
Leakage depends on many variables, including seating surface finish (waviness and roughness), seat materials, seat contact width, and seating load. Recommended seat loads (pounds force per inch of seat circumference) for metal seated valves range from 100 lb/in. for high pressure drop nearly leak-tight surface [6] to 100 lb/in to 200 lb/in for Class V shutoff with metal seats [7]. Fortunately, LLRT valves are proven to meet acceptable leakage criteria under the tested conditions which provides assurance that the seating surfaces are in good condition and that minimum seat loads (lb/in) required to achieve sealing have been obtained.

For valves where "…service pressure will tend to diminish the overall leakage channel opening, as by pressing the disk into or onto the seat with greater force," the ASME OM Code ISTC-3630

[8] allows use of the following formula to estimate the leakage, L_{max}, at DP_{max} given a corresponding leakage, L_{test}, and a test differential pressure DP_{test} (lower than DP_{max}) as shown in the following formula:

$$\frac{L_{max}}{L_{test}} = \sqrt{\frac{DP_{max}}{DP_{test}}} \qquad (15)$$

This equation conservatively assumes the microscopic flow passages at the seating interface providing the flow resistance remain constant in size with increasing seal load due to a higher-differential pressure condition. It also assumes the leakage is proportional to the square root of the test differential pressure. Higher pressure would tend to decrease the size of microscopic flow passages at the seating interface as shown in Figure 2-2.



(a) Under Light Seating Load **(b) Under Heavy Seating Load**

Figure 2-2: Microscopic Flow Path Under Light and Heavy Seating Load [6]

In this analysis, the seat load <u>decreases</u> with <u>decreasing</u> test differential pressure. The amount of seat load decrease is limited to the portion of seat load produced by differential pressure. For an MOV, the total seat load will change as the new test differential pressure, DP2, is reduced from the LLRT test pressure, DP1 as shown in Figure 2-3. However, the seat load due to mechanical wedging is typically much greater than that due to differential pressure such that total seat load change with decreasing differential pressure is small.

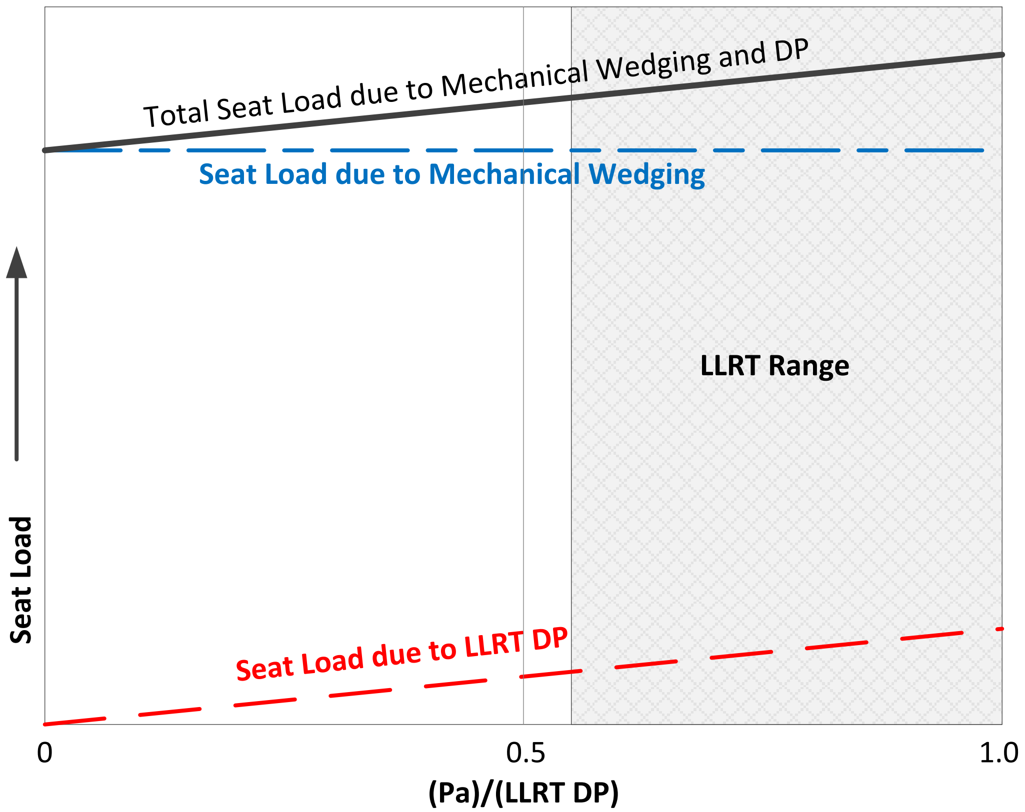


Figure 2-3: Change in Seat Load as a Ratio of LLRT test DP (DP1) to Pa (DP2)

For a given leak flow path, the leakage, L, is proportional to the square root of the differential pressure according to ISTC-3630. A leakage coefficient proportionality constant, C_L, is given to relate the square root of the pressure differential to the leakage flow rate.

$$L = C_L \cdot \sqrt{DP} \tag{16}$$

Over the small change in test air pressure, any physical properties associated with C_L would be relatively constant (density, etc.) such that only the change in flow passage size is of importance. Therefore, leakage at Condition 1 and Condition 2 can be determined as follows:

$$L_1 = C_{L1} \cdot \sqrt{DP1}$$

$$L_2 = C_{L2} \cdot \sqrt{DP2}$$

To maintain the same leakage at test DP condition 1 (DP1) and test DP condition 2 (DP2) by setting L1 = L2, and the following relationship between the leakage coefficient, C_L, and DP is obtained from Equation 13:

$$\frac{C_{L2}}{C_{L1}} = \sqrt{\frac{DP1}{DP2}} \tag{17}$$

Using Equation 14, if the test DP changed from 16.5 psi to 9 psi then the leakage coefficient needs to increase by 35% before the measured leakage at the lower DP2 would increase from the measured leakage at the higher DP1. If the relationship between leakage flow rate and DP were linear or squared, as suggested by some references [6] for compressible flow, the predicted allowed change in leakage coefficient would be larger. Therefore, it is conservative to assume a square root relationship.

To determine the expected change in seat leakage coefficient, C_L, with seat load, seat leakage testing performed by KEI [10, 11] for a 4-inch, 150 lb and a 4-inch, 900-lb Powell Flexible Wedge gate valve are examined. This testing showed the expected increase in seat leakage as the seat load was decreased. In this testing, the valves were closed to different stem thrust values to produce mechanical wedging and then differential pressure was applied in the opposite direction to reduce the seat load. The differential pressure was increased until high leakage was obtained. Although the test DP is acting in the opposite direction to that simulated during the LLRT, this testing does provide an indication of the leakage as a function of seat load. A plot of seat leakage versus decrease in seat load is shown in Figure 2-4 for the 150 lb class valve and Figure 2-5 for the 900 lb class valve. The initial seat load was at a high enough level where the leakage was zero or near zero as in the case for the LLRT. As can be seen from this figure, decreases in seat load of [redacted] or less for the 150 lb class valve and [redacted] or less for the 900 lb class valve produced very little increase, if any, in seat leakage.

Based on this testing, a conservative approach is to assume that the leak path constant, C_L, is inversely proportional to the seat load such that an X% decrease in seat load results in an X% increase in C_L up to a bounding [redacted] reduction in seat load based on test data for the 150 lb class valve. It is then possible to show that the decrease in seat load due to reduced DP conditions would not increase the measured seat leakage.

As described in the previous example, if the test DP change from 16.5 psi to 9 psi resulted in a 10% reduction in seat load, the leak path constant, C_L, could increase by 35% before the enlarged leak path is offset by the decrease in differential pressure and the measured seat leakage would increase.

The approach can be summarized as follows:

1. Determine the seat load produced by mechanical wedging and LLRT test DP at 16.5 psi and the portion produced by the test DP.
2. Determine the reduction in seat load for a change in test pressure from 16.5 psi to 9.0 psi.
3. If the reduction in seat load is less than 10% then, based on previous testing, the leakage is not expected to increase. 10% is also considered to be conservative since, per Equation 14,

the leak path leakage coefficient, C_L, could change by Sqrt(16.5/9) = 1.35 (35% increase) before the leakage is expected to increase.

4. Determine the theoretical LLRT test DP that would result in a 10% reduction in seat load at Pa = 9.0 psi.
5. Determine the minimum mechanical seating thrust required to achieve no greater than a 10% reduction in seating load or a minimum seat contact load of 100 lb/in, whichever thrust is greater.

Figure 2-4: Seat Leakage vs. Reduction in Seating Load Test Data for 4-inch 150 lb Flexible Wedge Gate Valve

(Note: Different colors represent different closing wedge thrust loads)

Figure 2-5: Seat Leakage vs. Reduction in Seating Load Test Data for 4-inch 900 lb Flexible Wedge Gate Valve

(Note: Different colors represent different closing wedge thrust loads)

3

INPUTS

3.1 CALCULATION INPUTS

The input data for the analyses are documented in Table 3-1 and Table 3-2 and were obtained from calculations, drawings, specifications, and other information provided by TVA. Some of these inputs are provided in Appendix B. Inputs that require additional clarification are documented below, if applicable. Justified assumptions were made where data were not available. It is important to note that the results of this analysis may be significantly affected by changing key inputs. It will be necessary to perform an impact analysis if key data are changed in the future.

Table 3-1: Common Input Data

Item	Variable	Value	Reference
Area based on mean seat diameter	A_o	Calculated	Section 2.1
Stem area at packing	As	Calculated	Section 2.1
LLRT test differential pressure, psi	DP_{test}	16.5	See 3.1.1
Adj. calculated peak containment internal pressure during LOCA, psig	Pa	9.0	See 3.1.1
Torque reaction radius, ft	r_t	Calculated	Section 2.1
Friction coefficient at torque reaction surface	μ_t	0.5	[5]

3.1.1 LLTR Test Pressure and Adjusted Maximum Containment Design Pressure

The maximum permissible LLRT test pressure is 1.1 x 15= 16.5 psi [15, 16]. The calculated peak containment internal pressure during a loss-of-coolant accident (LOCA) for Watts Bar is 9.36 psig [15]. For purposes of this analysis, a lower and more conservative value of 9 psig is used.

Table 3-2: Valve-Specific Input Data

Valve ID	**Input Parameter [12, 13, 14]**							
	F_C lb	**Fpack lb**	**FI lb**	**ds in**	**Dm in**	**θ deg**	**μ**	**SF ft**
1-FCV-26-240	2716	1000	3306	1.0	4.25	5	0.57	0.0148
2-FCV-26-240	3004	1250	438	1.0	4.15	5	0.57	0.0148
1-FCV-26-243	2640	1000	2873	1.0	4.25	5	0.57	0.0148
2-FCV-26-243	2640	1000	452	1.0	4.15	5	0.57	0.0148
1-FCV-62-61	3624	1250	645	1.250	4.064	7	0.6582	0.0116
2-FCV-62-61 Note 1	4290	1200	1062	1.250	4.064	7	0.6582	0.0116
1-FCV-62-63	3095	1250	489	1.250	4.064	7	0.57	0.0116
2-FCV-62-63 Note 1	3847	1555	810	1.250	4.064	7	0.57	0.0116
1-FCV-70-87	13158	1000	1338	1.0	2.625	5	0.6	0.0126
2-FCV-70-87	13158	1000	3362	1.0	2.625	5	0.6	0.0126
1-FCV-70-134	2000	875	1298	0.875	3.422	5	0.6393	.0097
2-FCV-70-134 Note 1	2108	762	1098	0.875	3.45	5	0.641	0.0170
1-FCV-70-90	13158	1000	1803	1.0	2.625	5	0.6	0.0126
2-FCV-70-90	12710	1750	1243	1.125	2.625	5	0.6	0.0126

Note 1: Three Unit 2 MOVs, 2-FCV-62-061, 2-FCV-62-063, and 2-FCV-70-134 were found to be set below the minimum required thrust values. For these three MOVs, the thrust at switch trip and packing loads are taken from CR-1604752 [9] instead of the set-up sheets or calculations.

4

ASSUMPTIONS

Data that have not been formally verified are treated as assumptions. Where possible, the basis of the data has been noted. The following general assumptions were used in this analysis.

1. Seat leakage is proportional to the square root of differential pressure for purposes of determining the allowable increase in the seat leakage coefficient. Use of this relationship in lieu of a linear or squared relationship for this purpose is shown to be conservative in Section 2.6 and does not require verification.
2. The weight of stem and disk are neglected in determining the stem forces acting to push the disk into the seat. Since the weight term will generally provide additional closing force, this is a conservative assumption and does not require verification.
3. 75% of the inertia overshoot load is credited to provide additional stem force after actuator switch-off and is taken from the latest static diagnostic test data. Future variation in inertia overshoot will occur but is reasonably bounded by using the 75% reduction, minimum required thrust from the MOV set-up sheet, and the maximum packing force.

5

RESULTS AND CONCLUSION

5.1 SEAT LOAD RESULTS

Seating load results for the applicable MOV Gate valves are shown below. As can be seen, the seat load contribution from the test differential is a small contribution to the total seat load for most MOVs.

Table 5-1: Seat Load Results

Tag Number	Seat Contact Force at DPtest, lb/in	Seat Contact Force due to DP, lb/in	DP Seat Contact Force as a Percent of Total
1-FCV-26-240	246.6	17.5	7.1
2-FCV-26-240	133.1	17.1	12.9
1-FCV-26-243	224.7	17.5	7.8
2-FCV-26-243	127.3	17.1	13.5
1-FCV-62-61	155.2	16.8	10.8
2-FCV-62-61	205.4	16.8	8.2
1-FCV-62-63	137.3	16.8	12.2
2-FCV-62-63	175.1	16.8	9.6
1-FCV-70-87	1107.7	10.8	1.0
2-FCV-70-87	1234.4	10.8	0.9
1-FCV-70-134	143.7	14.1	9.8
2-FCV-70-134	143.4	14.2	9.9
1-FCV-70-90	1136.8	10.8	1.0
2-FCV-70-90	1001.5	10.8	1.1

5.2 SEAT LOAD REDUCTION RESULTS

Seating load reduction due to a decrease in LLRT test pressure from the normal test DP_{test} to Pa (16.5 psig to 9 psig) is shown in Table 5-2. As can be seen, all values are bounded by a 6% reduction in seat load and the seat contact force values all exceed 100 lb/in, which is the minimum recommended value for metal seats per References 6 and 7. Also, the corresponding leakage coefficient, C_L, is not expected to increase seat leakage at the lower test pressure of 9 psig unless the seat contact force decreased by more than 35%.

Table 5-2: Seat Load Reduction

Tag Number	Seat Contact Force at DPtest, lb/in	Reduction in Seat Contact Force at Pa, lb/in	Pct Reduction
1-FCV-26-240	246.6	7.6	3.1
2-FCV-26-240	133.1	7.4	5.6
1-FCV-26-243	224.7	7.6	3.4
2-FCV-26-243	127.3	7.4	5.8
1-FCV-62-61	155.2	7.2	4.6
2-FCV-62-61	205.4	7.2	3.5
1-FCV-62-63	137.3	7.1	5.2
2-FCV-62-63	175.1	7.1	4.1
1-FCV-70-87	1107.7	4.4	0.4
2-FCV-70-87	1234.4	4.4	0.4
1-FCV-70-134	143.7	6.1	4.3
2-FCV-70-134	143.4	6.2	4.3
1-FCV-70-90	1136.8	4.4	0.4
2-FCV-70-90	1001.5	4.3	0.4

5.3 MINIMUM SEAT THRUST REQUIREMENTS

Table 5-3 presents the minimum seat thrust required to maintain no more than a 10% reduction in seat load and 100 lb/in seat contact force using Equations 13 and 14. For MOVs, the seat load is typically determined by the difference between static diagnostic trace markers C16 (maximum thrust) and C11 (thrust at seat contact). The fourth column is the maximum of columns 2 and 3.

Table 5-3: Minimum Seating Thrust, F_{ST}, for Static MOV Test

Tag Number	Seat Thrust to achieve 10% Reduction in Seat Contact Force, lb.	Seat Thrust to achieve 100 lb/in of Seat Contact Force, lb.	Minimum Required Thrust, lb.
1-FCV-26-240	1087	1519	1519
2-FCV-26-240	1035	1492	1492
1-FCV-26-243	1087	1519	1519
2-FCV-26-243	1035	1492	1492
1-FCV-62-61	1144	1727	1727
2-FCV-62-61	1144	1727	1727
1-FCV-62-63	1006	1534	1534
2-FCV-62-63	1006	1534	1534
1-FCV-70-87	411	1083	1083
2-FCV-70-87	411	1083	1083
1-FCV-70-134	770	1394	1394
2-FCV-70-134	806	1445	1445
1-FCV-70-90	411	1083	1083
2-FCV-70-90	398	1086	1086

5.4 MAXIMUM LLRT TEST PRESSURE FOR 10% SEAL LOAD REDUCTION

The maximum LLRT test pressure (DP_{test}) to ensure no greater than a 10% seal load reduction at Pa is shown in Table 5-4. As can be seen, the bounding (lowest) test pressure is 22.1 psi, which exceeds the current maximum LLRT pressure of 16.5 psi.

Table 5-4: Maximum DPtest for 10% Reduction in Seat Load

Tag Number	DP_{test}
1-FCV-26-240	34.8
2-FCV-26-240	22.7
1-FCV-26-243	32.4
2-FCV-26-243	22.1
1-FCV-62-61	26.0
2-FCV-62-61	31.8
1-FCV-62-63	24.0
2-FCV-62-63	28.4
1-FCV-70-87	217.0
2-FCV-70-87	241.0
1-FCV-70-134	27.5
2-FCV-70-134	27.1
1-FCV-70-90	222.5
2-FCV-70-90	202.3

5.5 CONCLUSION

To be at risk for increased leakage at a Pa = 9.0 psi, the seat load would need to decrease by 35%. KEI test results show that [redacted] is a "best available" bounding reduction in seat load, above which seat leakage can increase for wedge gate valves. Table 5.1 shows that many of the MOVs have seat load contributions due to DP that are less than 10%. Table 5.2 shows that the total reduction in seat load for all MOVs is less than 6% such that an increase in seat leakage is not expected if the LLRT test pressure were to decrease from 16.5 psi to 9 psi. Table 5-3 provides the minimum seat thrust from MOV static diagnostic testing to achieve no greater than a 10% reduction in seating load or a minimum seat contact load of 100 lb/in, whichever thrust is greater. Table 5.4 shows that the limiting maximum LLRT pressure for all MOVs such that the seat load would not drop by more than 10% is 22.1 psi.

Based on these results, seat leakage for all MOV Gate valves within the scope of this assessment is not expected to increase if tested at a lower differential pressure of 9.0 psig.

6

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1. KEI Document No. 1500C Rev. 15; Kalsi Engineering, Inc. *Quality Assurance Manual*.
2. TVA Purchase Order 6232543, Rev. Num: 0.
3. TVA Engineering Work Request, EWR20MECH088032, *Generate List of U1 Containment Isolation Valves for Kalsi Engineering Pa impact evaluation*. 06/09/20.
4. *Evaluation Guide for Valve Thrust and Torque Requirements*. EPRI, Palo Alto, CA: 2016. 3002008055.
5. *Nuclear Maintenance Applications Center, Application Guide for Motor-Operated Valves in Nuclear Power Plants – Revision 2, Volume 1: Gate and Globe Valves*, EPRI, Palo Alto, CA, August 2007, 1015396.
6. *ISA Handbook of Control Valves*, 2nd Edition, J.W. Hutchison, Instrument Society of America, 1979.
7. *Control Valve Handbook*, Fifth Edition, Emerson Automation Solutions, 2017.
8. ASME OM-2004 Edition through 2006 Addenda, *Operation and Maintenance of Nuclear Power Plants*.
9. *TVA Watts Bar, White Paper for Appendix J Leak Tightness for Program MOVs Using Close Torque Switch Bypass Motor Control Set at no Less than 98%*, CR 1604752, WF Cetta, 4/29/2020, Rev. 1, 07/06/2020.
10. KEI Document 2083C, Rev. 0 *Grand Gulf Nuclear Station Engineering Report for Disc Bypass Leakage Test and Analysis for 4-inch, 150-pound William Powell Flexible Wedge Gate Valve*, September 1999.
11. KEI Document 2116C, Rev. 0 *Grand Gulf Nuclear Station Engineering Report for Disc Bypass Leakage Test and Analysis for 4-inch, 900-pound and Analysis for 6-inch, 600-pound William Powell Flexible Wedge Gate Valves*, October 2000.
12. *MOV Set-Point Sheets*
    a. *1-FCV-26-240-A*, 1-47A8910-26-07, R5

b. *1-FCV-26-243-A*, 1-47A8910-26-10, R5
c. *2-FCV-26-240-A*, 2-47A8910-26-07, R4
d. *2-FCV-26-243-A*, 2-47A8910-26-10, R2
e. *1-FCV-62-61-B*, 1-47A8910-62-01, R3
f. *1-FCV-62-63-B*, 1-47A8910-62-2, R4
g. *2-FCV-62-61-B*, 2-47A8910-62-01, R2
h. *2-FCV-62-63-B*, 2-47A8910-62-02, R2
i. *1-FCV-70-87-B*, 1-47A8910-70-03, R3
j. *1-FCV-70-134-B*, 1-47A8910-70-09, R2
k. *2-FCV-70-87-B*, 2-47A8910-70-03, R2
l. *2-FCV-70-134-B*, 2-47A8910-70-09, R3
m. *1-FCV-70-90-A*, 1-47A8910-70-05, R3
n. *2-FCV-70-90-A*, 2-47A8910-70-05, R3

13. *MOV Set-up Calculations*

a. TVA Calculation T71191007812, Rev. 009, *Documentation of Design Basis Review, Required Thrust/Torque Calculations and Valve and Actuator Capability Assessment for Valve 1-FCV-26-240.*

b. TVA Calculation T93150924008, Rev. 004, *Documentation of Design Basis Review, Required Thrust/Torque Calculations and Valve and Actuator Capability Assessment for Valve 2-FCV-26-0240.*

c. TVA Calculation T71191007813, Rev. 010, *Documentation of Design Basis Review, Required Thrust/Torque Calculations and Valve and Actuator Capability Assessment for Valve 1-FCV-26-243.*

d. TVA Calculation T93150807008, Rev. 003, *Documentation of Design Basis Review, Required Thrust/Torque Calculations and Valve and Actuator Capability Assessment for Valve 2-FCV-26-0243.*

e. TVA Calculation T71030218808, Rev. 5, *Documentation of Design Basis Review, Required Thrust/Torque Calculations and Valve and Actuator Capability Assessment for Valve 1-FCV-62-61.*

f. TVA Calculation T93150112024, Rev. 005, *Documentation of Design Basis Review, Required Thrust/Torque Calculations and Valve and Actuator Capability Assessment for Valve 2-FCV-62-061*.

g. TVA Calculation T71110212844, Rev. 006, *Documentation of Design Basis Review, Required Thrust/Torque Calculations and Valve and Actuator Capability Assessment for Valve 1-FCV-62-63*.

h. TVA Calculation T93140404009, Rev. 003, *Documentation of Design Basis Review, Required Thrust/Torque Calculations and Valve and Actuator Capability Assessment for Valve 2-FCV-62-063*.

i. TVA Calculation T71191007811, Rev. 010, *Documentation of Design Basis Review, Required Thrust/Torque Calculations and Valve and Actuator Capability Assessment for Valve 1-FCV-70-87*.

j. TVA Calculation T71191007816, Rev. 002, *Documentation of Design Basis Review, Required Thrust/Torque Calculations and Valve and Actuator Capability Assessment for Valve 2-FCV-70-087*.

k. TVA Calculation T71030613801, Rev. 9, *Documentation of Design Basis Review, Required Thrust/Torque Calculations and Valve and Actuator Capability Assessment for Valve 1-FCV-70-90*.

l. TVA Calculation T93140426049, Rev. 003, *Documentation of Design Basis Review, Required Thrust/Torque Calculations and Valve and Actuator Capability Assessment for Valve 2-FCV-70-090*.

m. TVA Calculation T71191007810, Rev. 007, *Documentation of Design Basis Review, Required Thrust/Torque Calculations and Valve and Actuator Capability Assessment for Valve 1-FCV-70-134*.

n. TVA Calculation T71191007818, Rev. 008, *Documentation of Design Basis Review, Required Thrust/Torque Calculations and Valve and Actuator Capability Assessment for Valve 2-FCV-70-134*.

14. Diagnostic Test Data

a. WID: 120295525, VOTES Infinity Valve Diagnostic System Report, WBN-1-FCV-026-0240-A, 5/17/2020.

b. WID: 120295526, VOTES Infinity Valve Diagnostic System Report, WBN-1-FCV-026-0243-A, 5/23/2020.

   c. WID: 111457730, MOVATS Testing of Motor Operated Valves, 2-FCV-026-0240, 7/27/2015.

   d. WID: 111457734, MOVATS Testing of Motor Operated Valves, 2-FCV-026-0243, 7/20/2015.

   e. WID: 119083315, MOVATS Testing of Motor Operated Valves, 1-MVOP-062-0061-B, As-Left, 9/29/2018.

   f. WID: 118305103, MOVATS Testing of Motor Operated Valves, 1-FCV-062-0063, As-Left, 3/4/17.

   g. WID: 118771402, MOVATS Testing of Motor Operated Valves, 2-FCV-62-61-B, As-Left, 11/04/2017.

   h. WID: 112216193, MOVATS Testing of Motor Operated Valves, 2-FCV-062-0063-A, 2/17/14.

   i. WID: 112800521, MOVATS Testing of Motor Operated Valves, 1-FCV-70-87, As-Left, 9/15/12.

   j. WID: 115752256, MOVATS Testing of Motor Operated Valves, 2-FCV-70-87-B, As-Left, 7/18/2014.

   k. WID: 117758166, MOVATS Testing of Motor Operated Valves, 1-FCV-070-0134-B, As-Left, 4/13/17.

   l. WID: 119475524, VOTES Infinity Valve Diagnostic System Report, 2-FCV-070-0134-B, As-Left, 5/5/19.

   m. WID: 118305123, MOVATS Testing of Motor Operated Valves, 1-FCV-070-0090-A, As-Left, 3/27/17.

   n. WID: 112241713, MOVATS Testing of Motor Operated Valves, 2-FCV-070-0090-A, As-Left, 8/21/2013.

15. Watts Bar UFSAR Section 6.6, *Containment Systems*.

16. ANSI/ANS-56-8-1994, *American National Standard for Containment System Leakage Testing Requirements*.

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Wedge Gate Valve Leak Testing

Input data from References 10 and 11:

Description	Variable	Value		Units
		150-lb	900-lb	
Seat ring OD	d_{OD}	4.628	4.242	in
Seat ring ID	d_{ID}	3.975	3.469	in
Mean seat ring diameter	dm	4.3015	3.8555	in
Stem diameter at packing	ds	0.997	1.123	in
Measured packing load	Fpack-1	275	770	lb
Measured Packing load	Fpack-2	230	690	lb
Measured Packing load	Fpack-3		685	lb
Measured disk-to-seat friction	Mu-1	0.136	0.25 (average)	
Measured disk-to-seat friction	Mu-2	0.158	0.13 (average)	
Measured disk-to-seat friction	Mu-3		0.115 (average)	
Half wedge angle	θ	4.75	5	deg
Area based on dm	Ao	14.53	11.67	in^2
Area based on ds	As	0.78	0.78	in^2

Mean seat diameter, dm, is the average of d_{OD} and d_{ID}.

Mechanical Seat Load, lb, is determined using Equation 6.

$$R_r = \frac{\left(F_c \cdot TRF - F_{pack} - DP \cdot A_s\right)}{2 * (\sin\theta + \mu * \cos\theta)} \tag{6}$$

Mechanical Seat Contact Load, lb/in, is determined by dividing Equation 6 by the seat contact circumference, π*dm.

DP Seat Load is determined using Equation 7

$$F_{s\_DP} = A_o \cdot DP \tag{7}$$

DP Seat Contact Load, lb/in, is determined by dividing Equation 7 by the seat contact circumference, π*dm.

4-inch, 150-lb Flexible Wedge Gate Valve, Reference 10

Disk Side A										
Pu psi	Thrust lb	Leakage ml	Disk Closing Thrust lb	Mech Seat Load		DP Seat Load		Total		Seat Load Decrease
				lb	lb/in	lb	lb/in	lb	lb/in	
Fpack = 275 lb, Mu = 0.136										
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Fpack = 275 lb, Mu = 0.136										
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Disk Side A										
Pu psi	Thrust lb	Leakage ml	Disk Closing Thrust lb	Mech Seat Load		DP Seat Load		Total		Seat Load Decrease
				lb	lb/in	lb	lb/in	lb	lb/in	
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Fpack = 275 lb, Mu = 0.136										
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Disk Side B										
Pu	Thrust	Leakage	Disk Closing Thrust lb	Mech Seat Load		DP Seat Load		Total		Seat Load Decrease
				lb	lb/in	lb	lb/in	lb	lb/in	
Fpack = 230 lb, Mu = 0.158										
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Fpack = 230 lb, Mu = 0.158										
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Fpack = 230 lb, Mu = 0.158										
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Disk Side B										
			Disk Closing	Mech Seat Load		DP Seat Load		Total		Seat Load
Pu	Thrust	Leakage	Thrust lb	lb	lb/in	lb	lb/in	lb	lb/in	Decrease
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
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Fpack = 230 lb, Mu = 0.158										
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4-inch, 900-lb Flexible Wedge Gate Valve, Reference 11

Disk Side A										
Pu psi	Thrust lb	Leakage ml	Disk Closing Thrust lb	Mech Seat Load		DP Seat Load		Total		Seat Load Decrease
				lb	lb/in	lb	lb/in	lb	lb/in	
Fpack = 770 lb, Mu = 0.25										
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Fpack = 690 lb, Mu = 0.25										
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Fpack = 685 lb, Mu = 0.25										
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Disk Side A										
Pu psi	Thrust lb	Leakage ml	Disk Closing Thrust lb	Mech Seat Load		DP Seat Load		Total		Seat Load Decrease
				lb	lb/in	lb	lb/in	lb	lb/in	
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Fpack = 685 lb, Mu = 0.13										
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Disk Side B										
Pu psi	Thrust lb	Leakage ml	Disk Closing Thrust lb	Mech Seat Load		DP Seat Load		Total		Seat Load Decrease
				lb	lb/in	lb	lb/in	lb	lb/in	
Fpack = 685 lb, Mu = 0.115										
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Fpack = 685 lb, Mu = 0.115										
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Local Leak Rate Test Leakage Evaluation at Watts Bar for MOV/AOV Plug Valves

Document No. 3960C, Rev. 0, Attachment 2

Prepared for

Watts Bar Nuclear Station
Tennessee Valley Authority
Spring City, TN

Prepared by

Nimish

Nimish Jagtap

Verified by

Neal Estep Sept 15, 2020

Neal Estep, P.E., Date

QA Approval by

Fabiola Rico Sept. 16, 2020

Fabiola Rico, Date

KEI File No.263.92.1
Client Purchase Order No. 6232543, Rev. 0
Date of Preparation: September 15, 2020

---Non-Proprietary Version---

Revisions

Rev. No.	DCR/N No.	Description of Changes	Pages Affected
0	N/A	Initial release	All

Description	**Pages**
Main Text	19
Total Pages	19

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1

OBJECTIVE AND SCOPE

1.1 OBJECTIVE

Kalsi Engineering, Inc. (KEI) has been contracted by Tennessee Valley Authority (TVA) to provide engineering services to evaluate the impact of local leak rate test (LLRT) pressures (DPtest) greater than the calculated peak containment internal pressure (Pa) caused by the design-basis loss-of-coolant accident (LOCA) for cases where greater test pressure tends to increase the sealing force. This work is being done in accordance with Purchase Order No. 6232543.

The objective of this report is to determine the impact of the reduced LLRT pressure from DPtest to Pa on the seat leakage. All work performed under this project is done in accordance with the requirements of the KEI Quality Assurance Program [1], which meets the intent of 10CFR50 Appendix B requirements.

1.2 SCOPE

The scope of this attachment is (Motor-Operated Valve) MOV and (Air-Operated Valve) AOV plug valves listed in Table 1-1. The Group 67-5 valves are MOVs whereas the Group 31-2 and 77-2 valves are AOVs. These valves are two-way 2-inch Xomox Tufline plug valves with socket weld ends [4]. A cut section of a valve is shown in Figure 1-1.

Table 1-1: Analysis Scope

Group	Component Id	Comp Description	Manufacturer
31-2	2-FCV-31-305	INCORE INSTR RM AHU 2A CWR ISOL	Xomox – Crane
31-2	2-FCV-31-306	INCORE INSTR RM AHU 2A CWR ISOL	Xomox – Crane
31-2	2-FCV-31-308	INCORE INSTR RM AHU 2A CWS ISOL	Xomox – Crane
31-2	2-FCV-31-309	INCORE INSTR RM AHU 2A CWS ISOL	Xomox – Crane
31-2	2-FCV-31-326	INCORE INSTR RM AHU 2B CWR ISOL	Xomox – Crane
31-2	2-FCV-31-327	INCORE INSTR RM AHU 2B CWR ISOL	Xomox – Crane

Group	Component Id	Comp Description	Manufacturer
31-2	2-FCV-31-329	INCORE INSTR RM AHU 2B CWS ISOL	Xomox – Crane
31-2	2-FCV-31-330	INCORE INSTR RM AHU 2B CWS ISOL	Xomox – Crane
67-5 (67-6)	1(2)-FCV-67-130	UPPER CNTMT VENT CLR 1(2)A ERCW SUP HDR ISOL	Xomox – Crane
67-5 (67-6)	1(2)-FCV-67-131	UPPER CNTMT VENT CLR 1(2)A ERCW RET HDR ISOL	Xomox – Crane
67-5 (67-6)	1(2)-FCV-67-133	UPPER CNTMT VENT CLR 1(2)C ERCW SUP HDR ISOL	Xomox – Crane
67-5 (67-6)	1(2)-FCV-67-134	UPPER CNTMT VENT CLR 1(2)C ERCW RET HDR ISOL	Xomox – Crane
67-5 (67-6)	1(2)-FCV-67-138	UPPER CNTMT VENT CLR 1(2)B ERCW SUP HDR ISOL	Xomox – Crane
67-5 (67-6)	1(2)-FCV-67-139	UPPER CNTMT VENT CLR 1(2)B ERCW RET HDR ISOL	Xomox – Crane
67-5 (67-6)	1(2)-FCV-67-141	UPPER CNTMT VENT CLR 1(2)D ERCW SUP HDR ISOL	Xomox – Crane
67-5 (67-6)	1(2)-FCV-67-142	UPPER CNTMT VENT CLR 1(2)D ERCW RET HDR ISOL	Xomox – Crane
67-5 (67-6)	1(2)-FCV-67-295	UPPER CNTMT VENT CLR 1(2)A ERCW RET ISOL	Xomox – Crane
67-5 (67-6)	1(2)-FCV-67-296	UPPER CNTMT VENT CLR 1(2)C ERCW RET ISOL	Xomox – Crane
67-5 (67-6)	1(2)-FCV-67-297	UPPER CNTMT VENT CLR 1(2)B ERCW RET ISOL	Xomox – Crane
67-5 (67-6)	1(2)-FCV-67-298	UPPER CNTMT VENT CLR 1(2)D ERCW RET ISOL	Xomox – Crane
77-2	1(2)-FCV-77-127	RB SUMP DISCHARGE FLOW CONTROL	Xomox – Crane
77-2	1(2)-FCV-77-128	RB SUMP DISCHARGE FLOW CONTROL	Xomox – Crane

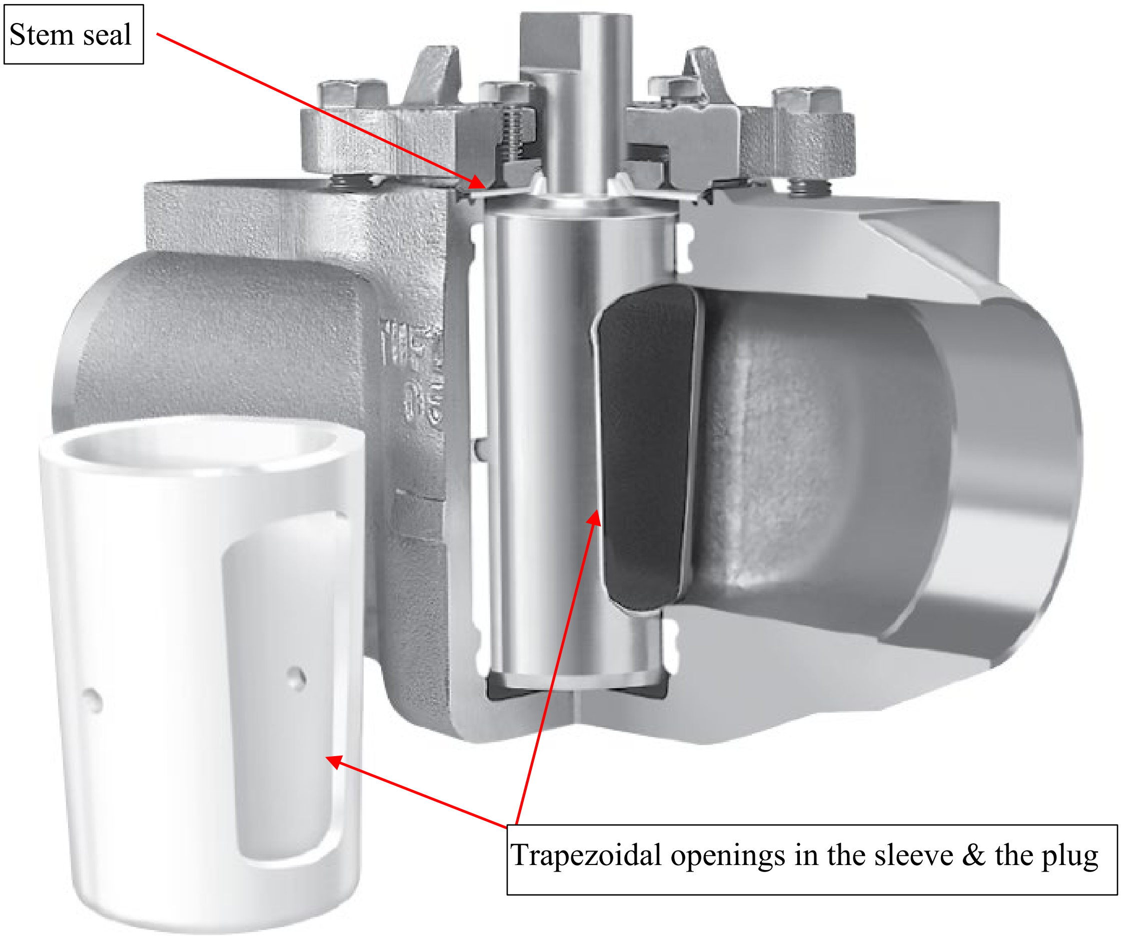

Figure 1-1: A Cut-section of the Xomox Tufline Plug Valve with Socket Weld Ends and the Sleeve [11]

1.3 HISTORICAL LEAKAGE

References [3] and [13] provide the LLRT history for the valves. Table 1-2, below, summarizes the results.

Table 1-2: LLRT Leakage History

Group	Component Id	Leakage Results
31-2	2-FCV-31-305	Favorable history
31-2	2-FCV-31-306	Favorable history
31-2	2-FCV-31-308	Favorable history
31-2	2-FCV-31-309	Favorable history
31-2	2-FCV-31-326	Favorable history
31-2	2-FCV-31-327	Unfavorable history
31-2	2-FCV-31-329	Unfavorable history
31-2	2-FCV-31-330	Favorable history
67-5 67-6	1-FCV-67-130 2-FCV-67-130	Favorable history Unfavorable history
67-5 67-6	1-FCV-67-131 2-FCV-67-131	Favorable history Favorable history
67-5 67-6	1-FCV-67-133 2-FCV-67-133	Favorable history Favorable history
67-5 67-6	1-FCV-67-134 2-FCV-67-134	Favorable history Favorable history
67-5 67-6	1-FCV-67-138 2-FCV-67-138	Favorable history Favorable history
67-5 67-6	1-FCV-67-139 2-FCV-67-139	Favorable history Favorable history
67-5 67-6	1-FCV-67-141 2-FCV-67-141	Favorable history Favorable history
67-5 67-6	1-FCV-67-142 2-FCV-67-142	Favorable history Favorable history
67-5 67-6	1-FCV-67-295 2-FCV-67-295	Favorable history Favorable history
67-5 67-6	1-FCV-67-296 2-FCV-67-296	Favorable history Favorable history
67-5 67-6	1-FCV-67-297 2-FCV-67-297	Favorable history Favorable history
67-5 67-6	1-FCV-67-298 2-FCV-67-298	Favorable history Favorable history
77-2 77-2	1-FCV-77-127 2-FCV-77-127	Favorable history Favorable history
77-2 77-2	1-FCV-77-128 2-FCV-77-128	Favorable history Favorable history

2

METHODOLOGY

2.1 VARIABLES

Variable	Description	Units
Dpo	Port diameter	Inch
A	Dimension A (see Figure 3-1)	Inch
B	Dimension B (see Figure 3-1)	Inch
Ap	Projected area over which the DP acts. Calculated as Dpo*(A+B)/2	Inch^2
R	Average plug radius	Inch
μ	Plug-to-sleeve friction coefficient	-
P_{test}	Differential pressure used for LLRT	Psi
Pa	Calculated peak containment internal pressure related to the design-basis loss-of-coolant accident (LOCA)	Psig
T_{unseat}	Unseating torque	Ft*lbf
%Reduction	Reduction in sealing load due to Pa vs. test DP	%

2.2 PLUG VALVE SEALING LOAD

During LLRT, the plug valve is closed and differential pressure (DP) is applied across the valve. In the closed condition, the seat torque on the plug is contributed by 1) actuator torque and 2) DP-induced torque. Actuator torque is proportional to the applied torque on top of the plug stem and coefficient of friction (COF) at the contacting surfaces. The plug contacts the sleeve and the stem seal shown in Figure 1-1. DP load is proportional to the DP and the area over which the DP acts.

The approach for this analysis is to:

1. Calculate the seat torque in the closed condition of the valve due to actuator torque
2. Calculate the DP-induced torque on the seat
3. Determine the reduction in total sealing torque due to changing the LLRT test DP from the current value, P_{test}, to the design basis containment pressure, Pa.

2.3 SLEEVE SEALING TORQUE DUE TO ACTUATOR LOAD

The plug valve in the assembled condition develops contact reactions at the sleeve and the stem seal. The actuator torque needs to overcome frictional resistance at these interfaces.

Since the actuator torque used in the LLRT is not available, it was estimated using the available unseating torque measurements. It was assumed that 75 % of the unseating torque is contributed by the plug-to-sleeve friction and the remaining 25 % is contributed by the plug-to-stem seal friction. As will be seen later in the report, this assumption does not affect the final conclusion. Therefore, the seat torque can be calculated using Equation 1.

$$T_{seat} = T_{unseat} - T_{stem_{seal}} = T_{unseat} - 0.25\, T_{unseat} = 0.75\, T_{unseat} \tag{1}$$

Figure 2-1 schematically shows the effect of zero DP and a positive DP on the valve under closed condition. Due to symmetry of the plug, sleeve and the valve body about the centerline shown in Figure 2-1, the plug-to-sleeve reaction would be symmetric about the centerline when there is no DP load acting on the plug. Therefore, the seat torque can be written as the sum of seat torque contributions from the upstream reaction (F_{US}) and downstream reaction (F_{DS}) of the seat.

$$T_{seat\_Zero\_DP} = \mu F_{US} R + \mu F_{DS} R = \mu R(F_{US} + F_{DS}) \tag{2}$$

where, μ is plug-to-sleeve coefficient of friction (COF) and R is the average plug radius.

2.4 SLEEVE SEALING TORQUE DUE TO DIFFERENTIAL PRESSURE

Differential pressure acts normal to the conical plug surface and results in a force equal to the differential pressure (DP) times area (Ap) over which the DP acts. This area of the trapezoidal opening in the sleeve shown in Figure 1-1. The DP force can be calculated as:

$$F_{DP} = A_p \cdot DP \tag{3}$$

Due to symmetry of the plug, sleeve and the valve body about the centerline shown in Figure 2-1, under the action of a higher pressure on the upstream side, the plug-to-sleeve reaction would reduce on the upstream side and increase on the downstream side by the same amount. For the low DP LLRT conditions, the upstream seat compression preload would not completely relax. The other variable contributing to the seat torque is the plug-to-sleeve COF, which is not expected to change for the LLRT DP range of 9 to 16.5 psid. Therefore, the net effect of the DP load on the valve torque would be zero as explained in the below equation.

$$\begin{aligned} T_{seat\_DP} &= \mu F_{DP\_US} R + \mu F_{DP\_DS} R \\ &= \mu R(F_{DP\_US} + F_{DP\_DS}) \\ &= \mu R(F_{US} - F_{DP} + F_{DS} + F_{DP}) = \mu R(F_{US} + F_{DS}) = T_{seat\_Zero\_DP} \end{aligned} \tag{4}$$

Therefore, the DP load will have no effect on the seat torque. This conclusion is in agreement with the valve manufacturer’s valve torque calculation report [5] in which it’s stated that, “Differential pressure applied across the valve has negligible effect on the valve torque. Increased differential pressure acts to increase frictional forces on the downstream side of the seal; however, decrease such forces on the upstream side.”

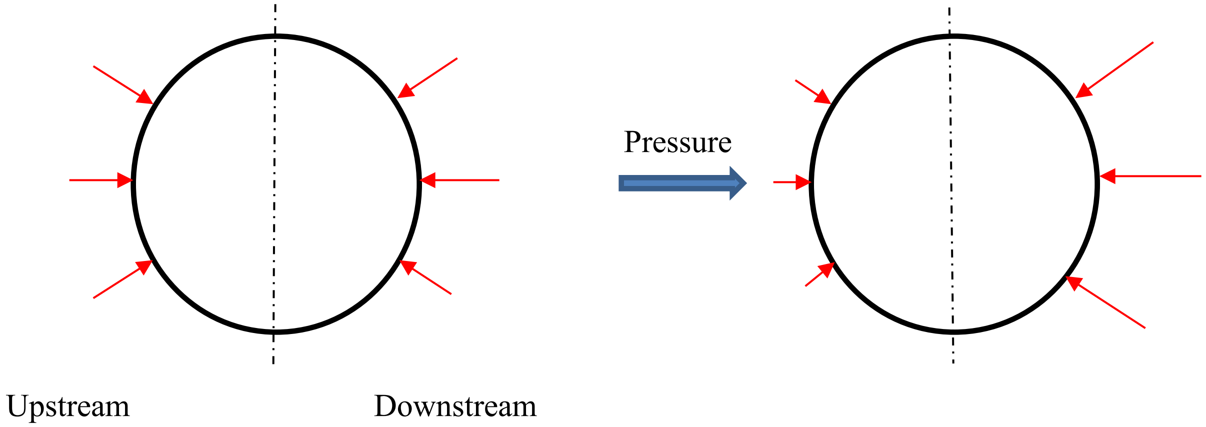

Figure 2-1: A schematic showing plug-to-sleeve reaction under zero DP (left) and positive DP (right)

Under the action of zero DP, the plug-to-sleeve reaction is symmetric about the centerline. Under the action of a higher pressure on the upstream side, the plug-to-sleeve reaction would reduce on the upstream side and increase on the downstream side by same amounts (the length of arrows indicate the force magnitude). The plug-to-sleeve COF is not expected to change for the LLRT pressure range of 9 to 16.5 psi. Therefore, the net effect on the valve torque would be negligible.

2.5 TOTAL SEALING FORCE AND SEAL FORCE REDUCTION

Based on the discussion in Section 2.4, the seat torque is independent of the DP load; especially for the range of DPs involved in the LLRT DP range of 9 to 16.5 psid. Therefore, reducing the LLRT pressure from 16.5 psid to 9 psid is expected to have negligible effect on the leakage.

3

INPUTS

3.1 CALCULATION INPUTS

The dimensions needed for the calculations are shown in Figure 3-1. The required dimensions for the plug valves were not available from TVA. The port diameter was used from Reference [6]. The other dimensions were obtained from a 2” Xomox plug valve with flanged ends procured by KEI for another project. These dimensions were used as the best available information. The unseating torque values were used from the MOVATs test reports for the individual valves.

The input data for the analyses are documented in Table 3-1. Justified assumptions were made where data were not available. It should be noted that the results of this analysis will not be affected by changing the inputs.

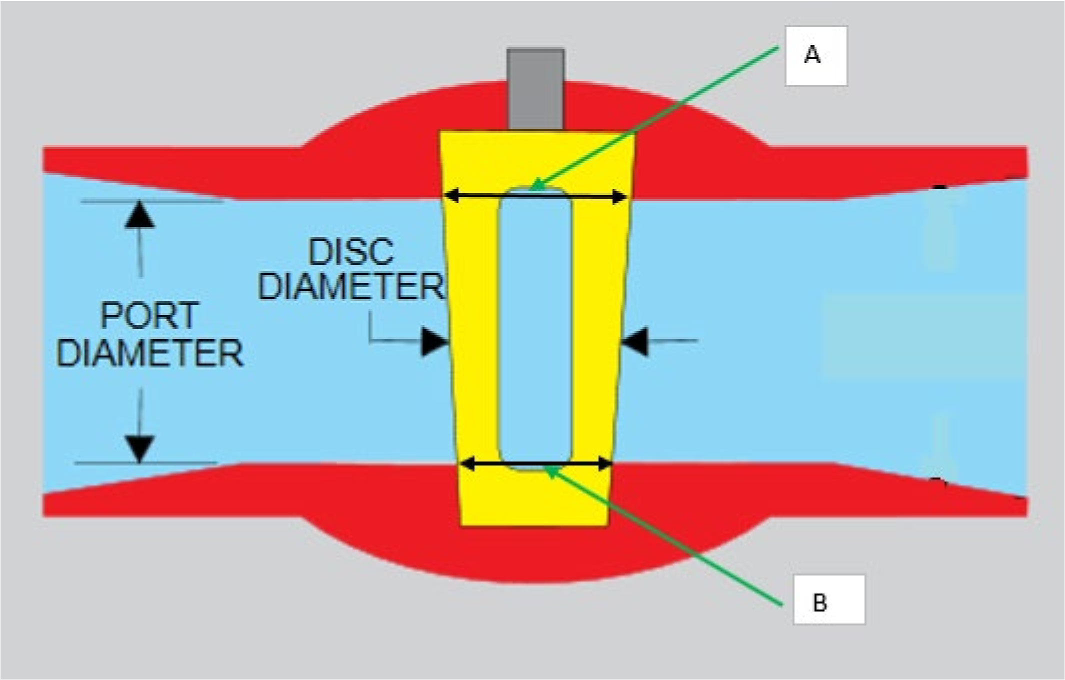

Figure 3-1: Dimensions needed for the calculations

Table 3-1: Input Data

Item	Variable	Value	Reference
Port diameter, Inch	Dpo	2.041	[6]
Dimension A (see Figure 3-1), Inch	A	2.252	Measured
Dimension B (see Figure 3-1), Inch	B	2.0975	Measured
Projected area over which the DP acts, in^2	Ap	4.44	Calculated as Dpo*(A+B)/2
Average plug radius, inch	R	1.087	Calculated as (A+B)/4
Plug-to-sleeve friction coefficient	μ	0.23	[7]
LLRT test differential pressure, psi	DP_{test}	16.5	See 3.1.1
Adj. maximum containment design pressure, psig	Pa	9.0	See 3.1.1
Unseating torque for 1-FCV-67-130, ft*lbf	T_{motor}	2.3$^{\text{Note 1}}$	[8]
Unseating torque for 1-FCV-67-131, ft*lbf	T_{motor}	3.1$^{\text{Note 1}}$	[8]
Unseating torque for 1-FCV-67-133, ft*lbf	T_{motor}	1.3$^{\text{Note 1}}$	[8]
Unseating torque for 1-FCV-67-134, ft*lbf	T_{motor}	2.4$^{\text{Note 1}}$	[8]
Unseating torque for 1-FCV-67-138, ft*lbf	T_{motor}	2.3$^{\text{Note 1}}$	[8]
Unseating torque for 1-FCV-67-139, ft*lbf	T_{motor}	1.5$^{\text{Note 1}}$	[8]
Unseating torque for 1-FCV-67-141, ft*lbf	T_{motor}	2.7$^{\text{Note 1}}$	[8]
Unseating torque for 1-FCV-67-142, ft*lbf	T_{motor}	2.7$^{\text{Note 1}}$	[8]
Unseating torque for 1-FCV-67-295, ft*lbf	T_{motor}	3$^{\text{Note 1}}$	[8]
Unseating torque for 1-FCV-67-296, ft*lbf	T_{motor}	2.3$^{\text{Note 1}}$	[8]
Unseating torque for 1-FCV-67-297, ft*lbf	T_{motor}	2.1$^{\text{Note 1}}$	[8]
Unseating torque for 1-FCV-67-298, ft*lbf	T_{motor}	6$^{\text{Note 1}}$	[8]
Actuator Overall Gear Ratio OAR	OAR	47.85	[12]
Actuator Pullout Efficiency	η_{act}	0.35	[12]
HBC Gear Ratio	GR	70	[12]
HBC Gear Efficiency	η_{HBC}	0.3	[12]
Note 1: The torque values were obtained using the MCC (Motor Control Center) method that measures actuator motor torque. The torque at the valve shaft can be obtained as $T_{unseat} = T_{motor} * OAR * \eta_{act} * GR * \eta_{HBC}$. Based on the values of the OAR, η_{act}, GR & η_{HBC}, the multiplication factor to obtain the torque at valve shaft is 47.85*0.35*70*0.3 = 351.7. Therefore, the motor torque values should be multiplied by 351.7 to obtain the valve shaft torque.			

3.1.1 Adjusted Maximum Containment Design Pressure

The maximum permissible LLRT test pressure is 1.1 x 15 = 16.5 psi [9][10]. The calculated peak containment internal pressure related to the design-basis loss-of-coolant accident (LOCA) for Watts Bar is 9.36 psig [9]. A more conservative value of 9 psig is used in the current calculations.

4

ASSUMPTIONS

Data that have not been formally verified are treated as assumptions. Where possible, the basis of the data has been noted. The following general assumptions were used in this analysis.

1. Reference [4] provided by TVA does not list all the plug valve tag IDs analyzed in this report. It is assumed that Reference [4] is applicable to valve tag IDs analyzed in this report. This assumption do not affect the final conclusion and does not need verification.
2. 75 % of the unseating torque is assumed to be contributed by the plug-to-sleeve friction and the remaining 25 % is assumed to be contributed by plug-to-stem seal friction. This % split between the two locations is reasonable and does not affect the final conclusion. This assumption does not need verification.
3. The plug has a small taper angle and therefore the DP force will have a small component along the plug axis. Based on the measurements of the 2” plug, the taper angle is approximately 2.75°. Therefore, the axial force component will be sin(2.75°) = 4.8 % of the total load. This small axial load is neglected in the current analysis. This assumption does not need verification
4. The plug and sleeve material is stainless steel and UHMWPE. A COF of 0.23 for this material pair for LLRT test medium of air is used per Reference [7]. This is a reasonable assumption and does not affect the final conclusion. This assumption does not need verification.
5. Plug/port dimensions were used from a 2” welded-end Xomox valve procured by KEI for another project. These dimensions do not affect the final conclusion. This assumption does not need verification.

5

RESULTS

5.1 SEAT TORQUE REDUCTION

Seating torque reduction for MOV plug valves due to a decrease in LLRT test pressure from the normal test DP_{test} (16 psi) to Pa (9 psi) is shown in Table 5-1. As can be seen, all values show 0 % reduction in seat torque. Even though the data to calculate the seat load reduction for the AOV plug valves is not available, based on the discussion presented in Sections 2.4 and 2.5, the seat torques for all the plug valves would be independent of the DP load.

5.2 MAXIMUM LLRT TEST PRESSURE FOR 10% SEAL TORQUE REDUCTION

Since the seat torque is independent of the DP load, the maximum LLRT test pressure (DP_{test}) to ensure no greater than a 10% seal load reduction at Pa is not applicable to these valves.

5.3 NOTES/ RECOMMENDATIONS

None.

Table 5-1: Seat Load Reduction

Group	Valve	Valve IDs	Port diameter, Inch	Dimension A, Inch	Dimension B, Inch	Motor torque, ft*lbf	Unseating torque, ft*lbf	Avg. plug radius, in	Projected area over which the DP acts, in^2	seat torque, ft*lbf	Force due to LLRT DP, lbf	Increase in friction torque on downstream seat, ft*lbf	Decrease in friction torque on upstream seat, ft*lbf	Net reduction in seat torque due to reduced LLRT pressure, ft*lbf	% reduction in seat torque due to reduced LLRT pressure, %
			Dp	A	B	T_{motor}	T_{unseat}	R	Ap	T_{seat}	F_{DP}				
67-5	plug valve - MOV	1-FCV-67-130	2.041	2.252	2.0975	2.3	808.90	1.09	4.44	606.68	39.95	0.83	-0.83	0.00	0.00%
		1-FCV-67-131	2.041	2.252	2.0975	3.1	1090.26	1.09	4.44	817.70	39.95	0.83	-0.83	0.00	0.00%
		1-FCV-67-133	2.041	2.252	2.0975	1.3	457.21	1.09	4.44	342.91	39.95	0.83	-0.83	0.00	0.00%
		1-FCV-67-134	2.041	2.252	2.0975	2.4	844.07	1.09	4.44	633.06	39.95	0.83	-0.83	0.00	0.00%
		1-FCV-67-138	2.041	2.252	2.0975	2.3	808.90	1.09	4.44	606.68	39.95	0.83	-0.83	0.00	0.00%
		1-FCV-67-139	2.041	2.252	2.0975	1.5	527.55	1.09	4.44	395.66	39.95	0.83	-0.83	0.00	0.00%
		1-FCV-67-141	2.041	2.252	2.0975	2.7	949.58	1.09	4.44	712.19	39.95	0.83	-0.83	0.00	0.00%
		1-FCV-67-142	2.041	2.252	2.0975	2.7	949.58	1.09	4.44	712.19	39.95	0.83	-0.83	0.00	0.00%
		1-FCV-67-295	2.041	2.252	2.0975	3	1055.09	1.09	4.44	791.32	39.95	0.83	-0.83	0.00	0.00%
		1-FCV-67-296	2.041	2.252	2.0975	2.3	808.90	1.09	4.44	606.68	39.95	0.83	-0.83	0.00	0.00%
		1-FCV-67-297	2.041	2.252	2.0975	2.1	738.56	1.09	4.44	553.92	39.95	0.83	-0.83	0.00	0.00%
		1-FCV-67-298	2.041	2.252	2.0975	6	2110.19	1.09	4.44	1582.64	39.95	0.83	-0.83	0.00	0.00%

6

REFERENCES

[1] KEI Document No. 1500C Rev. 15; Kalsi Engineering, Inc. *Quality Assurance Manual.*

[2] *TVA Purchase Order 6232543, Rev. Num: 0.*

[3] TVA Engineering Work Request, EWR20MECH088032, Generate List of U1Containment Isolation Valves for Kalsi Engineering Pa impact evaluation. 06/09/20.

[4] *Figure 1366SW Size 2" Limitorque SMB-000-2-H1BC, Tufline Division of Xomox Corporation Spec No. NP3491-C Rev.902, 2-5-79*

[5] *Calculation of Valve Torque for Tennessee Valley Authority Watts Bar Nuclear Plant, Xomox Corporation, Aug 1, 1989.* Record No. B26 0929 945, *TVA Ref. 89NNU-75552A-01, Xomox Ref. S. O. 90844*

[6] KEI Document No. 3738 Rev.0, ASME OM Code Appendix III Suitability Evaluation for Essential Raw Cooling Water MOVs 2-FCV-067-0130-A/0131-B/0133-A/0134-B/0138-B/0139-A/0141-B/0142-A/0295-A/0296-A/0297-B/0298-B, March 2018

[7] EPRI Technical Report Technical Report 3002010634, Bearing Friction Coefficients for Quarter-Turn Valves Review of Available Information, September 2017

[8] WBN Units 0, 1, & 2, Datasheets for MOVATs Testing Of Motor Operated Valves for MOVs: 1-FCV-67-130, 1-FCV-67-131, 1-FCV-67-133, 1-FCV-67-134, 1-FCV-67-138, 1-FCV-67-139, 1-FCV-67-141, 1-FCV-67-142, 1-FCV-67-295, 1-FCV-67-296, 1-FCV-67-297, 1-FCV-67-298.

[9] Watts Bar UFSAR Section 6.2, *Containment Systems*.

[10] ANSI/ANS-56.8-1994, *American National Standard for Containment System Leakage Testing Requirements*.

[11] Xomox Process Valves & Actuators, Publication PN329703 04/06 3M C&O, *Tufline Sleeved Plug Valves*.

[12] TVA WBN Calc No. MD000206720100376 Rev. 3, Document of Design Basis Review, Required Thrust/Torque Calculations, and Valve and Actuator Capability Assessment for

Valves 2-FCV-67-130, -131, -133, -134, -138, -139, -141, -142, -295, -296, -297, -298, July 2018.

[13] TVA Engineering Work Request, *EWR20MEC026076, Generate U2 Containment Isolation Valve List and Design Inputs for Kalsi Engineering Pa impact evaluation. 08/19/20.*

Local Leak Rate Test Leakage Evaluation at Watts Bar for Swing Check Valves

Document No. 3960C, Rev. 0, Attachment 3

Prepared for
Watts Bar Nuclear Station
Tennessee Valley Authority
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---NON-PROPRIETARY VERSION---

Revisions

Rev. No.	DCR/N No.	Description of Changes	Pages Affected
0	N/A	Initial release	All

Table of Contents

	Pages	**Rev**
Main Text	26	0
Appendix A	44	0
Total	70	

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1

OBJECTIVE AND SCOPE

1.1 OBJECTIVE

Kalsi Engineering, Inc. (KEI) has been contracted by Tennessee Valley Authority (TVA) to provide engineering services to evaluate the impact of local leak rate test (LLRT) pressures, DP_{test}, higher than the calculated peak containment internal pressure related to the design-basis loss-of-coolant accident (LOCA), P_a, for cases where higher test pressure tends to increase the sealing. This work is being done in accordance with the scope defined in Purchase Order No. 6232543 [2][1].

The objective of this report is to determine the impact of the reduced LLRT pressure from DP_{test} to P_a on the seat leakage. All work performed under this project was done in accordance with the requirements of the KEI Quality Assurance Program [1], which meets the intent of 10CFR50 Appendix B requirements.

1.2 SCOPE

The scope of this attachment is LLRT swing check valves. Component IDs and basic information are shown below in Table 1-1.

Table 1-1: Analysis Scope

Group	Component ID	Comp Description	Manufacturer/ Drawing No./ Seat Type
26-1	1-CKV-26-1260	REACTOR BLDG HPFP SUPPLY HDR CHECK	BORG-WARNER CORP./ 421JBB1-002/ Hard Seat
	2-CKV-26-1260		
	1-CKV-26-1296	REACTOR COOLANT PUMP SPRINKLER HDR ISOL CHK	
	2-CKV-26-1296		
67-2	1-CKV-67-580A	UPPER CNTMT VENT CLR 1A, 1B, 1C, 1D, 2A, 2B, 2C, 2D ERCW SUP HDR CHECK	A585-ATWOOD & MORRILL CO/ 14735-02/ Soft Seat
	1-CKV-67-580B		
	1-CKV-67-580C		
	1-CKV-67-580D		
	2-CKV-67-580A		
	2-CKV-67-580B		

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[1] The number in [] indicates reference number documented in Section 5.

Group	Component ID	Comp Description	Manufacturer/ Drawing No./ Seat Type
	2-CKV-67-580C		
	2-CKV-67-580D		
70-1	1-CKV-70-679	RCP THERMAL BARRIER CCS SUP HDR CHECK	ATWOOD & MORRILL/ 14735-01/ Soft Seat
	2-CKV-70-679		FLOWSERVE/ 13-103681-001/ Soft Seat
81-1	1-CKV-81-502	PRIMARY WATER CNTMT HDR CHECK VLV	W120-WESTINGHOUSE ELEC CORP/ 934D174/ Hard Seat
	2-CKV-81-502		

1.3 HISTORICAL LEAKAGE

Reference 3 and Reference 7 provide the LLRT history for the Unit 1 and Unit 2 AOVs. Table 1-2, below, summarizes the results.

Table 1-2: Unit 1 and Unit 2 LLRT Leakage History

Group	Component ID	Leakage Results	Seat Type	Notes
26-1	1-CKV-26-1260	Unfavorable history	Hard	None
	1-CKV-26-1296	Unfavorable history	Hard	None
	2-CKV-26-1260	Unfavorable history	Hard	None
	2-CKV-26-1296	Favorable history	Hard	None
67-2	1-CKV-67-580A	Favorable history	Soft	None
	1-CKV-67-580B	Favorable history	Soft	None
	1-CKV-67-580C	Favorable history	Soft	None
	1-CKV-67-580D	Favorable history	Soft	None
	2-CKV-67-580A	Favorable history	Soft	None
	2-CKV-67-580B	Favorable history	Soft	None
	2-CKV-67-580C	Favorable history	Soft	None
	2-CKV-67-580D	Favorable history	Soft	None
70-1	1-CKV-70-679	Unfavorable history	Soft	None
	2-CKV-70-679	Favorable history	Soft	None
81-1	1-CKV-81-502	Favorable history	Hard	None
	2-CKV-81-502	Favorable history	Hard	None

2

METHODOLOGY, CALCULATIONS, AND RESULTS

2.1 VARIABLES

Variable	Description	Units
A_m	Area based on mean seat diameter = $\frac{\pi}{4} \cdot D_m^2$	In^2
A_{ID}	Area based on seal ID = $\frac{\pi}{4} \cdot D_{ID}^2$	In^2
A_{hs}	[redacted]	In^2
A_s	Nominal seat contact area of swing check valve = $\pi \cdot D_m \cdot t$	In^2
A_I	Percentage increase in leakage flow area when pressure reduces from DP_{test} to P_a	%
A_{asp}	[redacted]	%
b	O-ring contact area per linear inch of seal	In^2/in
C_L	Seat leakage coefficient proportionality constant	-
d	O-ring cross-section diameter	In
d_a	[redacted]	In
D_{ID}	Seal inside diameter	In
D_m	Mean seat diameter	In
D_{OD}	Seal outside diameter	In
DP	Valve differential pressure	Psi
DP_{test}	Bounding LLRT test differential pressure	Psi
E	Young’s modulus	Psi
F	O-ring compression load	Lb
F_{DP}	Seat load due to differential pressure	Lb
F_{DP_DPtest}	Seat load due to differential pressure @ DP_{test}	Lb
$F_{DP\_DPtest\_Lin}$	Seat load per linear inch of seat diameter @ DP_{test}	Lb/in
F_{DP_Pa}	Seat load due to differential pressure @ P_a	Lb
$F_{DP\_Pa\_Lin}$	Seat load per linear inch of seat diameter @ P_a	Lb/in
F_{hs}	[redacted]	Lb
F_W	Sealing force due to disc and stem weight	Lb
f’	Peak seat contact stress	Psi
f_{avg}	Average seat contact stress	Psi
h_a	[redacted]	In

h_{a_DPtest}	[redacted]	In
h_{a_Pa}	[redacted]	In
Δh_a	[redacted]	In
N_{hs}	[redacted]	
P_a	Calculated peak containment internal pressure related to the design-basis loss-of-coolant accident (LOCA)	Psig
t	Seat contact band width of swing check valve	In
W	Disc and stem weight	Lb
x	O-ring deflection for a given % O-ring compression	in
R	Percentage reduction in sealing force due to the difference between P_a and DP_{test}	%

2.2 LLRT TEST PRESSURE AND CALCULATED PEAK PRESSURE

The maximum permissible LLRT test pressure, DP_{test}, is 1.1 x 15= 16.5 psig [8, 12]. Calculated peak containment internal pressure related to the design-basis loss-of-coolant accident (LOCA), P_a, for Watts Bar is 9.36 psig [8]. For purposes of this analysis, a lower and more conservative value of 9 psig is used.

2.3 METHODOLOGY FOR SWING CHECK VALVE SEALING LOAD ANALYSIS

The sealing load in a swing check valve, without any mechanical load, is equal to the differential pressure force acting on the disc[2]. The DP force, F_{DP}, is equal to the DP times the area over which the DP acts.

For the subject swing check valves, the percentage reduction in the sealing load, R, when the differential pressure reduces from DP_{test} to P_a is equal to the percentage reduction in the pressure which is given by:

$$R = \frac{DP_{test} - P_a}{DP_{test}} \cdot 100 = \frac{16.5 - 9.0}{16.5} \cdot 100 = 45.5\% \qquad (1)$$

This assessment includes soft-seated and metal-seated swing check valves.

2.3.1 Methodology for Soft-Seated Swing Check Valve

In a soft-seated swing check valve, a low modulus elastomeric seal will drape into the surface asperities of the metal seat under low sealing forces generated at low DP conditions. The LLRT DP range of 9 to 16.5 psig represent low DP conditions. Therefore, the seat leak path that forms due to the surface asperity contacts will not be present in the soft-seated swing check valves. The

---

[2] The seat load component due to the disc and arm weight is very small compared to the DP force; therefore, it is excluded from the seat load which is conservative.

following approach is used for the soft-seated valves to analyze the risk of increased leakage when the pressure is reduced to P_a:

a. Determine the peak seat contact stresses based on the seat load at DP_{test} and P_a pressures. The peak seat contact stress higher than the differential pressure will ensure a positive sealing margin at that pressure.

b. Determine the O-ring compression at DP_{test} and P_a pressures. The O-ring compression above the minimum recommended squeeze of 0.007 inches (0.2 mm) [5] will ensure a good sealing action.

2.3.2 Methodology for Metal-Seated Swing Check Valve

Unlike the soft-seated swing check valves, a tight sealing of a metal-seated valve requires yielding of one material into the surface "waviness" and surface roughness of the other to block direct leakage paths. At low pressures, the seat load will not be sufficient to plastically yield the asperities on the contacting surfaces and therefore, the asperities will deform elastically. Due to the fact that these valves were providing a reliable sealing at DP_{test} pressure, the microscopic leak paths at this pressure will have a very high flow resistance. Any reduction in the seat load will decrease the leak path flow resistance by increasing the leakage flow area due to [redacted]. This increase in the leakage flow area results in corresponding increase in the leakage coefficient, C_L. Based on Equation 3-3 in Section 3.2 of the main report, the C_L can increase by as much as 35% before the measured leakage at pressure P_a would exceed the measured leakage at DP_{test}. The following approach is used for the metal-seated valves to analyze the risk of increased leakage when the pressure is reduced to P_a:

a. The reduction in the seat load due to decrease in pressure from DPt_{est} to P_a will increase the leakage flow area due [redacted]. The increase in the leakage flow area will decrease the leakage flow resistance and result in a corresponding increase the leakage flow coefficient, C_L. The percentage increase in the leakage flow area, A_I, will be calculated to determine the corresponding effect on C_L.

b. If the calculated change in the leakage flow area is found to be negligible, the leak path resistance and the leakage coefficient, C_L, will remain constant. This will ensure that the increase in leakage coefficient, C_L, will be well below 35%. Therefore, the measured leakage at the lower pressure, P_a, will not be higher than the measured leakage at the higher pressure, DP_{test}.

2.4 SOFT-SEATED SWING CHECK VALVES

The valve Groups 67-2 and 70-1 have soft-seated disc (Table 1-1). The valves in Group 67-2 Units 1 and 2, and Group 70-1 Unit 1 has O-ring 2-332 [9.b, 9.c] on the disc to provide a soft sealing.

The valve in Group 70-1 Unit 2 has a special design resilient seat [9.d] to provide a sealing at low pressures along with a Stellite-6 hardfaced metal seat to provide sealing at higher pressures.

2.4.1 Group 67-2 (Unit 1 and Unit 2) and Group 70-1 (Unit 1) Valves

The valves in Group 67-2 (Unit 1 and Unit 2) and Group 70-1 (Unit 1) are shown in Figure 2-1 and Figure 2-2. The sealing load, F_{DP}, on these valves is calculated from the DP area, A_{ID}, and the differential pressure, DP.

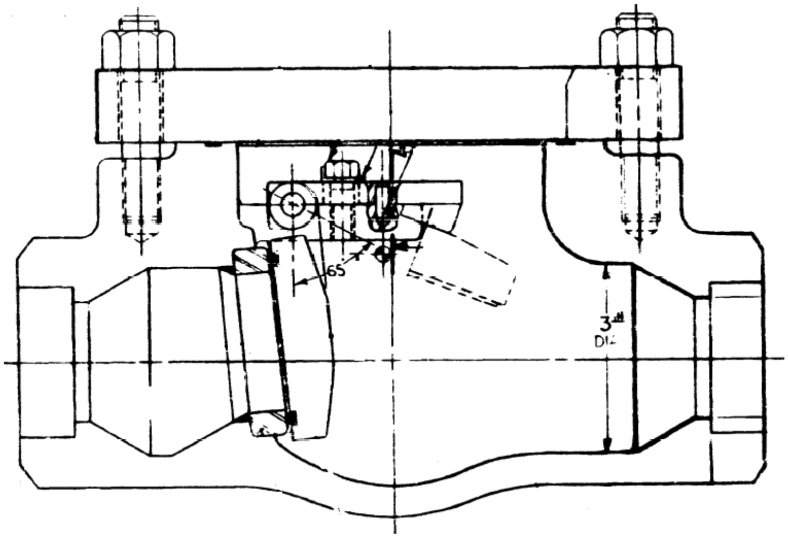


Figure 2-1: Group 67-2 Unit 1 and Unit 2 Valve [9.b]

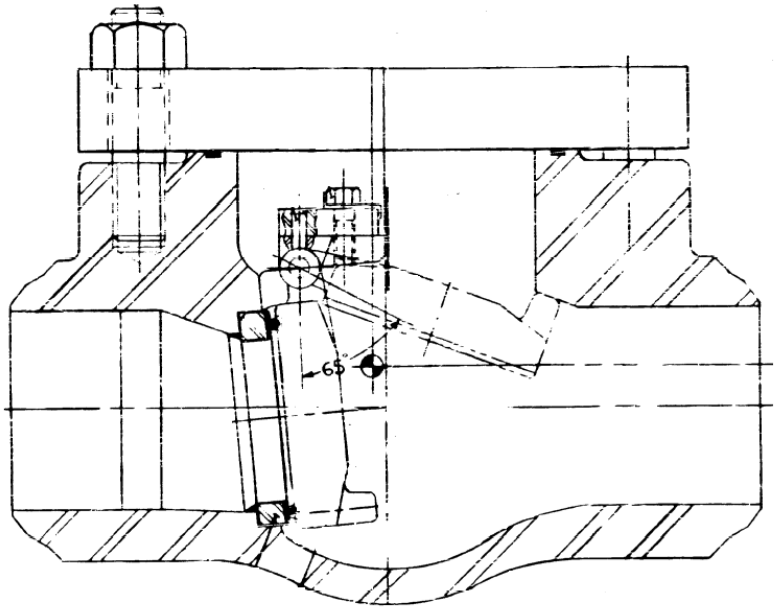


Figure 2-2: Group 70-1 Unit 1 Valve [9.c]

2.4.1.1 Design Inputs for Group 67-2 (Unit 1 and Unit 2) and Group 70-1 (Unit 1) Valves

These valves has O-ring 2-332 [9.b, 9.c] providing a soft sealing. O-ring 2-332 has a nominal cross-section, d, nominal seal ID, D_{ID}, and nominal seal OD, D_{OD}, of 0.210 inches, 2.350 inches, and 2.770 inches respectively [5]. The durometer hardness of the O-ring is not known but typically an O-ring with a Shore A Hardness of 70-durometer that has approximate room temperature Young's modulus of 1040 psi [4] is used in such applications. A softer O-ring with a lower Young's modulus will provide a conservative calculation of the peak seat contact stress; therefore, the O-ring Shore A Hardness of 60-durometer with Young's modulus of 630 psi [4] is used in this analysis. The percentage O-ring compression will be determined at 70 durometer and 60 durometer Shore A hardness to ensure that the sufficient O-ring compression is achieved at pressure P_a.

2.4.1.2 Peak Seat Contact Stress Calculation

[redacted]

[redacted] [redacted]

[redacted] [redacted]

[redacted]

[redacted] [redacted]

[redacted]

[redacted]

[redacted] [redacted]

[redacted]

[redacted] [redacted]

[redacted]

[redacted] [redacted]

[redacted]

[redacted] [redacted]

[redacted]

Table 2-1: Peak Seat Contact Stress Calculation Results at O-Ring Shore A Hardness of 60 Durometer

LLRT Pressure	**DP_{test}**	**P_a**
Pressure, psi	16.50	9.00
Seat Load due to DP (F_{DP}), lb	71.57	39.04
Seat Load Per Linear Inch, lb/in	8.90	4.85
O-ring Compression (x), in	0.0298	0.0200
Percentage O-ring Compression, %	14.2	9.5
O-ring Contact Area Per Linear Inch (b), in^2/in	0.072	0.048
Calculated O-ring Compression Load (F), lb	71.53	39.13
Peak Seat Contact Stress (f'), psi	158.34	129.06
Average Seat Contact Stress (f'_{avg}), psi	123.53	101.36

As shown in Table 2-1, the calculated percentage O-ring compressions, at DP_{test} and P_a pressures, are 14.2% and 9.5% for Shore A Hardness of 60 durometer. The percentage O-ring compression will decrease at 70 durometer hardness. The percentage O-ring compression at pressure P_a for Shore A hardness of 70 durometer is 6.8% (0.014 inches) which is higher than the minimum recommended squeeze of 0.007 inches (0.2 mm) [5]. The Parker O-ring Handbook [5] documents the compression load per linear inch of seal for 0.210 cross-section O-ring which is shown in Figure 2-3. Per Figure 2-3, the compression load per linear inch ranges from approximately 5 lb/in to 12 lb/in for Shore A Hardness of 60-durometer and at 10% compression. The seat load per linear inch for the subject O-ring at the pressures DP_{test} and P_a are 8.90 lb/in and 4.85 lb/in (Table 2-1) which is within the range discussed above. The calculated peak seat contact stresses are 158.34 psi at DP_{test} (16.5 psig) and 129.06 psi at P_a (9.0 psig). The calculated average seat contact stresses at DP_{test} and P_a are 123.53 psi and 101.36 psi, respectively.

The percentage reduction in the sealing load, R, is 45.5% when the pressure is reduced from 16.5 psig to 9.0 psig. However, the peak and average seat contact stresses are well above the DP_{test} and P_a pressures. The peak contact stress well above the differential pressure will ensure a proper sealing. Therefore, the leakage is not expected to increase when the pressure is reduced from DP_{test} to P_a.

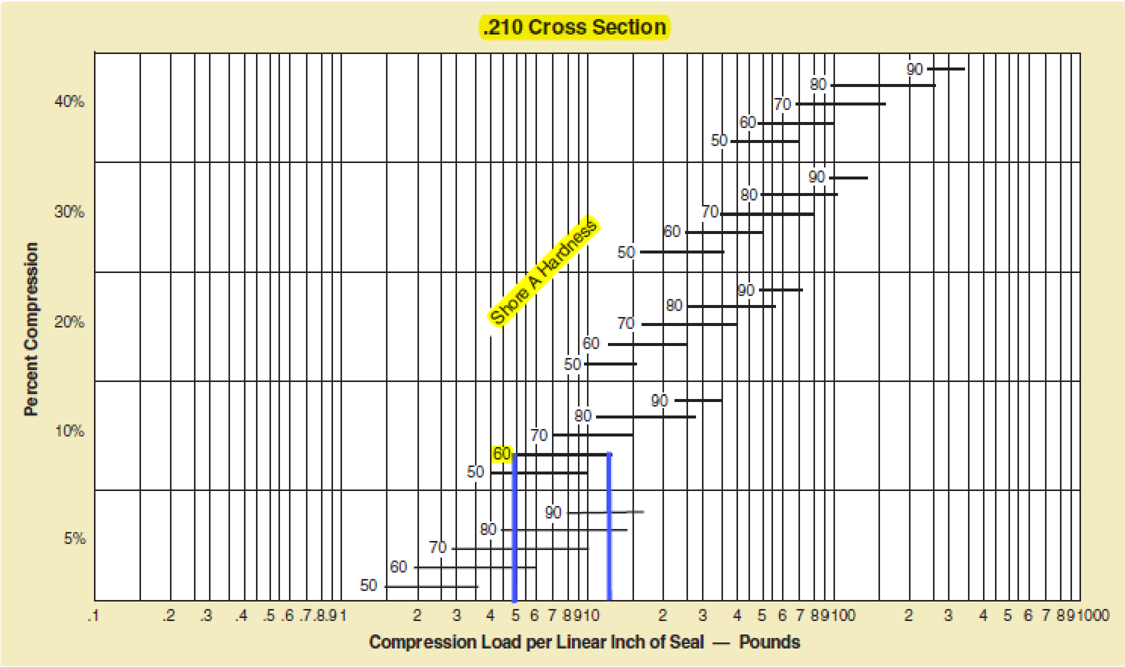
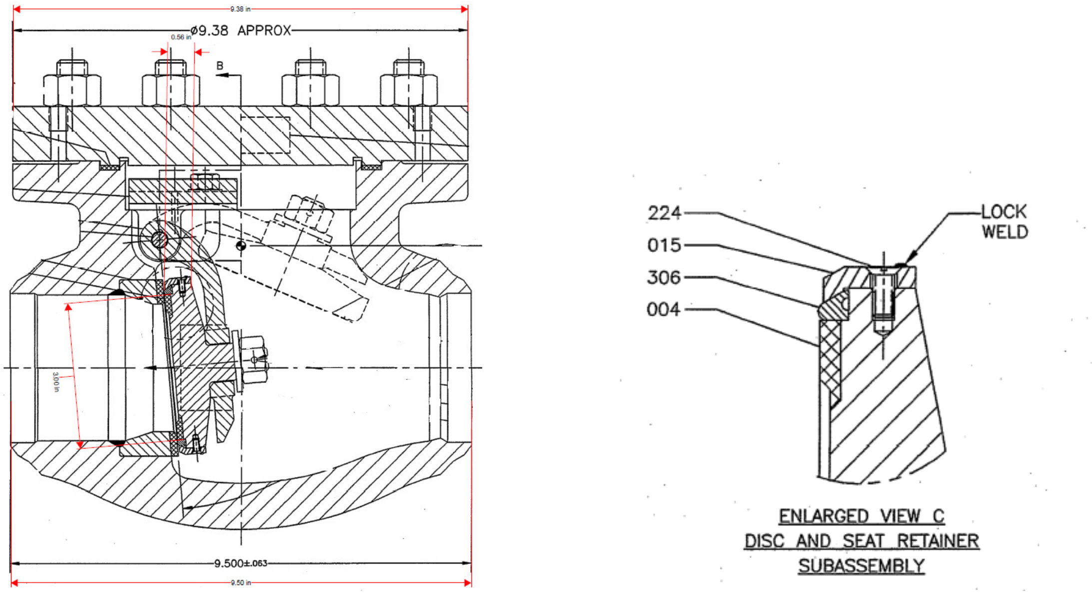


Figure 2-3: Compression Load per Linear Inch of Seal for 0.210 Cross Section O-ring and 60 Shore A Hardness [5]

2.4.2 Group 70-1 (Unit 2) Valve

The valve in Group 70-1 (Unit 2) is shown in Figure 2-4. The sealing load, F_{DP}, on this valve is calculated from the DP area, A_{ID}, and the differential pressure, DP.



(a) **(b)**

Figure 2-4: Group 70-1 Unit 2 Valve [9.d]

2.4.2.1 Design Inputs for Group 70-1 (Unit 2) Valves

This valve has a resilient elastomer seat (Item 306 in Figure 2-4b) to provide sealing at low pressures along with a Stellite-6 hardfaced metal seat (Item 004 in Figure 2-4b) to provide sealing at higher pressures. The mean seat diameter, D_m, of the seal is 3.170 inches [9.d]. KEI has performed Finite Element Analysis (FEA) on a similar design and size (3-inch) valve [11]. Based on Reference 11, the resilient seal seat ring groove ID, D_{ID}, is 2.938 inches, seal height/diameter, d, is 0.194±0.006 inches, and the seal projection above the seal groove (maximum seal deflection) is 0.025±0.011 inches. To be conservative, the seal height, d, of 0.188 inches, and maximum seal deflection, x, of 0.014 inches corresponding to seal least material condition are used in the analysis. This gives the maximum seal compression of 7.45% (0.014/0.188*100). The seal dimensions scaled from the valve drawing [9.d] matches with the dimensions in Reference 11. The durometer hardness of the seal is not known but typically a seal with a Shore A Hardness of 70-durometer that has approximate room temperature Young's modulus of 1040 psi [4] is used in such applications. A softer seal with a lower Young's modulus will provide a conservative peak seat contact stress; therefore, the seal Shore A Hardness of 60-durometer with Young's modulus of 630 psi [4] is used in this analysis.

2.4.2.2 Peak Seat Contact Stress Calculation

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

The maximum allowable seal compression, x, of the subject valve occurs at the compression load of 29.97 lb and develops the peak seat contact stresses of 114.05 psi which is higher than DP_{test} and P_a pressures. Based on FEA performed by KEI on a similar valve design [11], the peak seat contact stresses were found to be much higher even at 1 psi differential pressure. Therefore, based on an engineering judgement, it is concluded that the use of Equations 4 and 5 for calculating the peak seat contact stresses and compression load is conservative. The seal compression load of 29.97 lb is significantly lower than the DP induced seat load of 111.86 lb and 61.01 lb at DP_{test} and P_a pressures. This shows that the seal will stay fully compressed at DP_{test} and P_a and will develop peak seat contact stresses high enough to ensure good sealing action. Therefore, leakage is not expected to increase when the pressure is reduced from DP_{test} to P_a.

2.5 METAL-SEATED SWING CHECK VALVES

The valves in Groups 26-1 and 81-1 have metal-seated disc (Table 1-1) which is shown in Figure 2-5 and Figure 2-6.

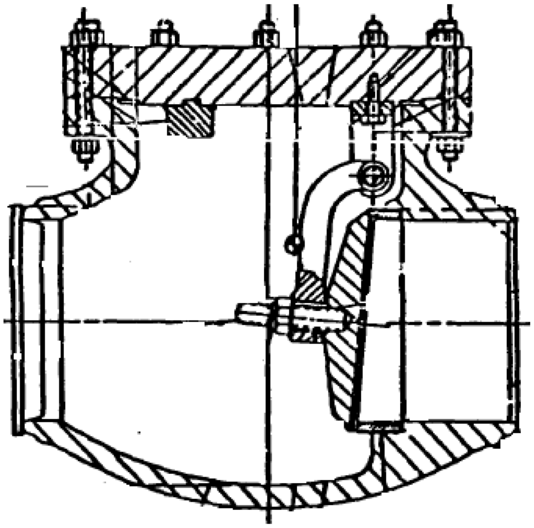


Figure 2-5: Group 26-1 Unit 1 and Unit 2 Valves [9.a]

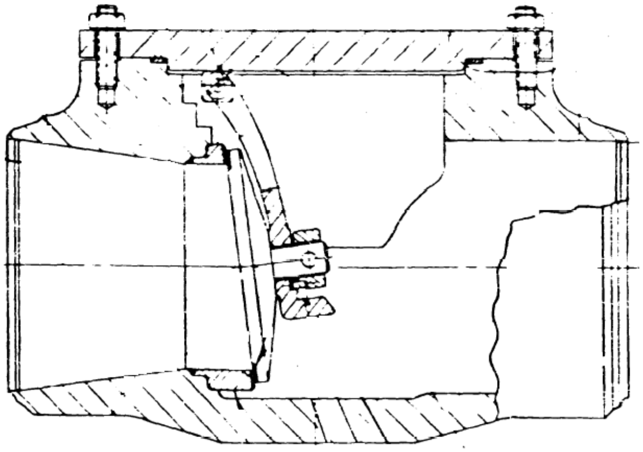
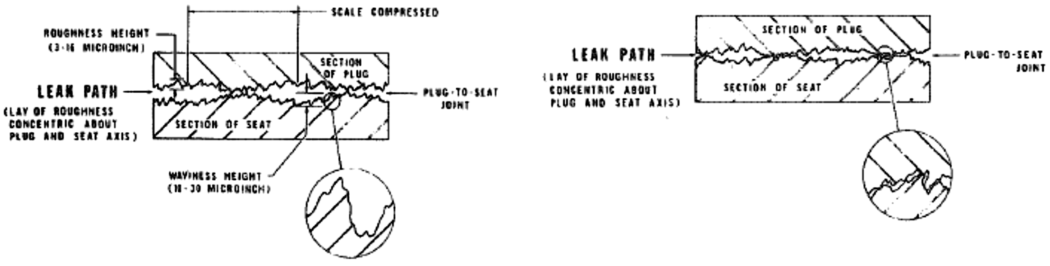


Figure 2-6: Group 81-1 Unit 1 and Unit 2 Valves [9.e]

Unlike the soft-seated swing check valves, a tight sealing of a metal-seated valve requires yielding of one material into the surface "waviness" and surface roughness of the other to block direct leakage paths. Even, seemingly smooth machined surfaces have surface asperities as illustrated in Figure 2-7. When the two surfaces contact each other, the surface asperities initially establish the contact. With an increasing load, the asperities initially deform elastically and then plastically. To ensure a tight shut-off metal-to-metal seal, the surface asperities within the contact band need to deform plastically over a reasonable amount of bandwidth. At low pressures, the seat load will not be sufficient to plastically yield the asperities on the contacting surfaces and therefore, the asperities will deform elastically. Due to the fact that these valves were providing a reliable sealing at DP_{test} pressure, the leak path at this pressure will have a very high flow resistance. [redacted] As discussed in Section 2.3, the seat load will decrease by 45.5% when the pressure reduces from the DP_{test} of 16.5 psig to P_a of 9.0 psig. The reduction in the seat load will reduce the leak path flow resistance. A reduction in the flow resistance is equivalent to an increase in the leakage coefficient, C_L. <u>Based on Equation 3-3 in Section 3.2 of the main report,</u> the C_L can increase by 35% before the measured leakage at pressure P_a would increase from the measured leakage at DP_{test}.



(a) Under Light Seating Load

(b) Under Heavy Seating Load

Figure 2-7: Microscopic Flow Path Under Light and Heavy Seating Load [6]

A calculation has been performed to estimate an increase in the leakage flow area, A_I, when the pressure is reduced from DP_{test} to P_a. The calculation is based on a simple, but conservative assumption (see Section 2.5.2) of a leak flow area developed by surface asperities (high spots) on the disc/seat surfaces that comes in contact when the swing check valve disc closes. [redacted]

Figure 2-8: Surface Asperities (High Spots) on a Seat Contact Band

[redacted]

2.5.1 Design Inputs for Groups 26-1 and 81-1 Valves

The design inputs used in the calculations are as follow:

- The LLRT test pressure, DP_{test}, and calculated peak pressures, P_a, are documented in Section 2.2.
- The mean seat diameter, D_m, of the valve Groups 26-1 and 81-1 are 4.625 inches and 3.590 inches [7] respectively.

2.5.2 Assumptions for Groups 26-1 and 81-1 Valves

Assumptions 1 to 5 documented in Section 3 are used for the calculation of percentage increase in the leakage flow area.

2.5.3 Calculation of Percentage Increase in Leakage Flow Area

[redacted]

[redacted]

[redacted] [redacted]

[redacted]

[redacted] [redacted]

[redacted] [redacted]

[redacted]

[redacted] [redacted]

[redacted]

[redacted] [redacted]

[redacted] [redacted]

[redacted] [redacted]

[redacted]

Table 2-2: Percentage Increase in Leakage Flow Area Calculation Results

Valve Group	26-1	81-1
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
A_I, %	0.003	0.002

Table 2-2 shows that the calculated increase in the leakage flow area, A_I, is 0.003% and 0.002% for Groups 26-1 and 81-1 valves which is negligible and is not expected to increase the leakage coefficient, C_L, by 35% which is a threshold for the measured leakage at the lower pressure, P_a, to increase from the measured leakage at the higher pressure, DP_{test}.

3

ASSUMPTIONS

Data that have not been formally verified are treated as assumptions. Where possible, the basis of the data has been noted. The following assumptions are used for the calculations performed in Section 2.5.3 for Groups 26-1 and 81-1 metal-seated valves:

1. [redacted]
2. [redacted]
3. The seat contact band width, t, is assumed to be 0.10 inches. Typically, for a swing check valve, the seat contact width is larger than 0.10 inches. A lower seat contact width provides conservative results. Therefore, this assumption does not require a verification.
4. [redacted].

5. The modulus of elasticity, E, of the seat/disc material is assumed to be equal to 3.0e7 psi. The valve drawings [9.a and 9.e] shows that the disc and seat surfaces are hardfaced which typically has a higher modulus than the one used here. A lower modulus provides a conservative result. Therefore, this assumption does not require a verification.

4

CONCLUSIONS AND RECOMMENDATIONS

The subject valve groups include soft-seated and metal-seated swing check valves.

4.1 SOFT-SEATED SWING CHECK VALVES ANALYSIS CONCLUSIONS

The soft seal of check valves provides very reliable sealing action at low differential pressure conditions. The LLRT DP range of 9 to 16.5 psig represent low DP conditions. Industry experience shows that in general, the soft-seated valves are expected to provide a good sealing action for this DP range. Calculations performed by KEI further solidify this general conclusion.

The soft-seated disc of the valves in Groups 67-2 (Unit 1 and Unit 2) and 70-1 (Unit1) have an O-ring that provides a soft sealing. The percentage reduction in the sealing load, R, is 45.5% when the pressure is reduced from 16.5 psig to 9.0 psig (see Section 2.3). However, both, the peak and average seat contact stresses are well above the differential pressure at both DP_{test} and P_a pressures (Table 2-1). The peak seat contact stress must exceed the differential pressure to ensure sealing. Therefore, the leakage is not expected to increase when the pressure is reduced from DP_{test} to P_a.

The valve in Group 70-1 Unit 2 has a special design resilient seat to provide a sealing at low pressures along with a Stellite-6 hardfaced metal seat to provide sealing at higher pressures. The calculation showed that maximum allowable seal compression of the subject valve occurs at the compression load of 29.97 lb which develops the peak seat contact stresses of 114.05 psi. The DP induced seat loads of 111.86 lb and 61.01 lb at DP_{test} and P_a pressures (see Section 2.4.2.2) are higher than the compression load (29.97 lb) required to fully compress the seal and establish a metal-to-metal contact. Therefore, at DP_{test} and P_a pressures, the seal will remain fully compressed and will establish a metal-to-metal sealing. The peak seat contact stresses at DP_{test} and P_a pressures will be significantly higher than the peak seat contact stress of 114.05 psi calculated at 29.97 lb of seat load. Therefore, the leakage is not expected to increase when the pressure is reduced from DP_{test} to P_a.

4.2 METAL-SEATED SWING CHECK VALVES ANALYSIS CONCLUSIONS

The valves in Groups 26-1 and 81-1 have metal-seated disc. The percentage reduction in the sealing load, R, for these valves is 45.5% when the pressure is reduced from 16.5 psig to 9.0 psig (see Section 2.3). The reduction in the seat load will increase the leakage coefficient, C_L, by some amount by increasing the leakage flow area due to [redacted] The leakage coefficient, C_L, is discussed in Section 3.2 of the main report which determines that the C_L can increase by 35% before the measured leakage at the lower pressure, P_a, would increase from the measured leakage at the higher pressure, DP_{test}. Table 2-2 shows that the calculated percentage increase in the leakage flow area, A_I, is negligible. The negligible increase in the leakage flow area will result in a negligible (well below 35%) increase in the leakage coefficient, C_L. Therefore, the measured leakage at pressure P_a is not expected to increase from the measured leakage at pressure DP_{test}.

4.3 RECOMMENDATIONS

Based on the simplified but conservative calculation performed in Section 2.5 for the metal-seated swing check valves (Group 26-1 and 81-1), it is expected that the change in the leakage flow area will be negligible with the reduction in seat load. Therefore, it is expected that the leakage coefficient, C_L, will not increase by 35% which is a threshold for the measured leakage at the lower pressure, P_a, to increase from the measured leakage at the higher pressure, DP_{test}. However, to further support the conclusion, it is recommended to test at least one metal-seated swing check valve from each group.

5

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    c. Atwood & Morrill Co. Inc., 3 IN Class 210 WE Swing Check Valve W/Soft Seat Disc, Dwg. No. 14735-01, Approved Dated: 11-20-1981.
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11. KEI Document No. 2628, Rev. 2, *Dual Seat Check Valve Soft Seat Analysis*, Dated: 05-06-2009.
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Appendix A

SUPPORTING DOCUMENTS

REPRINTED FROM

MACHINE DESIGN

April 12, 1979

O-RINGS FOR LOW-PRESSURE SERVICE

SEALS EASTERN, INC.

P.O. BOX 519 , RED BANK, NEW JERSEY 07701 (201) 747-9200

O-RINGS FOR LOW-PRESSURE SERVICE

DANIEL L. HERTZ, JR.
President Seals Eastern
Inc. Red Bank, N.J.

O-RINGS normally operate with about 15% squeeze to ensure a tight seal. But at system pressures below 400 psi, this amount of squeeze can cause high friction and excessively high actuating forces.

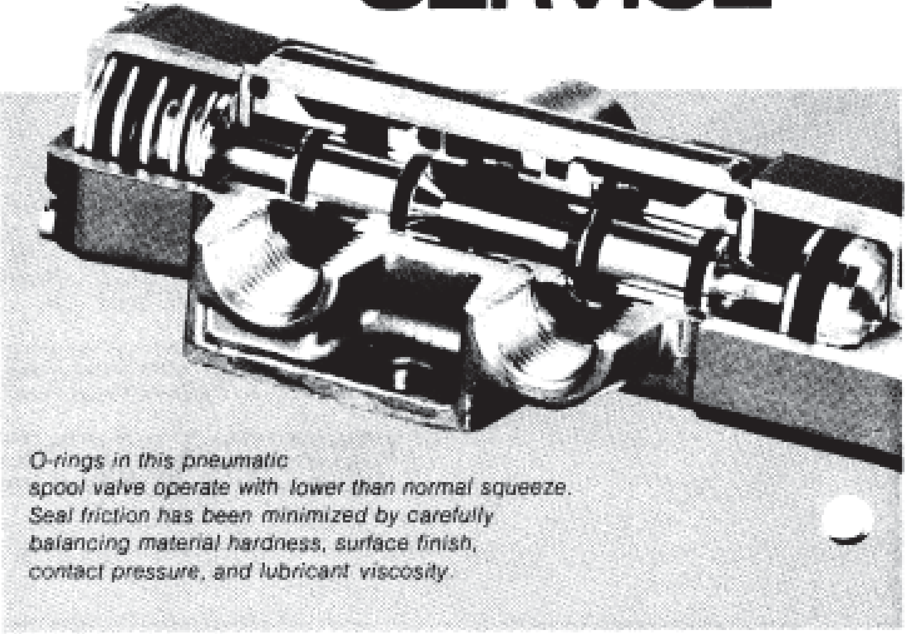
Reducing the amount of squeeze lowers friction to acceptable levels; however, lower squeeze also means lower sealing pressure and greater potential for leakage. This problem is aggravated by the stress relaxation characteristics of the seal material. Thus, an O-ring that seals well initially may lose resilience with time and fail suddenly.

Designing O-ring seals for low pressures, therefore, is not simply a matter of reducing the amount of squeeze: it involves a delicate balancing of material hardness, dimensional tolerances, stress relaxation, and friction characteristics.

Material Hardness

The initial phase of designing a low-pressure O-ring seal is the same as that for a conventional O-ring. Size and fluid compatibility requirements are evaluated and O-ring dimensions selected from a catalog. The catalogs usually list a recommended range of squeeze values, as shown in Table 1.

Squeeze is defined as the ratio

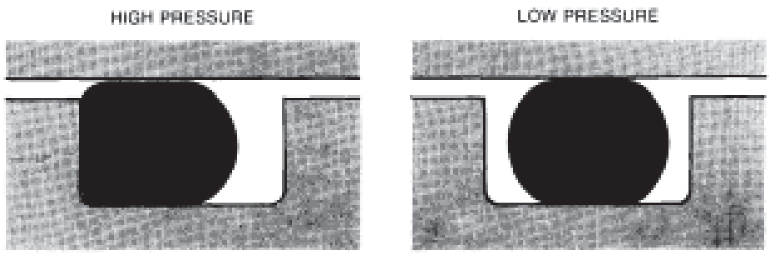


O-rings in this pneumatic spool valve operate with lower than normal squeeze. Seal friction has been minimized by carefully balancing material hardness, surface finish, contact pressure, and lubricant viscosity.

Table 1—Recommended Squeeze for O-rings

Seal Thickness (in.)	Squeeze (%)	Max % Squeeze Taken by Thickness Tolerance
0.070 ± 0.003	14.9-24.7	8.6
0.103 ± 0.003	8.1-15.0	5.8
0.139 ± 0.004	8.5-15.0	5.8
0.210 ± 0.005	8.3-13.5	4.8
0.275 ± 0.006	10.2-15.1	4.4

How Trouble Starts



High system pressures deform an O-ring into a D-shape, increasing contact area and sealing force. However, pressures below 400 psi are not strong enough to deflect the seal, and sealing force comes only from the compressive stress developed in the O-ring.

Most O-rings operate with enough "squeeze" to provide a reliable seal under almost any conditions. But low-pressure systems generate less squeeze, increasing the potential for leakage. Only a careful balancing of O-ring material properties ensures leak-free operation at low pressures.

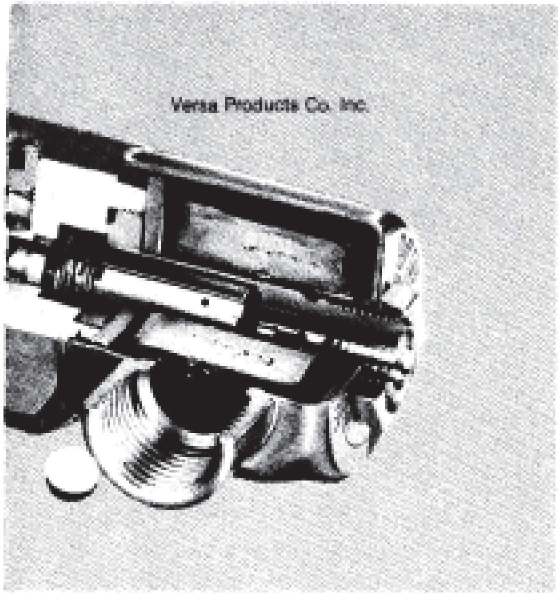


Table 2—Young's Modulus for O-ring Materials

Shore A Hardness (±2)	Young's Modulus (psi)
40	213
45	256
50	310
55	460
60	630
65	830
70	1.040
75	1340

of seal deflection to seal thickness, x/d. Generally, the seal is designed to operate at the high end of the squeeze range to ensure a tight seal. But at low system pressures, squeeze must be specified at the low end of the range.

The squeeze values listed in Table 1 are based on nominal seal thickness. One problem with specifying squeeze at the low end of the range is that dimensional tolerances can reduce the amount of squeeze actually placed on the O-ring. For instance, tolerance on the 0.070-in. thick O-ring is ±0.003 in. In the worst case (0.067-in. thickness), this tolerance can account for 8.6% of the squeeze allowance, leaving only 6.3% to be supplied by the fit between parts. In other words, an undersize O-ring has less material to compress and cannot be squeezed as tightly against the sealing surfaces. This problem can be minimized by specifying O-rings with one-half the normal dimensional tolerances. Such seals are available from most manufacturers at a premium price.

The next step in the design procedure is to calculate the compression force developed in the O-ring. This force is directly related to the sealing ability of the ring and is calculated from

$$F = \pi d D_m E \left[1.25\left(\frac{x}{d}\right)^{1.5} + 50\left(\frac{x}{d}\right)^{6} \right]$$

To use this equation, Young's Modulus must be determined first. This value depends on material hardness, and typical values are listed in Table 2. For most applications, a Shore A hardness of 70 is sufficient; therefore, the initial calculation of F is based on this hardness.

From the specified squeeze and seal thickness, contact area can be calculated from

$$b = 2.4x$$

Then, the peak contact stress can be found from

$$f' = \frac{4F}{\pi^2 b D_m}$$

If f' *is* greater than the system pressure, the O-ring will seal the joint. If f' *is* less than system pressure, the ring will leak and a material with a higher Young's Modulus must be specified, thereby increasing compressive force and contact stress.

Seal Friction

In low-pressure systems, seal friction can raise the required actuating pressure to many times that available in the system. Therefore, seal friction must be minimized for the system to operate properly. Generally, seal friction force should be maintained below 20 lb to keep actuating force within reasonable limits.

The friction force for an O-ring seal can be estimated from

$$F_f = \mu F$$

where coefficient of friction, μ, can change from 0.001 to over 10, depending on the operating conditions.

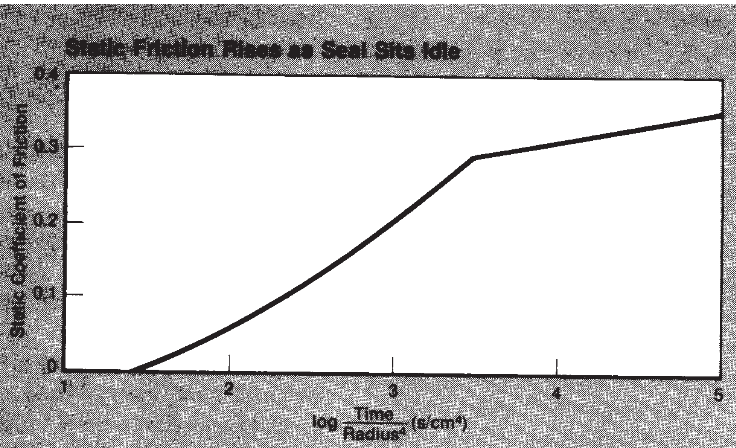
When more than one O-ring is used in the system, the friction forces from all the seals must be combined to determine the total friction force. If the calculated force is greater than

20 lb, a softer seal material should be used; this lowers Young's Modulus and compressive force. However, the change to a softer seal material must be made with care because a lower compressive force also means a lower contact stress. Thus, the change could lower peak contact stress below system pressure, resulting in a leaky seal.

If a softer material lowers contact stress too much, friction force must be lowered by reducing the coefficient of friction. This factor is a complex function of lubricant film thickness, time, contact stress, sliding speed, and surface finish.

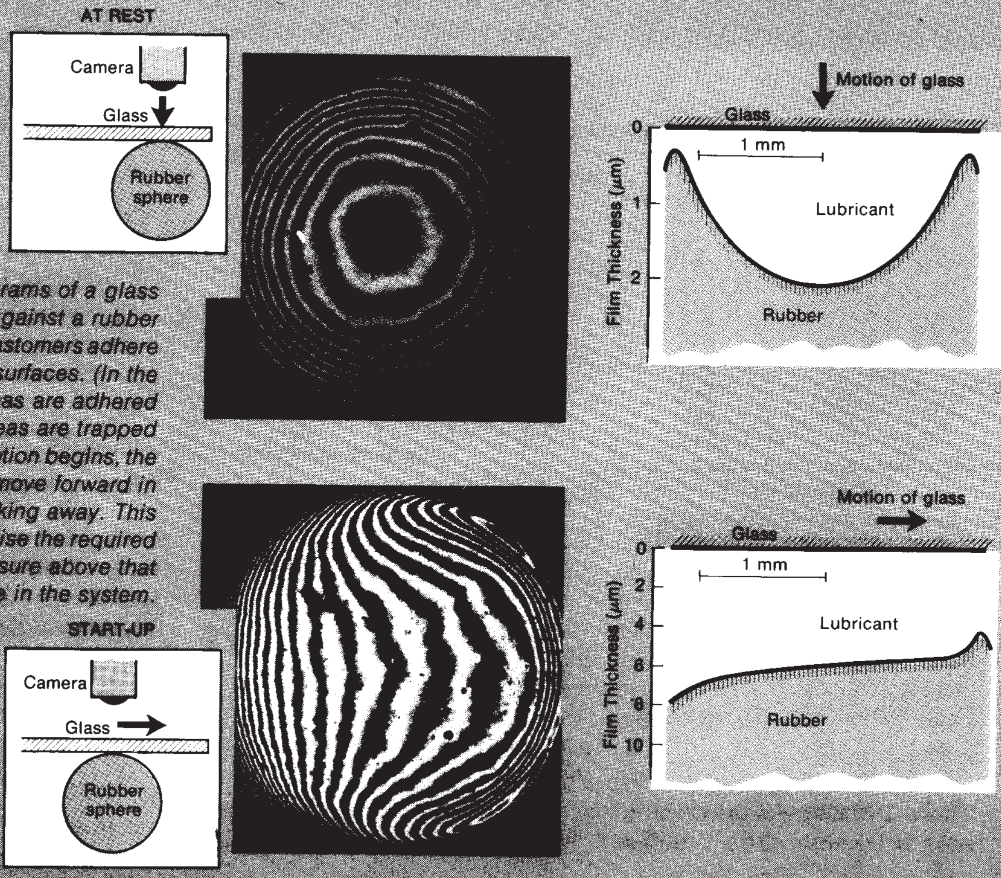
Tests have shown that the longer a lubricated seal sits idle, the higher its static, or breakaway, coefficient of friction. Eventually, the friction coefficient reaches a maximum value almost as high as that for an unlubricated seal.

This increase with time is caused by the atomic interaction between the O-ring and its sealing surface, which causes the two surfaces to adhere tightly. The adhesive force can be quite high and eventually squeezes most of the lubricant from under the contact area. On start-up, the adhered O-ring peels away in progressive waves that break away and reform



Tests of lubricated rubber sliding against a steel surface show how static friction increases the longer an O-ring sits idle. The increase is caused by the interatomic attraction between the rubber and steel, which slowly squeezes lubricant from under the contact surface.

Seal Adhesion Increases Friction



Optical interferograms of a glass plate pressing against a rubber sphere show how elastomers adhere to their sealing surfaces. (In the photos, dark areas are adhered rubber and light areas are trapped lubricant.) When motion begins, the adhered areas move forward in waves prior to breaking away. This phenomenon can raise the required actuation pressure above that available in the system.

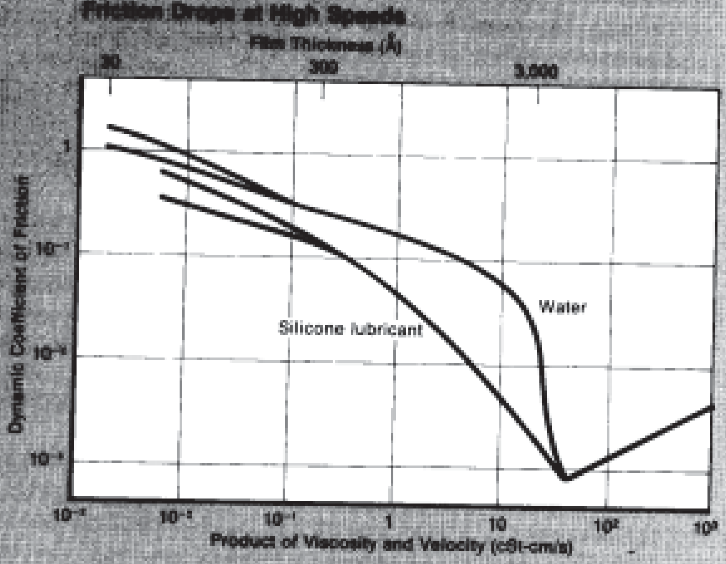
on the moving surface, This action shears what little lubricant is present and traps it in the rubber folds.

Seal adhesion can be minimized by optimizing surface finish and lubricant viscosity. Experience has shown that the optimum surface finish is 0.4μm. This finish leaves tiny pockets that collect lubricant, making it available at startup. Too smooth a finish leaves no pockets for the lubricant, while too rough a finish causes high wear.

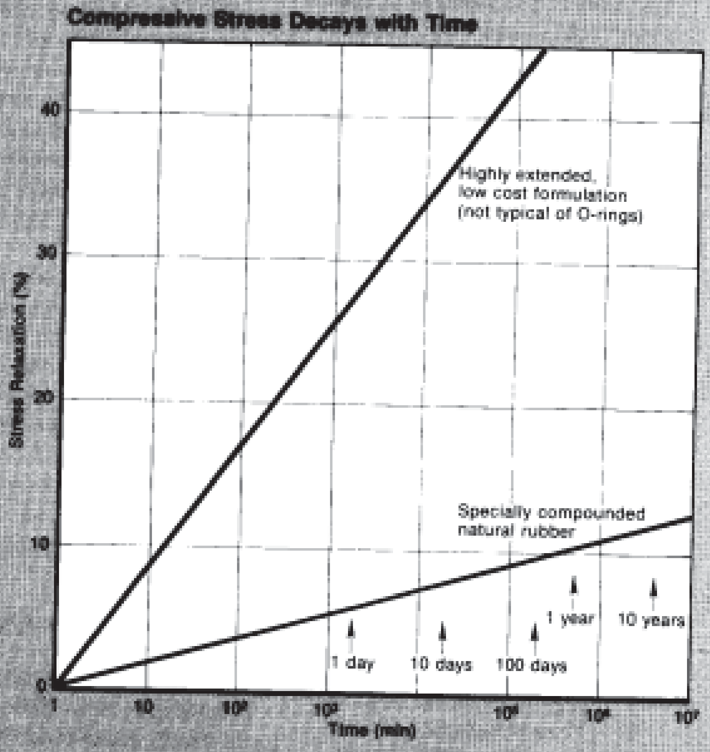
A reciprocating seal should be lubricated with high viscosity lubricants because they produce a strong hydrodynamic film. This film resists displacement by the adhesive forces when the seal is stationary. A rotary seal, on the other hand, can be lubricated with low-viscosity lubricants because rotary motion aids development of a hydrodynamic film.

Thickness of the hydrodynamic film between asperities on the O-ring and sealing surface has been calculated as 6 x 10 in. Shear of this film is the prime cause of dynamic or running friction. In general, the dynamic coefficient of friction is a function of lubricant viscosity and sliding velocity. The coefficient generally starts high, decreases to a minimum value, then increases again. Thus, running friction can be minimized by optimizing viscosity and velocity.

Several tests have been run to determine the effect of material-formula modifications on seal friction. The addition of materials such as graphite, molybdenum disulphide, and PTFE sometimes reduce friction, but the reduction is more likely a result of lowering Young's Modulus than a lubricating effect. Also, the incorporation in the elastomer of high-molecular-weight waxes and oils that migrate to the surface has proved unsuccessful in


Friction Drops at High Speeds

Dynamic (or running) friction is caused by viscous shear of the lubricant film. Tests of a steel ball sliding on a rubber surface show that at high speeds, friction is proportional to the square root of the viscosity-velocity product. This condition corresponds to hydrodynamic lubrication. Friction rises at lower speeds as the contact approaches boundary conditions.


Compressive Stress Decays with Time

Relaxometer tests provide data on the stress relaxation rates of O-ring materials. The relaxation rate for natural rubber generally is lower than that for rubber with additives. Knowing the relaxation rate allows prediction of a seal's useful life.

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lowering friction.

Surface treatments have been more successful. Halogenation with chlorine or bromine reduces friction by lowering the surface free energy (and, therefore, attraction force) and by creating lubricant pockets. Fluorination, although far less common, has similar effects.

Surface treatments of PTFE-resin binder coatings and tumble treatment in molybdenum disulphide or graphite have been used along with silicone oil dips with limited success. Also, polymerization of monomers on the O-ring surface with plasma techniques offers some improvement; however, the techniques are costly and slow. Finally, the grafting onto the seal surface of high-molecular-weight oils having reactive end groups shows promise for the future.

Stress Relaxation

The useful sealing life of an O-ring depends on two viscoelastic material properties: compression set, the residual deformation of a material after the load is removed; and stress relaxation, the decrease in stress after a given time at a constant strain. These properties reduce the resiliency of the seal material and must be taken into account when specifying material hardness.

When a seal is under constant compression, the initial stress decays at a rate proportional to the logarithm of time. The stress relaxation rate varies with material composition, temperature, and fluid reactions. Typical values range from 0.5% to 10% per time decade. (The time from 1 to 10 min is designated as one decade, as is the much longer time from 1 to 10 weeks.)

Nomenclature

b = Seal contact area, in.^{2}
D_i = Seal inside diam, in.
D_m = Seal mean diam, in.
D = Seal outside diam, in.
d = Seal thickness, in.
E = Young's Modulus, psi
F = Compressive load, lb
F_f = Friction force, lb
f' = Peak contact stress, psi
x = Seal deflection, in.
μ= Coefficient of friction

Table 3-Glass-Transition Temperatures for O-ring Materials

Material	Transition Temperature (°F)
Nitrile (NBR) 34% ACN	-21
38% ACN	-13
Fluoro Rubber (FKM)	-4
Silicone (VMQ)	-85
Chloroprene (CR)	-40
Ethylene Propylene (EPDM)	-85

The result of stress relaxation is that peak compressive stress eventually drops below system pressure, and the seal leaks. Thus, stress relaxation effects must be factored into the determination of material hardness and compressive stress.

Stress relaxation rates are available from O-ring manufacturers; however, the ratings may be for a temperature or fluid condition different from that required. If the correct data are not available, the stress relaxation rate can be determined from a simple relaxometer test, such as that described in ASTM D-1395, or with a Lucas relaxometer.

Once the stress relaxation rate is known, the time for peak contact stress to equal system pressure can be calculated easily. In general, if the calculated time period produces a seal life lower than 20 x 10^6 cycles, then a harder seal material (higher Young's Modulus and higher compressive stress) must be used.

Temperature Effects

The effects of operating temperature are more pronounced for low-squeeze O-rings because the seal has a lower tolerance for change. The volumetric expansion rate for rubber is about 15 times higher than that for steel. Therefore, at high temperatures, insufficient groove volume can produce expansion forces that extrude the seal into the clearances. This problem can be minimized by increasing groove dimensions to provide sufficient room for expansion.

Lowering operating temperature results in a continuous decrease in the physical volume of the seal. Eventually, the seal reaches its so-called glass-transition temperature, where it seals only along two thin lines. Further reduction of temperature shrinks the seal even more, resulting in leakage.

The glass-transition temperature corresponds to 100% compression set. At this temperature, the seal can shatter like glass if subjected to a shock or impact load. Values of glass transition temperature for O-ring materials are listed in Table 3. To avoid low temperature problems, O-rings should operate at temperatures 10° to 15°F higher than those listed in the table.

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Softer sealing materials, with lower hardness readings, will flow more easily into the microfine grooves and imperfections of the mating parts (the gland, bore, rod or seal flanges). This is particularly important in low-pressure seals because they are not activated by fluid pressure. Conversely, the harder materials offer greater resistance to extrusion. Referring back to the O-ring seal diagrams, Figures 1-4 through 1-7, it can be seen that a harder O-ring will have greater resistance to extrusion into the narrow gap between the piston and bore. There are certain applications in which the compressive load available for assembly is limited. In these situations, Figures 2-4 through 2-8 are helpful, providing compression load requirements for O-rings of different hardnesses, for each of the five standard O-ring cross-sections.

In dynamic applications, the hardness of the O-ring is doubly important because it also affects both breakout and running friction. Although a harder compound will, in general, have a lower coefficient of friction than a softer material, the actual running and breakout friction values are actually higher because the compressive load required to achieve the proper squeeze and force the harder material into a given O-ring cavity is so much greater.

For most applications, compounds having a Shore A durometer hardness of 70 to 80 is the most suitable compromise. This is particularly true of dynamic applications where 90 durometer or harder compounds often allow a few drops of fluid to pass with each cycle, and 50 durometer compounds tend to abrade, wear, and extrude very quickly.

Normally durometer hardness is referred to in increments of five or ten, as **60** durometer, **75** durometer, etc. — not as **62** durometer, **66** durometer or **73** durometer. This practice is based on:

(1) The fact that durometer is generally called out in specifications with a tolerance of ±5 (i.e., 65±5, 70±5, 90±5);

(2) The inherent minor variance from batch to batch of a given rubber compound due to slight differences in raw materials and processing techniques; and

(3) The human variance encountered in reading durometer hardness. On a 70-durometer stock, for example, one person might read 69 and another 71. This small difference is to be expected and is considered to be within acceptable experimental error and the accuracy of the testing equipment.

2.4.3 Toughness

Toughness is not a measured property or parameter but rather a qualitative term frequently used to summarize the combination of resistance to physical forces other than chemical action. It is used as a relative term in practice. The following six terms (paragraphs 2.4.4 through 2.4.9) are major indicators of, and describe the "toughness" of a compound.

2.4.4 Tensile Strength

Tensile strength is measured as the psi (pounds per square inch) or MPa (Mega Pascals) required to rupture a specimen of a given elastomer material when stressed. Tensile strength is one quality assurance measurement used to insure compound uniformity. It is also useful as an indication of deterioration of the compound after it has been in contact with a fluid for long periods. If fluid contact results in only a small reduction in tensile strength, seal life may still be relatively long, yet if a large reduction of tensile strength occurs, seal life may be relatively short. Exceptions to this rule do occur. Tensile strength is **not** a proper indication of resistance to extrusion, nor is it ordinarily used in design calculations. However, in dynamic applications a minimum of 1,000 psi (7 MPa) is normally necessary to assure good strength characteristics required for long-term sealability and wear resistance in moving systems.

2.4.5 Elongation

Elongation is defined as the increase in length, expressed numerically, as a percent of initial length. It is generally reported as ultimate elongation, the increase over the original dimension at break. This property primarily determines the stretch which can be tolerated during the installation of an O-ring. Elongation increases in importance as the diameters of a gland become smaller. It is also a measure of the ability of a compound to recover from peak overload, or a force localized in one small area of a seal, when considered in conjunction with tensile strength. An adverse change in the elongation of a compound after exposure to a fluid is a definite sign of degradation of the material. Elongation, like tensile strength, is used throughout the industry as a quality assurance measure on production batches of elastomer materials.

2.4.6 O-Ring Compression Force

O-ring compression force is the force required to compress an O-ring the amount necessary to maintain an adequate sealing line of contact. See Table 2-3 and Figures 2-4 through 2-8. It is very important in some applications, particularly in face-type seals where the available compression load is limited. The factors that influence compression force for a given application, and a method of finding its approximate magnitude are explained in Section III, O-Ring Applications.

O-Ring Compression Force

Durometer Range	Diameter	Compression Load
Less than normal	Less than 25.4 mm (1")	Middle third of range
Less than normal	Over 25.4 mm (1")	Lower half of range
Over normal	Less than 25.4 mm (1")	Upper third of range
Over normal	Over 25.4 mm (1")	Upper half of range

Table 2-3: O-Ring Compression Force

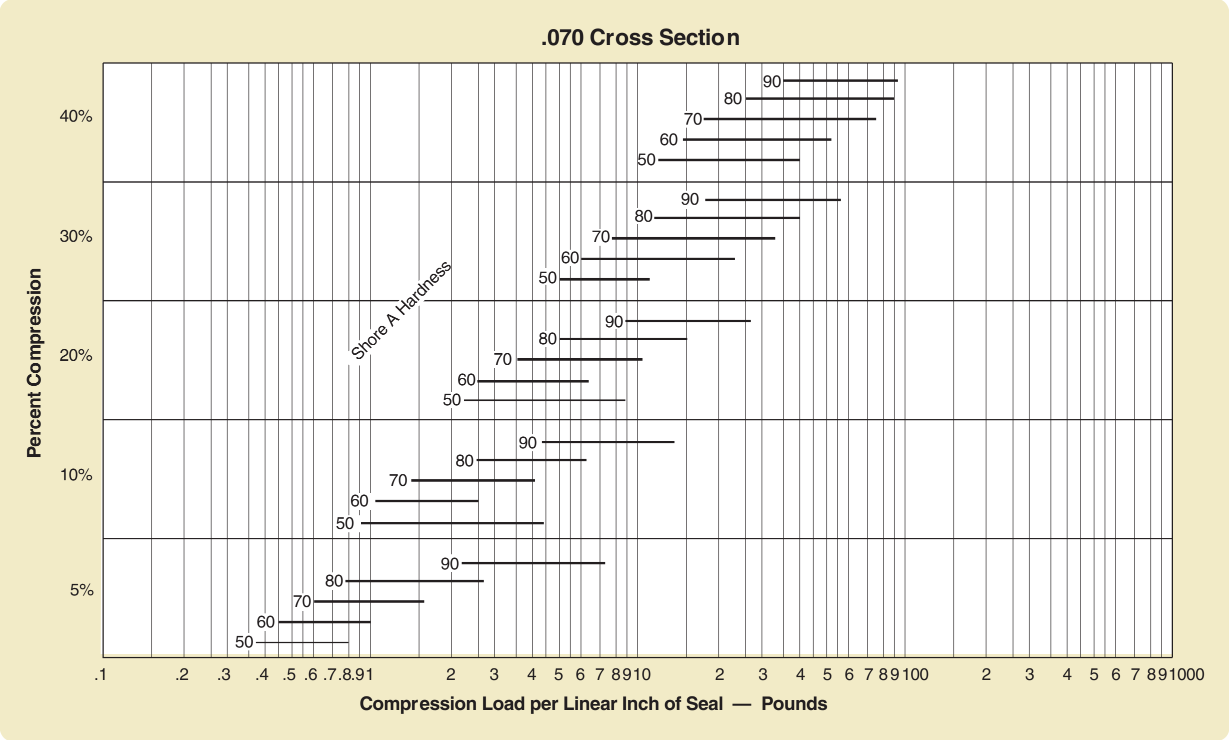

Figure 2-4: .070 Cross Section

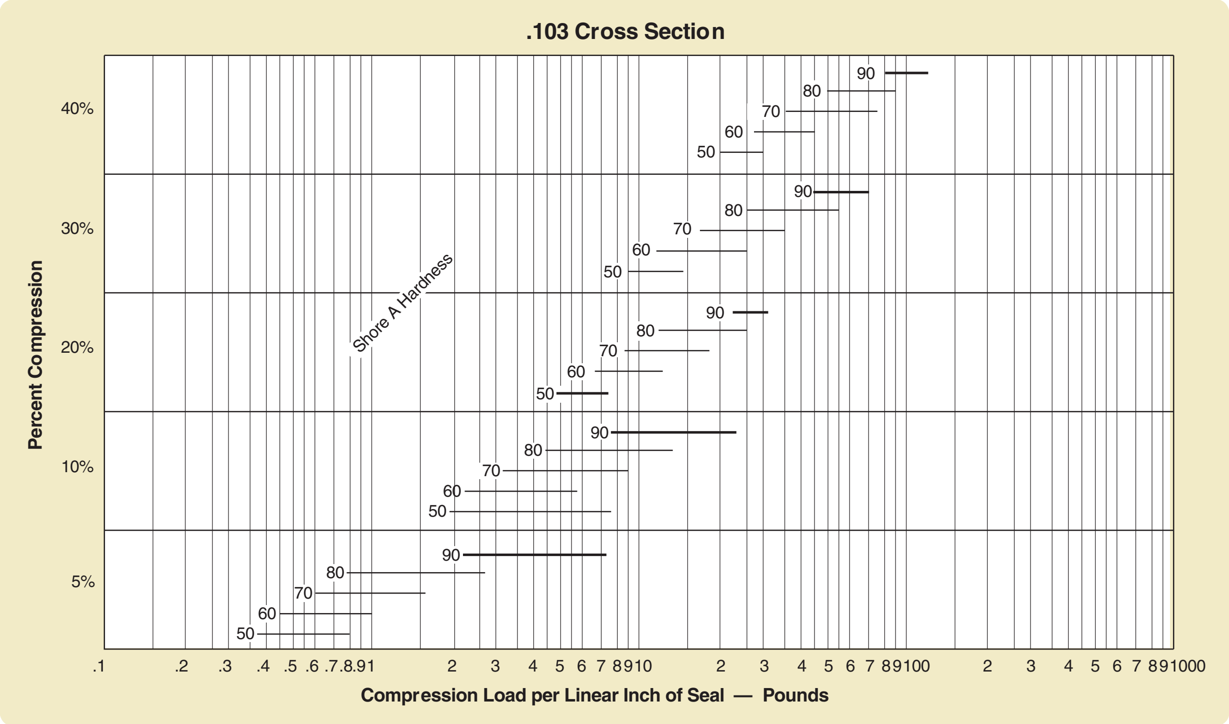

Figure 2-5: .103 Cross Section

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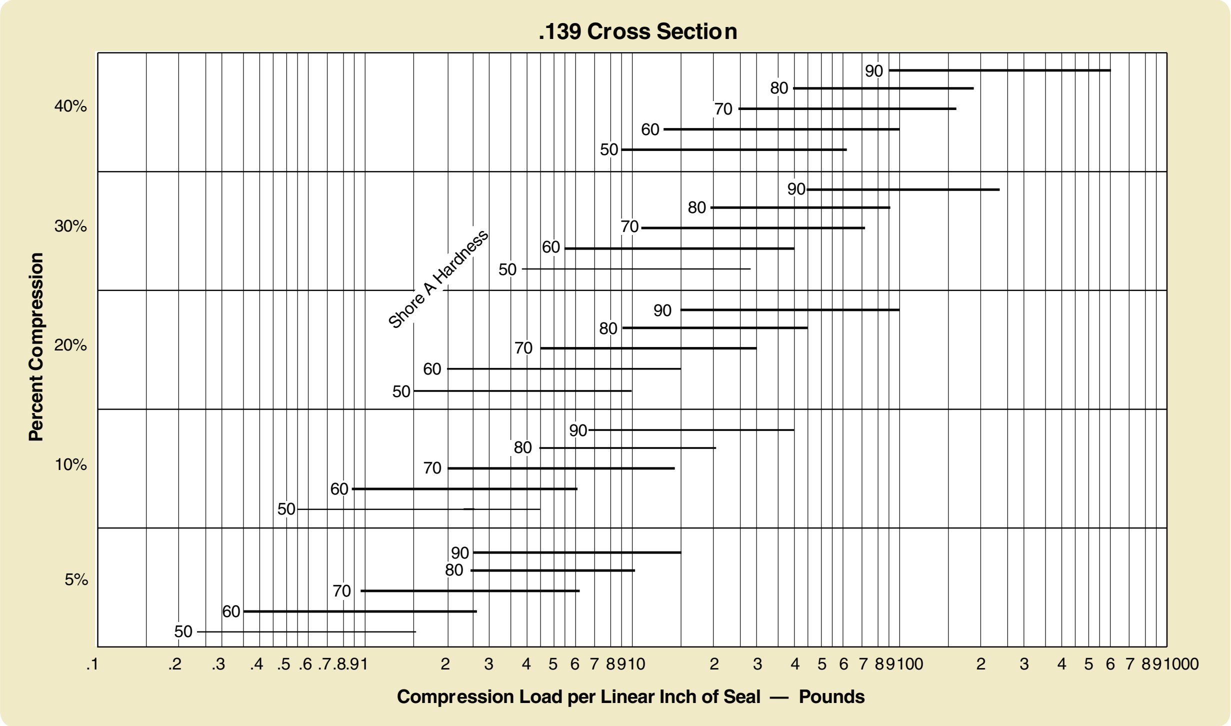

Figure 2-6: .139 Cross Section

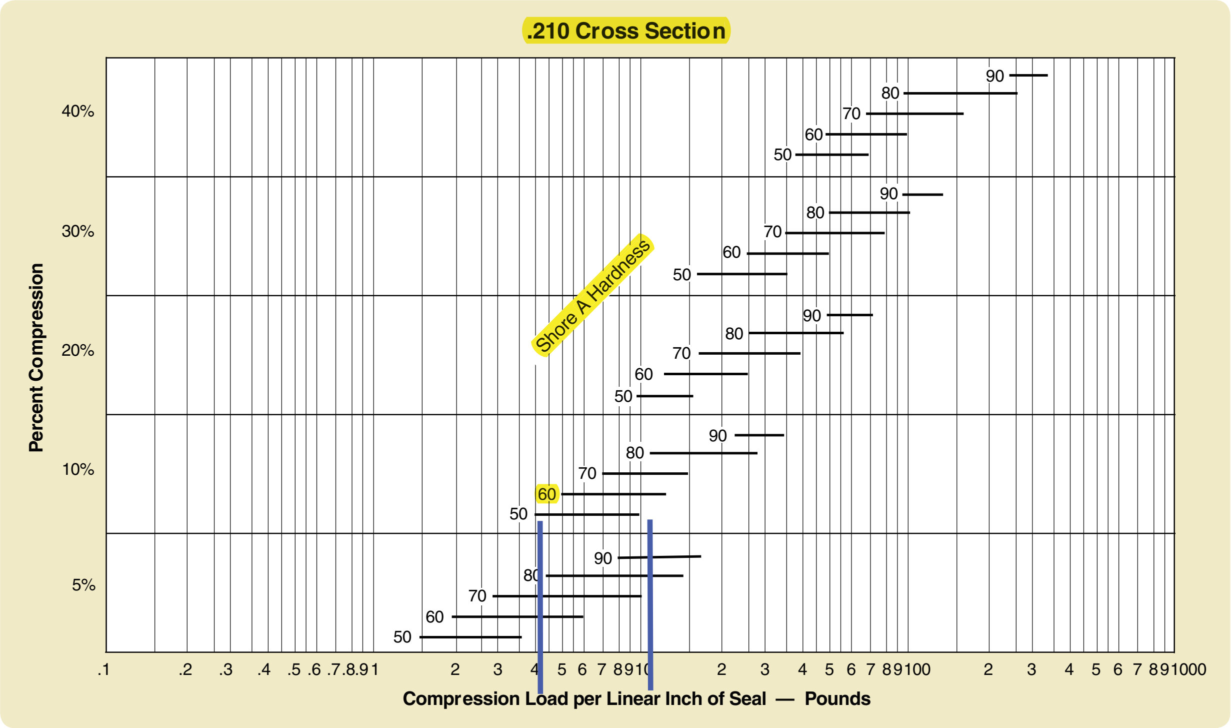

Figure 2-7: .210 Cross Section

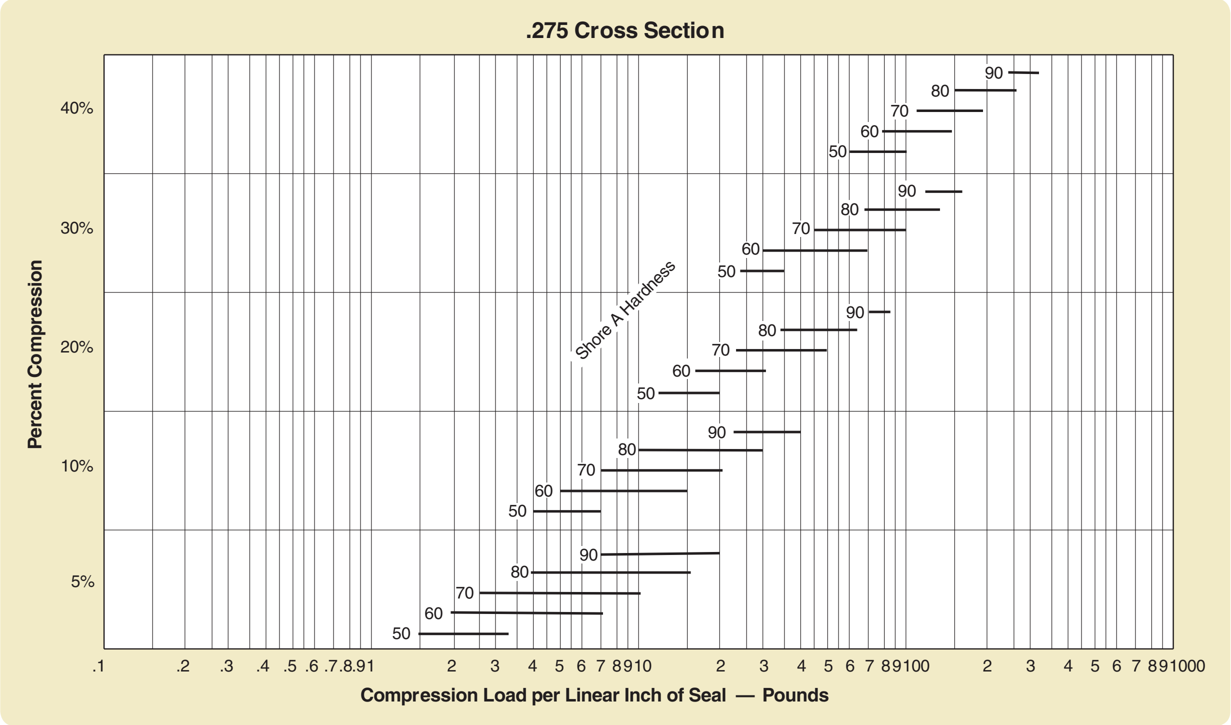

Figure 2-8: .275 Cross Section

2.4.7 Modulus

Modulus, as used in rubber terminology, refers to stress at a predetermined elongation, usually 100%. It is expressed in pounds per square inch (psi) or MPa (Mega Pascals). This is actually the elastic modulus of the material.

The higher the modulus of a compound, the more apt it is to recover from peak overload or localized force, and the better its resistance to extrusion. Modulus normally increases with an increase in hardness. It is probably the best overall indicator of the toughness of a given compound, all other factors being equal.

2.4.8 Tear Resistance

Tear strength is relatively low for most compounds. However, if it is extremely low (less than 100 lbs./in.) (17.5 kn/m), there is increased danger of nicking or cutting the O-ring during assembly, especially if it must pass over ports, sharp edges or burrs. Compounds with poor tear resistance will fail quickly under further flexing or stress once a crack is started. In dynamic seal applications, inferior tear strength of a compound is also indicative of poor abrasion resistance which may lead to premature wear and early failure of the seal. Usually however, this property need not be considered for static applications.

2.4.9 Abrasion Resistance

Abrasion resistance is a general term that indicates the wear resistance of a compound. Where "tear resistance" essentially concerns cutting or otherwise rupturing the surface, "abrasion resistance" concerns scraping or rubbing of the surface. This is of major importance for dynamic seal materials. Only certain elastomers are recommended for dynamic O-ring service where moving parts actually contact the seal material. Harder compounds, up to 90 durometer, are normally more resistant to abrasion than softer compounds. Of course, as with all sealing compromises, abrasion resistance must be considered in conjunction with other physical and chemical requirements.

2.4.10 Volume Change

Volume change is the increase or decrease of the volume of an elastomer after it has been in contact with a fluid, measured in percent (%).

Swell or increase in volume is almost always accompanied by a decrease in hardness. As might be surmised, excessive swell will result in marked softening of the rubber. This condition will lead to reduced abrasion and tear resistance, and may permit extrusion of the seal under high pressure.

For static O-ring applications volume swell up to 30% can usually be tolerated. For dynamic applications, 10 or 15% swell is a reasonable maximum unless special provisions are made in the gland design itself. This is a rule-of-thumb and there will be occasional exceptions to the rule.

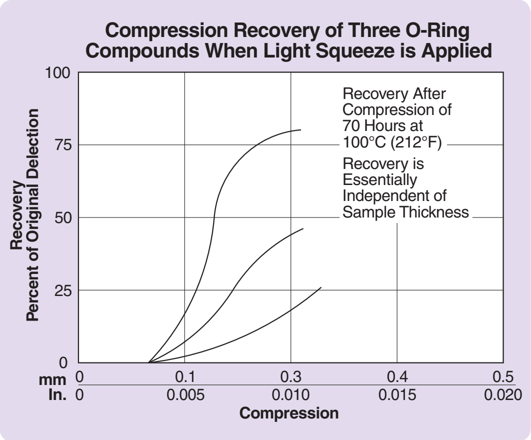

Figure 3-5: Compression Recovery of Three O-ring Compounds When Light Squeeze is Applied

An assembled stretch greater than five percent is not recommended because the internal stress on the O-ring causes more rapid aging. Over five percent stretch may sometimes be used, however, if a shorter useful life is acceptable.

Of the commonly used O-ring seal elastomers, the reduction in useful life is probably greatest with nitrile materials. Therefore, where high stretch is necessary, it is best to use ethylene propylene, fluorocarbon, polyurethane or neoprene, whichever material has the necessary resistance to the temperatures and fluids involved.

3.6 Squeeze

The tendency of an O-ring to attempt to return to its original uncompressed shape when the cross-section is deflected is the basic reason why O-rings make such excellent seals. Obviously then, squeeze is a major consideration in O-ring seal design.

In dynamic applications, the *maximum* recommended squeeze is approximately 16%, due to friction and wear considerations, though smaller cross-sections may be squeezed as much as 25%.

When used as a static seal, the maximum recommended squeeze for most elastomers is 30%, though this amount may cause assembly problems in a radial squeeze seal design. In a face seal situation, however, a 30% squeeze is often beneficial because recovery is more complete in this range, and the seal may function at a somewhat lower temperature. There is a danger in squeezing much more than 30% since the extra stress induced may contribute to early seal deterioration. Somewhat higher squeeze may be used if the seal will not be exposed to high temperatures nor to fluids that tend to attack the elastomer and cause additional swell.

The minimum squeeze for all seals, regardless of cross-section should be about .2 mm (.007 inches). The reason is that with a very light squeeze almost all elastomers quickly take 100% compression set. Figure 3-5 illustrates this lack of recovery when the squeeze is less than .1 mm (.005 inch). The three curves, representing three nitrile compounds, show very clearly that a good compression set resistant compound can be distinguished from a poor one only when the applied squeeze exceeds .1 mm (.005 inches).

Most seal applications cannot tolerate a "no" or zero squeeze condition. Exceptions include low-pressure air valves, for which the floating pneumatic piston ring design is commonly used, and some rotary O-ring seal applications. See the Dynamic O-Ring Sealing, Section V, and Tables A6-6 and A6-7 for more information on pneumatic and rotary O-ring seal design.

3.7 Gland Fill

The percentage of gland volume that an O-ring cross-section displaces in its confining gland is called "gland fill". Most O-ring seal applications call for a gland fill of between 60% to 85% of the available volume with the optimum fill being 75% (or 25% void). The reason for the 60% to 85% range is because of potential tolerance stacking, O-ring volume swell and possible thermal expansion of the seal. It is essential to allow at least a 10% void in any elastomer sealing gland.

3.8 O-Ring Compression Force

The force required to compress each linear inch of an O-ring seal depends principally on the shore hardness of the O-ring, its cross-section, and the amount of compression desired. Even if all these factors are the same, the compressive force per linear inch for two rings will still vary if the rings are made from different compounds or if their inside diameters are different. The anticipated load for a given installation is not fixed, but is a range of values. The values obtained from a large number of tests are expressed in the bar charts of Figures 2-4 through 2-8 in Section II. If the hardness of the compound is known quite accurately, the table for O-ring compression force, Table 2-3 may be used to determine which portion of the bar is most likely to apply.

Increased service temperatures generally tend to soften elastomeric materials (at least at first). Yet the compression force decreases very little except for the hardest compounds. For instance, the compression force for O-rings in compound N0674-70 decreased only 10% as the temperature was increased from 24°C (75°F) to 126°C (258°F). In compound N0552-90 the compression force decrease was 22% through the same temperature range.

Refer to Figure 3-6 for the following information:

> The dotted line indicates the approximate linear change in the cross section (W) of an O-ring when the gland prevents any change in the I.D. with shrinkage, or the O.D., with swell. Hence this curve indicates the change in the effective squeeze on an O-ring due to shrinkage or swell. Note that volumetric change may not be such a disadvantage as it appears at first glance. A volumetric shrinkage of six percent results in only three percent linear shrinkage when the O-ring is confined in a gland. This represents a reduction of only .003" of squeeze on an O-ring having a .103" cross-section (W)

Section IV – Static O-Ring Sealing

Gland Dimensions for Industrial O-Ring Static Seals, 103.5 Bar (1500 psi) Max.†

O-Ring Size	Dimensions				A	A-1		B	B-1			C	D	G†
					Bore Dia. (Male Gland)	Groove Dia. (Female Gland)		Tube OD (Female Gland)	Groove Dia. (Male Gland)			Plug Dia. (Male Gland)	Throat Dia. (Female Gland)	Groove Width
Parker No. 2-	ID	±	W	Mean OD (Ref)	+.002 -.000	-.000	+	+.000 -.002	+.000	–		+.000 .001	+.001 -.000	+.005 -.000
2-001	.029	.004	.040	.109	.105	.101	.002	.040	.044	.002	*	.103	.042	.055
002	.042	.004	.050	.142	.138	.132		.053	.059		*	.136	.055	.070
003	.056	.004	.060	.176	.172	.162		.067	.077		*	.170	.069	.083
004	.070	.005	.070 ±.003	.210	.206	.181	.002	.081	.106	.002	*	.204	.083	.093
005	.101	.005		.241	.237	.212		.112	.137		*	.235	.114	
006	.114	.005		.254	.250	.225		.125	.150		*	.248	.127	
007	.145	.005		.285	.281	.256		.156	.181		*	.279	.158	
008	.176	.005		.316	.312	.287		.187	.212		*	.310	.189	
009	.208	.005		.348	.343	.318		.218	.243		*	.341	.220	
010	.239	.005		.379	.375	.350		.250	.275		*	.373	.252	
011	.301	.005		.441	.437	.412		.312	.337		*	.435	.314	
012	.364	.005		.504	.500	.475		.375	.400		*	.498	.377	
013	.426	.005		.566	.562	.537		.437	.462			.560	.439	
014	.489	.005		.629	.625	.600		.500	.525			.623	.502	
015	.551	.007		.691	.687	.662		.562	.587			.685	.564	
016	.614	.009		.754	.750	.725		.625	.650			.748	.627	
017	.676	.009		.816	.812	.787		.687	.712			.810	.689	
018	.739	.009		.879	.875	.850		.750	.775			.873	.752	
019	.801	.009		.941	.937	.912		.812	.837			.935	.814	
020	.864	.009		1.004	1.000	.975		.875	.900			.998	.877	
021	.926	.009		1.066	1.062	1.037		.937	.962			1.060	.939	
022	.989	.010		1.129	1.125	1.100		1.000	1.025			1.123	1.002	
023	1.051	.010		1.191	1.187	1.162		1.062	1.087			1.185	1.064	
024	1.114	.010		1.254	1.250	1.225		1.125	1.150			1.248	1.127	
025	1.176	.011		1.316	1.312	1.287		1.187	1.212			1.310	1.189	
026	1.239	.011		1.379	1.375	1.350		1.250	1.275			1.373	1.252	
027	1.301	.011		1.441	1.437	1.412		1.312	1.337			1.435	1.314	
028	1.364	.013		1.504	1.500	1.475		1.375	1.400			1.498	1.377	
029	1.489	.013		1.629	1.625	1.600		1.500	1.525			1.623	1.502	
030	1.614	.013		1.754	1.750	1.725		1.625	1.650			1.748	1.627	
031	1.739	.015		1.879	1.875	1.850		1.750	1.775			1.873	1.752	
032	1.864	.015		2.004	2.000	1.975		1.875	1.900			1.998	1.877	
033	1.989	.018		2.129	2.125	2.100		2.000	2.025			2.123	2.002	
034	2.114	.018		2.254	2.250	2.225		2.125	2.150			2.248	2.127	
035	2.239	.018		2.379	2.375	2.350		2.250	2.275			2.373	2.252	
036	2.364	.018		2.504	2.500	2.475		2.375	2.400			2.498	2.377	
037	2.489	.018		2.629	2.625	2.600		2.500	2.525			2.623	2.502	
038	2.614	.020		2.754	2.750	2.725		2.625	2.650			2.748	2.627	
039	2.739	.020		2.879	2.875	2.850		2.750	2.775			2.873	2.752	
040	2.864	.020		3.004	3.000	2.975		2.875	2.900			2.998	2.877	
041	2.989	.024		3.129	3.125	3.100		3.000	3.025			3.123	3.002	
042	3.239	.024		3.379	3.375	3.350		3.250	3.275			3.373	3.252	
043	3.489	.024		3.629	3.625	3.600		3.500	3.525			3.623	3.502	

† This groove width does not permit the use of Parbak rings. For pressures above 103.5 Bar (1500 psi), consult Design Chart 4-2 for groove widths where back-up rings must be used.

* These designs require considerable installation stretch. If assembly breakage is incurred, use a compound having higher elongation or use a two-piece piston.

Design Table 4-2: Gland Dimensions for Industrial O-Ring Static Seals, 103.5 Bar (1500 psi) Max.

Gland Dimensions for Industrial O-Ring Static Seals, 103.5 Bar (1500 psi) Max.† (Continued)

O-Ring Size Parker No. 2-	Dimensions ID	±	W	Mean OD (Ref)	A Bore Dia. (Male Gland) +.002 -.000	A-1 Groove Dia. (Female Gland) -.000	+	B Tube OD (Female Gland) +.000 -.002	B-1 Groove Dia. (Male Gland) +.000	–		C Plug Dia. (Male Gland) +.000 .001	D Throat Dia. (Female Gland) +.001 -.000	G† Groove Width +.005 -.000
044	3.739	.027	.070 ±.003	3.879	3.875	3.850	.002	3.750	3.775	.002		3.873	3.752	.093
045	3.989	.027		4.129	4.125	4.100		4.000	4.025			4.123	4.002	
046	4.239	.030		4.379	4.375	4.350		4.250	4.275			4.373	4.252	
047	4.489	.030		4.629	4.625	4.600		4.500	4.525			4.623	4.502	
048	4.739	.030		4.879	4.875	4.850		4.750	4.775			4.873	4.752	
049	4.989	.037		5.129	5.125	5.100		5.000	5.025			5.123	5.002	
050	5.239	.037		5.379	5.375	5.350		5.250	5.275			5.373	5.252	
102	.049	.005	.103 ±.003	.255	.247	.224	.002	.062	.085	.002	*	.245	.064	.140
103	.081	.005		.287	.278	.256		.094	.116		*	.276	.095	
104	.112	.005		.318	.310	.287		.125	.148		*	.308	.127	
105	.143	.005		.349	.342	.318		.156	.180		*	.340	.158	
106	.174	.005		.380	.374	.349		.187	.212		*	.372	.189	
107	.206	.005		.412	.405	.381		.219	.243		*	.403	.221	
108	.237	.005		.443	.437	.412		.250	.275		*	.435	.252	
109	.299	.005		.505	.500	.474		.312	.338		*	.498	.314	
110	.362	.005		.568	.562	.537		.375	.400		*	.560	.377	
111	.424	.005		.630	.625	.599		.437	.463		*	.623	.439	
112	.487	.005		.693	.687	.662		.500	.525		*	.685	.502	
113	.549	.007		.755	.750	.724		.562	.588		*	.748	.564	
114	.612	.009		.818	.812	.787		.625	.650			.810	.627	
115	.674	.009		.880	.875	.849		.687	.713			.873	.689	
116	.737	.009		.943	.937	.912		.750	.775			.935	.752	
117	.799	.010		1.005	1.000	.974		.812	.838			.998	.814	
118	.862	.010		1.068	1.062	1.037		.875	.900			1.060	.877	
119	.924	.010		1.130	1.125	1.099		.937	.963			1.123	.939	
120	.987	.010		1.193	1.187	1.162		1.000	1.025			1.185	1.002	
121	1.049	.010		1.255	1.250	1.224		1.062	1.088			1.248	1.064	
122	1.112	.010		1.318	1.312	1.287		1.125	1.150			1.310	1.127	
123	1.174	.012		1.380	1.375	1.349		1.187	1.213			1.373	1.189	
124	1.237	.012		1.443	1.437	1.412		1.250	1.275			1.435	1.252	
125	1.299	.012		1.505	1.500	1.474		1.312	1.338			1.498	1.314	
126	1.362	.012		1.568	1.562	1.537		1.375	1.400			1.560	1.377	
127	1.424	.012		1.630	1.625	1.599		1.437	1.463			1.623	1.439	
128	1.487	.012		1.693	1.687	1.662		1.500	1.525			1.685	1.502	
129	1.549	.015		1.755	1.750	1.724		1.562	1.588			1.748	1.564	
130	1.612	.015		1.818	1.812	1.787		1.625	1.650			1.810	1.627	
131	1.674	.015		1.880	1.875	1.849		1.687	1.713			1.873	1.689	
132	1.737	.015		1.943	1.937	1.912		1.750	1.775			1.935	1.752	
133	1.799	.015		2.005	2.000	1.974		1.812	1.838			1.998	1.814	
134	1.862	.015		2.068	2.062	2.037		1.875	1.900			2.060	1.877	
135	1.925	.017		2.131	2.125	2.099		1.937	1.963			2.123	1.939	
136	1.987	.017		2.193	2.187	2.162		2.000	2.025			2.185	2.002	
137	2.050	.017		2.256	2.250	2.224		2.062	2.088			2.248	2.064	

† This groove width does not permit the use of Parbak rings. For pressures above 103.5 Bar (1500 psi), consult Design Chart 4-2 for groove widths where back-up rings must be used.

* These designs require considerable installation stretch. If assembly breakage is incurred, use a compound having higher elongation or use a two-piece piston.

Design Table 4-2: Gland Dimensions for Industrial O-Ring Static Seals, 103.5 Bar (1500 psi) Max.

Gland Dimensions for Industrial O-Ring Static Seals, 103.5 Bar (1500 psi) Max.† (Continued)

O-Ring Size	Dimensions				A	A-1		B	B-1			C	D	G†
Parker No. 2-	ID	±	W	Mean OD (Ref)	Bore Dia. (Male Gland) +.002 -.000	Groove Dia. (Female Gland) -.000	+	Tube OD (Female Gland) +.000 -.002	Groove Dia. (Male Gland) +.000	–		Plug Dia. (Male Gland) +.000 .001	Throat Dia. (Female Gland) +.001 -.000	Groove Width +.005 -.000
138	2.112	.017	↑	2.318	2.312	2.287	↑	2.125	2.150	↑		2.310	2.127	↑
139	2.175	.017		2.381	2.375	2.349		2.187	2.213			2.373	2.189	
140	2.237	.017		2.443	2.437	2.412		2.250	2.275			2.435	2.252	
141	2.300	.020		2.506	2.500	2.474		2.312	2.338			2.498	2.315	
142	2.362	.020		2.568	2.562	2.537		2.375	2.400			2.560	2.377	
143	2.425	.020		2.631	2.625	2.599		2.437	2.463			2.623	2.439	
144	2.487	.020		2.693	2.687	2.662		2.500	2.525			2.685	2.502	
145	2.550	.020		2.756	2.750	2.724		2.562	2.588			2.748	2.564	
146	2.612	.020		2.818	2.812	2.787		2.625	2.650			2.810	2.627	
147	2.675	.022		2.881	2.875	2.849		2.687	2.713			2.873	2.689	
148	2.737	.022		2.943	2.937	2.912		2.750	2.775			2.935	2.752	
149	2.800	.022		3.006	3.000	2.974		2.812	2.838			2.998	2.814	
150	2.862	.022		3.068	3.062	3.037		2.875	2.900			3.060	2.877	
151	2.987	.024		3.193	3.187	3.162		3.000	3.025			3.185	3.002	
152	3.237	.024		3.443	3.437	3.412		3.250	3.275			3.435	3.252	
153	3.487	.024		3.693	3.687	3.662		3.500	3.525			3.685	3.502	
154	3.737	.028	.103	3.943	3.937	3.912	.002	3.750	3.775	.002		3.935	3.752	.140
155	3.987	.028	±.003	4.193	4.187	4.162		4.000	4.025			4.185	4.002	
156	4.237	.030		4.443	4.437	4.412		4.250	4.275			4.435	4.252	
157	4.487	.030		4.693	4.687	4.662		4.500	4.525			4.685	4.502	
158	4.737	.030		4.943	4.937	4.912		4.750	4.775			4.935	4.752	
159	4.987	.035		5.193	5.187	5.162		5.000	5.025			5.185	5.002	
160	5.237	.035		5.443	5.437	5.412		5.250	5.275			5.435	5.252	
161	5.487	.035		5.693	5.687	5.662		5.500	5.525			5.685	5.502	
162	5.737	.035		5.943	5.937	5.912		5.750	5.775			5.935	5.752	
163	5.987	.035		6.193	6.187	6.162		6.000	6.025			6.185	6.002	
164	6.237	.040		6.443	6.437	6.412		6.250	6.275			6.435	6.252	
165	6.487	.040		6.693	6.687	6.662		6.500	6.525			6.685	6.502	
166	6.737	.040		6.943	6.937	6.912		6.750	6.775			6.935	6.752	
167	6.987	.040		7.193	7.187	7.162		7.000	7.025			7.185	7.002	
168	7.237	.045		7.443	7.437	7.412		7.250	7.275			7.435	7.252	
169	7.487	.045		7.693	7.687	7.662		7.500	7.525			7.685	7.502	
170	7.737	.045		7.943	7.937	7.912		7.750	7.775			7.935	7.752	
171	7.987	.045		8.193	8.187	8.162		8.000	8.025			8.185	8.002	
172	8.237	.050		8.443	8.437	8.412		8.250	8.275			8.435	8.252	
173	8.487	.050		8.693	8.687	8.662		8.500	8.525			8.685	8.502	
174	8.737	.050		8.943	8.937	8.912		8.750	8.775			8.935	8.752	
175	8.987	.050		9.193	9.187	9.162		9.000	9.025			9.185	9.002	
176	9.237	.055		9.443	9.437	9.412		9.250	9.275			9.435	9.252	
177	9.487	.055		9.693	9.687	9.662		9.500	9.525			9.685	9.502	
178	9.737	.055	↓	9.943	9.937	9.912	↓	9.750	9.775	↓		9.935	9.752	↓
201	.171	.005	.139	.449	.437	.409	↑	.187	.215	↑	*	.434	.190	↑
202	.234	.005	±.004	.512	.500	.472	.002	.250	.278	.002	*	.497	.253	.187
203	.296	.005	↓	.574	.562	.534	↓	.312	.340	↓	*	.559	.315	↓

† This groove width does not permit the use of Parbak rings. For pressures above 103.5 Bar (1500 psi), consult Design Chart 4-2 for groove widths where back-up rings must be used.

* These designs require considerable installation stretch. If assembly breakage is incurred, use a compound having higher elongation or use a two-piece piston.

Design Table 4-2: Gland Dimensions for Industrial O-Ring Static Seals, 103.5 Bar (1500 psi) Max.

Gland Dimensions for Industrial O-Ring Static Seals, 103.5 Bar (1500 psi) Max.† (Continued)

O-Ring Size	Dimensions				A	A-1		B	B-1		C	D	G†
Parker No. 2-	ID	±	W	Mean OD (Ref)	Bore Dia. (Male Gland) +.002 -.000	Groove Dia. (Female Gland) -.000	+	Tube OD (Female Gland) +.000 -.002	Groove Dia. (Male Gland) +.000	–	Plug Dia. (Male Gland) +.000 .001	Throat Dia. (Female Gland) +.001 -.000	Groove Width +.005 -.000
204	.359	.005	↑	.637	.625	.597	↑	.375	.403	↑	.622	.378	↑
205	.421	.005		.699	.687	.659		.437	.465		.684	.440	
206	.484	.005		.762	.750	.722		.500	.528		.747	.503	
207	.546	.007		.824	.812	.784		.562	.590		.809	.565	
208	.609	.009		.887	.875	.847		.625	.653		.872	.628	
209	.671	.009		.949	.937	.909		.687	.715		.934	.690	
210	.734	.010		1.012	1.000	.972		.750	.778		.997	.753	
211	.796	.010		1.074	1.062	1.034		.812	.840		1.059	.815	
212	.859	.010		1.137	1.125	1.097		.875	.903		1.122	.878	
213	.921	.010		1.199	1.187	1.159		.937	.965		1.184	.940	
214	.984	.010		1.262	1.250	1.222		1.000	1.028		1.247	1.003	
215	1.046	.010		1.324	1.312	1.284		1.062	1.090		1.309	1.065	
216	1.109	.012		1.387	1.375	1.347		1.125	1.153		1.372	1.128	
217	1.171	.012		1.449	1.437	1.409		1.187	1.215		1.434	1.190	
218	1.234	.012		1.512	1.500	1.472		1.250	1.278		1.497	1.253	
219	1.296	.012		1.574	1.562	1.534		1.312	1.340		1.559	1.315	
220	1.359	.012	.139	1.637	1.625	1.597	.002	1.375	1.403	.002	1.622	1.378	.187
221	1.421	.012	±.004	1.700	1.687	1.659		1.437	1.465		1.684	1.440	
222	1.484	.015		1.762	1.750	1.722		1.500	1.528		1.747	1.503	
223	1.609	.015		1.887	1.875	1.847		1.625	1.653		1.872	1.628	
224	1.734	.015		2.012	2.000	1.972		1.750	1.778		1.997	1.753	
225	1.859	.015		2.137	2.125	2.097		1.875	1.903		2.122	1.878	
226	1.984	.018		2.262	2.250	2.222		2.000	2.028		2.247	2.003	
227	2.109	.018		2.387	2.375	2.347		2.125	2.153		2.372	2.128	
228	2.234	.020		2.512	2.500	2.472		2.250	2.278		2.497	2.253	
229	2.359	.020		2.637	2.625	2.597		2.375	2.403		2.622	2.378	
230	2.484	.020		2.762	2.750	2.722		2.500	2.528		2.747	2.503	
231	2.609	.020		2.887	2.875	2.847		2.625	2.653		2.872	2.628	
232	2.734	.024		3.012	3.000	2.972		2.750	2.778		2.997	2.753	
233	2.859	.024		3.137	3.125	3.097		2.875	2.903		3.122	2.878	
234	2.984	.024		3.262	3.250	3.222		3.000	3.028		3.247	3.003	
235	3.109	.024		3.387	3.375	3.347		3.125	3.153		3.372	3.128	
236	3.234	.024		3.512	3.500	3.472		3.250	3.278		3.497	3.253	
237	3.359	.024		3.637	3.625	3.597		3.375	3.403		3.622	3.378	
238	3.484	.024		3.762	3.750	3.722		3.500	3.528		3.747	3.503	
239	3.609	.028		3.887	3.875	3.847		3.625	3.653		3.872	3.628	
240	3.734	.028		4.012	4.000	3.972		3.750	3.778		3.997	3.753	
241	3.859	.028		4.137	4.125	4.097		3.875	3.903		4.122	3.878	
242	3.984	.028		4.262	4.250	4.222		4.000	4.028		4.247	4.003	
243	4.109	.028		4.387	4.375	4.347		4.125	4.153		4.372	4.128	
244	4.234	.030		4.512	4.500	4.472		4.250	4.278		4.497	4.253	
245	4.359	.030		4.637	4.625	4.597		4.375	4.403		4.622	4.378	
246	4.484	.030		4.762	4.750	4.722		4.500	4.528		4.747	4.503	
247	4.609	.030	↓	4.887	4.875	4.847	↓	4.625	4.653	↓	4.872	4.628	↓

† This groove width does not permit the use of Parbak rings. For pressures above 103.5 Bar (1500 psi), consult Design Chart 4-2 for groove widths where back-up rings must be used.

* These designs require considerable installation stretch. If assembly breakage is incurred, use a compound having higher elongation or use a two-piece piston.

Design Table 4-2: Gland Dimensions for Industrial O-Ring Static Seals, 103.5 Bar (1500 psi) Max.

Gland Dimensions for Industrial O-Ring Static Seals, 103.5 Bar (1500 psi) Max.† (Continued)

O-Ring Size Parker No. 2-	Dimensions ID	±	W	Mean OD (Ref)	A Bore Dia. (Male Gland) +.002 -.000	A-1 Groove Dia. (Female Gland) -.000	+	B Tube OD (Female Gland) +.000 -.002	B-1 Groove Dia. (Male Gland) +.000	–		C Plug Dia. (Male Gland) +.000 .001	D Throat Dia. (Female Gland) +.001 -.000	G† Groove Width +.005 -.000
248	4.734	.030		5.012	5.000	4.972		4.750	4.778			4.997	4.753	
249	4.859	.035		5.137	5.125	5.097		4.875	4.903			5.122	4.878	
250	4.984	.035		5.262	5.250	5.222		5.000	5.028			5.247	5.003	
251	5.109	.035		5.387	5.375	5.347		5.125	5.153			5.372	5.128	
252	5.234	.035		5.512	5.500	5.472		5.250	5.278			5.497	5.253	
253	5.359	.035		5.637	5.625	5.597		5.375	5.403			5.622	5.378	
254	5.484	.035		5.762	5.750	5.722		5.500	5.528			5.747	5.503	
255	5.609	.035		5.887	5.875	5.847		5.625	5.653			5.872	5.628	
256	5.734	.035		6.012	6.000	5.972		5.750	5.778			5.997	5.753	
257	5.859	.035		6.137	6.125	6.097		5.875	5.903			6.122	5.878	
258	5.984	.035		6.262	6.250	6.222		6.000	6.028			6.247	6.003	
259	6.234	.040		6.512	6.500	6.472		6.250	6.278			6.497	6.253	
260	6.484	.040		6.762	6.750	6.722		6.500	6.528			6.747	6.503	
261	6.734	.040		7.012	7.000	6.972		6.750	6.778			6.997	6.753	
262	6.984	.040		7.262	7.250	7.222		7.000	7.028			7.247	7.003	
263	7.234	.045		7.512	7.500	7.472		7.250	7.278			7.497	7.253	
264	7.484	.045		7.762	7.750	7.722		7.500	7.528			7.747	7.503	
265	7.734	.045	.139	8.012	8.000	7.972	.002	7.750	7.778	.002		7.997	7.753	.187
266	7.984	.045	±.004	8.262	8.250	8.222		8.000	8.028			8.247	8.003	
267	8.234	.050		8.512	8.500	8.472		8.250	8.278			8.497	8.253	
268	8.484	.050		8.762	8.750	8.722		8.500	8.528			8.747	8.503	
269	8.734	.050		9.012	9.000	8.972		8.750	8.778			8.997	8.753	
270	8.984	.050		9.262	9.250	9.222		9.000	9.028			9.247	9.003	
271	9.234	.055		9.512	9.500	9.472		9.250	9.278			9.497	9.253	
272	9.484	.055		9.762	9.750	9.722		9.500	9.528			9.747	9.503	
273	9.734	.055		10.012	10.000	9.972		9.750	9.778			9.997	9.753	
274	9.984	.055		10.262	10.250	10.222		10.000	10.028			10.247	10.003	
275	10.484	.055		10.762	10.750	10.722		10.500	10.528			10.747	10.503	
276	10.984	.065		11.262	11.250	11.222		11.000	11.028			11.247	11.003	
277	11.484	.065		11.762	11.750	11.722		11.500	11.528			11.747	11.503	
278	11.984	.065		12.262	12.250	12.222		12.000	12.028			12.247	12.003	
279	12.984	.065		13.262	13.250	13.222		13.000	13.028			13.247	13.003	
280	13.984	.065		14.262	14.250	14.222		14.000	14.028			14.247	14.003	
281	14.984	.065		15.262	15.250	15.222		15.000	15.028			15.247	15.003	
282	15.955	.075		16.233	16.250	16.222		16.000	16.028			16.247	16.003	
283	16.955	.080		17.233	17.250	17.222		17.000	17.028			17.247	17.003	
284	17.955	.085		18.233	18.250	18.222		18.000	18.028			18.247	18.003	
309	.412	.005		.832	.812	.777		.437	.472		*	.809	.440	
310	.475	.005	.210	.895	.875	.840		.500	.535		*	.872	.503	
311	.537	.007	±.005	.957	.937	.902	.004	.562	.597	.004	*	.934	.565	.281
312	.600	.009		1.020	1.000	.965		.625	.660			.997	.628	
313	.662	.009		1.082	1.062	1.027		.687	.722			1.059	.690	
314	.725	.010		1.145	1.125	1.090		.750	.785			1.122	.753	

† This groove width does not permit the use of Parbak rings. For pressures above 103.5 Bar (1500 psi), consult Design Chart 4-2 for groove widths where back-up rings must be used.

* These designs require considerable installation stretch. If assembly breakage is incurred, use a compound having higher elongation or use a two-piece piston.

Design Table 4-2: Gland Dimensions for Industrial O-Ring Static Seals, 103.5 Bar (1500 psi) Max.

Gland Dimensions for Industrial O-Ring Static Seals, 103.5 Bar (1500 psi) Max.† (Continued)

O-Ring Size Parker No. 2-	Dimensions ID	±	W	Mean OD (Ref)	A Bore Dia. (Male Gland) +.002 -.000	A-1 Groove Dia. (Female Gland) -.000	+	B Tube OD (Female Gland) +.000 -.002	B-1 Groove Dia. (Male Gland) +.000	–	C Plug Dia. (Male Gland) +.000 .001	D Throat Dia. (Female Gland) +.001 -.000	G† Groove Width +.005 -.000
315	.787	.010	↑	1.207	1.187	1.152	↑	.812	.847	↑	1.184	.815	↑
316	.850	.010		1.270	1.250	1.215		.875	.910		1.247	.878	
317	.912	.010		1.332	1.312	1.277		.937	.972		1.309	.940	
318	.975	.010		1.395	1.375	1.340		1.000	1.035		1.372	1.003	
319	1.037	.010		1.457	1.437	1.402		1.062	1.097		1.434	1.065	
320	1.100	.012		1.520	1.500	1.465		1.125	1.160		1.497	1.128	
321	1.162	.012		1.582	1.562	1.527		1.187	1.222		1.559	1.190	
322	1.225	.012		1.645	1.625	1.590		1.250	1.285		1.622	1.253	
323	1.287	.012		1.707	1.687	1.652		1.312	1.347		1.684	1.315	
324	1.350	.012		1.770	1.750	1.715		1.375	1.410		1.747	1.378	
325	1.475	.015		1.895	1.875	1.840		1.500	1.535		1.872	1.503	
326	1.600	.015		2.020	2.000	1.965		1.625	1.660		1.997	1.628	
327	1.725	.015		2.145	2.125	2.090		1.750	1.785		2.122	1.753	
328	1.850	.015		2.270	2.250	2.215		1.875	1.910		2.247	1.878	
329	1.975	.018		2.395	2.375	2.340		2.000	2.035		2.372	2.003	
330	2.100	.018		2.520	2.500	2.465		2.125	2.160		2.497	2.128	
331	2.225	.018		2.645	2.625	2.590		2.250	2.285		2.622	2.253	
332	2.350	.018		2.770	2.750	2.715		2.375	2.410		2.747	2.378	
333	2.475	.020		2.895	2.875	2.840		2.500	2.535		2.872	2.503	
334	2.600	.020		3.020	3.000	2.965		2.625	2.660		2.997	2.628	
335	2.725	.020		3.145	3.125	3.090		2.750	2.785		3.122	2.753	
336	2.850	.020	.210	3.270	3.250	3.215	.004	2.875	2.910	.004	3.247	2.878	.281
337	2.975	.024	±.005	3.395	3.375	3.340		3.000	3.035		3.372	3.003	
338	3.100	.024		3.520	3.500	3.465		3.125	3.160		3.497	3.128	
339	3.225	.024		3.645	3.625	3.590		3.250	3.285		3.622	3.253	
340	3.350	.024		3.770	3.750	3.715		3.375	3.410		3.747	3.378	
341	3.475	.024		3.895	3.875	3.840		3.500	3.535		3.872	3.502	
342	3.600	.028		4.020	4.000	3.965		3.625	3.660		3.997	3.628	
343	3.725	.028		4.145	4.125	4.090		3.750	3.785		4.122	3.753	
344	3.850	.028		4.270	4.250	4.215		3.875	3.910		4.247	3.878	
345	3.975	.028		4.395	4.375	4.340		4.000	4.035		4.372	4.003	
346	4.100	.028		4.520	4.500	4.465		4.125	4.160		4.497	4.128	
347	4.225	.030		4.645	4.625	4.590		4.250	4.285		4.622	4.253	
348	4.350	.030		4.770	4.750	4.717		4.375	4.410		4.747	4.378	
349	4.475	.030		4.895	4.875	4.840		4.500	4.535		4.872	4.503	
350	4.600	.030		5.020	5.000	4.965		4.625	4.660		4.997	4.628	
351	4.725	.030		5.145	5.125	5.090		4.750	4.785		5.122	4.753	
352	4.850	.030		5.270	5.250	5.215		4.875	4.910		5.247	4.878	
353	4.975	.037		5.395	5.375	5.340		5.000	5.035		5.372	5.003	
354	5.100	.037		5.520	5.500	5.465		5.125	5.160		5.497	5.128	
355	5.225	.037		5.645	5.625	5.590		5.250	5.285		5.622	5.253	
356	5.350	.037		5.770	5.750	5.715		5.375	5.410		5.747	5.378	
357	5.475	.037		5.895	5.875	5.840		5.500	5.535		5.872	5.503	
358	5.600	.037	↓	6.020	6.000	5.965	↓	5.625	5.660	↓	5.997	5.628	↓

† This groove width does not permit the use of Parbak rings. For pressures above 103.5 Bar (1500 psi), consult Design Chart 4-2 for groove widths where back-up rings must be used.

* These designs require considerable installation stretch. If assembly breakage is incurred, use a compound having higher elongation or use a two-piece piston.

Design Table 4-2: Gland Dimensions for Industrial O-Ring Static Seals, 103.5 Bar (1500 psi) Max.

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Gland Dimensions for Industrial O-Ring Static Seals, 103.5 Bar (1500 psi) Max.† (Continued)

O-Ring Size Parker No. 2-	Dimensions ID	±	W	Mean OD (Ref)	A Bore Dia. (Male Gland) +.002 -.000	A-1 Groove Dia. (Female Gland) -.000	+	B Tube OD (Female Gland) +.000 -.002	B-1 Groove Dia. (Male Gland) +.000	–	C Plug Dia. (Male Gland) +.000 .001	D Throat Dia. (Female Gland) +.001 -.000	G† Groove Width +.005 -.000
359	5.725	.037		6.145	6.125	6.090		5.750	5.785		6.122	5.753	
360	5.850	.037		6.270	6.250	6.215		5.875	5.910		6.247	5.878	
361	5.975	.037		6.395	6.375	6.340		6.000	6.035		6.372	6.003	
362	6.225	.040		6.645	6.625	6.590		6.250	6.285		6.622	6.253	
363	6.475	.040		6.895	6.875	6.840		6.500	6.535		6.872	6.503	
364	6.725	.040		7.145	7.125	7.090		6.750	6.785		7.122	6.753	
365	6.975	.040		7.395	7.375	7.340		7.000	7.035		7.372	7.003	
366	7.225	.045		7.645	7.625	7.590		7.250	7.285		7.622	7.253	
367	7.475	.045		7.895	7.875	7.840		7.500	7.535		7.872	7.503	
368	7.725	.045		8.145	8.125	8.090		7.750	7.785		8.122	7.753	
369	7.975	.045		8.395	8.375	8.340		8.000	8.035		8.372	8.003	
370	8.225	.050		8.645	8.625	8.590		8.250	8.285		8.622	8.253	
371	8.475	.050		8.895	8.875	8.840		8.500	8.535		8.872	8.503	
372	8.725	.050		9.145	9.125	9.090		8.750	8.785		9.122	8.753	
373	8.975	.050		9.395	9.375	9.340		9.000	9.035		9.372	9.003	
374	9.225	.055		9.645	9.625	9.590		9.250	9.285		9.622	9.253	
375	9.475	.055		9.895	9.875	9.840		9.500	9.535		9.872	9.503	
376	9.725	.055		10.145	10.125	10.090		9.750	9.785		10.122	9.753	
377	9.975	.055	.210	10.395	10.375	10.340	.004	10.000	10.035	.004	10.372	10.003	.281
378	10.475	.060	±.005	10.895	10.875	10.840		10.500	10.535		10.872	10.503	
379	10.975	.060		11.395	11.375	11.340		11.000	11.035		11.372	11.003	
380	11.475	.065		11.895	11.875	11.840		11.500	11.535		11.872	11.503	
381	11.975	.065		12.395	12.375	12.340		12.000	12.035		12.372	12.003	
382	12.975	.065		13.395	13.375	13.340		13.000	13.035		13.372	13.003	
383	13.975	.070		14.395	14.375	14.340		14.000	14.035		14.372	14.003	
384	14.975	.070		15.395	15.375	15.340		15.000	15.035		15.372	15.003	
385	15.955	.075		16.375	16.375	16.340		16.000	16.035		16.372	16.003	
386	16.955	.080		17.375	17.375	17.340		17.000	17.035		17.372	17.003	
387	17.955	.085		18.375	18.375	18.340		18.000	18.035		18.372	18.003	
388	18.955	.090		19.373	19.375	19.340		19.000	19.035		19.372	19.003	
389	19.955	.095		20.373	20.375	20.340		20.000	20.035		20.372	20.003	
390	20.955	.095		21.373	21.375	21.340		21.000	21.035		21.372	21.003	
391	21.955	.100		22.373	22.375	22.340		22.000	22.035		22.372	22.003	
392	22.940	.105		23.360	23.375	23.340		23.000	23.035		23.372	23.003	
393	23.940	.110		24.360	24.375	24.340		24.000	24.035		24.372	24.003	
394	24.940	.115		25.360	25.375	25.340		25.000	25.035		25.372	25.003	
395	25.940	.120		26.360	26.375	26.340		26.000	26.035		26.372	26.003	
425	4.475	.033		5.025	5.000	4.952		4.500	4.548		4.996	4.504	
426	4.600	.033		5.150	5.125	5.077		4.625	4.673		5.121	4.629	
427	4.725	.033	.275	5.275	5.250	5.202	.004	4.750	4.798	.004	5.246	4.754	.375
428	4.850	.033	±.006	5.400	5.375	5.327		4.875	4.923		5.371	4.879	
429	4.975	.037		5.525	5.500	5.452		5.000	5.048		5.496	5.004	
430	5.100	.037		5.650	5.625	5.577		5.125	5.173		5.621	5.129	
431	5.225	.037		5.775	5.750	5.702		5.250	5.298		5.746	5.254	

† This groove width does not permit the use of Parbak rings. For pressures above 103.5 Bar (1500 psi), consult Design Chart 4-2 for groove widths where back-up rings must be used.

* These designs require considerable installation stretch. If assembly breakage is incurred, use a compound having higher elongation or use a two-piece piston.

Design Table 4-2: Gland Dimensions for Industrial O-Ring Static Seals, 103.5 Bar (1500 psi) Max.

Gland Dimensions for Industrial O-Ring Static Seals, 103.5 Bar (1500 psi) Max.† (Continued)

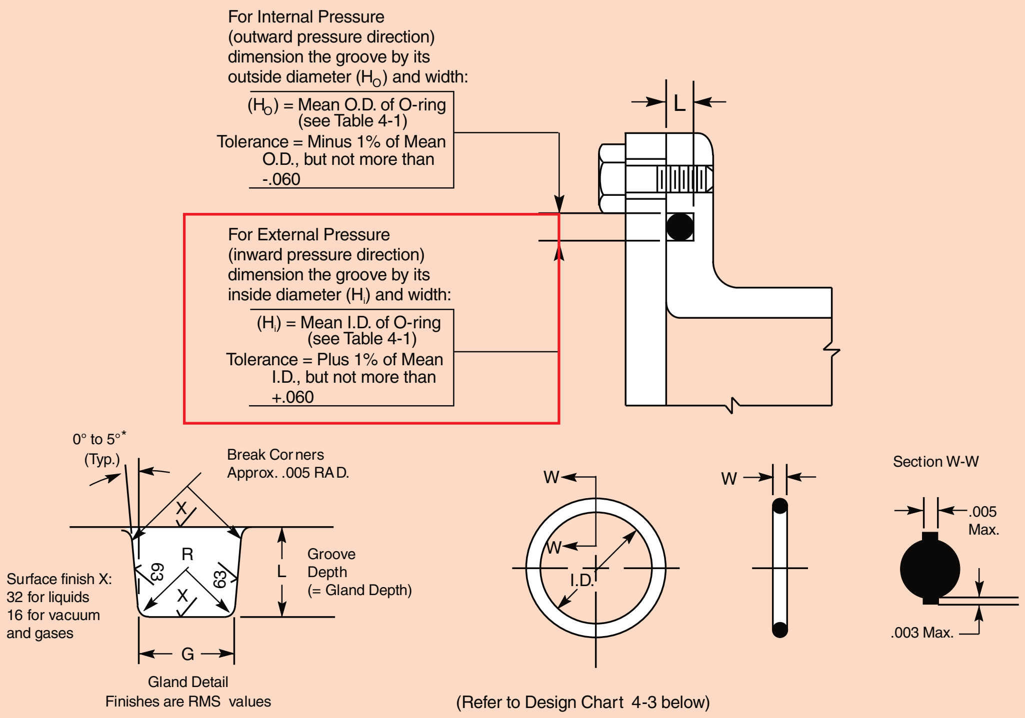
O-Ring Size	Dimensions				A	A-1		B	B-1		C	D	G†
Parker No. 2-	ID	±	W	Mean OD (Ref)	Bore Dia. (Male Gland) +.002 -.000	Groove Dia. (Female Gland) -.000	+	Tube OD (Female Gland) +.000 -.002	Groove Dia. (Male Gland) +.000	–	Plug Dia. (Male Gland) +.000 .001	Throat Dia. (Female Gland) +.001 -.000	Groove Width +.005 -.000
432	5.350	.037	.275 ±.006	5.900	5.875	5.827	.004	5.375	5.423	.004	5.871	5.379	.375
433	5.475	.037		6.025	6.000	5.952		5.500	5.548		5.996	5.504	
434	5.600	.037		6.150	6.125	6.077		5.625	5.673		6.121	5.629	
435	5.725	.037		6.275	6.250	6.202		5.750	5.798		6.246	5.754	
436	5.850	.037		6.400	6.375	6.327		5.875	5.923		6.371	5.879	
437	5.975	.037		6.525	6.500	6.452		6.000	6.048		6.496	6.004	
438	6.225	.040		6.775	6.750	6.702		6.250	6.298		6.746	6.254	
439	6.475	.040		7.025	7.000	6.952		6.500	6.548		6.996	6.504	
440	6.725	.040		7.275	7.250	7.202		6.750	6.798		7.246	6.754	
441	6.975	.040		7.525	7.500	7.452		7.000	7.048		7.496	7.004	
442	7.225	.045		7.775	7.750	7.702		7.250	7.298		7.746	7.254	
443	7.475	.045		8.025	8.000	7.952		7.500	7.548		7.996	7.504	
444	7.725	.045		8.275	8.250	8.202		7.750	7.798		8.246	7.754	
445	7.975	.045		8.525	8.500	8.452		8.000	8.048		8.496	8.004	
446	8.475	.055		9.025	9.000	8.952		8.500	8.548		8.996	8.504	
447	8.975	.055		9.525	9.500	9.452		9.000	9.048		9.496	9.004	
448	9.475	.055		10.025	10.000	9.952		9.500	9.548		9.996	9.504	
449	9.975	.055		10.525	10.500	10.452		10.000	10.048		10.496	10.000	
450	10.475	.060		11.025	11.000	10.952		10.500	10.548		10.996	10.504	
451	10.975	.060		11.525	11.500	11.452		11.000	11.048		11.496	11.004	
452	11.475	.060		12.025	12.000	11.952		11.500	11.548		11.996	11.504	
453	11.975	.060		12.525	12.500	12.452		12.000	12.048		12.496	12.004	
454	12.475	.060		13.025	13.000	12.952		12.500	12.548		12.996	12.504	
455	12.975	.060		13.525	13.500	13.452		13.000	13.048		13.496	13.004	
456	13.475	.070		14.025	14.000	13.952		13.500	13.548		13.996	13.504	
457	13.975	.070		14.525	14.500	14.452		14.000	14.048		14.496	14.004	
458	14.475	.070		15.025	15.000	14.952		14.500	14.548		14.996	14.504	
459	14.975	.070		15.525	15.500	15.452		15.000	15.048		15.496	15.004	
460	15.475	.070		16.025	16.000	15.952		15.500	15.548		15.996	15.504	
461	15.955	.075		16.505	16.500	16.452		16.000	16.048		16.496	16.004	
462	16.455	.075		17.005	17.000	16.952		16.500	16.548		16.996	16.504	
463	16.955	.080		17.505	17.500	17.452		17.000	17.048		17.496	17.004	
464	17.455	.085		18.005	18.000	17.952		17.500	17.548		17.996	17.504	
465	17.955	.085		18.505	18.500	18.452		18.000	18.048		18.496	18.004	
466	18.455	.085		19.005	19.000	18.952		18.500	18.548		18.996	18.504	
467	18.955	.090		19.505	19.500	19.452		19.000	19.048		19.496	19.004	
468	19.455	.090		20.005	20.000	19.952		19.500	19.548		19.996	19.504	
469	19.955	.095		20.505	20.500	20.452		20.000	20.048		20.496	20.004	
470	20.955	.095		21.505	21.500	21.452		21.000	21.048		21.496	21.004	
471	21.955	.100		22.505	22.500	22.452		22.000	22.048		22.496	22.004	
472	22.940	.105		23.490	23.500	23.452		23.000	23.048		23.496	23.004	
473	23.940	.110		24.490	24.500	24.452		24.000	24.048		24.496	24.004	
474	24.940	.115		25.490	25.500	25.452		25.000	25.048		25.496	25.004	
475	25.940	.120		26.490	26.500	26.452		26.000	26.048		26.496	26.004	

† This groove width does not permit the use of Parbak rings. For pressures above 103.5 Bar (1500 psi), consult Design Chart 4-2 for groove widths where back-up rings must be used.

* These designs require considerable installation stretch. If assembly breakage is incurred, use a compound having higher elongation or use a two-piece piston.

Design Table 4-2: Gland Dimensions for Industrial O-Ring Static Seals, 103.5 Bar (1500 psi) Max.

Face Seal Glands



(Refer to Design Chart 4-3 below)

O-Ring Face Seal Glands These dimensions are intended primarily for face type O-ring seals and low temperature applications.

O-Ring Size Parker No. 2	W Cross Section		L Gland Depth	Squeeze		G Groove Width		R Groove Radius
	Nominal	Actual		Actual	%	Liquids	Vacuum and Gases	
004 through 050	1/16	.070 ±.003 (1.78 mm)	.050 to .054	.013 to .023	19 to 32	.101 to .107	.084 to .089	.005 to .015
102 through 178	3/32	.103 ±.003 (2.62 mm)	.074 to .080	.020 to .032	20 to 30	.136 to .142	.120 to .125	.005 to .015
201 through 284	1/8	.139 ±.004 (3.53 mm	.101 to .107	.028 to .042	20 to 30	.177 to .187	.158 to .164	.010 to .025
309 through 395	3/16	.210 ±.005 (5.33 mm)	.152 to .162	.043 to .063	21 to 30	.270 to .290	.239 to .244	.020 to .035
425 through 475	1/4	.275 ±.006 (6.99 mm)	.201 to .211	.058 to .080	21 to 29	.342 to .362	.309 to .314	.020 to .035
Special	3/8	.375 ±.007 (9.52 mm)	.276 to .286	.082 to .106	22 to 28	.475 to .485	.419 to .424	.030 to .045
Special	1/2	.500 ±.008 (12.7 mm)	.370 to .380	.112 to .138	22 to 27	.638 to .645	.560 to .565	.030 to .045

Design Chart 4-3: Design Chart for O-Ring Face Seal Glands

Application

1) Simpler to apply, because of fewer restrictions, such as flow direction, air supply, orifice size, pressure drop, etc.
2) Fewer requirements for positioners.
3) A hydraulic snubber is never required.
4) Quick change trim.

SEATING, SEALING AND LEAKAGE

The three problems discussed in this section include:

Seating - The alignment and contact of the plug with the seat, including joint design and loading.

Sealing - The parameters of metal finish, joint width, and metal yielding which lead to tight sealing.

Leakage - The amount of leakage that may be expected for different sealing parameters and joint designs.

Tight sealing is becoming of greater importance to control valve users, now that improvements in designs of both valve trim and actuators allow tight shut-off. One valve may be used for both stop and throttling service at a cost saving. Diaphragm control, valve actuators with 15 to 35 psi air supplies do not develop the high seating forces used in stop valve designs with manual or automatic operation. If they did, they would be bulky and would be sluggish in their speed of stem movement for throttling action. A small amount of leakage is to be expected, because of the lower seating forces. Manufacturers normally rate their valves for maximum leakage as follows:

Double Seated Valves –
$<0.1\%$ C_V maximum[1]

Single Seated Valves –
$<0.01\%$ C_V maximum[1]

Development of the springless piston actuator, air loaded on both sides and using a much higher supply pressure (100-150 psi), coupled with a positioner, led to higher seating forces and tighter shut-off. Single seated valves can now be sealed, drop-tight to high pressure drops. Some cage balanced valve designs also shut off drop-tight with small diaphragm actuators.

Seating

To make a seal, a plug must first be perfectly aligned and then must fully contact the seat joint as the seating load is applied by the actuator.

If the plug strikes the seat joint slightly cocked, it will remain cocked until a higher seating load causes it to jump sideways as it slides down into the taper and slams into full joint contact. This deforms the seat, causing leakage. In time, the plug indenture will extend to form a new off center, nearly 360° seat contact. Above a certain plug cocking angle, the plug will not jump into place regardless of loading; therefore, pre-guiding and alignment of the plug before seating, is necessary.

The two principal types of mis-alignment are *Concentric* as shown in Figure 68(a) and *Axial* as shown in Figure 68(b).

Alignment

Alignment of the plug on the seat for a single ported, top and bottom guided valve involves concentric alignment of eight components and axial alignment of eleven, fit combinations; plus consideration of the operating clearances.

One can readily see the precision machining, required of the control valve manufacturer to maintain alignment of these parts. Each part must have an assembly or sliding clearance which allows a minute horizontal axial shift and a very slight cock. The flexibility of the stem is sufficient to allow the plug to move into true seat joint contact with light, initial seat-contact loading.

Seat Joint Design

Flat joints, normal to the plug axis, are used on some low pressure stop valves and soft seated control valves. It is not practical to manufacture them for high pressure service. As discussed later, tighter sealing occurs through a sliding and burnishing action of a tapered joint. Tapered joints turn the fluid gradually and are the best for high pressure drop and for erosive service. The control valve industry uses joints from 15° to 45°. Smaller angles would begin to form sticking tapers and larger angles give too much of a poppet effect, when cracked open at high pressure differentials, which would cause unstable, low-range throttling. In summary:

1) 45° seat angles find their best applications in either normally open or normally closed valves.
2) 30° seat angles are a compromise between high seating forces and streamlined flow, at low lifts, for low erosion service.

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[1] Seat leakage flow is laminar rather than turbulent and the C_V formula is not applicable; therefore, this is simply a means of specifying an amount of acceptable leakage.

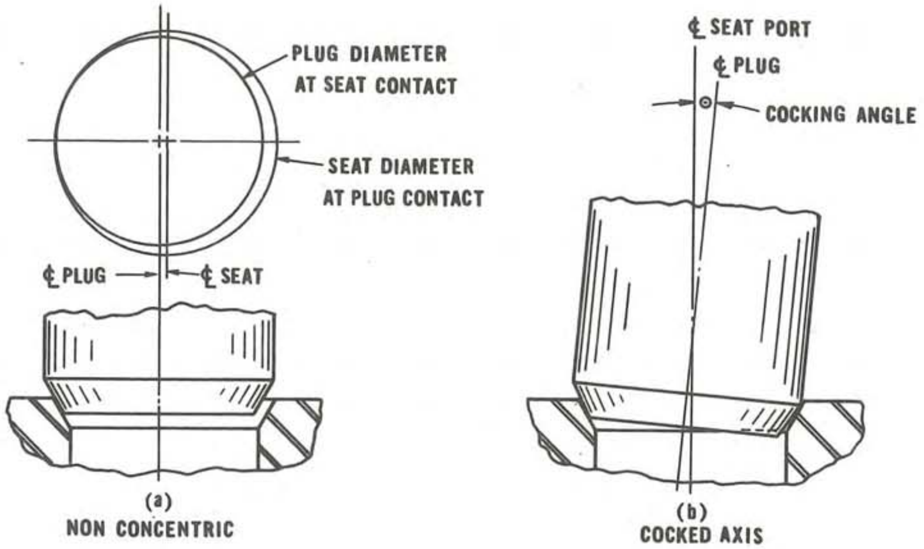

Figure 68. PLUG MISALIGNMENT WITH SEAT.

3) 15° seat angles are best applied to high pressure drop, erosive service.

Seat Joint Width

Seat joint width is a balance of adding length to the flow path to increase flow resistance vs. reduction of the seating force for a given actuator seating load. A certain minimum width is essential to establish a tight seal; however, the joint must have sufficient backup strength to support the compressive seating load and must be wide enough to prevent indention of the plug. Narrow joints are much tighter than wide joints, provided they exceed the minimum width requirements.

Seat Joint Loading

Seat joint loading is usually expressed as pounds of force per linear inch of mean seat joint circumference. Loading may vary from 25-600 lb./inch as given below:

1) 25 lb./in. - Low pressure drop service; leak-tight shut-off is not required; metal-to-metal joint.
2) 50 lb./in. - Moderate pressure drop service; slight leakage expected (0.1% C_V maximum).
3) 100 lb./in. - High pressure drop service; nearly drop-tight service (0.01% C_V maximum); will seal 3000 psi pressure drop on 0.015 in. width, 30° joint of 316 SS[1].
4) 300 lb./in. - Very high pressure drop service; drop-tight (will seal 6000 psi on 0.025 in. width, 20° joint of 440-C SS, hardness 55 R_C).
5) 600 lb./in. - Extremely high pressure service.

The apparent compressive seating stresses on joints described in items 3) and 4) above, are 13,000 psi and 35,000 psi respectively, which is well below the yield point of the given trim materials. These are the stresses normal to the joint. Elastomeric and plastic yielding is occuring at the high points of each surface making a tortuous flow path for leakage restriction.

By contrast, stop-valve seat loading with hard-faced seats in steam service may be 50,000 psi, apparent stress, or four times a nominal control valve, seating load of 100 lb/linear inch for a diaphragm actuator.

eg. (Steels vs Stellite)

To obtain the best circular seat-joint contact at low stem loading use:

1) Cage guided trim with the seat integral with the cage. Horizontal and axial alignment for seating involves

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[1] 100 lbs/linear inch vertical seating force is equivalent to a force of 200 lbs/linear inch normal to a 30° joint (100 lb./sin 30°). The compressive seating stress is 200 lb/0.015 in.x 1 in.=13,300 psi.

only two parts in sliding contact. Alignment of regular trim must be transferred from the seat to the body, to the bonnet, to the guide, to the plug, and back to the seat.

2) Cage guided trim with the seat aligned by the cage.
3) A seat that is integral with body; or
4) Extend a thin flexible seat lip above the means of seat retention as shown in Figure 29.

A radial expandable, seat ring design is illustrated by Figure 69. In this design the seating angle creates a large radial component of force which expands the seat ring against the retaining collar. The spring-out action of the non-circular ring allows a near-perfect joint contact giving drop-tight shut-off in severe thermal cycle service. This design has been successfully used on pressure drops to 4,400 psi. The large flow, entrant passage also makes the valve suitable for erosive service.

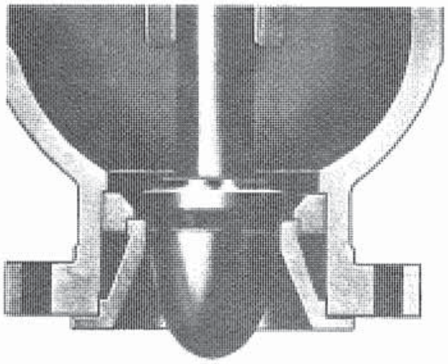


Figure 69. RADIALLY EXPANDABLE SEAT RING DESIGN.

Courtesy Conoflow Corporation

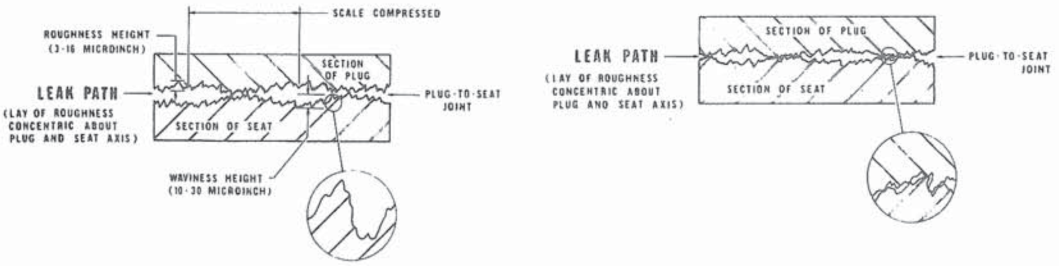
Trim Sealing

Tight sealing requires the yielding of one material into the surface "waviness" and surface roughness of the other, as illustrated by Figure 70, to block direct leakage paths; thus, making these paths long and tortuous. Compressive stresses are far below those that would yield the entire joint; therefore, the contact area is apparent. Actually, only the peaks of each surface are in contact and the concentration of force may then exceed the yield and will plastically deform the high spots on each valve closure. Additional closures require a higher seating load to achieve the same degree of tightness, until the wear particles are formed and conditions tend to stabilize.

Tapered joints provide for a sliding and burnishing action as contact is made and loading occurs. This gives a tighter initial seal than a perpendicular contact and the seal remains tighter with repeated closures.

The minimum width of a joint to seal gas to 1 x 10^{-7} cc/s/linear inch, maximum leakage, is 0.04 inch. Wider joints with the same surface finish and loading will not seal tighter. This width insures sufficient high point contact to form an adequate flow resistance path as shown by the graph of Figure 71.

Extra "super-finishing" of seat joints is unnecessary for tight sealing, because as the joint opens and closes, wear particles ball up on the surface, quickly returning it to a rougher finish. Also, some fluid contaminants tend to remain in the joint on closure and indent the surfaces. Excessive lapping generally either reduces seat tightness by increasing the actual contact area, thus, reducing the unit compressive seating stress provided by a fixed actuator seating force or it destroys the original surface geometry.



(a) Under Light Seating Load

(b) Under Heavy Seating Load

Figure 70. MATING OF SEAT JOINT SURFACES.

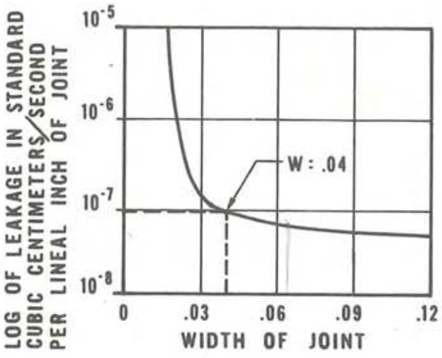


Figure 71. MINIMUM JOINT WIDTH FOR A TIGHT SEAL.

(Leakage rates for 14.7 psi Δ P helium on a flat circular joint.)

Consolidated graph taken from Reference No. 48.

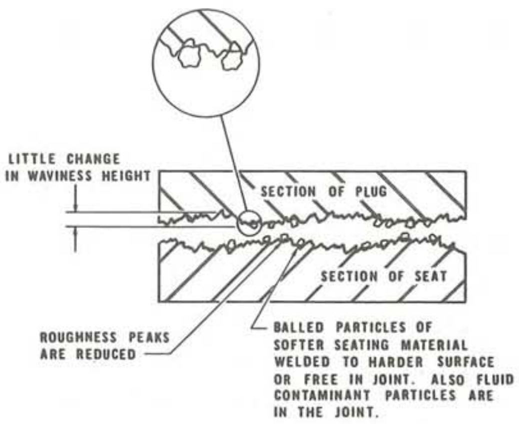


Figure 72. JOINT SURFACE AFTER REPEATED CLOSURES.

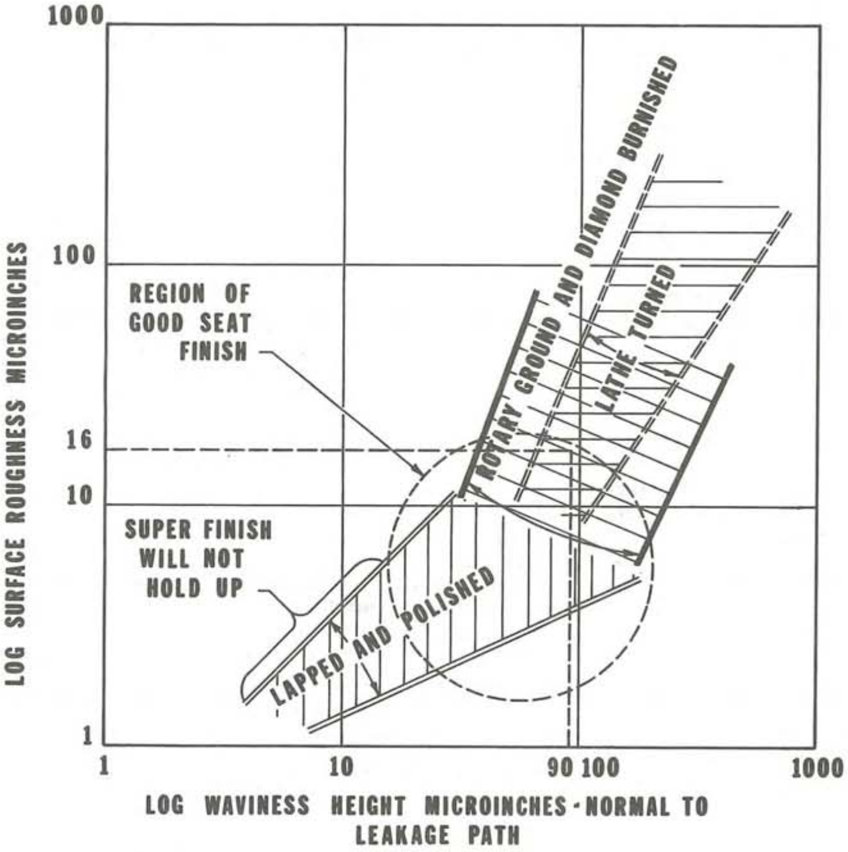


Figure 73. DEGREE OF SEAT JOINT FINISH VS. METHOD OBTAINING FINISH.

Chart presented in "Investigation of Leakage and Sealing Parameters", Paul Bauer, ITT Research Institute, Technical Report AFRPL-TF-65-153, August, 1965.

The following comparison illustrates the relative seating force to obtain same degree of tightness vs. the seat joint finishing method (concentric lay of finishing pattern). Refer to Figures 72 and 73.

Finishing Method	*Relative Seating Force*
diamond burnished (after grinding)	1.0
lathe turned	1.3
ground	2.5
lapped (excessive) (90% of apparent area of) (contact actually mated)	2.9

Trim Leakage

Definitions Relative to Trim Leakage:

Drop tight, to be meaningful, must be specified in terms of the maximum allowed number of drops per unit of time (drops/minute, cc/hour or no visible drop).

Bubble tight, to gas, should be specified as the maximum allowed number of bubbles of a given size per minute (usually 1/8 in. diameter).

Zero leakage is defined as 1 x10^{-8} cc/s or about 0.3 cc/year (helium leak rate at standard conditions). Zero leakage is often specified in critical service and requires very careful joint design, material selection, finish control, and sufficient seating force on narrow joints. It is practical only for small valves, at extra cost, and may last for only a few closing cycles.

Stop valve maximum leakage rates are given in the Valve Manufacturers Standardization Society, SP-61 as:

1) Water tests at ΔP = Body CWP rating (10 cc/hour/inch of valve pipe size or about 3/drops/minute).
2) Air tests at ΔP=80 psi (0.1 SCFM/inch of valve pipe size).

Leakage Specifications, to be meaningful and allow comparison, should include test fluid, temperature, pressure, pressure drop, seating force and duration of test.

Control Valve Leakage

Properly designed control valves can achieve stop valve tightness and maintain it throughout a long service life before trim replacement; particularly with cage guided, balanced trim having elastomer plug-to-cage seals. The control valve, however, is expected to throttle and often shuts off much more frequently than stop valves. For example, some dump valves may have from 4000 to 7000 opening and closing cycles per day, handling high pressure and erosive fluids at 1000 to 4000 psi pressure drop. Few stop valves could match this performance and remain tight.

It is customary to expect a slight degree of leakage and, in general control valve service applications, this has presented few problems. Specified permissible leakage should be based on process considerations (hazards resulting from leakage after emergency shut off, etc.). Tight shut off should be specified only when necessary, because a higher quality more expensive valve is required.

Liquid Leakage is to a great extent affected by surface tension and the particular fluid wetting the joint surface, before the new fluid attempts to enter. For precise leak testing, the joint and body should be free of all traces of oil, which would preferentially wet the metal joint surfaces. Water leakage rates of an oil-free joint are higher. Oil clinging to the roughness, blocks some leakage paths, causing a higher capillary displacement pressure to establish flow of the test fluid.

Seat Leakage Specifications

Single Seated Globe Valves

A maximim allowable leakage of 0.01% of Rated C_V is often based on the nominal or catalog listed actuator size for the given valve tested with 50psi of air across the seat joint.

Double Seated Globe Valves

These valves are specified to have a maximum leakage rate of 0.5% to 0.1% of rated C_V depending upon quality purchased. They are tested with 50 psi of air across the seat joint. See ISA standard 39.1.

Extra Tight Shut Off for Single Seated Globe Valves

A water test is often conducted at the differential pressure rating assigned to the valve by the manufacturer and which is based upon actuator size, air loading, spring force and direction of leakage across the plug (either over or under the plug). Maximum leakage may be specified as 0.0005 cubic centimeters of water per minute per inch of valve seat orifice diameter (not pipe size of valve end) per psi pressure drop. Example: A valve having a 4 inch seat orifice and tested to 2000 psi differential pressure would have a maximum water leakage rate of 4cc/minute. Leakage may be checked with a gas instead of a liquid. The maximum allowable rate is often specified at 6 x 10^{-7} cubic centimeters per second per inch of seat diameter.

Soft Seats in Globe Valves

These may be leak tested in accordance with SAMA Standard#PMC23.2c. Under this standard valve actuators are sized to provide a minimum stem force of 150 pounds per inch of seat diameter over and above the plug unbalance force created by the maximum rated differential pressure. The test pressure using air is the maximum rated differential pressure or 300psi, whichever is the *least*, but not to exceed the maximum operating pressure at ambient temperature.

Elastomer Lined Butterfly Valves

These are often tested with 50psi of air as a minimum, or maximum differential operating pressure across the disc. With the downstream side of the disc covered with water, the maximum allowable leakage rate may be specified at one bubble of air in ten seconds, per inch of vane diameter.

Elastomer Sealed Ball and Plug Valves

They are usually bubble tight to their rated differential pressure. Metal seated valves have relatively high leak rates compared to globe style valves. One exception is a rotary cam type plug valve with leakage rates comparable with globe valves.

Theoretical Leakage Formula

The equation relating the fluid properties, flow path geometry, and flow rate is:

$$Q_o = \frac{\pi (p_1^2 - p_2^2) \bar{h}^3}{12 \mu p_o \ln r_o / r_i} \quad \text{(See }^1\text{)}$$

where:

$\bar{h}$ = uniform channel clearance[2]
p_o = pressure at standard conditions
p_2 = exit fluid pressure
p_1 = inlet fluid pressure
Q_o = volume rate of flow at standard conditions
r_o, r_i = outside and inside radii of joint sealing area
μ = absolute viscosity

When the terms are rearranged, the uniform channel clearance is:

$$\bar{h} = \sqrt[3]{\frac{12 p_o \mu \ln r_o / r_i \, Q_o}{\pi (p_2^2 - p_1^2)}}$$

for gases the leakage formula becomes

$$Q_o = \left[\frac{\pi h^3 (r_o + r_i)(p_1^2 - p_2^2)}{12 \mu (r_o - r_i) p_o} \right] X$$

$$\left[1 + \frac{12.76 \, \epsilon p_o \cdot \lambda o)}{(p_1 + p_2) h} \right]$$

λo = molecular mean free path at standard conditions.
ϵ = correction factor, 0.9 for a single gas and 0.66 for a mixture.

The problem is that the leakage test gives no indication of whether the leak path is one large scratch or the sum of leakage through millions of tiny tortorous paths. Refinishing the joint may eliminate the first cause, but the condition may already be at the practical limit of seal tightness for the latter.

Type Of Gas Flow Through Seat Joint Leakage Pattern

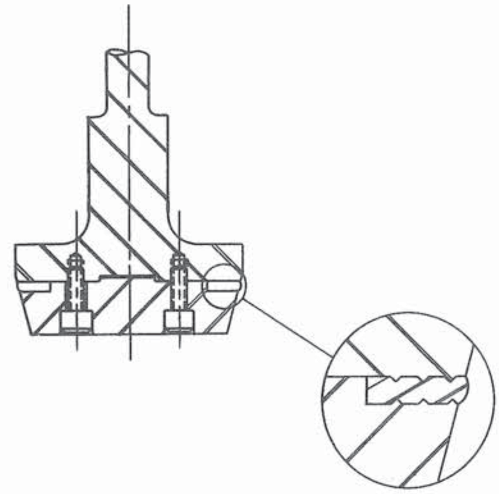
The following is a summary of characteristics for various leak conditions.

Plug Position	*Type of Flow*	*Minimum Restricting Dimension in Leakage Path*
cracked open	nozzle flow	> 0.005 in.
seating load build up zone	turbulent channel flow	0.0005 to 0.005 in.
valve seated and leakage begins	laminar flow	0.0001 to 0.0005 in.
joint surface waviness, then roughness provides leak paths as deformation begins	transition flow (molecular and laminar)	0.000001 to 0.0001 in.
elastic and plastic yielding of joint has closed large paths	molecular flow	< 0.000001 in.

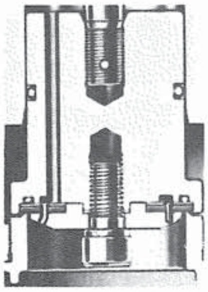
---

[1] Taken from Reference 50, the formula applies to a flat seat joint.

[2] This is the theoretical separation of two truly plane surfaces to give an equivalent rate of leakage caused by channels, imperfections, etc.

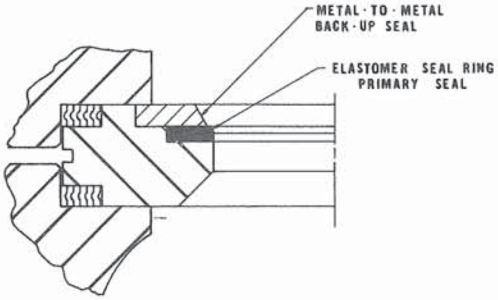


(a) Nylon seal retained in plug.

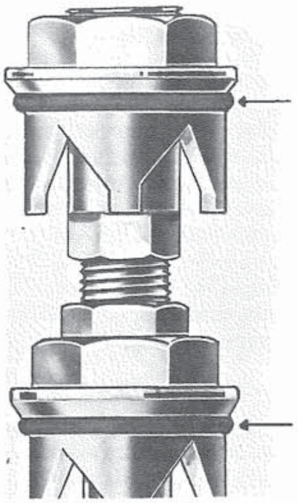


(b) TFE seal in plug of cage guided, balanced valve.

Courtesy Fisher Controls Company

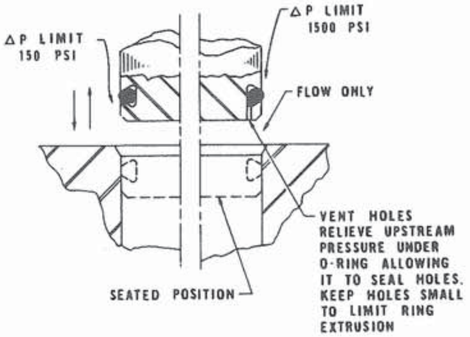


(c) Elastomer seal in seat ring of split body valve.

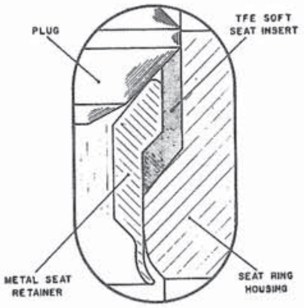


(d) Lightly restrained O-rings for low pressure drop, installed on double V-port plug.

Courtesy Fisher Controls Company



(e) O-ring in dove-tail groove for higher pressure drop. Vent holes relieve pressure under O-ring retaining it in the groove as the seat joint cracks open. Holes are small to prevent seal extrusion.



(f) Soft seat design used in boiler feedwater pump recirculation anticavitation low noise valve.

Handles fluids to 475°F and 6000 psig inlet pressure.

Courtesy of Masoneilan International, Inc.

Figure 74. SOFT SEAT RETENTION.

When sealing to the point of achieving molecular flow, the lighter, smaller and higher velocity molecules, such as helium and hydrogen, will have the highest leakage rates.

Determination of Seat Leakage Rate

Determining the Seat Leakage Rate is not as simple as it may appear. Fluids are subject to thermal expansion and contraction during tests and air may go in or out of solution, causing volume changes in the downstream measuring system.

For accurate testing, maintain the valves and the fluids at an equal temperature and air dissolved in water at equilibrium conditions.

Helium leak detection requires a clean background with large amounts of fresh air for maximum sensitivity.

The following is a summary of the sensitivity of various test methods, given in cc/s at atmospheric conditions.

air bubbles in water (also air and soap bubbles)	1 x 10^{-3} to 1 x 10^{-4} cc/s
thermal detectors	1 x 10^{-4} cc/s
halogen detectors	1 x 10^{-5} cc/s
mass spectrometer using "sniffer" (helium leak pick up probe)	1 x 10^{-6} to 1 x 10^{-8} cc/s

Soft Seating

Resilient composition sealing materials are used to obtain bubble tight sealing with a small actuator force. Compressive seating stresses are such, that the material is elastically deformed into the surface roughness of the mating metal part, to block all leak paths. The permeability of the material, to the fluid, is the source of a very minor leakage.

Materials which are too soft, or that tend to cold-flow (creep) under load, may be stiffened with fillers such as glass. When used in thin sections, and adequately retained, the cold-flow or permanent-set problems may be eliminated.

Seals must be carefully restrained against rupture and blow-out by differential pressure. Several designs of soft-seat retention are illustrated by Figure 74. The bonding of seats to metal parts is an aid, but not a total solution, because bonds are subject to thermal shock cracking and to degradation. Sufficient pressure drop will rupture the bonding material.

A secondary advantage of soft sealing is that the seal, once compressed, is free to re-expand and to follow seat distortion as the pressure drop loading increases. To do this, the sealing material should have a rapid recovery rate upon removal of the load. This action will occur only at resilient temperatures.

Hard materials such as nylon, in thin sections carefully restrained, can handle pressure drops of several thousand psi; whereas, TFE materials are readily abraded.

Soft seals are useful for sealing where contaminants or solid material are trapped in the closed joint. Material as hard as 60D in a raised-seal beadform is capable of sealing 0.01 in. particles, bubble-tight, to 1500 psi pressure drop.

The softer the seal, the better its abrasive resistance, up to the point where it is damaged by pressure drop forces.

Large volume, high pressure blowdown systems are necessary to adequately test elastomer seals and retention means for pressure drop strength. Elastomers, under high loading, tend to act as a fluid and extrusion may occur unless the load is limited or unless a metal-to-metal stop is used. Some joint designs allow soft sealing first, followed by a metal-to-metal closure as a secondary seal in case of soft seal rupture.

The material properties to be considered in the selection of a soft seat are:

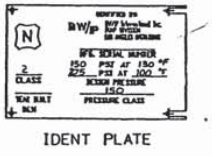
1) Fluid compatibility including, swelling, loss of hardness, permeability, degradation;
2) Hardness;
3) Permanent set;
4) Rate of recovery upon removal of load;
5) Tensile and compressive strength;
6) Distortion before rupture;
7) Modulus of elasticity.

Rarely do the physical properties given for sealing materials relate to the actual conditions of loading and strain in valve seals. There is no substitute for thermal and blow-down testing as the means to prove material, seal configuration and joint design.

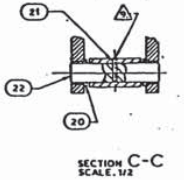
SEAT ATTACHMENT AND SEALING TO BODY

Seat attachment and sealing to the body is a major consideration of valve sealing, equal in importance to joint seal, bonnet seal, and stem seal. Lack of seat-to-body sealing gives a continuous leak, often blamed on the seat-to-plug joint. In high pressure and/or steam service, leakage behind the seal will actually erode through

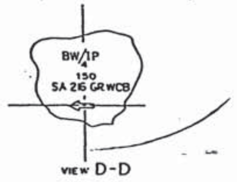
LTR	ZONE	DESCRIPTION	DATE	DWN	CHK	APPD
A	B&A	ADDED 1974 ED. W 76 ADDENDA IN NOTES 2 AND 22. DELETED [illegible] 7878 IN NOTE 4. DELET NOTES 5, 6, 10 AND 11; NOTE 7 WAS: PER NPS 5-3, NOTE 13 WAS: PER NPS [illegible] NOTE 14 WAS: PER NPS 70005. NOTE 16 WAS: PER NPS 70119. NOTE 17 WAS: PER NPS 5-4; NOTE 20 WAS: [illegible] 70478. NOTE 21 WAS: PER NPS 6-5. NOTE 22 WAS: PER NPS 70308. NOTE 24 & 25 WAS: PER NPS 5-3. NOTE 26 WAS: PAINT PER NPS 70708 [illegible] FIND #1 MAT'L WAS: ASTM A[illegible]. FIND # 17 & 19 ADDED IN MAT'L: PER NPS 71093, ALLOY NO. 1 OR CO-CR-W PER AMS 5387. ADDED COND H-1075 OR H-1100 IN FIND # 22 & 23. FIND # 23 MAT'L WAS: 17-4PH CRES PER AMS [illegible] FIND # 27 MAT'L WAS: 304 CRES & ASBESTOS. FIND # 30 P/N 2000086 WAS: 72313. ADDED P/N 7236716 IN FIND # 33. ZONE 6B CHANGE IDENT PLATE PICTORIAL. NOTE 19 WAS: TORQUE TO 50-60 FOOT POUNDS. ADDED NOTE 14 IN FIND NO: 18, 23 & 24	[illegible]			



IDENT PLATE



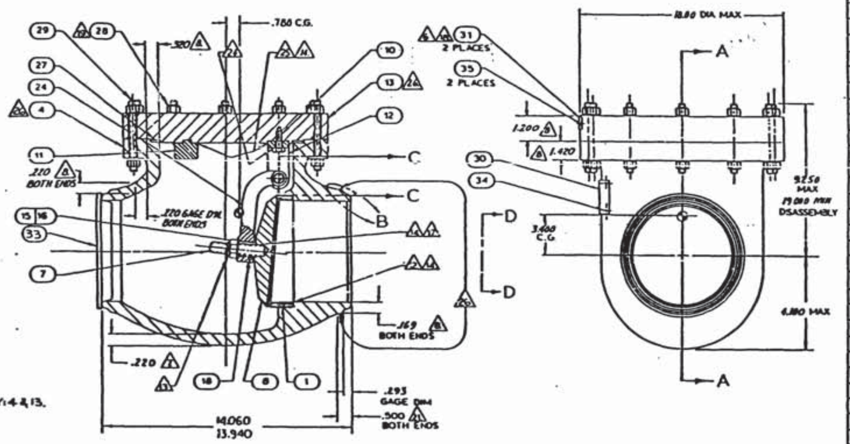
SECTION C-C
SCALE 1/2



VIEW D-D

PROJECT WBNP DISCIPLINE Mech
CONTRACT 93N3F-42062E UNIT 1
DESC Valve
DWG/DOC NO 421JBB1-002
SHEET 1 OF 1 REV A
DATE 1/2/95 DCN N/A FILE N/A

APPROVED
This approval does not relieve his Contractor from any part of his responsibility for the correctness of design, details and dimensions.
Date JAN 0 2 1995
TENNESSEE VALLEY AUTHORITY
Watts Bar Engineering Manager



SECTION A-A

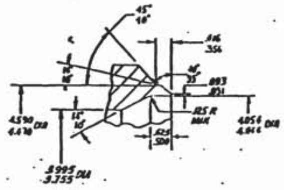
NOTE

AS BUIILT CONDITION FOR ONE (1) VALVE ONLY

S/N 931A0112
R/S # 305359
TVA P.O. P-93N3F-42062E

WELD END DIA. SHOULD BE : 4.590/4.470
IS : 4.440/4.438

TENNESSEE VALLEY AUTHORITY
SEQUOYAH & WATTS BAR NUCLEAR PLANTS
VALVE TAG NO. 47W492-300



DETAIL B
SCH 40S
SCALE FULL
BOTH ENDS

△26 PAINT PER APPROVED PROCEDURE ON FOLLOWING ITEMS ONLY: 4 & 13. DO NOT PAINT WELD PREP AND INTERNAL SURFACES.
△25 FILLET WELDED PER APPROVED PROCEDURE.
△24 TACK WELDED PER APPROVED PROCEDURE.
23. HARD FACED PER APPROVED PROCEDURE.
22. PRESSURE BOUNDARY ITEM PER ASME BOILER AND PRESSURE VESSEL CODE, SECTION III, CLASS 1, 1974 ED. THRU W' 76 ADDENDA.
△21 RADIOGRAPHIC EXAMINATION PER APPROVED PROCEDURE
20. MATERIAL CONFORMS TO ASME BOILER AND PRESSURE VESSEL CODE, SECTION III, EXCEPT ULTRASONIC EXAMINATION.
△19 TORQUE TO 60-135 FOOT POUNDS.
△18 STAMP CUSTOMER VALVE TAG NO.
△17 FILLET WELDED PER APPROVED PROCEDURE.
16. CLEANING AND PACKAGING PER APPROVED PROCEDURE.
15. COEFFICIENT OF FLOW: C_v = 462 (CALCULATED)
△14 PENETRANT EXAMINATION PER APPROVED PROCEDURE.
△13 FILLET WELDED PER APPROVED PROCEDURE.
△12 SEAL WELDED PER APPROVED PROCEDURE.
11. DELETED.
10. DELETED.
△9 TACK WELDED PER APPROVED PROCEDURE.
△8 MIN. WALL THICKNESS AS MEASURED 4 PLACES, 85°-95° APART.
△7 MIN. WALL THICKNESS AS MEASURED 3 PLACES, 85°-95° APART.
△6 DELETED.
△5 DELETED.
4. MATERIAL CONFORMS TO ASME BOILER AND PRESSURE VESSEL CODE, SECTION III, EXCEPT RADIOGRAPHIC EXAMINATION.
3. TESTING SHALL BE IN ACCORDANCE WITH ATP 421JBB1-002.
2. PRESSURE BOUNDARY ITEM PER ASME BOILER AND PRESSURE VESSEL CODE, SECTION III, CLASS 2, 1974 ED. THRU W' 76 ADDENDA.
1. INTERPRET DRAWING DIMENSIONS AND TOLERANCES IN ACCORDANCE WITH ANSI STANDARD Y14.5.

N-PRODUCTS

NOTES, UNLESS OTHERWISE SPECIFIED:

FIND NO.	QTY REQ.	PART OR IDENTIFYING NO.	MATERIAL AND SPECIFICATION	NOMENCLATURE OR DESCRIPTION	SEE NOTES
50					
49					
48					
47					
46					
45					
44					
43					
42					
41					
40					
39					
38					
37					
36					
35	2	7000040-853	300 SERIES CRES	DRIVE SCREW	
34	4	7000040-851	300 SERIES CRES	DRIVE SCREW	
33	2	7236716	POLYETHYLENE	CAPLUG	
32					
31	1	72205	ASTM A240 TYPE 302	MARKING PLATE	
30	1	2000086	ASTM A240 TYPE 302	IDENT. PLATE	
29	12	72183 -12	ASME SA 564 TYPE 630 COND. H-1075 OR H-1100	STUD	22
28	24	72184-12	ASME SA194 GR. 8M	HEX NUT	22
27	1	78734	321 SST W/FLEXITALLIC FLEXITE SUPER CORE OR EQU.	GASKET (SPIRAL WOUND)	
26					
25	1	78978		BONNET ARM & DISC ASSY	
24	1	72225		ARM, MACHINED	14
23	1	72224	ASTM A 747 GR CB7Cu-1 COND. H-1075 OR H-1100	ARM, CASTING	14
22	1	72079	ASTM A564 TYPE 630. COND H-1075 OR H-1100	PIN, PIVOT	14
21	1	71648-13	ASTM A276 TYPE 316 COND A	PIN	
20	2	72083		BUSHING, MACHINED	
19	1	77224	STELLITE #6 PER AMS 5385 ALLOY #1 OR CO-CR-W PER AMS 5387	BUSHING, CASTING	
18	1	72086		BALL, MACHINED	14
17	1	77223	STELLITE #6 PER AMS 5385 ALLOY #1 OR CO-CR-W PER AMS 5387	BALL, CASTING	14
16	1	7000020-300	316 CRES	WASHER	
15	1	7000111-300	ASTM A194 GR 8M	HEX JAM NUT	
14	1	78395		BONNET ASSEMBLY	2
13	1	72333	ASME SA105	BONNET	2, 14, 20
12	1	72356-11	ASTM A515 GR. 70	CLEVIS	14
11	1	73274-12		STOP	
10	1	7000008-208	ASTM A193 GR. B7	HEX BOLT	
9	1	78977		DISC & STUD ASSEMBLY	2
8	1	78978	ASME SA105	DISC	2, 14, 20, 23
7	1	72085	ASTM A276 TYPE	STUD	
6					
5	1	78975		BODY ASSEMBLY	2
4	1	78974		BODY, MACHINED	2, 14
3	1	78389-11	ASME SA 216 GR. WCB	BODY, CASTING	2, 4
2	1	78388	ASME SA216 GR. WCB	BODY CASTING, COMP	
1	1	72327	ASTM A 216 GR. WCB	SEAT	14, 23

LIST OF MATERIALS

421JBB1-002

CERTIFIED BY Olsen DATE Oct 77

VALVE ASSEMBLY - 4 INCH, 150LBS, SWING CHECK VALVE, C.S.

SIZE	CODE IDENT NO.	DWG NO.	REV
E	79294	421JBB1-002	A

SCALE NONE | WT 125 LBS (CALC) | SHEET 1 OF 1

ORIGINAL ORIGINAL

PARTS LIST

PRESS RETAIN	LINE NO	NAME	QTY	MATERIAL	SPEC & GRADE
X	1	BODY	1	CAST SST	SA 351 CF 8M
	2	BODY RING	1	SST PL	A 240 316
X	3	DISC	1	CAST SST	SA351 CF 8M
	4	BRACKET	1	CAST SST	A487 CA6NM
	5	SHAFT	1	SST	A564-630 HTC 1100
X	6	COVER	1	SST PL	SA240-316
	7*	GASKET	1	SST ASB	FLEXITALLIC
X	8	STUD	8	ALY STL	SA193-B7
X	9	HEX NUT	8	ALY STL	SA194-2H
	10	DOWEL	2	SST	18-8
	11	CAP SCW HEX HD	2	SST	A193-B6 410
	12	LOCKING TAB	2	SST SHT	18-8
	13*	"O" RING	1	ETHYLENE PROPELENE	PARKER # 2-332
					18-8
	14	NAMEPLATE MFR	1	SST	18-8
	15	DRIVE SCW	4	ALY STL	
	16	NAMEPLATE ASME CODE	1	SST	18-8

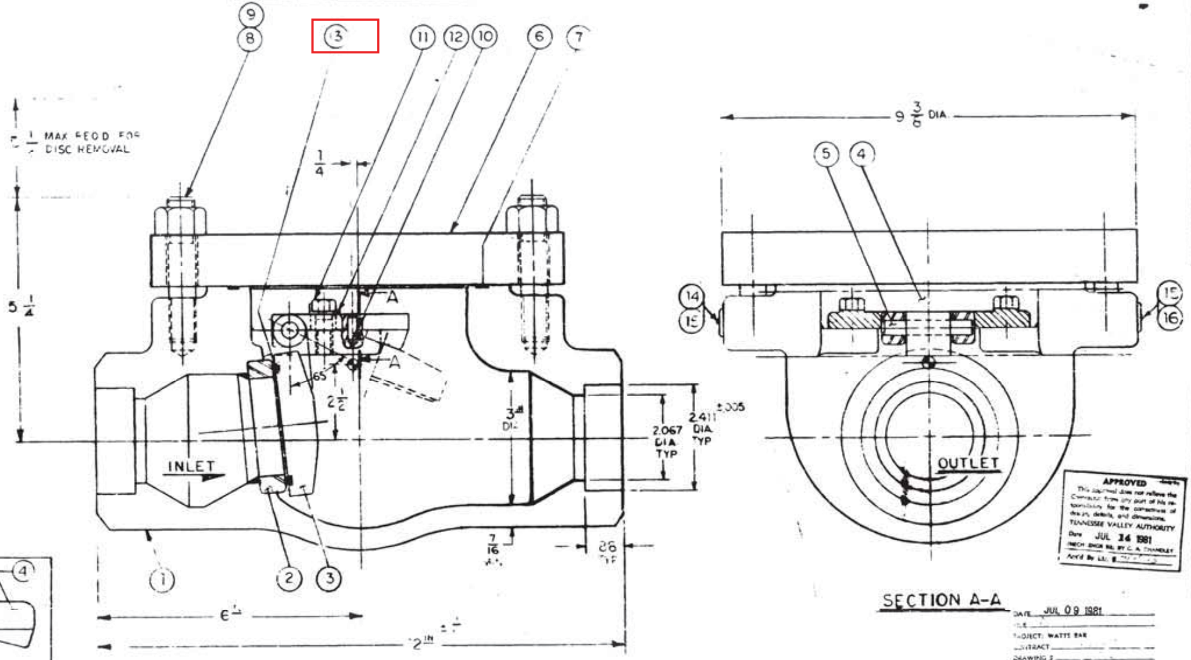
X-MATERIALS FOR PRESSURE RETAINING PARTS WILL BE ASME-SA
* RECOMMENDED SPARE PART

ATWOOD & MORRILL CO., INC.
SALEM, MASS. WASHINGTON, D.C.

SERVICE DESIGNATION	CL 210 ASME SECT III (77) ADDENDA SUMMER '79				
SIZE	2 IN	STEM	17-4	DISC	ETH PRO
SEAT		A & M ORDER NO	14735-02		
47W450-202A		81KA2-827840			

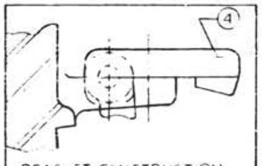
ATWOOD & MORRILL CO. INC.
DESIGN PRESSURE 160 PSI AT 130 °F
MFR'S SERIAL NO
CLASS 2 YEAR BUILT ANSI PRESSURE CL RATING 210

	E.C.N. NO.	REVISION DESCRIPTION	DRAWN	CHK'D	CH. DR.	ENG.	Q.C.	MFG ENG.
REV. 0	———	DRAWN & RELEASED	L.A.P. 2 12 81	7-17-81	2-18-81	2/18/81	6/4/81	6/14/81
REV. 1	———	ADDED NOTE #5	MJS 6-24-81	6-24-81	6-24-81	6/24/81	6/24/81	
REV. 2								
REV. 3								



APPROVED
This approval does not relieve the Contractor from any part of his responsibility for the correctness of design, details, and dimensions.
TENNESSEE VALLEY AUTHORITY
Date JUL 24 1981
MECH ENGR BR. BY C. A. CHANDLEY
Apr'd By

DATE JUL 09 1981
FILE
PROJECT: WATTS BAR
CONTRACT
DRAWING #
SHEET
REVISION
UNIT
USE



BRACKET CONSTRUCTION FOR 2" & 3" VALVES ONLY

TVA PROJECT TITLE WATTS BAR NUCLEAR PLANT
TVA MARK NO 47 W 450-202A
PO NO 81KA2-827840
TVA REF NO N3M-615

NOTES

1 VALVE MAY BE INSTALLED IN VERTICAL OR HORIZONTAL PIPE RUN. VALVE TOP COVER MUST BE INSTALLED IN HORIZONTAL POSITION ABOVE THE PIPE [illegible] CENTERLINE OF THE FLOW MUST BE UPWARD
2 ALL DIMENSIONS ARE REFERENCE EXCEPT AS NOTED
3 CV EQUALS 208 (BASED ON WATER @ [illegible])
4 DESIGN PRESS (160# DESIGN TEMP 130°F)
5 COLD WORKING PRESSURE 475 PSI

THIS PRINT CERTIFIED CORRECT FOR YOUR ORDER:	WHEN WRITING IN REGARD TO THIS EQUIPMENT REFER, TO:
81 KA2-827840	- 14735-02

THIS PRINT IS THE PROPERTY OF & CONTAINS PROPRIETARY INFORMATION OF ATWOOD & MORRILL CO. INC. AND IS TO BE KEPT CONFIDENTIAL. REPRODUCTION OF ANY PART THEREOF OR USE FOR PURPOSES OTHER THAN THOSE EXPRESSLY DESIGNATED BY ATWOOD & MORRILL CO. INC. IS NOT PERMITTED

SCALE
B.M. 15971
WT. 95#
PATT
REF

TOLERANCES ON MACHINE DIMENSIONS UNLESS OTHERWISE SPECIFIED	
FRACTIONAL DIMENSIONS	± 1/32
ANGULAR DIMENSIONS	± 1/2°
SURFACE FINISHES	125 ✓
ALL CORNERS 1/32 R. OR CHAM UNLESS OTHERWISE SPECIFIED	

2" CLASS 210 WE
SWING CHECK VALVE
W/SOFT SEAT DISC

ATWOOD & MORRILL CO INC
SALEM, MASS.

14735-02

PARTS LIST

	LINE NO	NAME	QTY	MATERIAL	SPEC & GRADE
X	1	BODY	1	CAST STL	SA216-WCB
	2	BODY RING	1	STL PL	A515-70
X	3	DISC	1	CAST SST	SA 351-CF8M
	4	BRACKET	1	CAST SST	A487-CA6NM
	5	SHAFT	1	SST	A564-630 HTC 1100°
X	6	COVER	1	STEEL	SA515 70
	7 *	GASKET	1	SST ASB	FLEXITALLIC
X	8	STUD	8	ALY STL	A193 B7
X	9	HEX NUT	8	ALY STL	SA194-2H
	10	DOWEL	2	SST	18-8
	11	CAP SCW HEX HD	2	ALY STL	A193-B7
	12	LOCKING PLATE	2	SST	18-8
	13 *	O RING	1	ETHYLENE PROPELENE	PARKER 2-332
	14	NAME PLATE MFR	1	SST SHT	18-8
	15	DRIVE SCREW	4	ALY STL	
	16	NAMEPLATE ASME CODE	1	SST SHT	18-8

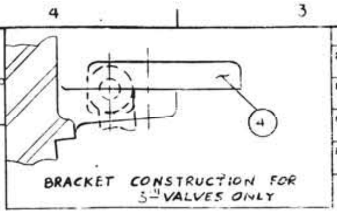
X-MATERIALS FOR PRESSURE RETAINING PARTS WILL BE ASME-SA

*-RECOMMENDED SPARE PARTS

TVA PROJECT TITLE WATTS BAR NUCLEAR PLANT
TVA MARK NO 47W464-89A
TVA P.O NO 81KA2-827840
TVA REF NO. N3M-615
QTY 2 VALVES

③
TVA PROJECT TITLE:
SEQUOYAH NUCLEAR POWER PLANT
TVA P.O NO 81KA2-827840
TVA REF NO N3Y-615
CHANGE ORDER NO 1
QTY 2 VALVES

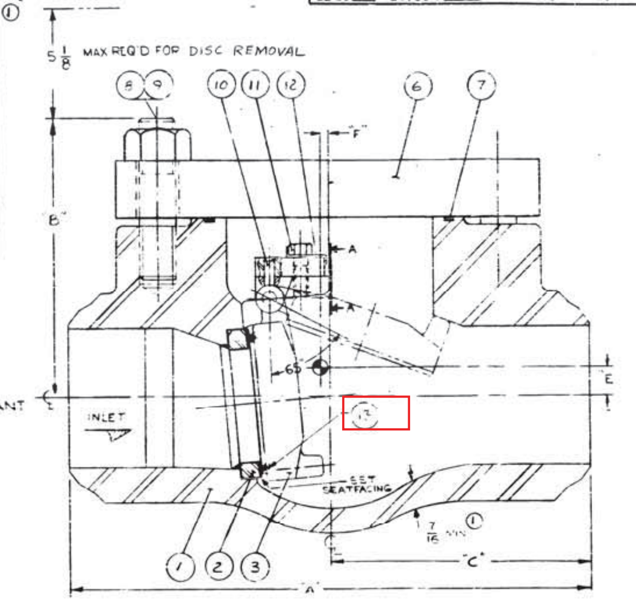
ATWOOD & MORRILL CO INC
SALEM MASS WASHINGTON D C
SERVICE DESIGNATION CL 2 10 ASME SECT III (77) ADDENDA
SIZE 3" STEM 17-4 DISC ETH PRO
SEAT 12-1 A & M ORDER NO 14735-01
47W464-89A 81KA2-827840

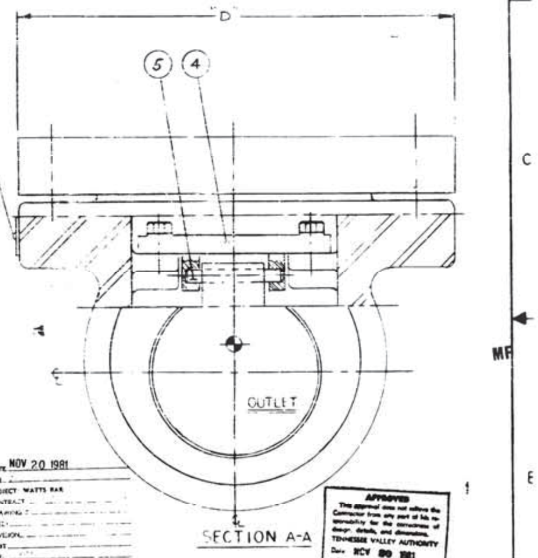


BRACKET CONSTRUCTION FOR 3" VALVES ONLY

REV	ECN NO	REVISION DESCRIPTION	DRAWN	CHK D	CH DR	ENG	Q.C.	MFG ENG
REV 0	—	DRAWN / RELEASED	L.A.P.					
REV 1	—	ADDED LOCATING TO BODY RING REVISED PER CUST COMMENTS DAT 5/26/81	L.A.P. 6.5.81	6-5-81	6-5-81			6/19/81
REV 2	—	ADDED NOTE #5	MJS 6.24.81		6-24-81			
REV 3	—	ADDED SEQUOYAH NOTE	L.A.P. 10.9.81	10-9-81	10-9-81	G.E.C. 9/30/81		10/5/81

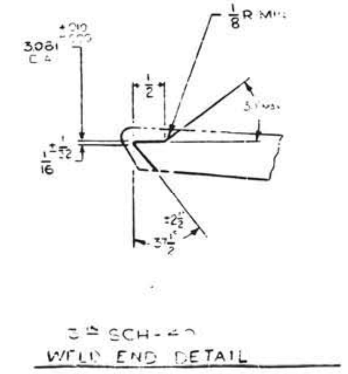
ATWOOD & MORRILL CO INC DESIGN PRESSURE 150 PSI AT 200 °F
MFR'S SERIAL NO
CLASS 2 YEAR BUILT ANSI PRESSURE CL RATING 2 ...





DATE NOV 20 1981
FILE
PROJECT WATTS BAR
CONTRACT
DRAWING
SHOP
REVISION
UNIT
USE

APPROVED
This approval does not relieve the Contractor from any part of his responsibility for the correctness of design, details, and dimensions.
TENNESSEE VALLEY AUTHORITY
Date NOV 20 1981
MECH. ENGR BR BY L. A. CHANDLEY
Rec'd By Lic. E 11-24-81



3" SCH-40
WELD END DETAIL

TABLE OF DIMENSIONS

SIZE	CLASS	WT	A	B	C	D	E	F	PRODUCT CODE
$2\frac{1}{2}$	300	95#	12"	$5\frac{1}{4}$	6"	$9\frac{3}{8}$	$2\frac{1}{8}$	$\frac{1}{16}$	54013-101-6001-214
3"	21	95#	12"	5	6"	$9\frac{3}{8}$	2	$\frac{1}{4}$	
4"	300	110#	13"	6"	$6\frac{1}{2}$	10"	$2\frac{1}{4}$	$\frac{1}{8}$	54013-101-6301-214
6"	300	200#	$15\frac{1}{2}$	$7\frac{1}{2}$	$7\frac{3}{4}$	$12\frac{1}{4}$	$2\frac{1}{8}$	$\frac{3}{16}$	54013-101-6501-214
8"	300	310#	$17\frac{1}{2}$	$9\frac{1}{4}$	$8\frac{3}{4}$	14"	$2\frac{3}{4}$	$\frac{5}{16}$	54013-101-6601-214
10"	300	450#	20"	$10\frac{3}{4}$	10"	$15\frac{3}{8}$	3	$\frac{3}{8}$	54013-101-6701-214
12"	300	[illegible]	$21\frac{1}{2}$	12"	$10\frac{3}{4}$	$17\frac{5}{8}$	3	$\frac{3}{8}$	54013-101-6801-214

①

NOTES

1. VALVE MAY BE INSTALLED IN VERTICAL OR HORIZONTAL PIPE RUN. VALVE TOP COVER MUST BE INSTALLED IN HORIZONTAL POSITION ABOVE THE PIPELINE CENTERLINE OR THE FLOW MUST BE UPWARD.
2. ALL DIMENSIONS ARE REFERENCE EXCEPT AS NOTED
3. CV EQUALS 383 BASED ON WATER [illegible]
4. DESIGN [illegible]
5. COLD WORKING [illegible] 475 PSI [illegible]

THIS PRINT CERTIFIED CORRECT FOR YOUR ORDER:	WHEN WRITING IN REGARD TO THIS EQUIPMENT REFER. TO:
81KA2-827840-2	14735-01

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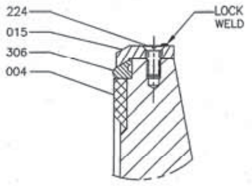
ATWOOD & MORRILL CO INC
SALEM MASS

B/M 15970
SHEET 1 OF 1
14735-01

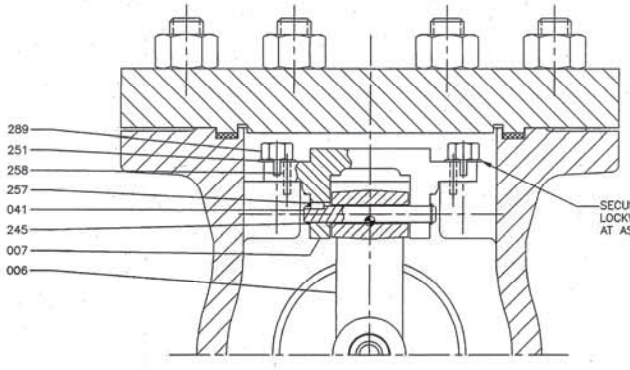
25402-011-V1A-PV00-00198-001

13-103681-001

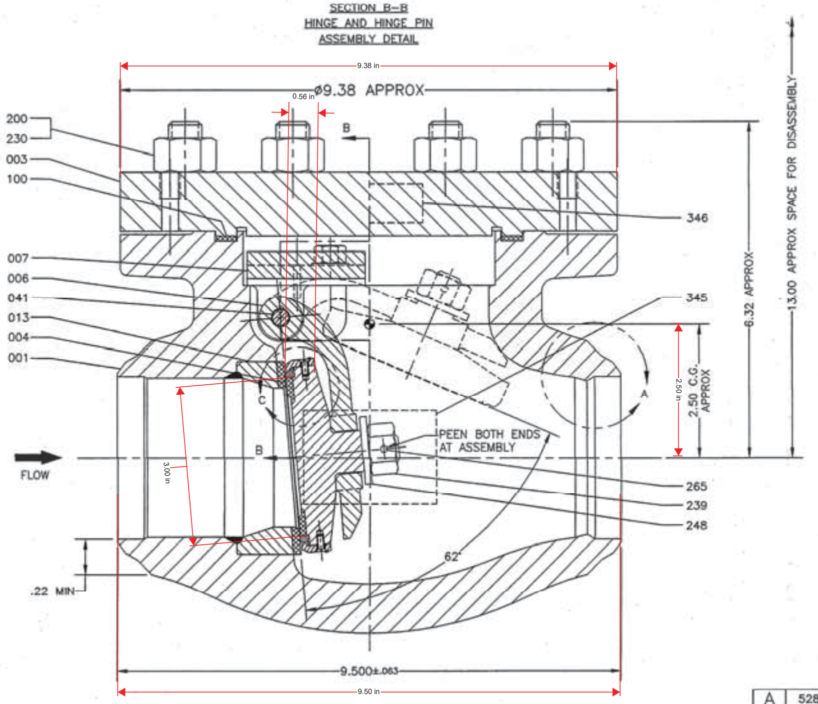
	PART NO	QTY	DESCRIPTION	MATERIAL	MAT'L NOTE
*	001	1	BODY	SA216-WCB	
*	003	1	BONNET CAP	SA516-70	
*	004	1	DISC	SA105 WITH STELLITE#6	
	006	1	HINGE	A216-WCB	
	007	1	HINGE SUPPORT	A216-WCB	
	013	1	SEAT RING	SA105 WITH STELLITE#6	
	015	1	SEAT RETAINER (DISC SEAT)	A479-T316	
	041	1	HINGE PIN	SA564-630-H1150	
△	100	1	GASKET (BONNET)	304SS AND GRAPHITE	4
*	200	8	BONNET STUDS	SA193-B7 W/MANG.PH.COAT .625-11UNC X 3.0	
	224	4	MACHINE SCREWS	AISI 316 #5-40UNC X .25	
*	230	8	BONNET NUTS	SA194-2H W/MANG.PH.COAT .625-11UNC	
	239	1	DISC NUT	A194-8M .50-13UNC	
	245	2	RETAINING RINGS	AISI 632	
	248	1	DISC WASHER	A479-316	
	251	2	WASHERS (TAB LOCK)	AISI 300	
	257	1	PIN (ANTI-ROTATION)	A479-316 .125 DIA X .25	
	258	2	SPRING PINS	AISI 304 .125 DIA X .625	
	265	1	DISC NUT PIN	A479-316 .125 DIA X 1.00	
	289	2	HEX HEAD BOLTS (H SUPP)	A193-B8M-1 .313-18UNC X .875	
△	306	1	RESILIENT SEAT	ETHYLENE-PROPYLENE RUBBER	
	345	1	NAMEPLATE	A167 304	
	346	1	IDENTIFICATION PLATE	A167 304	

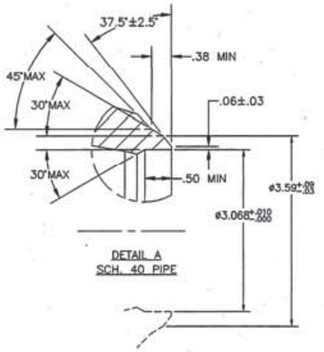


ENLARGED VIEW C
DISC AND SEAT RETAINER
SUBASSEMBLY



SECTION B-B
HINGE AND HINGE PIN
ASSEMBLY DETAIL





DETAIL A
SCH. 40 PIPE

NOTES:

1. APPROX VALVE WEIGHT = 82 LBS.
2. APPROX Cv = 275
3. VALVE TO BE INSTALLED IN HORIZONTAL RUN OF PIPE WITH THE HINGE PIN HORIZONTAL AND BONNET ON TOP OR IN A VERTICAL RUN OF PIPE WITH FLOW UPWARD
4. BONNET GASKET SIZE: 5.00 I.D., 5.75 O.D., .125 THICK
5. * DENOTES PRESSURE RETAINING PARTS
6. △ DENOTES RECOMMENDED SPARE PARTS
7. MEAN SEAT DIAMETER = 3.17
8. MINIMUM RECOMMENDED VELOCITY IS 9.5 FPS

CUSTOMER: TENNESSEE VALLEY AUTHORITY
SITE: WATTS BAR, UNIT 2
CUSTOMER P.O. NO.: 563000
CERTIFIED DESIGN SPECIFICATION: WBNP-DS-501433-0904
TVA MARK NO.: 47W464-A8403
ITEM NO.: CTN492J

BECHTEL POWER CORPORATION — Job Number: 25402
SUPPLIER DOCUMENT REVIEW STATUS

STATUS CODE:
1 ☒ Work may proceed.
1C ☐ Work may proceed. Editorial comments need only be incorporated if revised for other purposes.
2 ☐ Revise and resubmit. Work may proceed subject to incorporation of changes indicated.
3 ☐ Rejected. Revise and resubmit.
4 ☐ Review not required. Work may proceed.

PO 563000

Permission to proceed does not constitute acceptance or approval of design details, calculations, analysis, test methods, or materials developed or selected by the Supplier and does not relieve the Supplier from full compliance with contractual obligations.

Reviewed by	Arch	Civil	CS	Elect	Mech	MET	PD	Constr	Startup	STE
	N/A	←	→	N/A		N/A	←		→	N/A

Status By: Jeff K. Smith JEFF K. Smith
DATE 15 OCT 13

VALVE IS ASME SECTION III, CLASS 2
1971 EDITION. WITH SUMMER 1973 ADDENDA. WITH N-STAMP

VALVE DESIGN PRESSURE IS 200 PSIG AT 250°F
COLD WORKING PRESSURE IS 275 PSIG

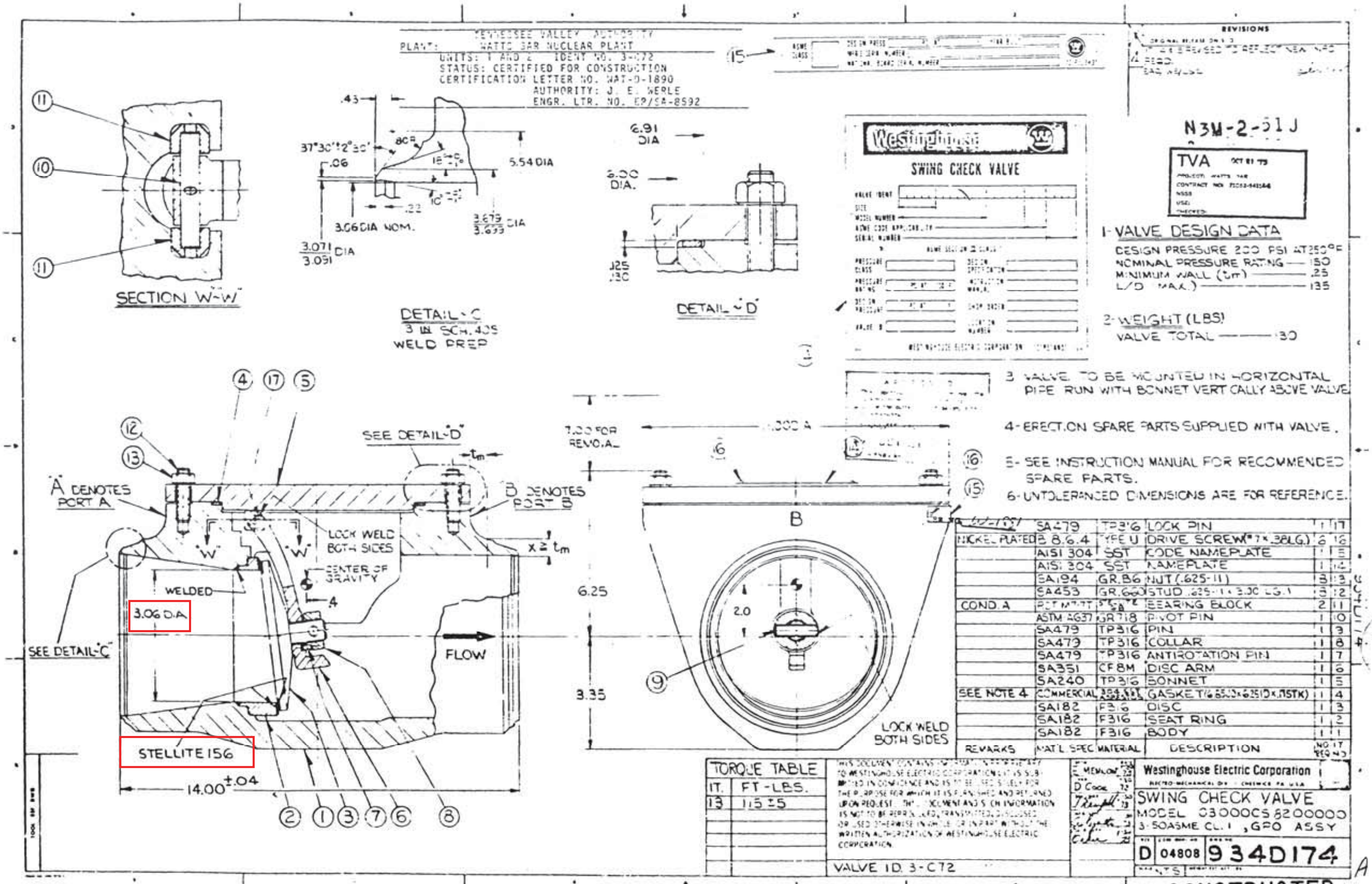
FLOWSERVE
Flow Control Division
Anchor/Darling, BW/IP, Durco and Valtek Valves
RALEIGH, NC

SWING CHECK VALVE
CARBON STEEL, WELD ENDS
WITH RESILIENT SEAT
SIZE: 3 CLASS: 150

REV	ADCN NO.	QAP REV	B/M DATE	DWN / DATE	CHK'D / DATE	APV'D / DATE
A	5286	1	08/01/13	BDK 09/30/13	CMS 10/01/13	JLH 10/9/13
Ø	----	1	08/01/13	BDK 08/27/13	ZJ 08/30/13	JH 08/30/13

REFERENCE DWG:
SCALE: 3/4
SIZE: C
DWG NO: 13-103681-001
REV: A
SHT NO: 1
OF SHTS: 2

TENNESSEE VALLEY AUTHORITY
PLANT: WATTS BAR NUCLEAR PLANT
UNITS: 1 AND 2 IDENT NO. 3-C72
STATUS: CERTIFIED FOR CONSTRUCTION
CERTIFICATION LETTER NO. WAT-D-1890
AUTHORITY: J. E. WERLE
ENGR. LTR. NO. EP/SA-8592



1- VALVE DESIGN DATA
DESIGN PRESSURE 200 PSI AT 250°F
NOMINAL PRESSURE RATING —— 150
MINIMUM WALL (tm) —— .25
L/D (MAX.) —— 135

2- WEIGHT (LBS)
VALVE TOTAL —— 130

3 VALVE TO BE MOUNTED IN HORIZONTAL PIPE RUN WITH BONNET VERTICALLY ABOVE VALVE.

4- ERECTION SPARE PARTS SUPPLIED WITH VALVE.

5- SEE INSTRUCTION MANUAL FOR RECOMMENDED SPARE PARTS.

6- UNTOLERANCED DIMENSIONS ARE FOR REFERENCE.

7- "Valve Installation Acceptance Criteria - 5-degrees maximum Down, 90-degrees maximum Up, 5-degrees maximum Roll"

FCR W-A-161

REMARKS	MAT'L SPEC	MATERIAL	DESCRIPTION	NO REQ'D	IT NO
60-1757	SA479	TP316	LOCK PIN	1	17
NICKEL PLATED	B 8.6.4	TYPE U	DRIVE SCREW(#7×.38LG.)	6	16
	AISI 304	SST	CODE NAMEPLATE	1	15
	AISI 304	SST	NAMEPLATE	1	14
	SA194	GR.B6	NUT(.625-11)	8	13
	SA453	GR.660	STUD (.625-11×3.00 LG.)	8	12
COND. A	PDT M7-77	STELLITE 6B	BEARING BLOCK	2	11
	ASTM A637	GR718	PIVOT PIN	1	10
	SA479	TP316	PIN	1	9
	SA479	TP316	COLLAR	1	8
	SA479	TP316	ANTIROTATION PIN	1	7
	SA351	CF8M	DISC ARM	1	6
	SA240	TP316	BONNET	1	5
SEE NOTE 4	COMMERCIAL	304 SST ASBESTOS	GASKET(6.85OD×6.25ID×.175TK)	1	4
	SA182	F316	DISC	1	3
	SA182	F316	SEAT RING	1	2
	SA182	F316	BODY	1	1

TORQUE TABLE	
IT.	FT-LBS.
13	115±5

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VALVE ID. 3-C72

MEMLOW
D Cook
Tkampf

Westinghouse Electric Corporation
ELECTRO-MECHANICAL DIV. CHESWICK PA U.S.A.

SWING CHECK VALVE
MODEL 03000CS820000O
3-150ASME CL.1, GPO ASSY

D 04808 934D174 A

REV	UNIT	SYS TRANS	ECN/FCR	SUBM	RECM	APPR	DATE	DIST	DATE
A	1	NA	NA	P	Don Perfour		4/1/85	Hesa	4-10-85
Issued to depict as constr. config. EN DES Rev. 4					Update	Paper to Mylar		ACINA2	

AS CONSTRUCTED
UNIT 1 ONLY

HpA
www.hpaec.com

O-ring Seal Design Best Practices

12-15-12
Rev. 1

Table of Contents

1.0 O-RING SEALS – THEORY AND DESIGN PRACTICES

Theory:

An o-ring seal consists of an o-ring and a properly designed gland which applies a predictable deformation to the o-ring. The gland is basically a groove dimensioned to a certain height “H” and width “W” (Figure 1) to allow a fixed compression of the o-ring when the gland flanges make metal to metal contact. It is also oversized volumetrically such to allow accommodation of the o-ring as it flows under compression. Unlike gaskets which seal just by the resiliency of the material under mechanical compression of the joint, an o-ring can provide a seal both through the resiliency of the pre-compressed material and the pressure activation of the seal. The pre-compression of the o-ring applies a calculated mechanical contact stress or pressure at the o-ring contacting surfaces in the gland. As the o-ring seal is pressurized or “activated” the pressure on the o-ring further increases the contact stress on the o-ring contacting surfaces of the gland as the o-ring moves or “flows” toward the low pressure side. This means the pressure of the contained fluid transfers through the essentially incompressible o-ring material, and the contact stress rises with increasing pressure. As long as the pressure of the fluid does not exceed the contact stress of the o-ring, leakage should not occur.

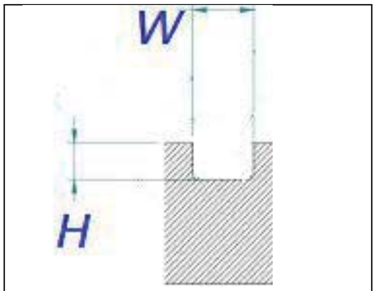


Figure 1 - O-Ring Groove Dimensions

At zero gauge pressure, only the pre-compressed resiliency of the o-ring provides the seal (see Figure 2). If the system pressure is in the range of 0 - 100 or even to 400 pounds per square inch (psi) it can be considered as low pressure (in this paper 400 psi or less is considered low pressure), and the seal is maintained predominantly by the pre-compression or “squeeze” on the o-ring and its resulting contact stress. As the pressure increases, the o-ring is forced to the low pressure side of the gland. This provides an additional increase in contact stress as the o-ring deforms to a “D” shape (see Figure 3) and the contact area of sealing under pressure increases to almost twice the original zero-pressure area. For this reason, an o-ring can easily seal a high pressure as long as it does not mechanically fail.

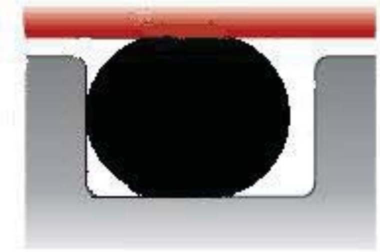


Figure 2 - O-ring un-pressurized

Figure 3 - O-ring with high pressure

Best Design Practices:

a. The flexible nature of o-ring materials accommodates imperfections and/or waviness in the gland parts. But it is still important to maintain a good surface finish of those mating parts. The following best practices are suggested: 32 micro-inch finish on the contact surfaces (top of gland and bottom or groove); 63 micro-inch finish on the sides of the groove; machined radii in bottom of groove of 1/32" (reference 2); holding waviness of groove bottom to less than 2% of o-ring thickness per 12" length of groove.

Figure 4 shows a poor surface finish and affect the tool mark direction. Such a finish can cause leaks.

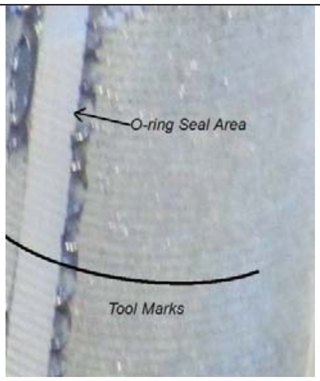


Figure 4 - Surface Finish Can Cause Leaks

b. As for o-ring compression or "squeeze" it is a result of three factors: the force to compress the o-ring, durometer, and cross section thickness. A 15-20% compression for dynamic (moving) applications (to mitigate wear) and 35-40% for static applications (reference 3) is generally suggested. Whereas, reference 2 (Parker) recommends 16% for dynamic applications and 30% for static. However, analysis and testing of the application will determine the ultimate compression. Compression % is defined as the deflection of the seal divided by the cross-section thickness (cord diameter) and the results times 100.

c. The rigidity of the gland closure and closure bolting spacing must be adequate to compress the o-ring without deflecting. Any deflection will reduce the design compression of the seal.

d. The area of the cross-section of the gland should be in the range of 15 to 40% greater than the area of the cross-section of the o-ring. A 75% fill is suggested which leaves 25% empty space in the gland groove (reference 2). However, it is very important that the installed o-ring contact the low pressure side of the gland groove (see Figure 1 in Appendix) such that the o-ring only has to move very little when pressurized or “activated”.

e. For o-ring gland grooves that are non-circular, the groove turn radii in rectangular and square layout (i.e. the corners), must be large enough so the o-ring will not kink and such that the o-ring will fully contact the low pressure side of the groove (Figure 5 shows an example of too sharp of a corner in the o-ring groove). Otherwise, the small radius turn may impede any “activation” of the seal. For example, the radius in the corners of an o-ring groove layout is suggested to be at least 2 inches for a ¼” (0.275”) nominal diameter o-ring stock, or 7 to 8 times the o-ring diameter. Fabricate the o-ring to snugly fit the low pressure side of the gland groove all the way around including the corner radii.

Figure 5 - Too Sharp of Corner

f. It is important not to stretch the o-ring since stretch affects seal compression by reducing cross section, which reduces the sealing potential of the o-ring. A stretch greater than 5% on the o-ring I.D. (equivalent ID in non-circular case) is not recommended because it can lead to a loss of seal compression (reference 3).

g. When sizing an o-ring, choose the largest cross-section thickness as practical. The larger the cross-section, the more effective the sealing and longer the life of the seal. However, with a dynamic application in which friction is a factor, a compromise will be required.

h. A 70 durometer (shore A) hardness should be used in the design whenever possible since it usually has the best combination of properties for most applications. It provides good conformability versus a mid-range contact stress capability (see Graph 1). It is also considered the standard o-ring hardness and is readily available from suppliers.

i. A lubricant compatible with the o-ring material should be applied to the o-ring as it is installed to decrease friction and assist in the “activation” of the seal under pressure.

j. O-ring re-use: reusing an o-ring in an assembly after some time in service is generally not recommended. Is the o-ring deformed, cracked, harder than when new, discolored, or less than clean? When in doubt, change out.

2.0 ANALYSIS OF O-RING SEAL DESIGNS

The maximum sealing capability of high pressure o-ring seal designs is dependent on seal "activation" as discussed earlier and is not solely dependent on the initial contact pressure as determined by the compression of the seal in its housing (groove). However for low pressure designs, an analysis of the contact stress makes it possible to better predict the success of the seal while assuming no "activation" of seal. Two methods are presented below:

Parker Method:
As an example referring to the "Parker O-ring Handbook, Figures 2-8" (reference 2) , below is an analysis of a ¼" o-ring design, Shore A durometer, with 20% compression:

For a 20% compression on a ¼ inch nominal o-ring, , the compression load per linear inch of the seal is at around 35 pounds from the Parker Figures. Referring to the paper "O-rings for Low Pressure Service", (reference 1), the contact area "b" per linear inch of seal is estimated by b=2.4x, where x is the deflection of the o-ring cross-section. Therefore, the contact area per inch is (2.4) (.20)(.275) = .132 square inch. The contact stress "S_{max}" per linear inch just from pre-compressed resiliency of the seal is 35 pounds divided by .132 square inches yielding 265 psi. This means, in theory with all things being perfect, the seal should not leak until the pressure exceeds 265 psig, as a minimum.

Lindly Method:
As an example using Lindly's analysis as referred to in reference 4, below is an analysis of a ¼" o-ring design, Shore A durometer, with 20% compression:

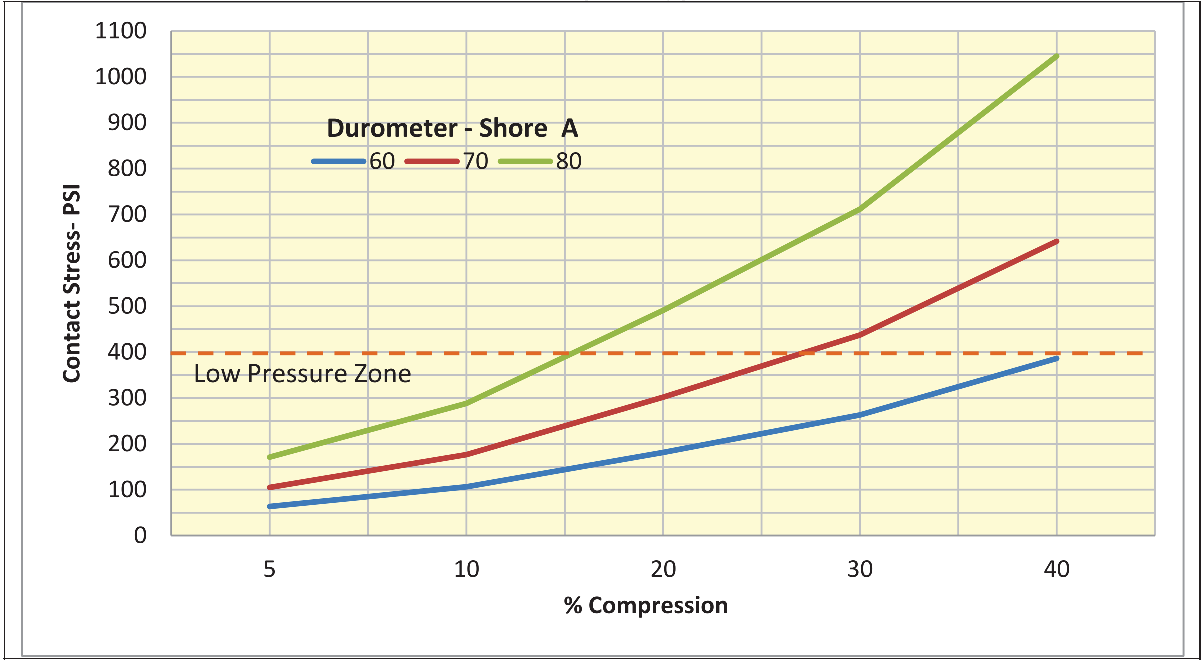
Lindly derived the equation below for predicting the contact stress "S_{max}" with respect to the modulus of elasticity "E" (E can be derived from Shore A durometer):

S_{max}=E $(0.849(1.25\delta^{1.5} + 50\delta^{6}))^{0.5}$
where: S_{max} = contact stress psi, δ = fractional compression, (20% = 0.2), E= modulus of elasticity (which can be found in reference 1, of E versus Shore A durometer; 60 = 630 psi, 70= 1,040 psi, 80 = 1,705 psi)

S_{max} is plotted in Graph 1 for Shore A durometer 60, 70, and 80. The Lindly Method gives a higher contact stress than the Parker, however, due to the simplicity of use, the Lindly Method is the preferred method.

Calculating contact stress is only a starting point in the seal design for determining the minimum required compression, however, with variables in the "less than perfect" sealing system, a margin above that is prudent, so it is suggested to follow the best practices in Section 1.0 in order to achieve a successful seal.

Graph 1 - Contact Stress vs. Compression (Lindly)



3.0 APPENDIX

References:

1. Hertz,D.L.,1979, "O-Rings for Low Pressure Service", Machine Design, 4/12/79, pp.94-98 (note, paper applies mainly to dynamic applications)
2. Parker Hannifin Corporation, O-Ring Handbook, Catalog ORD 5700A/US
3. Apple Rubber Products Inc.,www.applerubber.com
4. Green, Itzhak and English, Capel, “Stresses and Deformation of Compressed Elastomeric O-Ring Seals”

Local Leak Rate Test Leakage Evaluation at Watts Bar for Lift/Piston Check Valves

Document No. 3960C, Rev. 0, Attachment 4

Prepared for

Watts Bar Nuclear Station
Tennessee Valley Authority
Spring City, TN

Prepared by	*Verified by*
Sandhya	Mital Mistry 16 Sept. 2020
Sandhya Shankar, P.E.	Mital Mistry, Date

QA Approval by

Fabiola Rico Sept. 16, 2020

Fabiola Rico, Date

KEI File No.263.92.1
Client Purchase Order No. 6232543, Rev. 0
Date of Preparation: September 15, 2020

---Non-Proprietary Version---

Revisions

Rev. No.	**DCR/N No.**	**Description of Changes**	**Pages Affected**
0	N/A	Initial release	All

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Description	**Pages**
Main Text	29
Appendix A	66
Total Pages	95

List of Tables

List of Figures

1

OBJECTIVE AND SCOPE

1.1 OBJECTIVE

Kalsi Engineering, Inc. (KEI) has been contracted by Tennessee Valley Authority (TVA) to provide engineering services to evaluate the impact of local leak rate test (LLRT) pressures higher than the calculated peak containment internal pressure related to the design-basis loss-of-coolant accident (LOCA), Pa, for cases where higher test pressure tends to increase the sealing force. This work is being done in accordance with the scope defined in Purchase Order No. 6232543 [2][1].

The objective of this report is to determine the impact of the reduced LLRT pressure from DP_{test} to Pa on the seat leakage. All work performed under this project was done in accordance with the requirements of the KEI Quality Assurance Program [1], which meets the intent of 10CFR50 Appendix B requirements.

1.2 SCOPE

The scope of this attachment is LLRT lift and piston check valves. Valve IDs and basic information are shown below in Table 1-1. Group 61-1 and 67-1 have the same check valve as can be seen from the drawing number in Table 1-1. Hence, they will be treated identical for this assessment. Group 31-1 and Group 67-3 have identical disc, seat and spring part numbers as seen from the drawings [3a] and [3g] respectively. They will have similar seat sealing characteristics and are treated as identical valve for this assessment. Drawing for Group 32-2 [3b] shows metal seated configuration and an alternate soft seat assembly. All the valves in the Group 32-2 (both Unit 1 and Unit 2) have soft seat assembly per TVA documentation [12].

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[1] The number in [] indicates reference number documented in Section 6.

Table 1-1: Analysis Scope

Group	Seat Type	Vendor Dwg. No.	Component ID	Comp Description	Manufacturer
31-1	SOFT	TVSW-30604GS-(2)	2-CKV-31-3378	INCORE INSTR RM AHU 2B CWS LEAK RATE CHECK	F990/FLOWSERVE CORPORATION
			2-CKV-31-3392	INCORE INSTR RM AHU 2B CWR LEAK RATE CHECK	
			2-CKV-31-3407	INCORE INSTR RM AHU 2A CWS LEAK RATE CHECK	
			2-CKV-31-3421	INCORE INSTR RM AHU 2A CWR LEAK RATE CHECK	
32-2	SOFT[2]	TVD-D-9911-(2)	1-CKV-32-293	CONTROL AIR CNTMT CHECK	K085/KEROTEST
			1-CKV-32-303	ESSENT CNTL AIR CNTMT CHECK	
			1-CKV-32-313		
			2-CKV-32-323	ESSENT CNTL AIR CNTMT CHECK	
			2-CKV-32-333	ESSENT CNTL AIR CNTMT CHECK	
			2-CKV-32-343	CONTROL AIR CNTMT CHECK	
43-1	SOFT	N89-180	1-CKV-43-834	PAS WASTE TO CNTMT SUMP CHECK	CIRCLE SEALS
			1-CKV-43-841		
			1-CKV-43-883	PAS CONTAINMENT AIR RETURN CHECK	
			1-CKV-43-884		
61-1	SOFT	W9825144	1-CKV-61-533	GLYCOL SUPPLY HEADER BYPASS CHECK	Flowserve/A391/ANCHOR-DARLING
			1-CKV-61-680	GLYCOL RETURN HEADER BYPASS CHECK	
			1-CKV-61-692	GLYCOL COOLED FLOOR SUPPLY BYPASS CHECK	
			1-CKV-61-745	GLYCOL COOLED FLOOR RETURN BYPASS CHECK	
			2-CKV-61-533	GLYCOL SUPPLY HEADER BYPASS CHECK	
			2-CKV-61-680	GLYCOL RETURN HEADER BYPASS CHECK	

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[2] See Reference [12]

Group	Seat Type	Vendor Dwg. No.	Component ID	Comp Description	Manufacturer
			2-CKV-61-692	GLYCOL COOLED FLOOR SUPPLY BYPASS CHECK	
			2-CKV-61-745	GLYCOL COOLED FLOOR RETURN BYPASS CHECK	
62-4	HARD	TVD-D-9556-(2)	1-CKV-62-639	CVCS SEAL **WTR** 1-FCV-62-61 EQL CHECK	K085/KEROTEST
			2-CKV-62-639	CVCS SEAL WTR 2-FCV-62-61 EQL CHECK	
63-1	SOFT	TVW1-30608GS-(2)	1-CKV-63-868	1-CKV-63-868 CONTAINMENT N2 HEADER CHECK	K085/KEROTEST MANUFACTURING CORP.
			2-CKV-63-868	2-CKV-63-868 CONTAINMENT N2 HEADER CHECK	
67-1	SOFT	W9825144	1-CKV-67-575A	1-FCV-67-87 BYPASS CHECK	ANCHOR-DARLING
			1-CKV-67-575B	1-FCV-67-103 BYPASS CHECK	
			1-CKV-67-575C	1-FCV-67-95 BYPASS CHECK	
			1-CKV-67-575D	1-FCV-67-111 BYPASS CHECK	
			2-CKV-67-575A	2-FCV-67-87 BYPASS CHECK	
			2-CKV-67-575B	2-FCV-67-103 BYPASS CHECK	
			2-CKV-67-575C	2-FCV-67-95 BYPASS CHECK	
			2-CKV-67-575D	2-FCV-67-111 BYPASS CHECK	
67-3	SOFT	72576978	1-CKV-67-585A	1-FCV-67-295 BYPASS CHECK	FLOWSERVE CORPORATION
			1-CKV-67-585B	1-FCV-67-297 BYPASS CHECK	
			1-CKV-67-585C	1-FCV-67-296 BYPASS CHECK	
			1-CKV-67-585D	1-FCV-67-298 BYPASS CHECK	
			2-CKV-67-585A	2-FCV-67-295 BYPASS CHECK	
			2-CKV-67-585B	2-FCV-67-297 BYPASS CHECK	
			2-CKV-67-585C	2-FCV-67-296 BYPASS CHECK	
			2-CKV-67-585D	2-FCV-67-298 BYPASS CHECK	

Group	Seat Type	Vendor Dwg. No.	Component ID	Comp Description	Manufacturer
68-1	SOFT	TVA-30508GLS-(2)	1-CKV-68-849	PRESSURIZER RELIEF TANK N2 SUP HDR CHECK	K085/KEROTEST
			2-CKV-68-849	PRESSURIZER RELIEF TANK N2 SUP HDR CHECK	

1.3 HISTORICAL LEAKAGE

Reference 4 and Reference 15 provide the LLRT history for the Unit 1 and Unit 2 check valves respectively. Table 1-2 summarizes the results of the tests.

Table 1-2: Leakage History of Valves in Unit 1 and Unit 2

Group	Seat Type	Vendor Dwg. No.	Component ID	Leakage history
31-1	SOFT	TVSW-30604GS-(2)	2-CKV-31-3378	Unfavorable
			2-CKV-31-3392	Unfavorable
			2-CKV-31-3407	Favorable
			2-CKV-31-3421	Favorable
32-2	SOFT	TVD-D-9911-(2)	1-CKV-32-293	Favorable
			1-CKV-32-303	Favorable
			1-CKV-32-313	Favorable
			2-CKV-32-323	Favorable
			2-CKV-32-333	Favorable
			2-CKV-32-343	Favorable
43-1	SOFT	N89-180	1-CKV-43-834	Favorable
			1-CKV-43-841	Favorable
			1-CKV-43-883	Favorable
			1-CKV-43-884	Favorable
61-1	SOFT	W9825144	1-CKV-61-533	Favorable
			1-CKV-61-680	Favorable
			1-CKV-61-692	Favorable
			1-CKV-61-745	Favorable
			2-CKV-61-533	Favorable
			2-CKV-61-680	Favorable
			2-CKV-61-692	Favorable
			2-CKV-61-745	Favorable
62-4	HARD	TVD-D-9556-(2)	1-CKV-62-639	Unfavorable
			2-CKV-62-639	Favorable
63-1	SOFT	TVW1-30608GS-(2)	1-CKV-63-868	Favorable
			2-CKV-63-868	Favorable
67-1	SOFT	W9825144	1-CKV-67-575A	Favorable

Group	Seat Type	Vendor Dwg. No.	Component ID	Leakage history
			1-CKV-67-575B	Favorable
			1-CKV-67-575C	Favorable
			1-CKV-67-575D	Unfavorable
			2-CKV-67-575A	Favorable
			2-CKV-67-575B	Favorable
			2-CKV-67-575C	Favorable
			2-CKV-67-575D	Favorable
67-3	SOFT	72576978	1-CKV-67-585A	Favorable
			1-CKV-67-585B	Favorable
			1-CKV-67-585C	Favorable
			1-CKV-67-585D	Favorable
			2-CKV-67-585A	Favorable
			2-CKV-67-585B	Favorable
			2-CKV-67-585C	Favorable
			2-CKV-67-585D	Favorable
68-1	SOFT	TVA-30508GLS-(2)	1-CKV-68-849	Favorable
			2-CKV-68-849	Favorable

2

METHODOLOGY

2.1 VARIABLES

Variable	Description	Units
A_o	Area based on mean seat diameter $= \frac{\pi}{4} \cdot d_m^2$	in^2
A_s	Nominal seat contact area for metal seated check valve	in^2
A_{hs}	[redacted]	in^2
A_I	Percentage increase in leakage flow area when pressure reduces from DP_{test} to P_a	%
A_{asp}	[redacted]	%
C_L	Seat leakage coefficient proportionality constant	
d_m	Mean seat contact diameter	in
d_r	Maximum Cross section diameter of O-ring	in
d_a	[redacted]	in
DP	Difference between upstream and downstream pressure	psi
DP_{test}	Bounding LLRT test differential pressure	psig
E_s	Elastic modulus of O-ring material	psi
E	Elastic modulus of disc/seat material	psi
F_S	Sealing load due to differential pressure	lbf
F_{S_DP}	Sealing load due to differential pressure at DP_{test}	lbf
F_{S_Pa}	Sealing load due to differential pressure at P_a	lbf
F_{S_Total}	Total sealing load at DP_{test}	lbf
F_{spring}	Sealing load due to spring	lbf
$F_{S\_Total\_red}$	Reduced total sealing load at P_a	lbf
F_{hs}	[redacted]	lbf
h_a	[redacted]	in
h_{a_DPtest}	[redacted]	in
h_{a_Pa}	[redacted]	in
Δh_a	[redacted]	in
N_{hs}	[redacted]	
P_a	Calculated peak containment internal pressure related to the design-basis loss-of-coolant accident (LOCA)	psig
P_{cr}	Check valve cracking pressure	psi

S_{max}	Peak seat contact stress	psi
t	Seat contact band width of lift check valve	in
R	Percentage reduction in sealing load due to Pa vs. test DP	%
R_P	Percentage reduction of sealing load due to differential pressure	%
x	O-ring compressive displacement	in
σ	Average seat contact stresses	psi
σ_{DPtest}	Average seat contact stress at DP_{test}	psi
σ_{Pa}	Average seat contact stress at Pa	psi
δ	O-ring normalized squeeze	

2.2 TOTAL SEALING LOAD AND CONTACT STRESS

The lift check valves also known as globe check valves are analyzed in this attachment. They rely on the spring force, weight, and differential pressure of the fluid to provide seal.

During LLRT, sealing load includes differential pressure force, F_S, spring force, F_{spring}, and force due to the disc weight. All three force components are assisting the sealing action. Differential pressure load is proportional to the DP and the area over which the DP acts. The spring force is calculated using the cracking pressure of the valve. The weight of the disc assembly will be very small compared to the DP force and is excluded from the total sealing load which is conservative.

This assessment includes two types of lift check valves, 1) inline check valve (Figure 2-1) and 2) piston check valve (Figure 2-2).

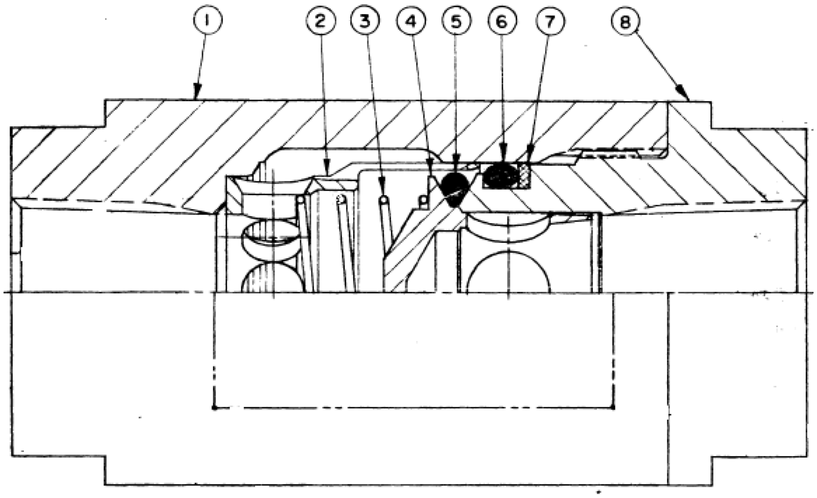

Figure 2-1: Inline Check Valve [3c]

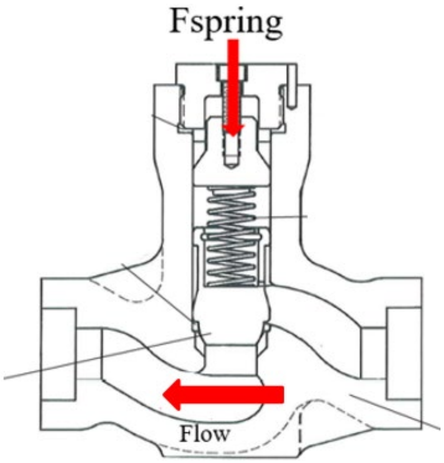

Figure 2-2: Piston Check Valve [13]

2.2.1 Calculation Approach for Piston Check Valve with Soft Seat

The piston check valve in Groups 32-2, 61-1, 67-1, 31-1, 67-3, 63-1 and 68-1 have soft seated elastomeric insert installed on the disc. The soft seat on these valves is installed in two different ways on the disc as shown in Figure 2-3.

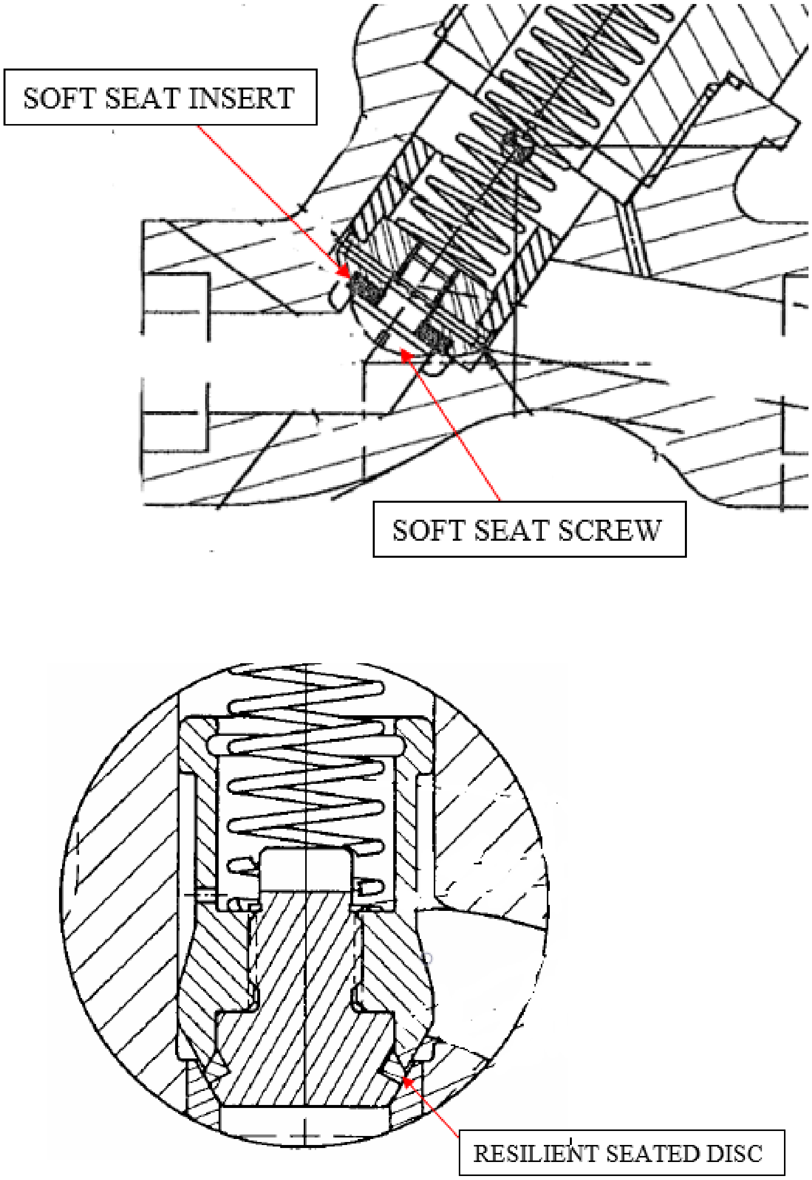

Figure 2-3: Piston Check Valve with Soft Seat Insert with Screw [3a] and Resilient Seated Disc [3d]

Initial contact develops between the seat and the elastomeric insert as the disc contacts the seat. The contact between the elastomeric insert and the seat will develop contact stresses. The contact stresses higher than the fluid differential pressure will ensure a positive sealing margin. The following calculations determines the seat contact stress for these valves.

The spring force acting on the seat assist the sealing load and is calculated using the check valve cracking pressure and the mean seat contact diameter.

$$F_{spring} = P_{cr} * A_o \tag{1}$$

Where,

$$A_o = \frac{\pi * d_m^2}{4}$$

The differential pressure acts normal to the valve disk surface and produces a sealing force equal to the differential pressure (DP) times the area over which the DP acts. The area defined by the seat contact diameter is used for the area over which the DP acts. The DP induced sealing force is given by Equation 2.

$$F_s = A_o \cdot DP \tag{2}$$

Total seat load is equal to the sum of the spring force and the force due to differential pressure acting on the seat.

$$F_{S\_Total} = F_s + F_{spring} \tag{3}$$

Under zero pressure condition, the soft insert and the metal seat develops a contact due to the spring force. As the differential pressure is applied across the valve, the contact width between the soft insert and the metal seat grows. The seat contact width is used for calculating the seat contact area. A larger seat contact width will develop lower average seat contact stresses. The average seat contact stress is calculated using Equation 4.

$$\sigma = \frac{F_{S\_Total}}{\pi * t * d_m} \tag{4}$$

It is assumed that the seat contact width will stay constant when the differential pressure changes from 16.5 psi to 9 psi. This is a conservative assumption because any decrease in the seat contact width will increase the seat contact stress per Equation 4. Therefore, this assumption does not require a verification.

The percentage reduction in total sealing load, R, due to reduction in pressure from DP_{test} to P_a is determined using Equation 5.

$$R = \frac{F_{S\_DP} - F_{S\_Pa}}{F_{S\_Total}} .100 \tag{5}$$

2.2.2 Calculation Approach for Piston Check Valve with Metal Seat

The piston check valves in Group 62-4 have metal seated disc. The sealing load in a metal-seated piston check valve, without any spring load or disc weight, is equal to the differential pressure force, F_S acting on the disc. F_S is equal to the DP times the area over which the DP acts as shown in Equation 2.

The area over which DP acts, A_o, is function of the geometry of the disc and seat and remains the same for all DP. Therefore, the percentage reduction in the sealing load, R_P, when the differential pressure reduces from DP_{test} to P_a is equal to the percentage reduction in the pressure which is given by:

$$R_P = \frac{DP_{test} - P_a}{DP_{test}} \cdot 100 = \frac{16.5 - 9.0}{16.5} \cdot 100 = 45.5\% \qquad (6)$$

Unlike the soft-seated piston check valves, a tight sealing of a metal-seated valve requires yielding of one material into the surface "waviness" and surface roughness of the other to block direct leakage paths. Even, seemingly smooth machined surfaces have surface asperities as illustrated in Figure 2-4. When the two surfaces contact each other, the surface asperities initially establish the contact. With an increasing load, the asperities initially deform elastically and then plastically. To ensure a reliable seal, the surface asperities within the contact band need to deform plastically over a reasonable amount of bandwidth. At low pressures, the seat load will not be sufficient to plastically yield the asperities on the contacting surfaces and therefore, the asperities will deform elastically. Due to the fact that these valves were providing a reliable sealing at DP_{test} pressure, the leak path at this pressure will have a very high flow resistance. Any reduction in the seat load will decrease the flow resistance by increasing the leakage flow area, A_I, due [redacted] As shown in Equation 6, the seat load will decrease by 45.5% when the pressure reduces from the DP_{test} of 16.5 psig to P_a of 9.0 psig. The reduction in the seat load will reduce the leak path flow resistance. A reduction in the flow resistance is equivalent to an increase in the leakage coefficient, C_L. Based on Equation 3-3 in Section 3.2 of the main report, the C_L can increase by 35% before the measured leakage at pressure P_a would increase from the measured leakage at DP_{test}.

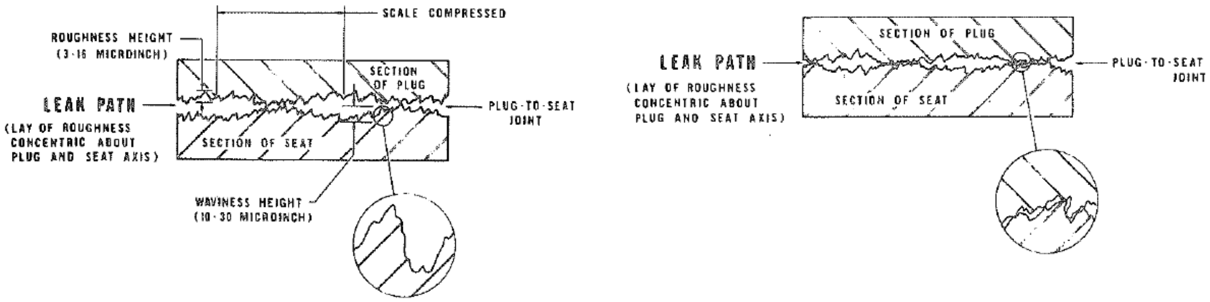

Figure 2-4: **Mating of Seat Joint Surface**

A calculation has been performed to estimate an increase in the leakage flow area, A_I, when the pressure is reduced from DP_{test} to P_a. The calculation is based on a simplified but conservative assumption (Assumptions 6 to 10 in Section 4) of a leak flow area developed by surface asperities (high spots) on the disc/seat surfaces that comes in contact when the piston check valve disc closes. The idea behind this calculation is to determine the effect of the seat load change on [redacted]

Figure 2-5: Surface Asperities (High Spot) on a Seat Contact Band

[redacted]

The percentage increase in leakage flow area, A_I, is calculated using Equation 7. [redacted].

[redacted] (7)

Where,

[redacted] (8)

[redacted] (9)

[redacted]

[redacted] (10)

Where,

[redacted] (11)

[redacted] (12)

[redacted] (13)

[redacted] (14)

Table 5-2 documents the percentage increase in the leakage flow area, A_I which is based on the design inputs in Section 3.1.5 and Assumptions 6 to 10 in Section 4.

2.2.3 Calculation Approach for Inline Check Valve

The inline check valve in Group 43-1 is shown in Figure 2-1. Figure 2-1 [3c] shows that an O-ring (Item 5) provides the primary seal at low pressures. This O-ring is installed on the poppet (Item 4). When the valve closes, the O-ring (Item 5) gets squeezed between the poppet (Item 4) and end (Item 8) providing a primary seal at low pressures. Theoretically, the peak seat contact stress, S_{max}, higher than the fluid differential pressure will ensure a positive sealing margin. The peak seat contact stress is calculated using Equation 15 [8] which depend on the amount of O-ring compressive displacement, x, and the modulus of elasticity, E_s.

$$S_{max} = E_s * \left[\frac{16}{6\pi} * (1.25 * \delta^{1.5} + 50 * \delta^6)\right]^{\frac{1}{2}} \qquad (15)$$

In the above equation, E_s is the elastic modulus and is a function of the Shore A hardness of the O-ring material. The normalized squeeze, δ, which is a ratio of compressive displacement, x, and the O-ring cross section diameter, d_r, is given by Equation 16 [8].

$$\delta = \frac{x}{d_r} \qquad (16)$$

3

INPUTS

3.1 CALCULATION INPUTS

The input data for the analyses are documented in this section and were obtained from calculations, drawings, specifications, and other information provided by TVA. Inputs that require additional clarification are documented below, if applicable. Justified assumptions were made where data were not available. It is important to note that the results of this analysis may be significantly affected by changing key inputs. It will be necessary to perform an impact analysis if key data are changed in the future.

Table 3-1: Common Input Data

Item	Variable	Value	Reference
Area based on mean seat diameter	A_o	Calculated	
LLRT test differential pressure, psi	DP_{test}	16.5	See 3.1.1
Calculated peak containment internal pressure related to the design-basis loss-of-coolant accident (LOCA)	Pa	9.0	See 3.1.1

3.1.1 LLTR Test Pressure and Adjusted Maximum Containment Design Pressure

The maximum permissible LLRT test pressure is 1.1 x 15= 16.5 psig [9, 14]. P_a for Watts Bar is 9.36 psig [9]. For purposes of this analysis, a lower and more conservative value of 9 psig is used.

3.1.2 Mean Seat Contact Diameter and Minimum Valve Cracking Pressure

The mean seat contact diameter are provided by TVA [11] which are documented in Table 3-2. The mean seat diameter for Groups 31-1 and 67-3 is not available. The mean seat diameter is assumed to be equal to the valve flow bore diameter which is 0.625 inch [3a]. The valve flow bore diameter looks larger than the mean seat diameter [3a]. A larger mean seat diameter will develop lower average seat contact stresses which is conservative. Therefore, this assumption does not require a verification.

The cracking pressure are provided by TVA [11] which are documented in Table 3-2. The minimum cracking pressure for Groups 32-2, 67-3, and 31-1 are not available. For conservatism, the minimum cracking pressure for these valves is set to zero. This means the spring force for these valves is not included in the average seat contact stress calculation. The check valve in Group 68-1 does not have a spring in the assembly as shown in the Reference 3h, therefore, the valve cracking pressure is set to zero.

3.1.3 Seat Contact Width for Piston Check Valves with Soft Seat

The seat contact width, between the elastomeric insert of the disc and the metal seat, for the valve Groups 61-1 and 67-1 is 0.06 inches based on the scaling from Reference 3e which is equal to 6% of the mean seat diameter. The scaling of seat contact width is not possible for the valves in Groups 31-1 and 67-3 [3a], 63-1 [3f], 32-2 [3b], and 68-1 [3h]. The seat contact width for the valves in these groups is assumed to be equal to 10% of the mean seat contact diameter but no larger than 1/8 inches. The seat contact width does not vary proportionally with the mean seat contact diameter. Typically, the seat contact width is smaller than 0.10 inches. A larger seat contact width will provide lower average seat contact stresses. Therefore, the assumption of upper bound seat contact width of 0.125 inches is conservative and it does not require verification.

The mean seat contact diameter, minimum valve cracking pressure, and seat contact width are summarized in Table 3-2.

Table 3-2: Mean Seat Contact Diameter, Minimum Valve Cracking Pressure, and Seat Contact Width

Group	Mean Seat Contact Diameter (d_m), in	Minimum Valve Cracking Pressure (P_{cr}), psi	Seat contact width (t), in
32-2	2.500	0	0.125
61-1/67-1	1.000	5	0.060
63-1	0.750[3]	2	0.075
67-3/31-1	0.625	0	0.063
68-1	1.375	0	0.125

3.1.4 Design Input for Inline Check Valve Group 43-1

The O-ring part number used in this inline check valve per Reference 3d is AS568-211. The cross-section diameter for the O-ring size 211 is 0.139±.004 inch [6]. The durometer hardness of the O-

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[3] Table in Reference 11 shows 1.0" for d_m and email dated 07/31/2020 states this is equal to 0.75". Therefore 0.75" is considered as mean seat contact diameter for conservatism.

ring is not known but typically an O-ring with a Shore A Hardness of 70-durometer that has approximate room temperature elastic modulus of 1040 psi [7] is used in such applications. A softer O-ring with a lower elastic modulus will provide a conservative peak seat contact stress; therefore, the O-ring Shore A Hardness of 60-durometer with the elastic modulus of 630 psi [7] is used in this analysis.

3.1.5 Design Input for Metal-Seated Check Valves Group 62-4

The mean seat contact diameter for the group 62-4 per Reference [11] is equal to 1.375 inches.

4

ASSUMPTIONS

Data that have not been formally verified are treated as assumptions. Where possible, the basis of the data has been noted. The following general assumptions were used in this analysis.

1. It is assumed that the seat contact width will stay constant when the differential pressure changes from 16.5 psi to 9 psi. This is a conservative assumption because any decrease in the seat contact width will increase the seat contact stress per Equation 4. Therefore, this assumption does not require a verification.
2. The seat contact width for the valves in Groups 31-1, 67-3, 63-1, 32-2, and 68-1 is assumed to be equal to 10% of the mean seat contact diameter but no larger than 1/8 inches (see Table 3-2). The seat contact width does not vary proportionally with the mean seat contact diameter. Typically, the seat contact width is smaller than 0.10 inches. A larger seat contact width will provide lower average seat contact stresses. Therefore, the assumption of upper bound seat contact width of 0.125 inches is conservative and it does not require verification.
3. The disc weight induced seat load component will be small compared to the DP induced seat load and is excluded from the total seat load calculation. Not including the disc weight induced seat load in the total seat load calculation will increase the percentage reduction in the total seat load when pressure reduced from 16.5 psi to 9.0 psi. Therefore, this is a conservative assumption and does not require verification.
4. The minimum cracking pressure of 0 psi is assumed for valves in Groups 32-2, 67-3, and 31-1. Not including the spring force induced seat load in the total seat load calculation will increase the percentage reduction in the total seat load when pressure reduced from 16.5 psi to 9.0 psi. Therefore, this is a conservative assumption and does not require verification.
5. The mean seat contact diameter for Groups 31-1 and 67-3 is not available. The mean seat contact diameter is assumed to be equal to the valve flow bore diameter which is 0.625 inch [3a]. The valve flow bore diameter looks larger than the mean seat diameter [3a]. A larger mean seat diameter will develop lower average seat contact stresses which is conservative. Therefore, this assumption does not require a verification.

The following assumptions are made to calculate percentage change in leakage flow area discussed in Section 2.2.2.

[redacted]

[redacted]

8. The seat contact band width, t, for Group 62-4 valve is <u>assumed to be of 0.005 inches</u> which is a reasonable assumption. A lower seat contact band width will provide a conservative result. A sensitivity analysis showed that lowering the seat contact band width to 0.001 inches does not change the overall conclusion because the percentage increase in the leakage area, A_I, remains below 0.1%. Therefore, this assumption does not require a verification.

9. [redacted]

10. The modulus of elasticity, E, of the seat/disc material is assumed to be equal to 3.0e7 psi. The valve drawings [3e] shows that the disc and seat surfaces are hard faced which typically has a higher modulus than the one used here. The lower modulus provides a conservative result. Therefore, this assumption does not require a verification.

The following assumptions are made to calculate peak seat contact stress for Group 43-1 valves as discussed in Section 2.2.3.

11. The O-ring compressive displacement, x, (squeeze) is not known. Per Parker O-ring Handbook [6], a minimum squeeze of 0.007 inches is recommended for any cross-section O-ring. Therefore, the minimum recommended squeeze of 0.007 inches is assumed for the peak seat contact stress calculation in Equation 15. Table 1-2 shows that all the valves in the Group 43-1 have a favorable history of LLRT leakage results. So, we can assume that the O-ring used in this check valve satisfy the requirement of minimum recommended squeeze of 0.007 inches. Therefore, the value of 0.007 inches for the O-ring compressive displacement is a conservative assumption and does not require verification.

5

RESULT, CONCLUSION AND RECOMMENDATION

This section documents the calculation results and conclusions derived based on the calculation approaches documented in Section 2, design inputs documented in Section 3, and the assumptions in Section 4.

5.1 SOFT SEAT PISTON CHECK VALVES

The average seat contact stress calculation results for the piston check valves in Groups 32-2, 61-1, 67-1, 31-1, 67-3, 63-1 and 68-1 are shown in Table 5-1.

Table 5-1: Seat Load and Contact Stress Results for Soft Seat Piston Check Valve

Valve Group	F_{S_DP} (lbf)	F_{S_Pa} (lbf)	F_{spring} (lbf)	F_{S_Total} (lbf)	$F_{S\_Total\_red}$ (lbf)	R (%)	σ_{DPtest} (psi)	σ_{Pa}(psi)
32-2	81.0	44.2	0	81	44.2	45.5	82.5	45.0
61-1/ 67-1	13.0	7.1	3.9	16.9	11.0	34.9	89.6	58.3
63-1	7.3	4.0	0.9	8.2	4.9	40.5	46.3	27.5
67-3/ 31-1	5.1	2.8	0	5.1	2.8	45.5	41.3	22.5
68-1	24.5	13.4	0	24.5	13.4	45.5	45.4	24.8

The percentage reduction in the seat load, R, varies between 35 % to 46%. However, the average seat contact stresses (σ_{DPtest} and σ_{Pa}) are higher than the differential pressures at both P_a and DP_{test} pressures. The peak seat contact stress is not calculated for these valves, but it will be higher than the average seat contact stresses calculated above. The peak seat contact stress must exceed the differential pressure to ensure sealing. Therefore, the leakage is not expected to increase when the pressure is reduced from DP_{test} to P_a for the valves in these groups.

5.2 METAL SEATED PISTON CHECK VALVES (GROUP 62-4)

The results of the calculation approach documented in Section 2.2.2 are included here. The calculation is performed based on the design inputs in Section 3.1.5 and Assumptions 6 to 10 in Section 4. Table 5-2 documents the percentage increase in the leakage flow area, A_I.

Table 5-2: Percentage Increase in Leakage Flow Area Calculation Results

Valve Group	62-4
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
A_I, %	0.02

Table 5-2 shows that the calculated increase in the leakage flow area, A_I, is [redacted] for Groups 62-4 valves which is negligible. Therefore, it not expected to increase the leakage coefficient, C_L, by 35% which is a threshold for the measured leakage at the lower pressure, P_a, to increase from the measured leakage at the higher pressure, DP_{test}.

5.3 INLINE CHECK VALVE (GROUP 43-1)

The results of the calculation approach documented in Section 2.2.3 are included here. These results are based on the design inputs in Section 3.1.4 and Assumption 11 in Section 4.

The normalized squeeze, δ, is calculated using Equation 16 and is equal to 0.05 based on the minimum squeeze of 0.007 inches and the maximum O-ring cross-section diameter of 0.143 inches (0.139+0.004).

Table 5-3 documents the peak contact stresses calculated using Equation 15 for different O-ring normalized squeezes, δ and elastic modulus.

Table 5-3: Peak Seat Contact Stress For Material With 60, 70 And 80 Durometer Shore A Hardness

δ	Durometer Hardness		
	60 (E_S =630 psi)	70 (E_S=1040 psi)	80 (E_S=1705 psi)
	Peak Seat Contact Stresses (S_{max}), psi		
0.05	68.6	113.3	185.7
0.1	115.5	190.6	312.5
0.15	157.0	259.2	425.0
0.2	196.9	325.0	532.8
0.25	238.3	393.3	644.8
0.3	285.5	471.3	772.6
0.35	343.8	567.5	930.4
0.4	419.0	691.7	1134.0
0.45	516.8	853.1	1398.6
0.5	642.0	1059.8	1737.5

The peak seat contact stress is 68.6 psi (see Table 5-3) for the normalized squeeze of 0.05 and the hardness of 60 durometer. The normalized squeeze for the minimum O-ring compressive displacement of 0.007 inches is 0.05. Typically, the minimum compressive displacement is achieved at a pressure well below 9.00 psig. Therefore, at 9 psig pressure, the peak seat contact stress will be well above 68.6 psi and which will ensure a positive sealing margin.

Therefore, the sealing capability of the inline check valve (Group 43-1) will not be affected by the change in DP.

5.4 RECOMMENDATION

The calculations for metal seated check valve (Group 62-4) show that the leakage will not increase due to change in DP, but the leakage test results (Table 1-2) show a unfavorable leakage history for the valve. Therefore testing of the valves in this group is recommended.

6

REFERENCES

1. KEI Document No. 1500C Rev. 15; Kalsi Engineering, Inc. *Quality Assurance Manual*.

2. TVA Purchase Order 6232543, Rev. Num: 0.

3. Valve Drawings

    a. Flowserve, Y-Type Check Valve, Order/Tag Information Size .50 Class 600, Dwg. No. TVSW-30604GS Rev B, Approved Date: 08/18/2010.

    b. Flowserve, 2” Series 1500 Y-Type Check Valve, Dwg. No. TVD-D-9911-(2) Rev A, Approved Date: 02/28/2011.

    c. Circle Seal Corporation, Check Valve, Dwg. No. N89-180, Approved Date: 04/29/1976.

    d. Flowserve, Piston Check Valve Socket Ends Stainless Steel with Resilient Seat and Non-Cobalt Trim Size:1/2 Class: 1878, Dwg. No. W9825144 Rev E, Approved Date:08/08/2012.

    e. Flowserve, ¾” Series 1500 Carbon Steel Y- Check Valve w/ Soft Seat, Dwg. No. TVD-D-9956-(2) Rev C, Approved Date:06/08/2010.

    f. Kerotest, 1” Series 600 Y-type Check Valve, Dwg. No. TVW1-30608GS-(2), Approved Date: 12/02/1980.

    g. Flowserve, Y- Check Valve Socket Weld Ends Size: .50 Class: 600, Dwg. No. TVW-D-30504-(2) Rev G, Approved Date: 09/15/2011.

    h. Kerotest, 1” 600# Y- Check Valve Stainless Steel w/ Soft Seat, Dwg. No. TVA-30508GLS-(2), Approved Date:7/24/1997.

4. TVA Engineering Work Request, EWR20MEC088032, *Generate List of U1 Containment Isolation Valves for Kalsi Engineering Pa impact evaluation*. 06/09/20.

5. Circle Seal Control Check Valve Catalog, Corona, USA.

6. Parker Hannifin Corporation, O-ring Handbook, Catalog ORD 5700A/US.

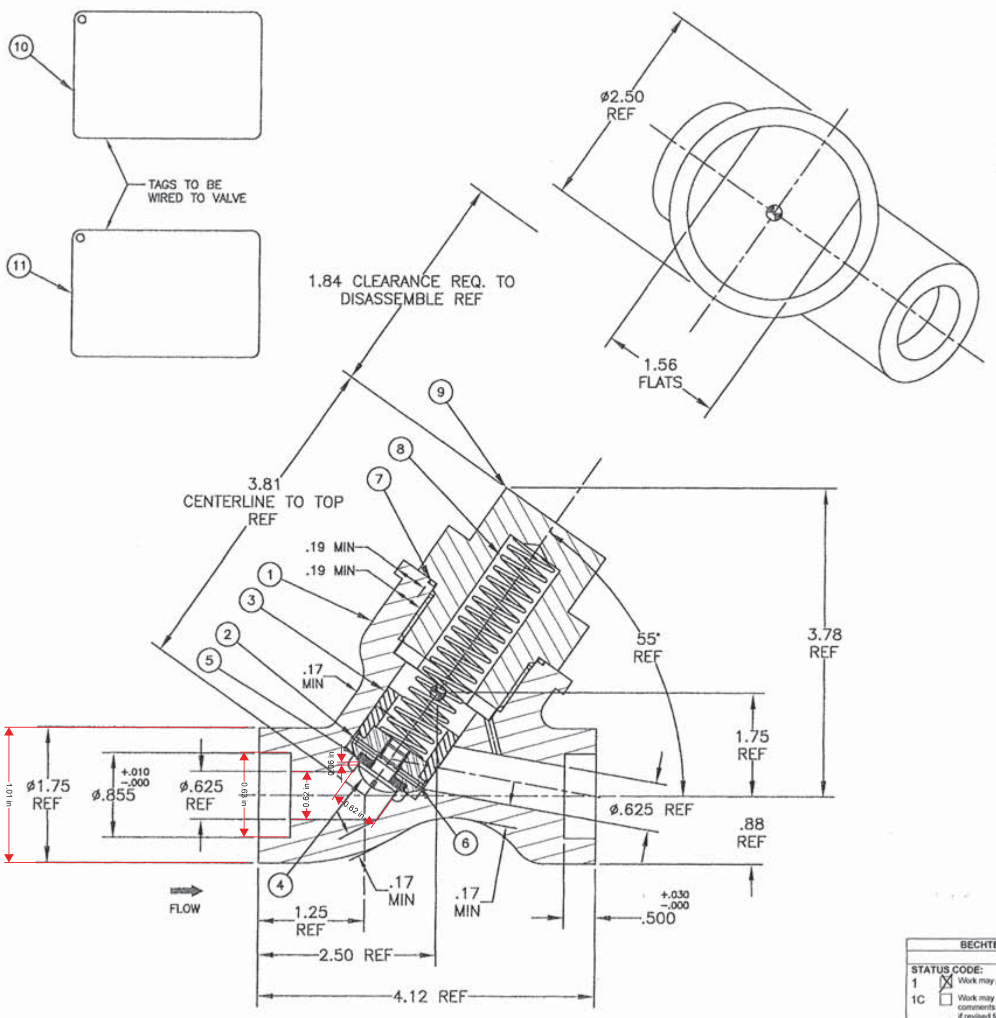
7. Hertz, D.L.,1979, "O-rings for Low Pressure Service", Machine Design, 4/12/79, pp.94-98 (note, paper applies mainly to dynamic applications).
8. Green, Itzhak and English, Capel, "Stresses and Deformation of Compressed Elastomeric O-ring Seals".
9. WBN UFSAR Section 6.2, *Containment Systems*.
10. O-ring Seal Design Best Practices, Rev 1, 2012.
11. Response from TVA For Valve Data Requested by KEI (7/16/2020).
12. TVA Clarification on Seat Type Used in The Lift Check Valves For Group 32-2 (08/17/2020).
13. Flowserve Instruction Manual for Piston Check Valves, Manual No 800-PC, March 2004.
14. ANSI/ANS-56.8-1994, *American National Standard for Containment System Leakage Testing Requirements*.
15. TVA Engineering Work Request, EWR20MEC026076, *Generate List of U2 Containment Isolation Valves for Kalsi Engineering Pa impact evaluation*. 08/19/2020

Appendix A

SUPPORTING DOCUMENTS

72592793

25402-011-V1A-PV01-00053-002



PARTS LIST

ITEM NO.	NAME OF PART	NO. REQ'D.	DRAWING NO.	MATERIAL	PART NO.	MAT'L NOTE
1	BODY	1	31604-404X-(1)	A.S.M.E. SA105 W/ STELLITE #6 SEAT	72796725	9A
	DISC ASSEMBLY	1	32506-55-(1)	CONTAINS ITEMS 2,3,4,5 AND 6	72527054	
2	DISC	1	22506-95-(1)	A.S.M.E. SA479 TYPE 316	72618465	9A
3	DISC GUIDE	1	32506-13A	A.S.T.M. A564 GR. 630 COND. H1100	72613735	9B
Δ 4	SOFT SEAT SCREW	1	A-22506-19	A.S.T.M. A479 TYPE 316	72616097	
5	SOFT SEAT INSERT	1	A-22506-87	ETHYLENE PROPYLENE TERPOLYMER	72616154	9B
Δ 6	PIN	1	A-22506-53	A.S.T.M. A581 TYPE 303 CONDITION B	88238498	
Δ 7	GASKET RING	1	A-22506-73	INCONEL X-750 W/ SILVER PLATING	88238530	
8	SPRING	1	32506-54	INCONEL X-750	88239405	9B
9	COVER	1	32606-3-(1)	A.S.M.E. SA105	72615966	9A
10	NAMEPLATE	1	A-9924-84	18-8 STAINLESS STEEL	00167384	
11	IDENTIFICATION PLATE	1	A-10018-90	18-8 STAINLESS STEEL	00655855	

⊕ REPRESENTS CENTER OF GRAVITY

NOTES:
1. VALVE TO SECTION III OF A.S.M.E. NUCLEAR CODE, CLASS (2) THROUGH THE SUMMER 1979 ADDENDA
2. MAXIMUM WORKING PRESSURE: 1075 P.S.I.G. @ 650°F
3. FLOW COEFFICIENT: Cv 6
4. VALVE WEIGHT: 5 LBS ± 10%
5. A.N.S.I. RATING: CLASS 600
6. DESIGN WORKING PRESSURE: 150 P.S.I.G. @ 200°F (47W464-96A)
   26 P.S.I.G. @ 45°F (47W915-89)
7. FOR S.O. 57496-14, P.O. 59516 FOR TVA WATTS BAR UNIT 2 THE FOLLOWING NOTES APPLY:
   A. VALVE TO SECTION III OF ASME CLASS 2, 1971 EDITION, SUMMER 1973 ADDENDA
   B. TVA DESIGN SPECIFICATION: WBNP-DS-501433-0905
   C. VALVE DESIGN PRESSURE 65 PSIG AT 110°F
Δ 8. DENOTES RECOMMENDED SPARE PARTS
9. COMPONENT CLASSIFICATION:
   A. PRESSURE RETAINING
   B. ESSENTIAL TO FUNCTION
10. APPROXIMATE MIN. VELOCITY FULLY OPEN 27 FT/SEC

CUSTOMER: TENNESSEE VALLEY AUTHORITY
SEQUOYAH OR WATTS BAR NUCLEAR PLANT
CUSTOMER P.O.: 80KA2-827318-2
TVA MARK NO. 47W915-89 & 47W464-96A

Group
31-1/67-3

BECHTEL POWER CORPORATION Job Number: 25402
SUPPLIER DOCUMENT REVIEW STATUS

STATUS CODE:
1 ☒ Work may proceed.
1C ☐ Work may proceed. Editorial comments need only be incorporated if revised for other purposes.
2 ☐ Revise and resubmit. Work may proceed subject to incorporation of changes indicated.
3 ☐ Rejected. Revise and resubmit.
4 ☐ Review not required. Work may proceed.

PO 59516

Permission to proceed does not constitute acceptance or approval of design details, calculations, analysis, test methods, or materials developed or selected by the Supplier and does not relieve the Supplier from full compliance with contractual obligations.

Reviewed by	Arch	Civil	CS	Elect	Mech	MET	PD	Constr	Startup	STE
	NA	RFB 8/17/10	NA	NA	NA	NA	VJ 8-30-10	NA	NA	NA

Status By: Mark R. Johnson
DATE 8/30/10

VALVE IS ASME SECTION III, CLASS 2
1971 EDITION, SUMMER 1973 ADDENDA, WITH N-STAMP

VALVE DESIGN PRESSURE IS 65 PSIG AT 110°F
COLD WORKING PRESSURE IS 1440 PSIG

FLOWSERVE
Flow Control Division
RALEIGH, NC

Y-TYPE CHECK VALVE
ORDER/TAG INFORMATION
SIZE: .50" CLASS: 600

REV	ADCN NO.	QAP REV	B/M DATE	DWN / DATE	CHK'D / DATE	APV'D / DATE
B	4651	3	05/25/10	BDK 08/17/10	CMS 8/17/10	EF 8/18/10
A	4607	1	05/25/10	BDK 06/14/10	CMS 06/22/10	EF 07/06/10

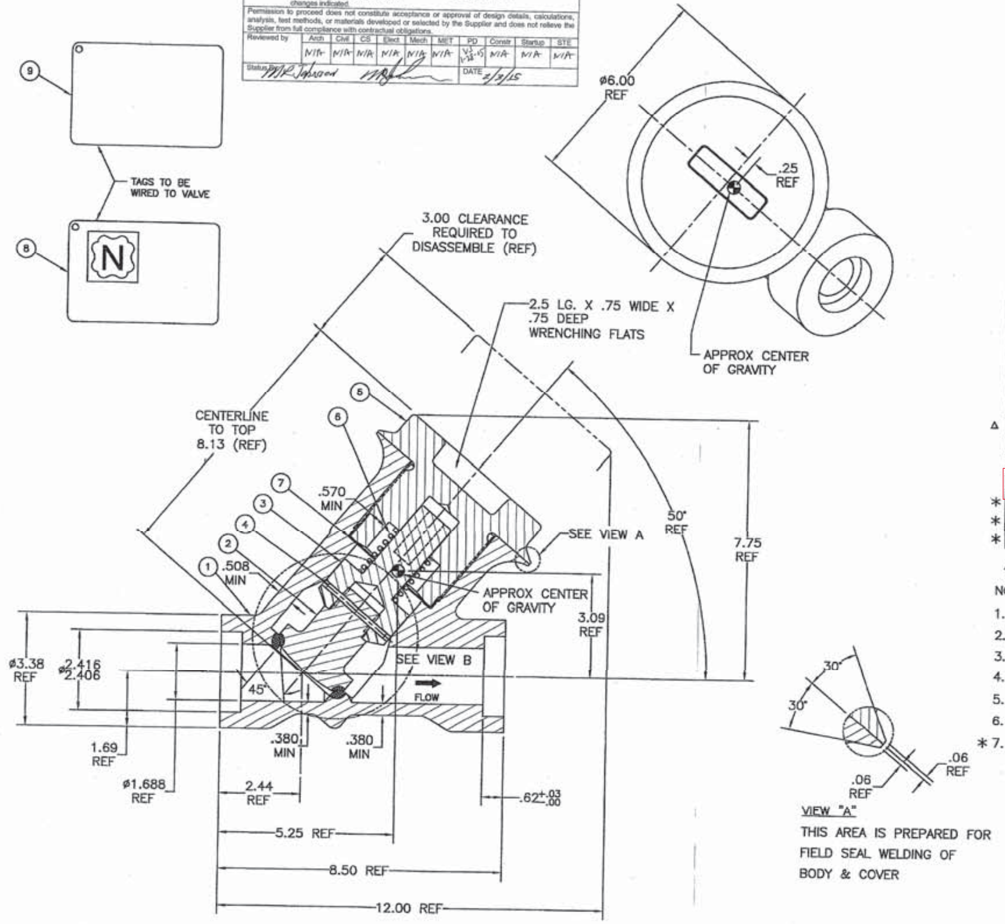
REFERENCE DWG:	SIZE:	DWG NO:	REV:
SCALE: -NTS-	C	72592793 TVSW-30604GS-(2)	B SHT NO: 1 OF SHTS: 2

25402-011-V1A-PV21-00021.002

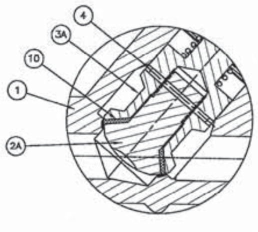
BECHTEL POWER CORPORATION Job Number: 25402
SUPPLIER DOCUMENT REVIEW STATUS
STATUS CODE:
1 ☐ Work may proceed.
1C ☒ Work may proceed. Editorial comments need only be incorporated if revised for other purposes.
2 ☐ Revise and resubmit. Work may proceed subject to incorporation of changes indicated.
3 ☐ Rejected. Revise and resubmit.
4 ☐ Review not required. Work may proceed.
PO 221004
Permission to proceed does not constitute acceptance or approval of design details, calculations, analysis, test methods, or materials developed or selected by the Supplier and does not relieve the Supplier from full compliance with contractual obligations.

Reviewed by	Arch	Civil	CS	Elect	Mech	MET	PD	Constr	Startup	STE
	N/A	N/A	N/A	N/A	N/A	N/A	[illegible]	N/A	N/A	N/A

Status By: M R Johnson DATE 2/3/15



VIEW "A"
THIS AREA IS PREPARED FOR FIELD SEAL WELDING OF BODY & COVER



ALTERNATE SOFT SEAT
VIEW "B"

TOLERANCES UNLESS OTHERWISE NOTED
FRACTIONS ± 1/64 DECIMALS ±.005 ANGLES ±1° MACH FINISH 250

~~**BECHTEL POWER CORPORATION** Job Number: 25402~~
~~**SUPPLIER DOCUMENT REVIEW STATUS**~~
~~STATUS CODE:~~
~~1 ☐ Work may proceed.~~
~~1C ☐ Work may proceed. Editorial comments need only be incorporated if revised for other purposes.~~
~~2 ☒ Revise and resubmit. Work may proceed subject to incorporation of changes indicated.~~
~~3 ☐ Rejected. Revise and resubmit.~~
~~4 ☐ Review not required. Work may proceed.~~
~~**PO 221004**~~
~~Permission to proceed does not constitute acceptance or approval of design details, calculations, analysis, test methods, or materials developed or selected by the Supplier and does not relieve the Supplier from full compliance with contractual obligations.~~

Reviewed by	Arch	Civil	CS	Elect	Mech	MET	PD	Constr	Startup	STE
	N/A	N/A	N/A	N/A	N/A	N/A	[illegible] 3-8-11	N/A	N/A	N/A

~~Status By: M R Johnson DATE 3/10/11~~

2/3/15

PARTS LIST

ITEM NO.	NAME OF PART	NO. REQ'D.	PART No.	MATERIAL	REMARKS
1	BODY	1	P-9911-1-(1)-Z	SA 182-GRADE F316	#6 HARD FACING MAT'L
	DISC ASSEMBLY	1	9911-55-(1)-Z		
2	DISC	1	9911-9-(1)-Z	SA479 TYPE 316	#6 HARD FACING MAT'L
3	DISC CAP	1	B-9911-15	ASTM A564 GR. 630 COND. H1100	
4	PIN	1	A-9911-51	ASTM A581 TYPE 303 COND. B	
5	COVER	1	P-9911-2-(1)-Z	SA 182 GR F316	
6	SPRING	1	A-9958-54	INCONEL X-750	
Δ 7	GASKET	1	A-9911-83	ASTM A177 TYPE 304 (1/2 HARD)	
8	NAMEPLATE	1	A-9924	18-8 STAINLESS STEEL	
9	TAG	1	A-10018-90	18-8 STAINLESS STEEL	
	ALTERNATE DISC ASSEMBLY		9911S-55-(1)		
* 2A	DISC	1	9911S-9-(1)-Z	SA479 TYPE 316	
* 3A	DISC CAP	1	B-9911-30	ASTM A564 GR. 630 COND. H1100	
* 10	DISC INSERT	1	A-9911-85	ETHYLENE PROPYLENE TERPOLYMER	

Δ RECOMMENDED SPARE PARTS.

NOTES:

1. VALVE TO SECTION III OF ASME NUCLEAR CODE, CLASS (2)
2. MAXIMUM OPERATING TEMPERATURE 650°F
3. FLOW COEFFICIENT Cv 60.
4. APPROX. WEIGHT: 43 LBS. ±10%.
5. #6 HARDFACING FACING ON SEAT OF BODY & FACE OF DISC TO BE 3/32 MIN.
6. ASME RATING CLASS 1500.
*7. ALTERNATE DISC ASSEMBLY 9911S-55-(1)

CAT ID = CQV749R
FMR-PV21-00036, R0
UNIDS:
WBN-2-CKV-032-0825-B
WBN-2-CKV-032-0543
WBN-2-CKV-032-0555-A

WATTS BAR NUCLEAR PLANT – UNITS 1 & 2
PRINCIPAL PIPING SYSTEM
TVA CONTRACT No.: 74C38-83015
DRAVO P.O. No.: (SEE LOG TVD-001)
TVA MARK No.: (SEE LOG TVD-001) CLASS B
ASME CLASS 2

FLOWSERVE
Flow Control Division
Anchor/Darling, BW/IP, Durco and Valtek Valves
RALEIGH, NC

A	4770	0	N/A	BRH 02/15/11	BDK 2/28/11	[illegible] 2/28/11
REV	ADCN NO.	QAP REV	B/M DATE	DWN / DATE	CHK'D / DATE	APV'D / DATE

DWN/DATE
CHK'D/DATE
APP'D/DATE
SCALE FULL

2" SERIES 1500
Y-TYPE CHECK VALVE

DWG NO. TVD-D-9911-(2)
REV A
SH NO 1
SHS 1

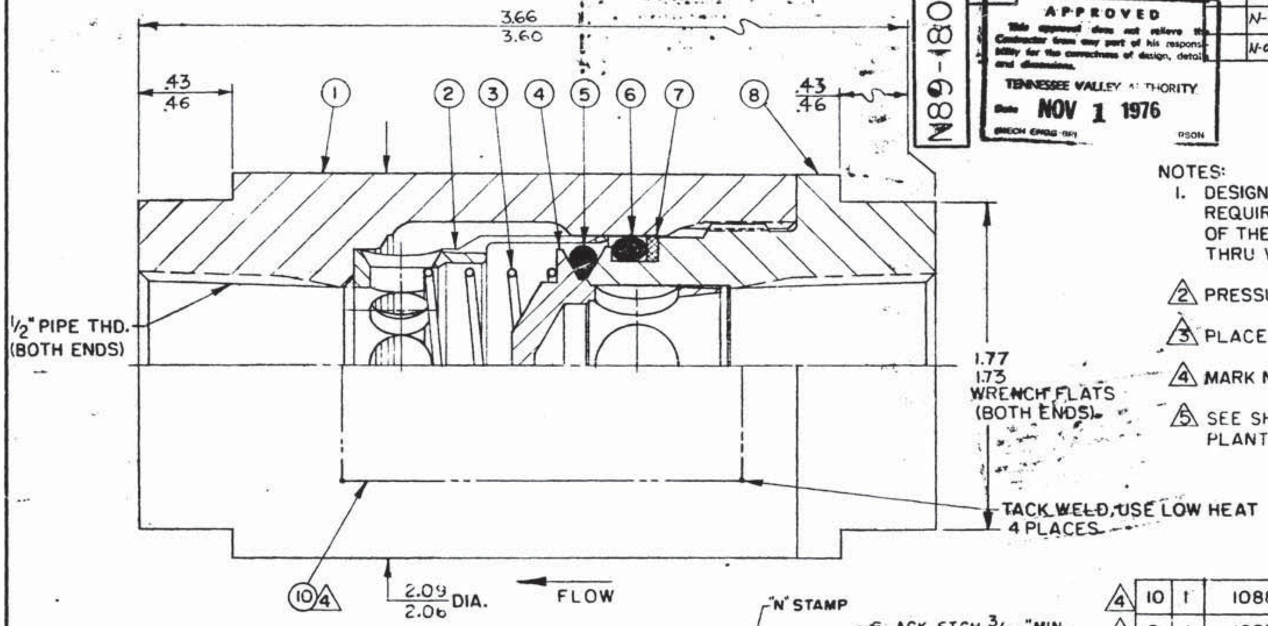
THIS DRAWING FOR REFERENCE ONLY. ARTICLES DESCRIBED HEREIN ARE EITHER PATENTED OR PROPIETARY OR DIRECTLY RELATED TO ARTICLES WHICH ARE PATENTED OR PROPRIETARY. PARTIAL COPYING OR REPRODUCTION OF THIS DRAWING IS PROHIBITED.

N89-180

LTR	C.O.	REVISIONS	DATE	BY	APPD
	N-0016	RELEASE	3-21-76	O.K.	GLH
	N-0024	ADDED TVA SPEC. NO.	6-16-76	P.V.E.	GLH
	N-0030	ADDED SHT. 2 & NOTE 5	9-3-76	PVE	GLH

APPROVED
This approval does not relieve the Contractor from any part of his responsibility for the correctness of design, details and dimensions.
TENNESSEE VALLEY AUTHORITY
Date NOV 1 1976
MECH ENGG BR PSON

Group 43-1



NOTES:

1. DESIGNED, MFG'D. & INSPECTED IN ACCORDANCE WITH THE REQUIREMENTS FOR CLASS 2 COMPONENTS. SECTION III OF THE ASME BOILER AND PRESSURE VESSEL CODE THRU WINTER 1974 ADDENDA.

△2 PRESSURE RETAINING PARTS.

△3 PLACE LABEL ON SHIPPING BAG. (NOT SHOWN)

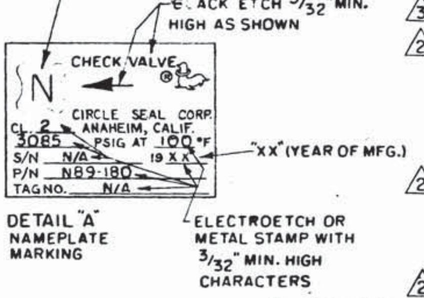
△4 MARK NAMEPLATE PER DETAIL "A" BEFORE WELDING.

△5 SEE SHEET 2 FOR TVA CONTRACT NO., SPEC.NO. & PLANT LOCATION.

TVA 10/29/76
PROJECT: WATTS BAR
CONTRACT NO: 76K51-820136-3
USE: Check Valve
CHECKED:

TECHNICAL DATA NOM. RATING- 1500# ANSI
OPERATING PRESSURE 105 PSIG
PROOF PRESSURE 4650 PSIG SHELL
3395 PSIG SEAT
OPERATING TEMP. -40° TO +250°F
INTERNAL LEAKAGE 0
CRACKING PRESSURE 2 - 4 PSID
EXTERNAL LEAKAGE 0
PRESSURE DROP 5 PSI
FLOW 75 SCFM FLUID AIR
CONDITIONS
SUITABLE FOR AIR
TEST PROCEDURE TM 503
SPECIAL TESTING
LUBRICANT - SEALS DC-7
- THD'S DC-7
SPECIAL CLEANING P.B.3
CONFORMS TO REQ'TS OF TVA △5

ASSEMBLY INFO
MARKING (METAL STAMP OR ELECTROETCH) PER DETAIL "A"
SERIALIZE YES NO X
ASSEMBLY INSTRUCTIONS INSTALL SPRING GUIDE PER 2113
TIGHTENING TORQUE 45 FT.LB.±10%
SPECIAL FLUSHING, PACKAGING and SHIPPING INSTRUCTIONS P.B.4



DETAIL "A"
NAMEPLATE MARKING

	ITEM	QTY	PART NO.	DESCRIPTION	MATERIAL	FINISH
△4	10	1	1088	NAMEPLATE	18-8 CRES	—
△3	9	1	1087	LABEL	—	—
△2	8	1	60034	END	SA 182, F316	PASSIVATE
	7	1	8213	BACKUP RING	TEFLON	—
	6	1	4213-49	O-RING	BUNA-N SIZE AS568-213	—
	5	1	4211-49	O-RING	BUNA-N SIZE AS568-211	—
△2	4	1	60035	POPPET	SA 182, F316	PASSIVATE
	3	1	455-2.5	SPRING	CRES, TYPE 302	PASSIVATE
	2	1	A 480 TIP	SPRING GUIDE	316 CRES	PASSIVATE
△2	1	1	60033	HOUSING	SA 182, F316	PASSIVATE

NUCLEAR

UNLESS NOTED:
DIMENSIONS IN INCHES
CONCENTRICITY .010 TIR
FILLET RADII .005 - .015
MACH. FINISH 125 ✓
DIM'S AFTER PLATING
REMOVE BURRS

QTY	NEXT ASSY			STOCK PER 100 PCS
		—	—	

APP O. O'Brien	12-2-75	TITLE CHECK VALVE
APP Q.A. RW	9/28/76	
APP MFG. RAS	4/29/76	
CHECK GLH	3-31-76	OUTLINE DIMENSIONED
DRAWN O.E.K.	DATE 12-1-75	SCALE NONE

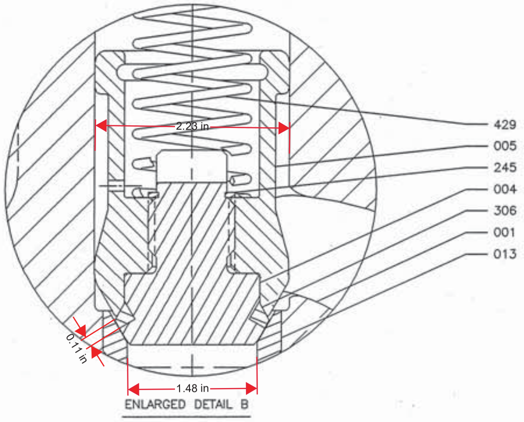
CIRCLE SEAL CORPORATION
ANAHEIM, CALIFORNIA
CODE
DRWG NO. N89-180
WT — LBS SHEET 1 OF

FORM E6-2506B

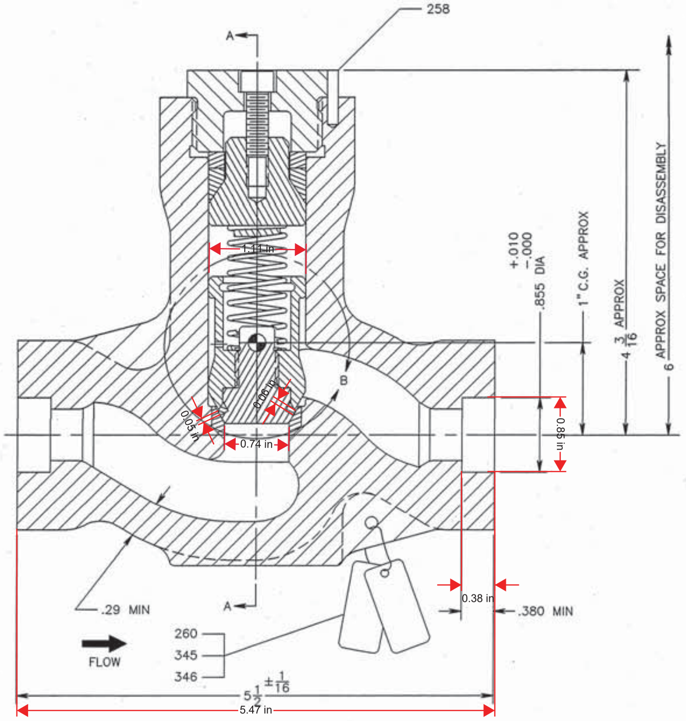
PART NO	QTY	DESCRIPTION	MATERIAL	MAT'L. NOTE
001	1	BODY	SA351-CF8M	
002	1	BONNET	SA479-316	
004	1	DISC	SA564-630-1075	
005	1	DISC SKIRT	A564-630-1075	
013	1	SEAT RING	A276-S21800A	
030	1	PRESSURE SEAL GASKET	GRAPHITE	
032	1	SPACER RING	A479-316	
034	1	BONNET RETAINER	SA479-316	
216	1	BONNET CAPSCREW	A574	
245	1	RETAINING RING	AISI 632	
258	1	ANTI-ROTATION PIN	AISI 302 (SPRING TYPE)	
260	1	WIRE	ER316	
10A 306	1	RESILIENT SEAT	E692-75 (SEE NOTE 6)	10A
345	1	NAMEPLATE	AISI 304	
346	1	IDENTIFICATION PLATE	AISI 304	
Δ 429A	1	SPRING (10 PSI CRACKING PRESS)	INCONEL X	

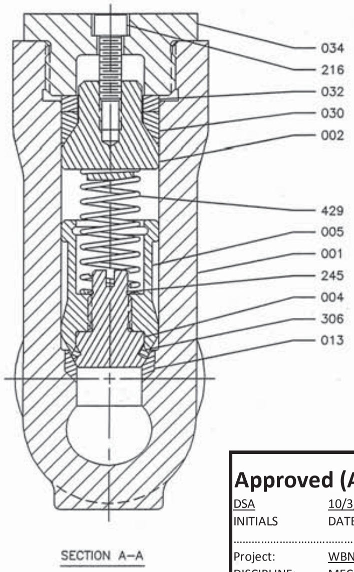
REV	REVISIONS	BY DATE	APP'D BY DATE
A	NOTE 7: 47W450-1200 WAS 47W462-1200	ACW 9-98	RHM 9-98
B	ADDED FLOWSERVE S.O. E830A-1 AND RELATED DATA TO CUSTOMER NOTE AND NOTE 7	ACW 7-99	JFD 7-99
C	PART NO. 429: ADDED (5 PSI CRACKING PRESSURE). ADDED NOTE 8 AND PART NO. 429A.	BDK 5-03	DSH 5-03

FOR REVISIONS SEE BELOW



ENLARGED DETAIL B





SECTION A-A

NOTES

1. VALVE IS ASME CLASS 1 PER 1986 ASME SECTION III
2. APPROX VALVE WEIGHT = 11 LBS
3. APPROX C_V= 7
4. PISTON CHECK VALVE DESIGNED FOR MOUNTING IN A HORIZONTAL RUN OF PIPE WITH VALVE ENDS HORIZONTAL AND BONNET ON TOP
5. VALVE DESIGN PRESSURE IS 2735 PSI AT 680°F
6. EPR SEAT MATERIAL IS SUITABLE FOR TEMBERATURES UP TO 450°F MATERIAL CAN BE USED FOR 6 YEAR SERVICE OF 420°F
7. TVA VALVE MARK NO'S:
   E579A-1-1 THRU -1-4: 47W462-300
   E579A-1-5 THRU -1-12: 47W450-1200
   E830A-1-1: CEA493Q
Δ 8. REF: TVA P.O. 0020077-00029, FLOWSERVE S.O.: 24328
* 9. 5 PSI CRACKING PRESSURE SPRING ORIGINALLY SUPPLIED ON THESE ORDERS.
10. ALTERNATE MATERIAL:
   A. RESILIENT SEAT (E740-75)

10 psi cracking pressure

Approved (A)
DSA 10/3/2015
INITIALS DATE
Project: WBN
DISCIPLINE: MECHANICAL
CONTRACT: 00403336
UNIT # 0
MAJOR EQUIP DESCRIPTION:
Piston Check Valve
System 061, 067
COMMENTS:

TENNESSEE VALLEY AUTHORITY
WATTS BAR NUCLEAR PLANT
CUSTOMER P.O. NO.:
* P92ZMB-45195C-000 RELEASE 1266304
CUSTOMER P.O. NO.:
* P92ZMB-45195C-000 RELEASE 1324327

BW/IP INT'L. INC. S.O.
E579A-1
FLOWSERVE CORP S.O.
E830A-1

FLOWSERVE
Flow Control Division
Anchor/Darling, BW/IP, Durco and Valtek Valves
RALEIGH, NC

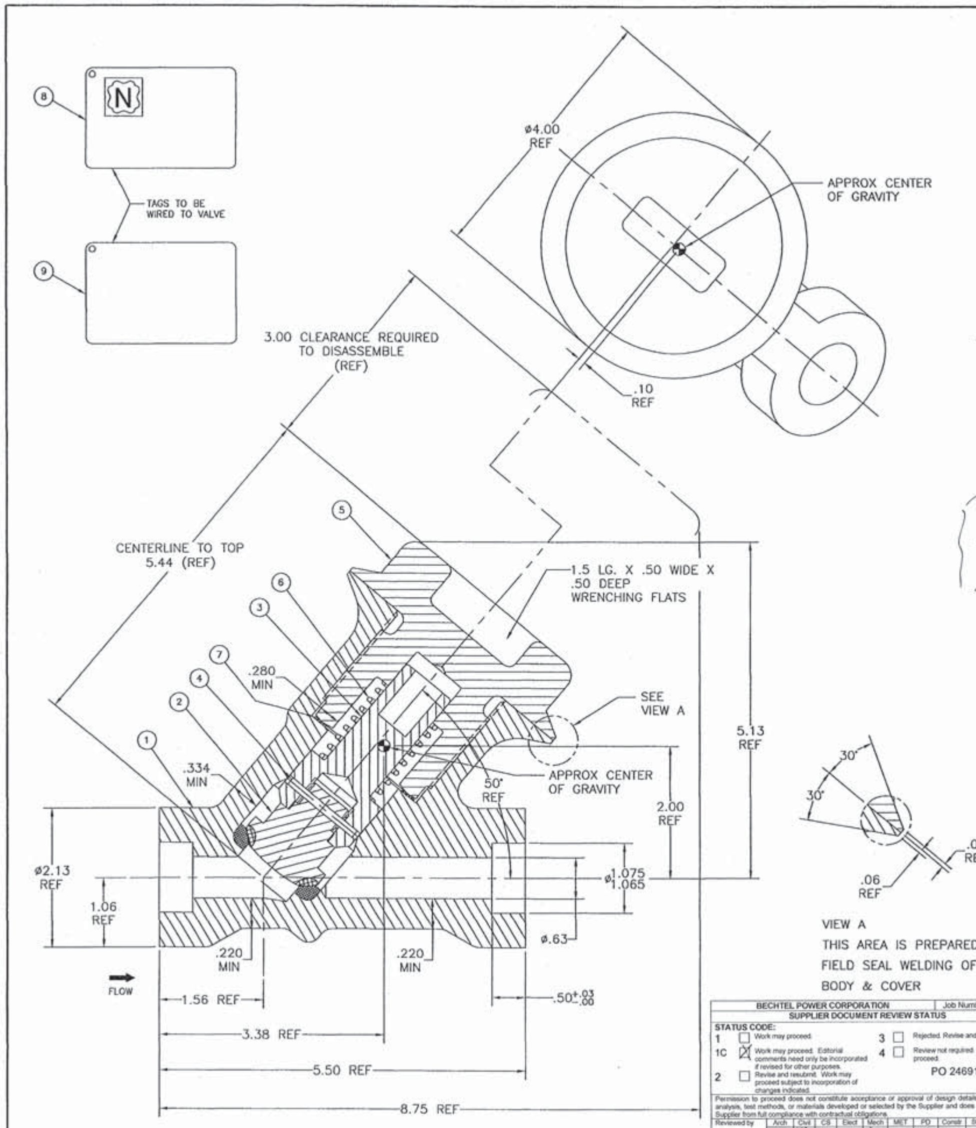
PISTON CHECK VALVE
SOCKET ENDS STAINLESS STEEL
WITH RESILIENT SEAT AND NON-COBALT TRIM
SIZE: 1/2 CLASS: 1878

REV	ADCN NO.	QAP REV	B/M DATE	DWN / DATE	CHK'D / DATE	APV'D / DATE
E	3706-1	1	05/31/12	TJW 08/08/12	BDK 8/08/12	AMR 8/8/12
D	3706	0	N/A	BDK 10/25/06	MVR 10/25/06	GC 10/25/06
0	----	0	N/A	ACW_8/19/98	BDK_8/24/98	RHM_8/25/98

REFERENCE DWG:	SIZE:	DWG NO:	REV:
N/A	C	W9825144	E
SCALE: NTS			SHT NO: 1 OF SHTS: 1

25402-011-V1A-PV00-00053-002

TOLERANCES UNLESS OTHERWISE NOTED
FRACTIONS ± 1/64
DECIMALS ±.005
ANGLES ±1°
MACH FINISH 250



VIEW A
THIS AREA IS PREPARED FOR
FIELD SEAL WELDING OF
BODY & COVER

~~NOT ACCEPTABLE~~

PARTS LIST

Δ RECOMMENDED SPARE PARTS

	ITEM NO.	NAME OF PART	NO. REQ'D.	DRAWING NO.	MATERIAL	PART NO.	MAT'L. NOTE
	1	BODY	1	P-9956-1-(1)	SA 182 GR. F316 W/COCR FACING	72624356	9A 10A
		DISC ASSEMBLY	1	9913-55-(1)		72609407	
	2	DISC	1	9913-9-(1)	SA479 TYPE 316 W/COCR FACING	72609449	9A 10A
	3	DISC CAP	1	B-9913-15	ASTM A564 GR. 630 COND. H1100	72609423	10B
	4	PIN	1	A-9913-51	ASTM A581 TYPE 303 COND. B	88240189	
	5	COVER	1	P-9913-2-(1)	SA 182 GR F316	72609324	10A
	6	SPRING	1	A-9956-54	INCONEL X-750	88240585	10B
Δ	7	GASKET	1	A-9913-83	ASTM A177 TYPE 304 (1/2 HARD)	88240197	9B
	8	NAMEPLATE	1	A-167384	AISI 316	00167384	
	9	IDENTIFICATION PLATE	1	A-655855	AISI 316	00655855	

NOTES:
1. VALVE TO SECTION III OF NUCLEAR CODE CLASS (2).
2. MAXIMUM OPERATING TEMPERATURE 650°F.
3. FLOW COEFFICIENT Cv 5.2
4. APPROX. WEIGHT: 13 LBS. ±10%.
5. #6 HARDFACING ON SEAT OF BODY & FACE OF DISC TO BE 3/32 MIN.
6. ASME RATING: CLASS 1500#.
7. 100% LP INSPECTION OF ALL ACCESSIBLE MACHINED SURFACES
8. FOR S.O. 56445 LINE ITEM 1, P.O. #24691
   TVA WATTS BAR THE FOLLOWING NOTES APPLY:
   A. VALVE TO ASME SECTION III OF CODE CLASS 2, 1971 EDITION, SUMMER 1973 ADDENDA.
   B. DESIGN SPECIFICATION WBNP-DS-501433-0905
   C. DESIGN PRESSURE: 200 PSIG @ 225°F
   D. APPROXIMATE MIN. VELOCITY FULLY OPEN: 27 FT/SEC
   E. APPROXIMATE CRACKING PRESSURE: 4 PSI
9. ALTERNATE MATERIALS:
   A. STOODY
   B. A-167 304
10. COMPONENT CLASSIFICATION
   A. PRESSURE RETAINING
   B. ESSENTIAL TO FUNCTION

~~Per VOS 47V5 406-9-3 Stellite #6 is not acceptable (Comment 2)~~

UNIT 2

WATTS BAR NUCLEAR PLANT, UNITS 1 & 2
PRINCIPAL PIPING SYSTEM
T.V.A. CONTRACT NO. 74C38-83015
DRAVO P.O. #-SEE LOG (TVD-001)
T.V.A. MARK NO. (SEE LOG (TVA-001)
CLASS B ASME CLASS (2)

ADDED PART NO.
COLUMN TO PARTS
LIST & NOTE 7
TITLE BLOCK:
FLOWSERVE WAS
KEROTEST
AMK 6-16-99
DSH 6-17-99

A

REVISIONS

BECHTEL POWER CORPORATION — Job Number: 25402
SUPPLIER DOCUMENT REVIEW STATUS
STATUS CODE:
1 ☐ Work may proceed.
1C ☒ Work may proceed. Editorial comments need only be incorporated if revised for other purposes.
2 ☐ Revise and resubmit. Work may proceed subject to incorporation of changes indicated.
3 ☐ Rejected. Revise and resubmit.
4 ☐ Review not required. Work may proceed.
PO 24691
Permission to proceed does not constitute acceptance or approval of design details, calculations, analysis, test methods, or materials developed or selected by the Supplier and does not relieve the Supplier from full compliance with contractual obligations.

Reviewed by	Arch	Civil	CS	Elect	Mech	MET	PD	Constr	Startup	STE
	NA	TB (3/21)	NA	NA	6/21/10	NA	VJ	NA	NA	NA

Status By: Mark Johnson
DATE 6/3/10

PO: VJ 6-18-10

Group 62-4

REV	ADCN NO.	QAP REV	B/M DATE	DWN / DATE	CHK'D / DATE	APV'D / DATE
C	4521-1	7	03/30/10	BRH 06/07/10	Jas. 06/08/10	EF 6/8/10
B	4521	Ø	N/A	BDK 03/05/10	CMS 03/09/10	EF 03/09/10

FLOWSERVE
Flow Control Division
Anchor/Darling, BW/IP, Durco and Valtek Valves
RALEIGH, NC CBR

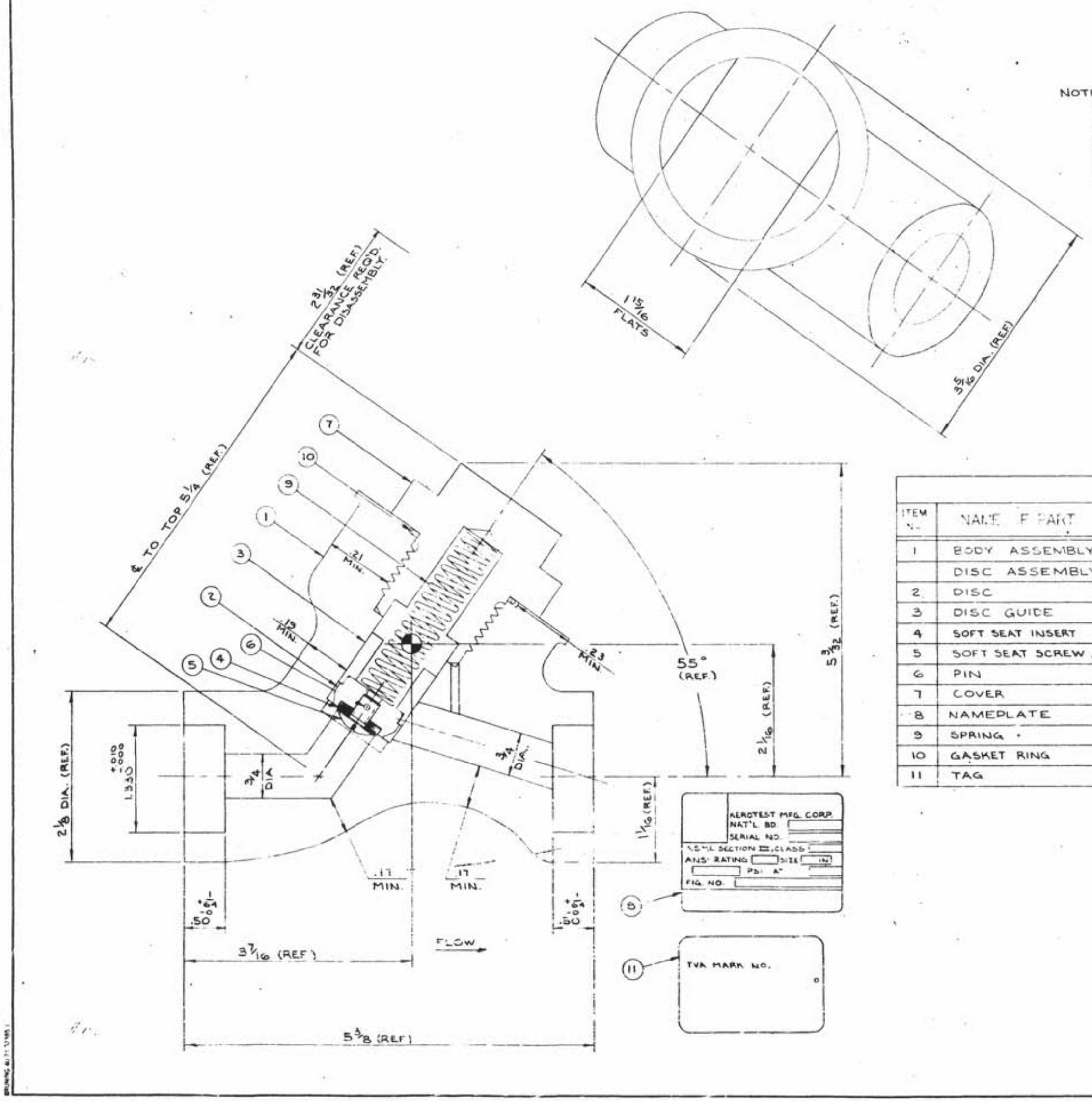
DWN/DATE EC 7-28-75
CHK'D/DATE
APP'D/DATE RTV 7-28-75
SCALE FULL

3/4" SERIES 1500
Y-TYPE CHECK VALVE

DWG NO. 7500001295
TVD-D-9956-(2)

REV C
SH NO 1
SHS 2

TOLERANCES UNLESS OTHERWISE NOTED
FRACTIONS ± 1/64
DECIMALS ± .005
ANGLES ± 1°
MACH. FINISH



NOTES:

1. VALVE BUILT TO SECTION III OF A.S.M.E. NUCLEAR CODE, CLASS (2) THRU. SUMMER 1979 ADDENDA.
2. DESIGN WORKING PRESSURE: 750 P.S.I.G. @ 200° F
3. FLOW COEFFICIENT: CV 13
4. APPROX. WEIGHT: 8 LBS. ±10%
5. A.N.S.I. RATING: CLASS 600
6. MAX. TEMP.: 300° F

PARTS LIST

ITEM NO.	NAME OF PART	NO. REQ'D	PART NO	MATERIAL
1	BODY ASSEMBLY	1	31608-404X-(1)	A.S.M.E. SA105 W/STELLITE #6 SEAT
	DISC ASSEMBLY	1	32508-55 -(1)	
2	DISC	1	22508-95-(1)-Z	A.S.M.E. SA 479 TYPE 316
3	DISC GUIDE	1	32508-13	A.S.T.M. A564 GR. 630 COND. H1100
4	SOFT SEAT INSERT	1	A-22508-87	ETHYLENE PROPYLENE TERPOLYMER
5	SOFT SEAT SCREW	1	A-22508-19	ASTM A479 TYPE 316
6	PIN	1	A-22508-53	ASTM A581 TYPE 303 COND. B
7	COVER	1	32608-3-(1)	ASME SA 105
8	NAMEPLATE	1	A-9924-B4	18-8 STAINLESS STEEL
9	SPRING	1	32508-54	INCONEL X-750
10	GASKET RING	1	A-22508-73	INCONEL X-750 W/SILVER PLATING
11	TAG	1	A-10018-90	18-8 STAINLESS STEEL

MF

APPROVED
This approval does not relieve the Contractor from any part of his responsibility for the correctness of design, details, and dimensions.
TENNESSEE VALLEY AUTHORITY
Date JAN 7 1981
[illegible]
Apv'd By Ltr. [illegible]

FILE: N3M-615
PROJECT: WBN
CONTRACT: 81K A2-827840-01
DRAWING #: TVW1-30608GS-(2)
SHEET:
REVISION: C
UNIT:
USE: VALVES

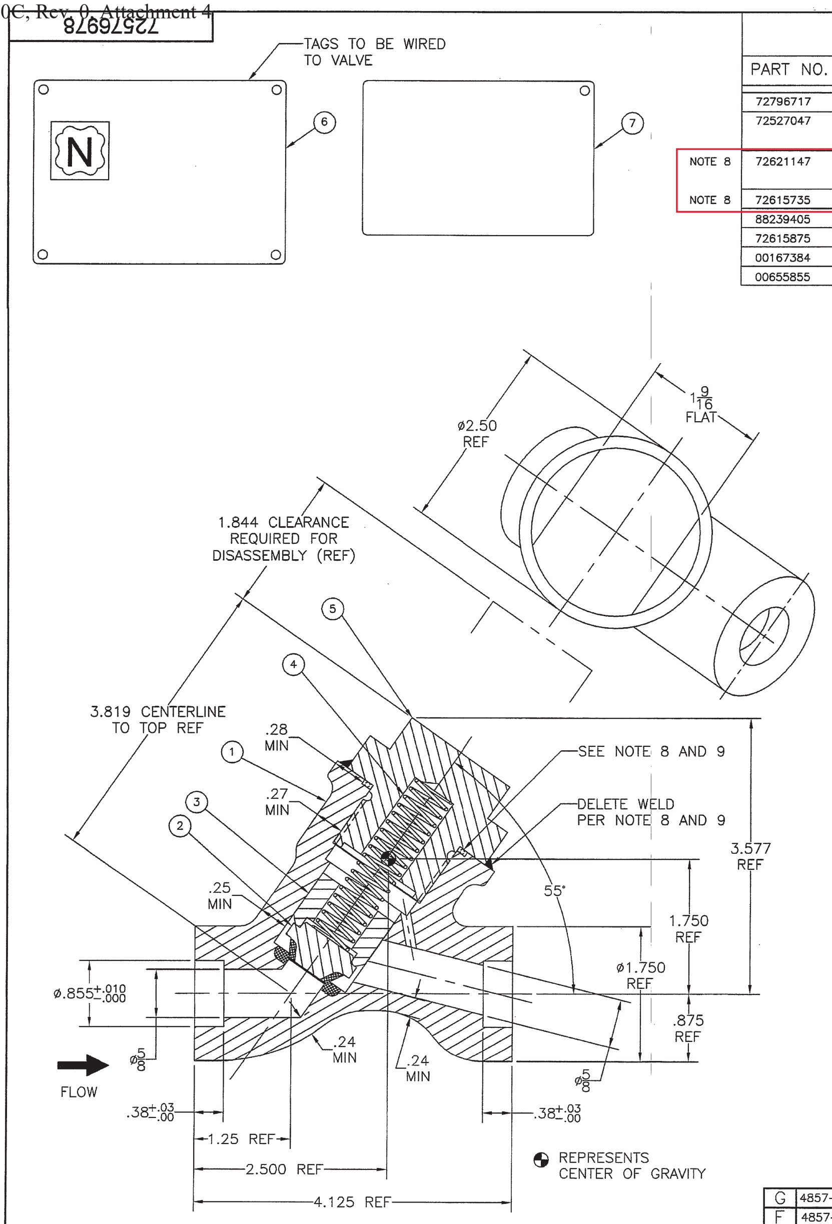
Group 63-1

REVISIONS

TENNESSEE VALLEY AUTHORITY
WATTS BAR NUCLEAR PLANT
P.O. NO.: 81K A2-827840-1
TVA MARK NO.: 47W560-817

1" SERIES 600 CARBON STL.
Y-CHECK VALVE W/ SOFT SEAT

DRAWN RJ 10-28-80
CHECKED [illegible]
APPROVED [illegible] 12/2/80
SCALE
KEROTEST
PITTSBURGH PA
NUMBER TVW1-30608GS-(2)



PARTS LIST

	PART NO.	ITEM NO.	NAME OF PART	NO. REQ'D.	DWG. NO.	MATERIAL
	72796717	1	BODY ASSEMBLY	1	31504-404X-(1)	ASME SA182 GR F316 W/STELLITE#6
	72527047		DISC ASSEMBLY	1	32506-99R-(1)-ZZ OR 32506-99A-(1)	CONTAINS ITEMS 2 & 3
NOTE 8	72621147	2	DISC	1	22506-95-(1) OR 22506-9-(1)-Z	ASME SA479 TYPE 316 W/STELLITE#6 STELLITE #6 (CAST SOLID)
NOTE 8	72615735	3	DISC GUIDE	1	32506-13A	ASTM A564 GRADE 630 COND H1100
	88239405	4	SPRING	1	32506-54	INCONEL X-750
	72615875	5	COVER	1	32506-3-(1)	ASME SA479 TYPE 316
	00167384	6	NAMEPLATE	1	A-167384	18-8 STAINLESS STEEL
	00655855	7	IDENTIFICATION PLATE	1	A-655855	18-8 STAINLESS STEEL

TOLERANCES UNLESS OTHERWISE NOTED

FRACTIONS ± 1/64
DECIMALS ±.005
ANGLES ±1°
MACH FINISH 250

NOTES:

1. VALVE TO SECTION III OF ASME, NUCLEAR CODE, CLASS (2) THROUGH SUMMER 1977 ADDENDA
2. MAXIMUM WORKING PRESSURE 1030 PSIG @ 650°F
3. FLOW COEFFICIENT Cv = 6
4. APPROX. WEIGHT: 5 LBS
5. A.S.M.E. RATING: CLASS 600
6. MIN WALLS INCLUED .08 CORROSION ALLOWANCE
7. DESIGN PRESSURE: 160 PSIG @ 130°F
8. ALTERNATE SOFT SEAT DISC ASS'Y. (72615651) COMPOSED OF

DISC	72618465	SA-479 316
DISC GUIDE	72615735	A564-630-H1100
SEAT INSERT	72616154	EPT
SEAT SCREW	72616097	A479 316
PIN	88238498	A581 303B

CAN BE USED IN PLACE OF ORIGINAL DISC ASS'Y. 72527047 GASKET COVER (88238530 INCONEL X-750) MUST BE USED WITH THE SOFT SEAT DISC ASS'Y. THESE CHANGES APPLY ONLY TO 8 VALVES MARK NO. 47W450-59 (1-CKV-67-575A, B, C, D AND 1-CKV-67-585A, B, C AND D) AND 4 UNIT 2 VALVES MARK NO. 47W450-59 (2-CKV-67-585A, B, C, D)

9. WELD MAY BE DELETED WITHOUT THE USE OF SOFT SEAT DISC ASS'Y. AS LONG AS GASKET COVER #88238530 IS USED TORQUE COVER (ITEM 5) TO 300 ±50 FT-LB

BECHTEL POWER CORPORATION Job Number: 25402
SUPPLIER DOCUMENT REVIEW STATUS

STATUS CODE:
1 ☒ Work may proceed.
1C ☐ Work may proceed. Editorial comments need only be incorporated if revised for other purposes.
2 ☐ Revise and resubmit. Work may proceed subject to incorporation of changes indicated.
3 ☐ Rejected. Revise and resubmit.
4 ☐ Review not required. Work may proceed.

PO 79KA2-824589-4

Permission to proceed does not constitute acceptance or approval of design details, calculations, analysis, test methods, or materials developed or selected by the Supplier and does not relieve the Supplier from full compliance with contractual obligations.

Reviewed by	Arch	Civil	CS	Elect	Mech	MET	PD	Constr	Startup	STE
	N/A	N/A	N/A	N/A	H1 9-20-11	N/A	MET 9/23/11	N/A	N/A	N/A

Status By: M.R. Johnson Mark Johnson DATE 9/23/11

REPLACEMENT CONTRACT
85KK4-706061
TVA MARK # 47W450-147
QUANITY 8

TVA WATTS BAR NUCLEAR PLANT
CONTRACT # 79KA2-824589-4
TVA MARK # 47W450-59
QUANITY 20

SEE NEW REV. FORMAT

MOVED CONTRACT NOTE TO BOX ADDED MARK NO. ADDED QUAN. 20 TVA MARK NO. WAS 47W450-147 RF 4-24-86 JAP 4-24-86

D

TVA MARK NO. WAS 47W450-59 2-10-86 C.T./JAP

C

ADDED CONTRACT NOTE-AND QUANTITY 8-6-85 ZTW/JAP

B

2-1/2 WAS 3 1-3/4 WAS 1-3/8 ADDED PART NO. & CENTER OF GRAVITY. REV. DISC ASS'Y. AND ITEMS 1,2,3&6 1-22-85 C.T./JAP

A

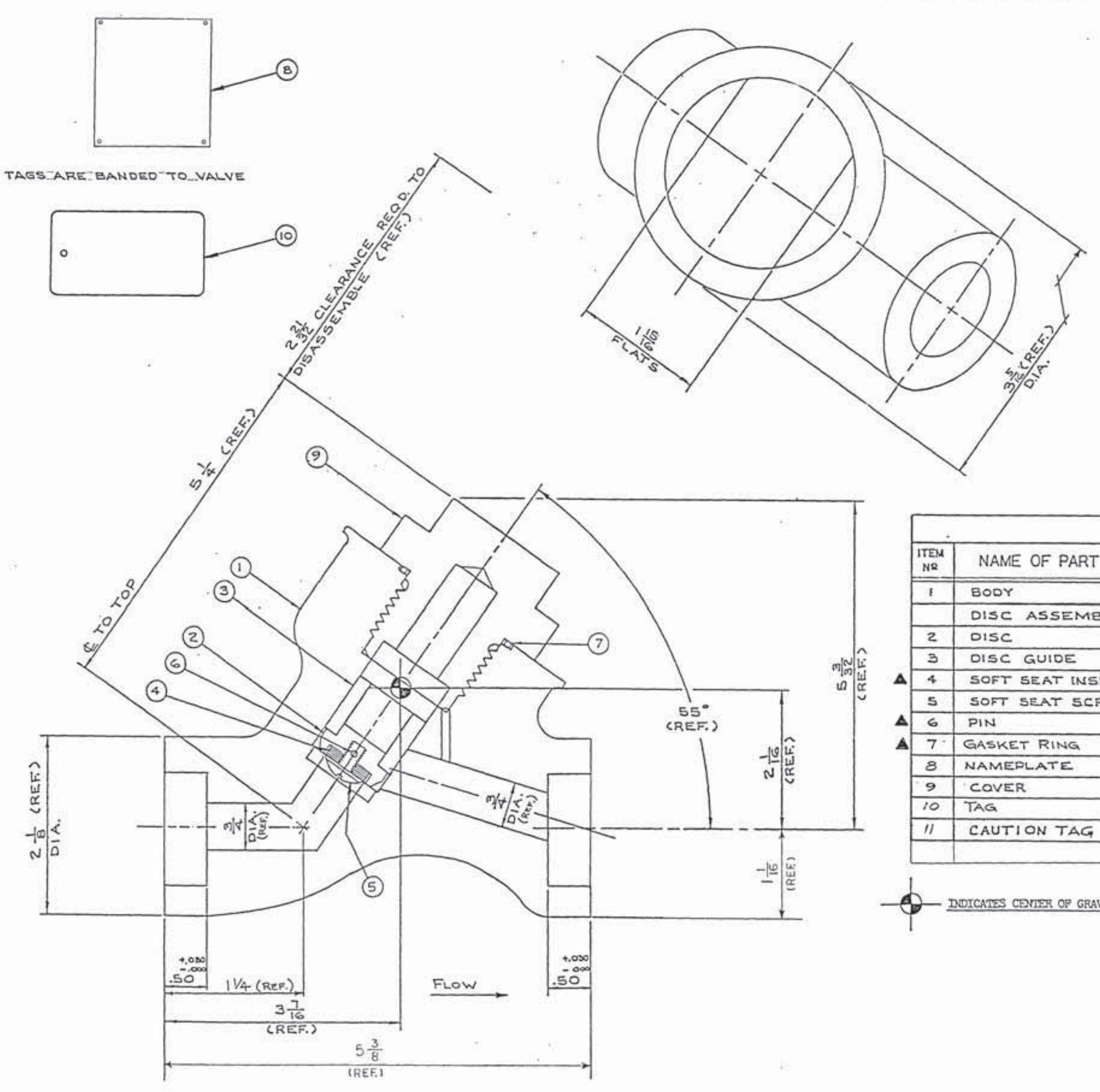
REVISIONS

FLOWSERVE
Flow Control Division
Anchor/Darling, BW/IP, Durco and Valtek Valves
RALEIGH, NC

Y-CHECK VALVE
STAINLESS STEEL
SOCKET WELD ENDS
SIZE: .50 CLASS: 600

REV	ADCN NO.	QAP REV	B/M DATE	DWN / DATE	CHK'D / DATE	APV'D / DATE
G	4857-2	3	07/11/11	BDK 09/14/11	CMS 9/15/11	KRM 9/15/11
F	4857-1	0	06/28/11	BDK 07/20/11	CMS 07/21/11	NP 07/21/11
E	4857	0	06/28/11	CMS 07/08/11	BDK 07/11/11	NP 07/11/10

REFERENCE DWG: N/A
SCALE: FULL
SIZE: C
DWG NO: 72576978
TVW-D-30504-(2)
REV: G
SHT NO: 1 OF SHTS: 1



NOTES:

1) ASME RATING: CLASS 600
2) FLOW COEFFICIENT: CV13
3) VALVE WEIGHT: 8 LBS ± 10%
4) VALVE BUILT TO ASME CODE, SECTION III, CL. 2
1986 EDITION, NO ADDENDA.
5) MAXIMUM OPERATING PRESSURE: 1120 PSIG @ 300°F
6) MAXIMUM OPERATING TEMPERATURE: 300°F
7) NAMEPLATE DATA:
1120 PSI AT 300° F
1440 PSI AT 100° F
8) CRACKING PRESSURE = .5 PSI MAX
9) SEAT LEAKAGE = BUBBLE TIGHT

APPROVED

FEB 10 1999

Release 1264447

PROJECT WBN DISCIPLINE Mech
CONTRACT 92RMB-45195C UNIT 1
DESC 1" 600 Pound Check Valve
DWG/DOC NO TVA-30508GLS-(2)
SHEET 1 OF 1 REV B
DATE 2/10/99 DCN N/A FILE N/A

TOLERANCES UNLESS OTHERWISE NOTED
FRACTIONS = 1/64
DECIMALS = .005
ANGLES = 1°
MACH. FINISH √

A	ADDED NOTE 7 & ** COCR NOTE TO ITEM 1, DELETED ITEM 12 AND RELATED DIMENSIONS, ITEM 8 PART NO. WAS 88238035 & ITEM 10 PART NO. WAS 88236567, TITLE BLOCK: DWG. NO. WAS TVA-30508GLSX-(2) AMK 8-25-98 D. Hall 8/28/98
B	ADDED NOTES 8 & 9, PARTS LIST ITEM 4 MAT'L. WAS ETHYLENE PROPYLENE TERPOLYMER CUSTOMER INFO. BLOCK: ADDED 47W560-48BAD TO T.V.A. MARK NO. AMK 2-5-99 D. Hall 2/9/99

PARTS LIST ▲ RECOMMENDED SPARE PARTS

	ITEM Nº	NAME OF PART	Nº REQ'D.	DWG. Nº.	MATERIAL	PART Nº.
	1	BODY	1	31508-404X-(1)	A.S.M.E. SA182 GR.F316 W/**COCRSEAT	72794837
		DISC ASSEMBLY	1	32508-55L-(1)	CONTAINS ITEMS 2, 3, 4, 5, AND 6	72802969
	2	DISC	1	22508-95-(1)	A.S.M.E. SA 479 TYPE 316	72618481
	3	DISC GUIDE	1	32508-13L	A.S.T.M. A564 GR. 630 COND. H1100	72615750
▲	4	SOFT SEAT INSERT	1	A-22508-87	EPDM	72616162
	5	SOFT SEAT SCREW	1	A-22508-19	A.S.T.M. A479 TYPE 316	72616105
▲	6	PIN	1	A-22508-53	A.S.T.M. A581 TYPE 303 CONDITION B	88238712
▲	7	GASKET RING	1	A-22508-73	INCONEL X-750 W/SILVER PLATING	88238738
	8	NAMEPLATE	1	—	18-8 STAINLESS STEEL	862580
	9	COVER	1	32508-3-(1)	A.S.M.E SA 479 TYPE 316	72615909
	10	TAG	1	—	18-8 STAINLESS STEEL	A11207
	11	CAUTION TAG	1	A-10155	18-8 STAINLESS STEEL (NOT SHOWN)	88237177

**COCR=STELLITE #6 OR EQUAL

⊕ INDICATES CENTER OF GRAVITY

REVISIONS

TENNESSEE VALLEY AUTHORITY
WATTS BAR NUCLEAR PLANT
P.O. NO. P-97N3D-211191
T.V.A. MARK NO. 47W560-48BAD

Group 68-1

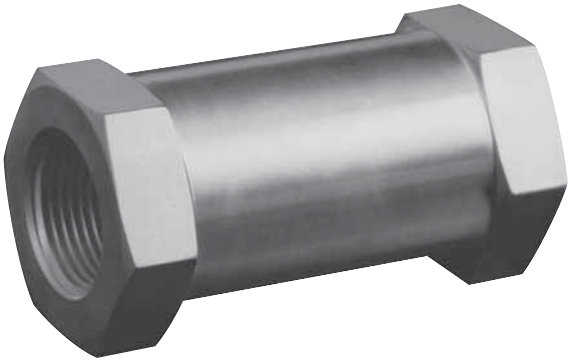
1" - 600 # Y-CHECK VALVE
STAINLESS STEEL ~ W/SOFT SEAT

DRAWN/DATE D. Hall 7/24/97
ENG APPROVED 7/24/97
MFG ENG APPROVED
Q.A. APPROVED
SCALE NTS

BW/IP BW/IP International, Inc.
7500000675
NUMBER
TVA-30508GLS -(2)

CIRCLE SEAL CONTROLS

200 Series *0 to 3000 psig Check Valves*
H200 Series *0 to 6000 psig Check Valves*



Features & Benefits

Quick opening/positive closing
- Provides a wide range of adaptability

Large flow capacity
- The patented sealing principle effects complete leakproof closing under all pressure conditions

Zero leakage
- Compact, easy installation. Efficient inline piston reduces size and weight

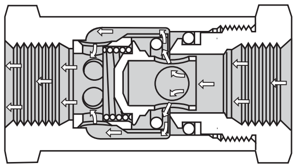
Floating o-ring
- The streamlined poppet and full ports offer minimum restriction to flow

Technical Data

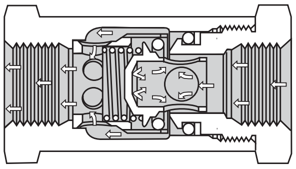
Body Construction Materials	Aluminum, brass, steel, 303 or 316 stainless steel
O-ring Materials	Buna N, ethylene propylene, fluorosilicone, Kalrez®, neoprene, PTFE, and Viton®
Operating Pressure	*200 Series:* to 3000 psig (207 bar) *H200 Series:* to 6000 psig (414 bar)
Proof Pressure	1.5 times operating pressure
Rated Burst Pressure	*200 Series:* 2.5 : 1 *H200 Series:* 4 : 1
Cracking Pressure	0.1 to 25 psig (0.007 to 1.72 bar)
Temperature Range	–320° F to +550° F (–196° C to +288° C) *Based on o-ring & body material, see "How to Order"*
Connection Sizes	⅛″ to 2″

Note: Proper filtration is recommended to prevent damage to sealing surfaces.

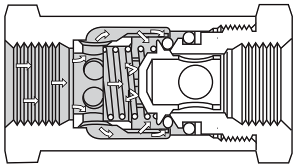
How it Works



Open
Full flow passages offer minimum restriction to flow. Spring is completely removed from flow path



Closing
Floating o-ring automatically establishes line contact with conical metal surfaces of poppet and seat to cushion closing and insure perfect sealing.



Closed
O-ring only seals. Full pressure load is carried by metal-to-metal seat. Increasing pressure increases sealing efficiency; metal seat prevents any possibility of deformation or extrusion of o-ring.

Circle Seal Controls
2301 Wardlow Circle • Corona, CA 92880
Phone (951) 270-6200 • Fax (951) 270-6201
www.circlesealcontrols.com

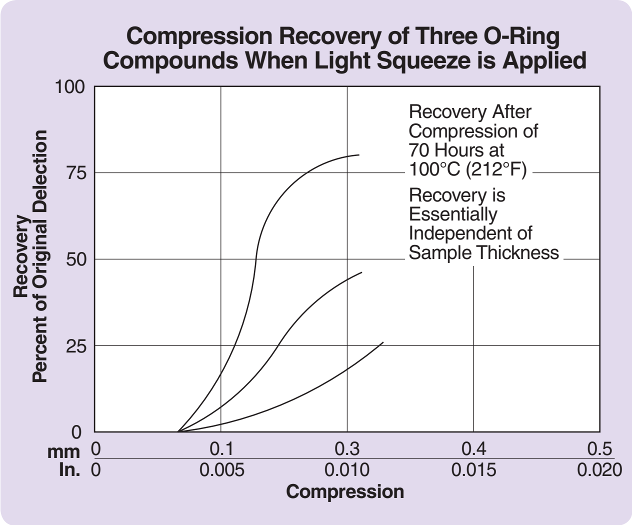


Figure 3-5: Compression Recovery of Three O-ring Compounds When Light Squeeze is Applied

An assembled stretch greater than five percent is not recommended because the internal stress on the O-ring causes more rapid aging. Over five percent stretch may sometimes be used, however, if a shorter useful life is acceptable.

Of the commonly used O-ring seal elastomers, the reduction in useful life is probably greatest with nitrile materials. Therefore, where high stretch is necessary, it is best to use ethylene propylene, fluorocarbon, polyurethane or neoprene, whichever material has the necessary resistance to the temperatures and fluids involved.

3.6 Squeeze

The tendency of an O-ring to attempt to return to its original uncompressed shape when the cross-section is deflected is the basic reason why O-rings make such excellent seals. Obviously then, squeeze is a major consideration in O-ring seal design.

In dynamic applications, the *maximum* recommended squeeze is approximately 16%, due to friction and wear considerations, though smaller cross-sections may be squeezed as much as 25%.

When used as a static seal, the maximum recommended squeeze for most elastomers is 30%, though this amount may cause assembly problems in a radial squeeze seal design. In a face seal situation, however, a 30% squeeze is often beneficial because recovery is more complete in this range, and the seal may function at a somewhat lower temperature. There is a danger in squeezing much more than 30% since the extra stress induced may contribute to early seal deterioration. Somewhat higher squeeze may be used if the seal will not be exposed to high temperatures nor to fluids that tend to attack the elastomer and cause additional swell.

The minimum squeeze for all seals, regardless of cross-section should be about .2 mm (.007 inches). The reason is that with a very light squeeze almost all elastomers quickly take 100% compression set. Figure 3-5 illustrates this lack of recovery when the squeeze is less than .1 mm (.005 inch). The three curves, representing three nitrile compounds, show very clearly that a good compression set resistant compound can be distinguished from a poor one only when the applied squeeze exceeds .1 mm (.005 inches).

Most seal applications cannot tolerate a "no" or zero squeeze condition. Exceptions include low-pressure air valves, for which the floating pneumatic piston ring design is commonly used, and some rotary O-ring seal applications. See the Dynamic O-Ring Sealing, Section V, and Tables A6-6 and A6-7 for more information on pneumatic and rotary O-ring seal design.

3.7 Gland Fill

The percentage of gland volume that an O-ring cross-section displaces in its confining gland is called "gland fill". Most O-ring seal applications call for a gland fill of between 60% to 85% of the available volume with the optimum fill being 75% (or 25% void). The reason for the 60% to 85% range is because of potential tolerance stacking, O-ring volume swell and possible thermal expansion of the seal. It is essential to allow at least a 10% void in any elastomer sealing gland.

3.8 O-Ring Compression Force

The force required to compress each linear inch of an O-ring seal depends principally on the shore hardness of the O-ring, its cross-section, and the amount of compression desired. Even if all these factors are the same, the compressive force per linear inch for two rings will still vary if the rings are made from different compounds or if their inside diameters are different. The anticipated load for a given installation is not fixed, but is a range of values. The values obtained from a large number of tests are expressed in the bar charts of Figures 2-4 through 2-8 in Section II. If the hardness of the compound is known quite accurately, the table for O-ring compression force, Table 2-3 may be used to determine which portion of the bar is most likely to apply.

Increased service temperatures generally tend to soften elastomeric materials (at least at first). Yet the compression force decreases very little except for the hardest compounds. For instance, the compression force for O-rings in compound N0674-70 decreased only 10% as the temperature was increased from 24°C (75°F) to 126°C (258°F). In compound N0552-90 the compression force decrease was 22% through the same temperature range.

Refer to Figure 3-6 for the following information:

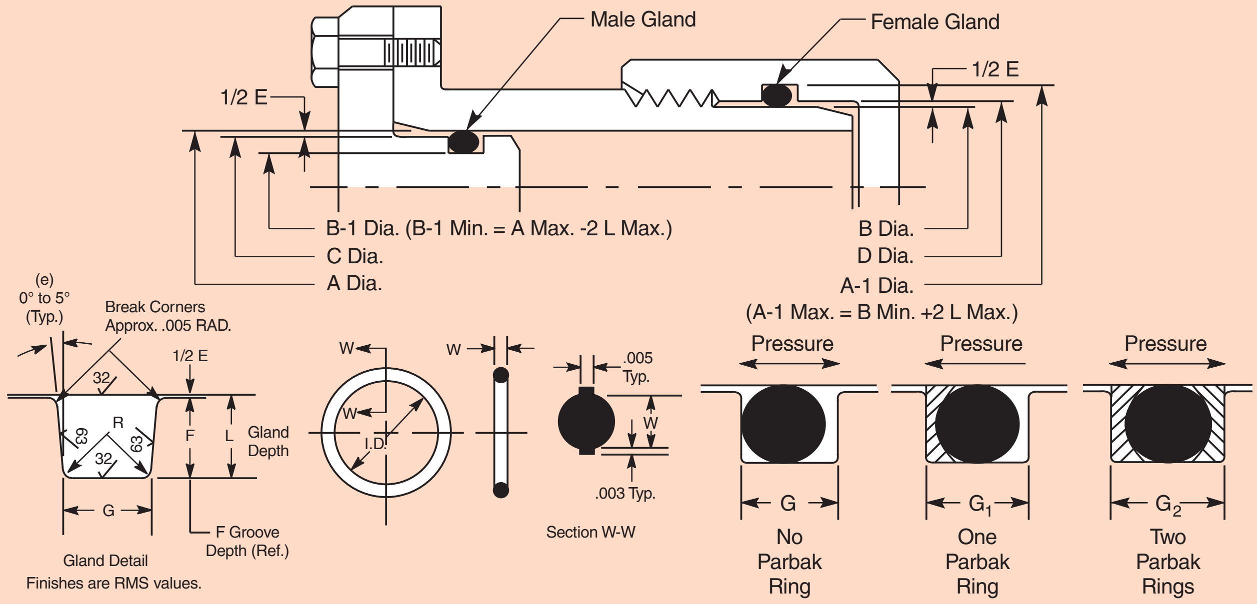
> The dotted line indicates the approximate linear change in the cross section (W) of an O-ring when the gland prevents any change in the I.D. with shrinkage, or the O.D., with swell. Hence this curve indicates the change in the effective squeeze on an O-ring due to shrinkage or swell. Note that volumetric change may not be such a disadvantage as it appears at first glance. A volumetric shrinkage of six percent results in only three percent

Guide for Design Table 4-2

If Desired Dimension is Known for	Select Closest Dimension in Column	Read Horizontally in Column	To Determine Dimension for
Bore Dia. male gland	A	B-1 C G	Groove Dia. (male gland) Plug Dia. (male gland) Groove width
Plug Dia. male gland	C	A B-1 G	Bore Dia. (male gland) Groove (male gland) Groove width
Tube OD female gland	B	A-1 D G	Groove Dia. (female gland) Throat Dia. (female gland) Groove width
Throat Dia. female gland	D	A-1 B G	Groove Dia. (female gland) Tube OD (female gland) Groove width

Design Guide 4-2: Guide for Design Table 4-2

Industrial Static Seal Glands



Refer to Design Chart 4-2 (below) and Design Table 4-2 for dimensions

metric conversion 32√ = .8√

Industrial O-Ring Static Seal Glands

O-Ring 2-Size AS568B-	W Cross-Section		L Gland Depth	Squeeze		E(a) Diametral Clearance	G - Groove Width			R Groove Radius	Max. Eccentricity (b)
	Nominal	Actual		Actual	%		No Parbak Ring (G)	One Parbak Ring (G₁)	Two Parbak Ring (G₂)		
004 through 050	1/16	.070 ±.003 (1.78 mm)	.050 to .052	.015 to .023	22 to 32	.002 to .005	.093 to .098	.138 to .143	.205 to .210	.005 to .015	.002
102 through 178	3/32	.103 ±.003 (2.62 mm)	.081 to .083	.017 to .025	17 to 24	.002 to .005	.140 to .145	.171 to .176	.238 to .243	.005 to .015	.002
201 through 284	1/8	.139 ±.004 (3.53 mm)	.111 to .113	.022 to .032	16 to 23	.003 to .006	.187 to .192	.208 to .213	.275 to .280	.010 to .025	.003
309 through 395	3/16	.210 ±.005 (5.33 mm)	.170 to .173	.032 to .045	15 to 21	.003 to .006	.281 to .286	.311 to .316	.410 to .415	.020 to .035	.004
425 through 475	1/4	.275 ±.006 (6.99 mm)	.226 to .229	.040 to .055	15 to 20	.004 to .007	.375 to .380	.408 to .413	.538 to .543	.020 to .035	.005

(a) Clearance (extrusion gap) must be held to a minimum consistent with design requirements for temperature range variation.
(b) Total indicator reading between groove and adjacent bearing surface.
(c) Reduce maximum diametral clearance 50% when using silicone or fluorosilicone O-rings.
(d) For ease of assembly, when Parbaks are used, gland depth may be increased up to 5%.

Design Chart 4-2: For Industrial O-Ring Static Seal Glands

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MACHINE DESIGN

April 12, 1979

O-RINGS FOR LOW-PRESSURE SERVICE

SEALS EASTERN, INC.

P.O. BOX 519 , RED BANK, NEW JERSEY 07701 (201) 747-9200

O-RINGS FOR LOW-PRESSURE SERVICE

DANIEL L. HERTZ, JR.
President Seals Eastern
Inc. Red Bank, N.J.

O-RINGS normally operate with about 15% squeeze to ensure a tight seal. But at system pressures below 400 psi, this amount of squeeze can cause high friction and excessively high actuating forces.

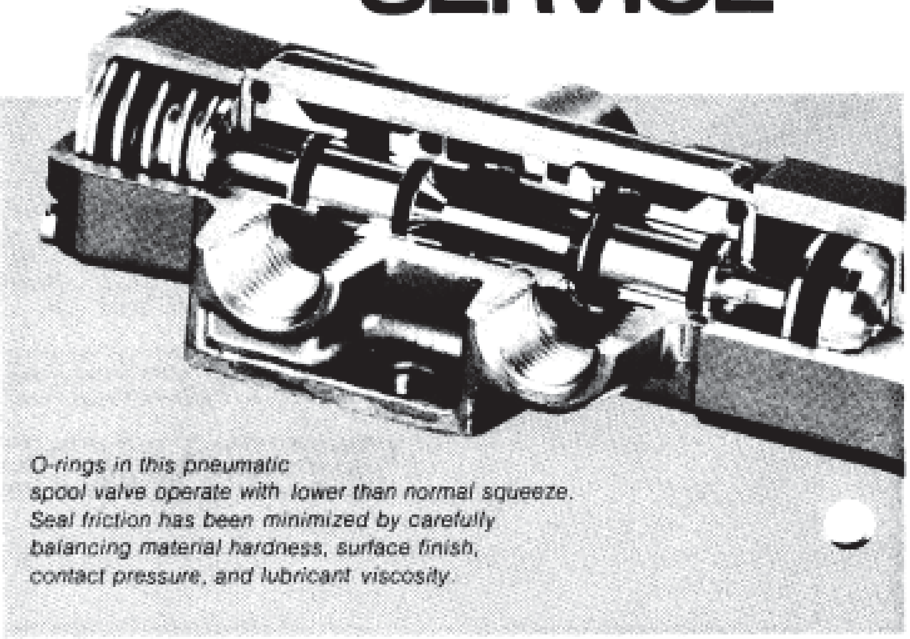
Reducing the amount of squeeze lowers friction to acceptable levels; however, lower squeeze also means lower sealing pressure and greater potential for leakage. This problem is aggravated by the stress relaxation characteristics of the seal material. Thus, an O-ring that seals well initially may lose resilience with time and fail suddenly.

Designing O-ring seals for low pressures, therefore, is not simply a matter of reducing the amount of squeeze: it involves a delicate balancing of material hardness, dimensional tolerances, stress relaxation, and friction characteristics.

Material Hardness

The initial phase of designing a low-pressure O-ring seal is the same as that for a conventional O-ring. Size and fluid compatibility requirements are evaluated and O-ring dimensions selected from a catalog. The catalogs usually list a recommended range of squeeze values, as shown in Table 1.

Squeeze is defined as the ratio

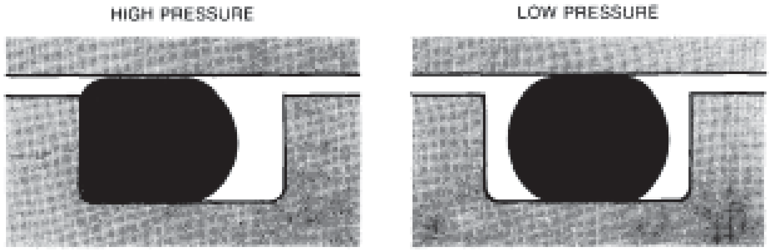


O-rings in this pneumatic spool valve operate with lower than normal squeeze. Seal friction has been minimized by carefully balancing material hardness, surface finish, contact pressure, and lubricant viscosity.

Table 1—Recommended Squeeze for O-rings

Seal Thickness (in.)	Squeeze (%)	Max % Squeeze Taken by Thickness Tolerance
0.070 ± 0.003	14.9-24.7	8.6
0.103 ± 0.003	8.1-15.0	5.8
0.139 ± 0.004	8.5-15.0	5.8
0.210 ± 0.005	8.3-13.5	4.8
0.275 ± 0.006	10.2-15.1	4.4

How Trouble Starts



High system pressures deform an O-ring into a D-shape, increasing contact area and sealing force. However, pressures below 400 psi are not strong enough to deflect the seal, and sealing force comes only from the compressive stress developed in the O-ring.

Most O-rings operate with enough "squeeze" to provide a reliable seal under almost any conditions. But low-pressure systems generate less squeeze, increasing the potential for leakage. Only a careful balancing of O-ring material properties ensures leak-free operation at low pressures.

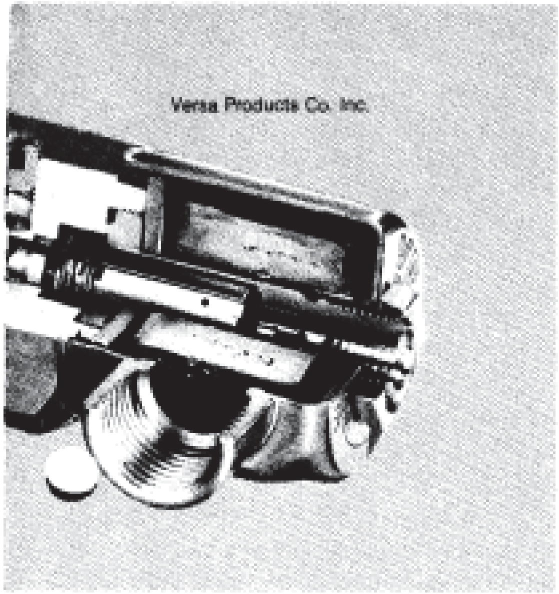


Table 2—Young's Modulus for O-ring Materials

Shore A Hardness (±2)	Young's Modulus (psi)
40	213
45	256
50	310
55	460
60	630
65	830
70	1.040
75	1340

of seal deflection to seal thickness, *x/d*. Generally, the seal is designed to operate at the high end of the squeeze range to ensure a tight seal. But at low system pressures, squeeze must be specified at the low end of the range.

The squeeze values listed in Table 1 are based on nominal seal thickness. One problem with specifying squeeze at the low end of the range is that dimensional tolerances can reduce the amount of squeeze actually placed on the O-ring. For instance, tolerance on the 0.070-in. thick O-ring is ±0.003 in. In the worst case (0.067-in. thickness), this tolerance can account for 8.6% of the squeeze allowance, leaving only 6.3% to be supplied by the fit between parts. In other words, an undersize O-ring has less material to compress and cannot be squeezed as tightly against the sealing surfaces. This problem can be minimized by specifying O-rings with one-half the normal dimensional tolerances. Such seals are available from most manufacturers at a premium price.

The next step in the design procedure is to calculate the compression force developed in the O-ring. This force is directly related to the sealing ability of the ring and is calculated from

$$F = \pi d D_w E \left[1.25\left(\frac{x}{d}\right)^{1.5} + 50\left(\frac{x}{d}\right)^{6} \right]$$

To use this equation, Young's Modulus must be determined first. This value depends on material hardness, and typical values are listed in Table 2. For most applications, a Shore A hardness of 70 is sufficient; therefore, the initial calculation of F is based on this hardness.

From the specified squeeze and seal thickness, contact area can be calculated from

$$b = 2.4x$$

Then, the peak contact stress can be found from

$$f' = \frac{4F}{\pi^2 b D_w}$$

If f' *is* greater than the system pressure, the O-ring will seal the joint. If f' *is* less than system pressure, the ring will leak and a material with a higher Young's Modulus must be specified, thereby increasing compressive force and contact stress.

Seal Friction

In low-pressure systems, seal friction can raise the required actuating pressure to many times that available in the system. Therefore, seal friction must be minimized for the system to operate properly. Generally, seal friction force should be maintained below 20 lb to keep actuating force within reasonable limits.

The friction force for an O-ring seal can be estimated from

$$F_f = \mu F$$

where coefficient of friction, μ, can change from 0.001 to over 10, depending on the operating conditions.

When more than one O-ring is used in the system, the friction forces from all the seals must be combined to determine the total friction force. If the calculated force is greater than

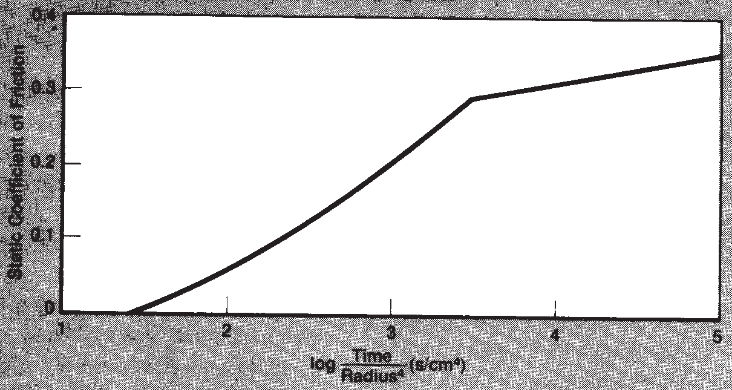
20 lb, a softer seal material should be used; this lowers Young's Modulus and compressive force. However, the change to a softer seal material must be made with care because a lower compressive force also means a lower contact stress. Thus, the change could lower peak contact stress below system pressure, resulting in a leaky seal.

If a softer material lowers contact stress too much, friction force must be lowered by reducing the coefficient of friction. This factor is a complex function of lubricant film thickness, time, contact stress, sliding speed, and surface finish.

Tests have shown that the longer a lubricated seal sits idle, the higher its static, or breakaway, coefficient of friction. Eventually, the friction coefficient reaches a maximum value almost as high as that for an unlubricated seal.

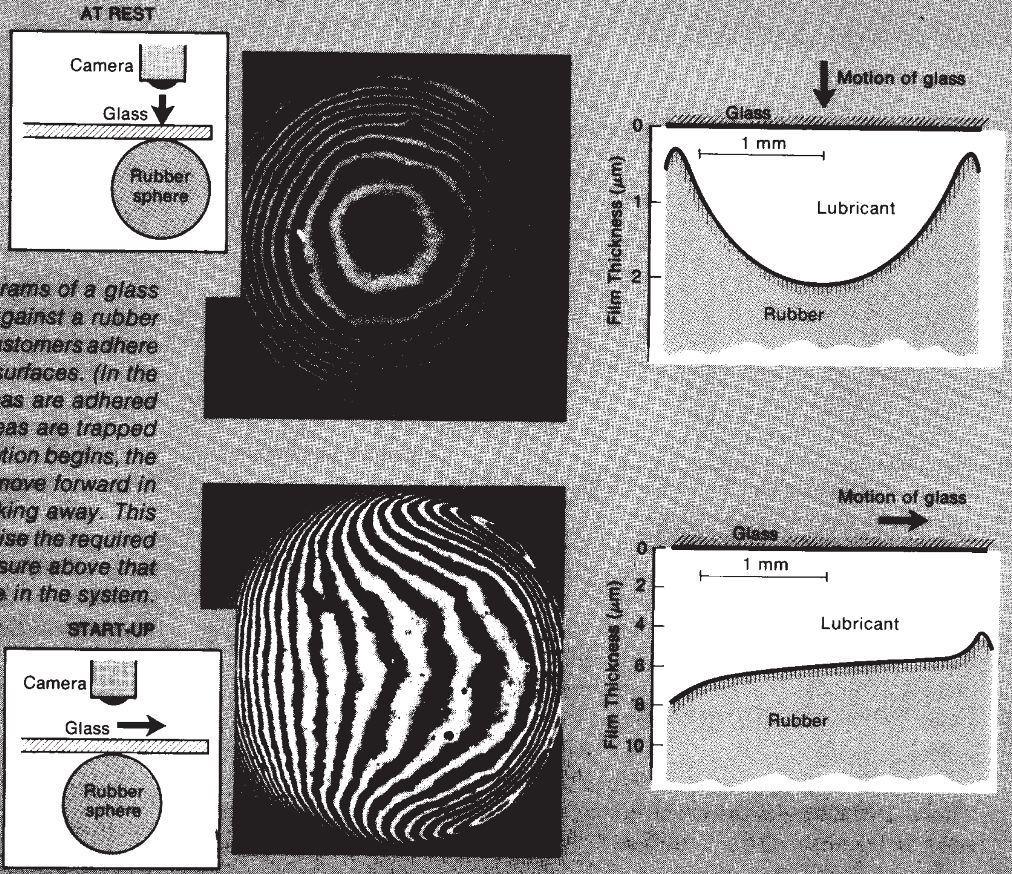
This increase with time is caused by the atomic interaction between the O-ring and its sealing surface, which causes the two surfaces to adhere tightly. The adhesive force can be quite high and eventually squeezes most of the lubricant from under the contact area. On start-up, the adhered O-ring peels away in progressive waves that break away and reform

Static Friction Rises as Seal Sits Idle



Tests of lubricated rubber sliding against a steel surface show how static friction increases the longer an O-ring sits idle. The increase is caused by the interatomic attraction between the rubber and steel, which slowly squeezes lubricant from under the contact surface.

Seal Adhesion Increases Friction



Optical interferograms of a glass plate pressing against a rubber sphere show how elastomers adhere to their sealing surfaces. (In the photos, dark areas are adhered rubber and light areas are trapped lubricant.) When motion begins, the adhered areas move forward in waves prior to breaking away. This phenomenon can raise the required actuation pressure above that available in the system.

on the moving surface, This action shears what little lubricant is present and traps it in the rubber folds.

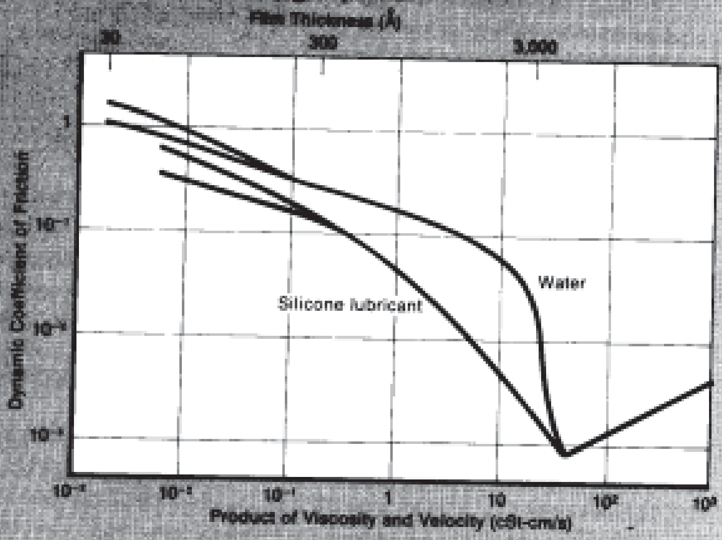
Seal adhesion can be minimized by optimizing surface finish and lubricant viscosity. Experience has shown that the optimum surface finish is 0.4μm. This finish leaves tiny pockets that collect lubricant, making it available at startup. Too smooth a finish leaves no pockets for the lubricant, while too rough a finish causes high wear.

A reciprocating seal should be lubricated with high viscosity lubricants because they produce a strong hydrodynamic film. This film resists displacement by the adhesive forces when the seal is stationary. A rotary seal, on the other hand, can be lubricated with low-viscosity lubricants because rotary motion aids development of a hydrodynamic film.

Thickness of the hydrodynamic film between asperities on the O-ring and sealing surface has been calculated as 6 x 10 in. Shear of this film is the prime cause of dynamic or running friction. In general, the dynamic coefficient of friction is a function of lubricant viscosity and sliding velocity. The coefficient generally starts high, decreases to a minimum value, then increases again. Thus, running friction can be minimized by optimizing viscosity and velocity.

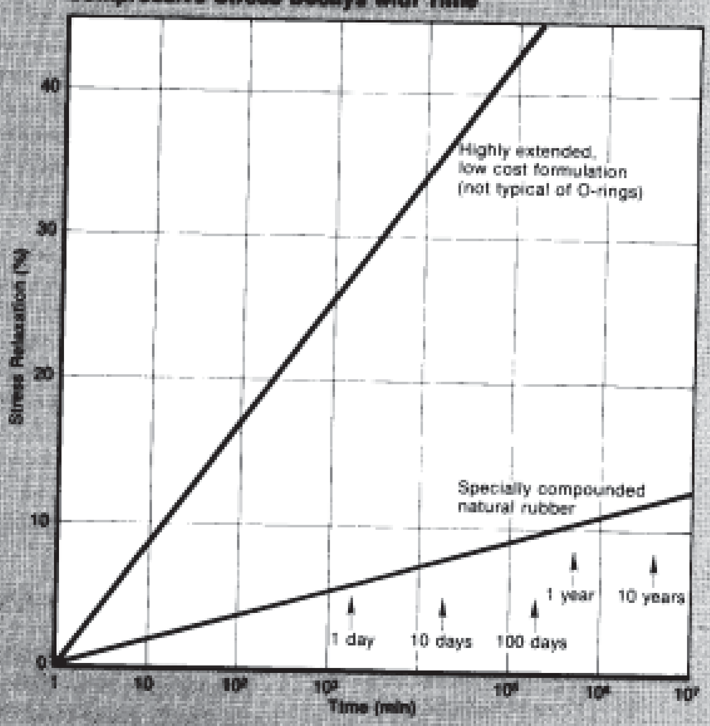
Several tests have been run to determine the effect of material-formula modifications on seal friction. The addition of materials such as graphite, molybdenum disulphide, and PTFE sometimes reduce friction, but the reduction is more likely a result of lowering Young's Modulus than a lubricating effect. Also, the incorporation in the elastomer of high-molecular-weight waxes and oils that migrate to the surface has proved unsuccessful in

Friction Drops at High Speeds



Dynamic (or running) friction is caused by viscous shear of the lubricant film. Tests of a steel ball sliding on a rubber surface show that at high speeds, friction is proportional to the square root of the viscosity-velocity product. This condition corresponds to hydrodynamic lubrication. Friction rises at lower speeds as the contact approaches boundary conditions.

Compressive Stress Decays with Time



Relaxometer tests provide data on the stress relaxation rates of O-ring materials. The relaxation rate for natural rubber generally is lower than that for rubber with additives. Knowing the relaxation rate allows prediction of a seal's useful life.

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lowering friction.

Surface treatments have been more successful. Halogenation with chlorine or bromine reduces friction by lowering the surface free energy (and, therefore, attraction force) and by creating lubricant pockets. Fluorination, although far less common, has similar effects.

Surface treatments of PTFE-resin binder coatings and tumble treatment in molybdenum disulphide or graphite have been used along with silicone oil dips with limited success. Also, polymerization of monomers on the O-ring surface with plasma techniques offers some improvement; however, the techniques are costly and slow. Finally, the grafting onto the seal surface of high-molecular-weight oils having reactive end groups shows promise for the future.

Stress Relaxation

The useful sealing life of an O-ring depends on two viscoelastic material properties: compression set, the residual deformation of a material after the load is removed; and stress relaxation, the decrease in stress after a given time at a constant strain. These properties reduce the resiliency of the seal material and must be taken into account when specifying material hardness.

When a seal is under constant compression, the initial stress decays at a rate proportional to the logarithm of time. The stress relaxation rate varies with material composition, temperature, and fluid reactions. Typical values range from 0.5% to 10% per time decade. (The time from 1 to 10 min is designated as one decade, as is the much longer time from 1 to 10 weeks.)

The result of stress relaxation is that peak compressive stress eventually drops below system pressure, and the seal leaks. Thus, stress relaxation effects must be factored into the determination of material hardness and compressive stress.

Stress relaxation rates are available from O-ring manufacturers; however, the ratings may be for a temperature or fluid condition different from that required. If the correct data are not available, the stress relaxation rate can be determined from a simple relaxometer test, such as that described in ASTM D-1395, or with a Lucas relaxometer.

Once the stress relaxation rate is known, the time for peak contact stress to equal system pressure can be calculated easily. In general, if the calculated time period produces a seal life lower than 20 x 10^6 cycles, then a harder seal material (higher Young's Modulus and higher compressive stress) must be used.

Temperature Effects

The effects of operating temperature are more pronounced for low-squeeze O-rings because the seal has a lower tolerance for change. The volumetric expansion rate for rubber is about 15 times higher than that for steel. Therefore, at high temperatures, insufficient groove volume can produce expansion forces that extrude the seal into the clearances. This problem can be minimized by increasing groove dimensions to provide sufficient room for expansion.

Lowering operating temperature results in a continuous decrease in the physical volume of the seal. Eventually, the seal reaches its so-called glass-transition temperature, where it seals only along two thin lines. Further reduction of temperature shrinks the seal even more, resulting in leakage.

The glass-transition temperature corresponds to 100% compression set. At this temperature, the seal can shatter like glass if subjected to a shock or impact load. Values of glass transition temperature for O-ring materials are listed in Table 3. To avoid low temperature problems, O-rings should operate at temperatures 10° to 15°F higher than those listed in the table.

Table 3-Glass-Transition Temperatures for O-ring Materials

Material	Transition Temperature (°F)
Nitrile (NBR) 34% ACN	-21
38% ACN	-13
Fluoro Rubber (FKM)	-4
Silicone (VMQ)	-85
Chloroprene (CR)	-40
Ethylene Propylene (EPDM)	-85

Nomenclature

b = Seal contact area, in.^{2}
D_i = Seal inside diam, in.
D_m = Seal mean diam, in.
D = Seal outside diam, in.
d = Seal thickness, in.
E = Young's Modulus, psi
F = Compressive load, lb
F_f = Friction force, lb
f' = Peak contact stress, psi
x = Seal deflection, in.
μ= Coefficient of friction

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14th International Conference on Fluid Sealing, Firenze, Italy,
6-8 April 1994, Organised by BHRGroup Limited, Cranfield,
Bedford, MK43 0AJ, UK

STRESSES AND DEFORMATION OF COMPRESSED ELASTOMERIC O-RING SEALS

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ABSTRACT

The sealing capability of an elastomeric O-ring seal depends upon the contact stresses that develop between the O-ring and the surfaces with which it comes into contact. It has been suggested in the literature that leakage will occur when the pressure differential across the seal just exceeds the initial (or static) peak contact stress. The stresses that develop in compressed O-rings, in common cases of restrained and unrestrained geometries (grooved and ungrooved), are investigated using the finite element method. The analysis includes material hyperelasticity and axisymmetry. Contact stress profiles, and peak contact stresses are plotted versus squeeze, up to 32 percent. The contact width, which is the length of the O-ring that touches the retaining surfaces when viewed from the cross-section, is also determined. Expressions are derived empirically to predict the peak contact stress and the contact width. These expressions are also compared to those obtained by other researchers (who assumed plain strain conditions) and conclusions to their validity are drawn.

NOMENCLATURE

b = contact width
d = wire diameter
D = nominal (mean) diameter
D_{def} = deformed mean diameter
E = modulus of elasticity
h = deformed O-ring thickness
l = groove width
q = chord diameter
Q = normalized chord diameter, q/d

S = compressive stress
x^* = displacement
x = radial coordinate
X = radial distance from O-ring center
y = axial coordinate
Y = axial distance from O-ring center
δ = normalized squeeze (i.e., fractional compression)
δ_{ij} = equivalent normalized squeeze

INTRODUCTION

Elastomeric O-ring seals have a broad range of service conditions that make the O-ring ideal for static and dynamic sealing functions. Its ability to seal on relatively rough surface finishes offers one of the economical solutions to sealing problems. Elastomeric O-rings are capable of undergoing large deformations under compression. Hence, grooves are often used to restrict this deformation, resulting in improved sealing capabilities and prevention of creep and extrusion. The complex geometry confederated with the deformation of restrained O-rings and nonlinear material hyperelasticity render analytical solutions infeasible. This complicated geometry and experimental inconvenience make experimental data hard to obtain. It is here where the utility of the finite element method becomes prominent. By performing a FEM analysis, comparison of the results can be made to cases where experimental data is procurable. Then, conclusions can be drawn as to the validity of FEM solutions of geometries where experimental data cannot be easily obtained.

The stiffness relationships associated with the compression of elastomeric torroidal O-ring seals have recently been studied by Green and English (1992) for the cases shown in Figure 1. That work provided empirical expressions for the prediction of compression forces and stiffnesses at squeeze levels up to 32 percent. Sealing capabilities, however, depend upon the stress related parameters at the interface. It was as early as Lindly's work (1967), who proposed that leakage onset occurs when the pressure differential across the seal, P, barely exceeds the initial (or static) peak contact stress, S_{max} (i.e., $P \ge S_{max}$). It should be noted that any increase in the contact stress, caused by the pressure loading, is ignored using this theory. Simplified expressions relating contact width to peak contact stress have been developed in order to predict S_{max}. Assuming unrestrained loading and plain strain Lindley (1967) obtained the contact width, b, normalized with respect to the wire diameter, d, [see Figures 2(a) and 3]

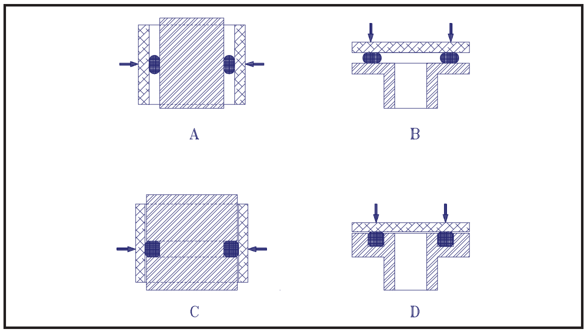

Figure 1 *(A) Unrestrained Radial Loading. (B) Unrestrained Axial Loading. (C) Restrained Radial Loading. (D) Restrained Axial loading.*

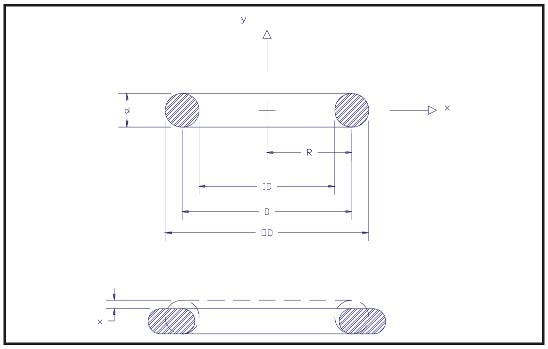

Figure 2(a) *Unrestrained geometry*

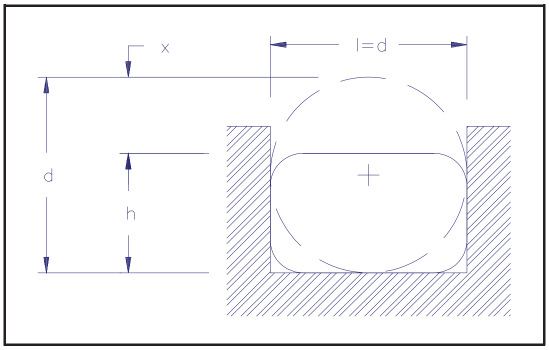

Figure 2(b) *Section of a restrained O-ring*

$$\frac{b}{d} = \left[\frac{6}{\pi} \; (1.25\delta^{\frac{3}{2}} + 50\delta^{6}) \right]^{\frac{1}{2}} \qquad (1)$$

and the peak contact stress, S_{max}, normalized with respect to the modulus of elasticity, E,

$$\frac{S_{\max}}{E} = \left[\frac{16}{6\pi} \; (1.25\delta^{\frac{3}{2}} + 50\delta^{6}) \right]^{\frac{1}{2}} \qquad (2)$$

Here $\delta = x^*/d$, is the normalized squeeze, i.e., the compressive displacement, x^*, divided by the wire diameter, d. The first term in the equations was obtained using Hertzian theory, and the second term was added to correct for empirical data at high squeeze levels.

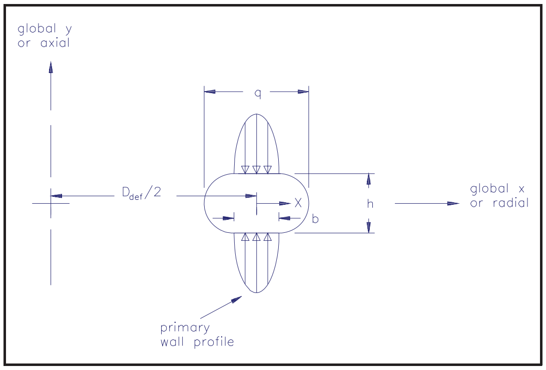

Figure 3 *Stress profile definition for unrestrained axial loading.*

Wendt (1971) examined stress distributions in O-rings and X-rings, with emphasis on groove design. The most significant result of his work includes an expression for contact width of an unrestrained axially loaded O-ring. Molari (1973), who examined the stress and contact related parameters of O-rings using photoelastic techniques, lent credence to the findings of Wendt and was one of the firsts to examine the problem of restrained O-ring seals. Molari's work, however, considered one lateral wall only. Dragoni and Strozzi (1988) also used photoelasticity, but investigated an O-ring restrained between two lateral walls as defined in Figure 2(b). These researchers assumed that plane strain conditions were prevailing and thus did not address the condition of axisymmetric loading.

George, Strozzi, and Rich (1987) supported Lindley's results using a finite element code developed especially for the task. Experimental data taken was compared to the results obtained by numerical solution. Later Dragoni and Strozzi (1988) examined the case of laterally restrained O-ring seals in a groove using a modification of the FEM code. The results were also limited to plain strain conditions. Using Lindley's model of Hertzian contact stress, they offered an approximate analytical method for "moderately" compressed O-rings up to about 15 percent squeeze. A stress related parameter was given in terms of a normalized deformed chord diameter, Q = q/d (see Figure 3). By fitting a curve to experimental results (Strozzi, 1986), they characterized Q as a function of δ

$$Q = 1 + 0.415\,\delta + 1.15\,\delta^{2} \equiv f(\delta) \qquad (3)$$

where the right-hand side emphasizes the functional form of the equation, as needed for later derivations. Using only the first term of Eq. (2) the peak contact stress was given as

$$\frac{S_{\max}}{E} = \sqrt{\frac{10}{3\pi}}\;\delta^{\frac{3}{4}} \qquad (4)$$

In a compromise between accuracy and simplicity they prefer Wendt's (1971) description of the contact width

$$\frac{b}{d} = \frac{3}{2}\,\delta^{\frac{2}{3}} \tag{5}$$

At this point Dragoni and Strozzi (1988) developed an equivalent normalized squeeze, δ_{ij}, which can be used in modeling the characteristics of restrained O-rings. The notation ij is used to denote the effects of the particular groove wall defined perpendicular to either the i or j direction. For example, for restrained radial loading the equivalent squeeze in the x direction, δ_{xy}, denotes the squeeze associated in part to the squeeze directly applied in the x direction and in part to the constraint of the walls which are perpendicular to the y direction. Alternately, for restrained axial loading, δ_{yx} is the equivalent normalized squeeze on the groove walls perpendicular to the top/bottom compressive surfaces. By definition δ_{yx} is estimated as a ratio. The numerator is the difference between two terms: (i) a virtual deformed chord diameter along the y-axis caused by the compression δ_{xy} [and is calculated by substituting δ_{xy} into Eq. (3)]; (ii) the deformed O-ring thickness, *h* [shown in Figure 2(b)]. The denominator is the undeformed wire diameter, d. Hence,

$$\delta_{yx} = \frac{d \cdot f(\delta_{xy}) - h}{d} = f(\delta_{xy}) - \frac{h}{d} \tag{6}$$

where *f* is the functional given in Eq. (3). Applying similar reasoning in the perpendicular x-direction, and using the groove width, *l* (as the O-ring thickness), gives the equivalent squeeze

$$\delta_{xy} = \frac{d \cdot f(\delta_{yx}) - l}{d} = f(\delta_{yx}) - \frac{l}{d} \tag{7}$$

These relationships provide estimates for any groove dimensions (allowing the possibility of a gap between the undeformed O-ring and the lateral walls, i.e., $l > d$). Next, we define the particular case (subscripted here with the letter *t*) where the groove lateral walls are tangent to the undeformed O-ring, i.e., $l = d$ as shown in Figure 2(b). Combination of Eqs. (6) and (7) yields

$$\delta_{tyx} = f(\,f(\delta_{tyx}) - 1\,) - \frac{h}{d} \tag{8}$$

where the functional form of Eq. (3) is used repeatedly. Eq. (8) can be solved iteratively for δ_{tyx}. Then δ_{txy} is calculated by Eq. (7), and by substitution into Eqs. (4) and (5) the normalized peak contact stress and the normalized contact width can be determined in the respective directions.

Since in all the aforementioned work plain strain conditions prevailed, it implies that no distinction exists between axial and radial loading. This was found invalid in some important loading conditions for the compression force and stiffness (Green and English, 1992). The loading cases in Figure 1 are investigated here to determine contact stresses and contact widths under axisymmetric conditions. These include a highly frictional ("unlubricated") contact where surface sliding is prevented in an unrestrained axial loading; and frictionless ("perfectly lubricated") contacts where forceless surface sliding exist in axial, radial, restrained, and unrestrained loadings. The commercial code ANSYS and the nonlinear techniques, described in Green and English (1992) and in greater detail in English (1989), are utilized. Reduced integration is exclusively applied as it was found to give most accurate results. These are best represented in normalized forms, proven indifferently to the aspect ratio, d/D. Convergence is discussed in whole in the last two references.

STRESS PARAMETERS RESULTS

Vernacular for this discussion includes "primary wall" and "lateral wall." The primary wall or walls are the surfaces which move together to force the compression of the O-ring. The lateral walls are the sides of the restraining groove. Initially all walls are tangent to the undeformed geometry of the O-ring. For the axial case the top and bottom walls are the primary walls, and for the radial case the inside and outside walls are the primary walls.

Contact stress profiles are plotted as the normalized nodal stress component, S_y/E or S_x/E, versus the normalized x or y coordinates (X/d or Y/d), respectively. For example, Figure 3 shows the X-coordinate, defined relative to the deformed nominal radius, $D_{def}/2$. X is the horizontal distance from the center of the O-ring cross-section to a node along the perimeter. The normalized stress of interest here is the y-component of the nodal stress, S_y/E. In the plots E_o is shown instead to designate neo-Hookean material representation, justified for use by Green and English (1992).

The first contact pressure profile, shown in Figure 4, was produced from a quadrilateral element mesh, using reduced integration (Green and English, 1992). Six profiles were chosen from ten load steps of 3.2 percent squeeze each, and are represented by the symbols given in the legend. Two other features can be extracted from the figure: (i) The normalized deformed chord diameter, Q=q/d, is the farthest distance between two opposite points on each profile, and (ii) the normalized contact width, b/d, is the distance between two points on each profile where the curve intersects the zero stress line. Notice that Q and b/d are different at each load step. Finally, there is a condition of symmetry about the x-z plane, of the global coordinate system, such that both the top and bottom profiles are identical and, therefore, only one is shown. While the profiles appear symmetric about X/d=0, close examination of the results reveals otherwise. This is due to the imposition of axisymmetric conditions upon the solution (rather than plain strain conditions).

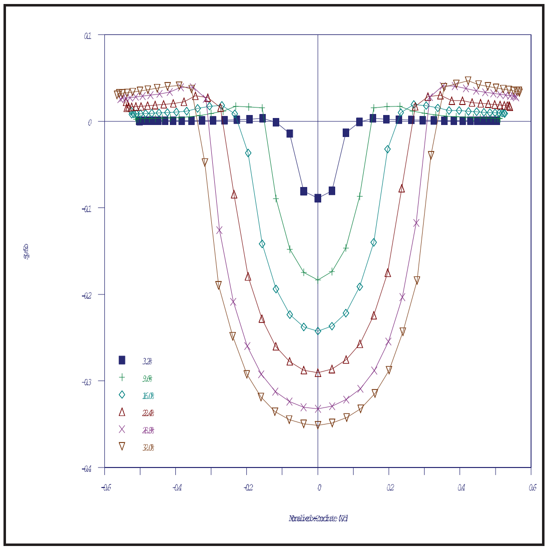

Figure 4 Primary wall contact stress profile for unrestrained - perfectly lubricated axially loaded O-ring.

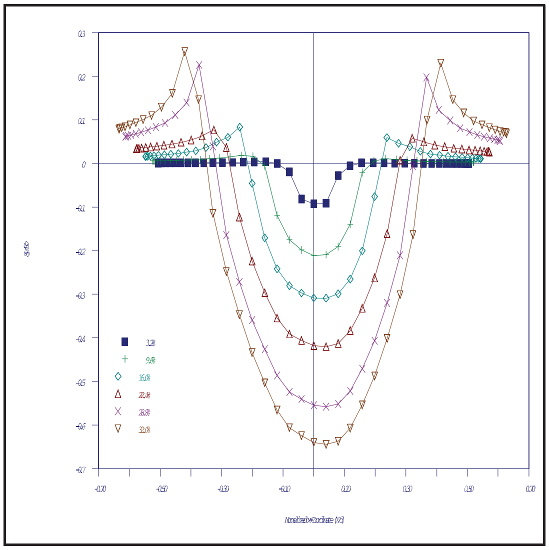

Figure 5 Primary wall contact stress profile for unrestrained - unlubricated axially loaded O-ring (the only fixed case)

Figure 5 shows the contact stress profile for the unlubricated case of unrestrained axial loading (where a coefficient of friction 0.9 was used). The asymmetry is much more pronounced in this case. It should also be noted that the peak value of S_y is roughly 85 percent higher than that for the lubricated case. This increase in peak contact stress can be explained by the fact that the deformed nominal diameter, D_{def}, does not expand as the load increases. Actually D_{def} decreases as the loading is applied, although, only a small amount. A comparison of Figures 4 and 5, shows that friction has a dominating role in stress profile development.

Turning to radial compression, Figure 6 shows how the contact stress profiles are defined. S_x is the stress component of interest here, and Y is the vertical distance from the center of the O-ring cross section to a node on the perimeter. q is the deformed chord diameter parallel to the compressive surfaces. Because the model is not symmetric about the y-z plane the stresses on both walls, the inside primary wall and the outside primary wall, must be examined.

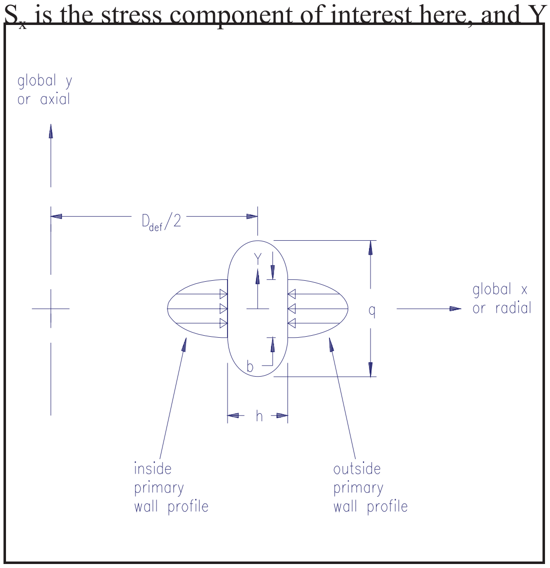

Figure 6 *Stress profile definition for unrestrained radial loading.*

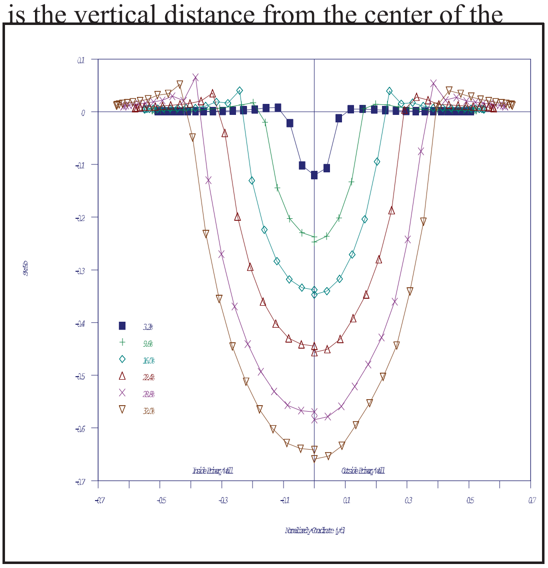

Figure 7 *Contact stress profile for unrestrained radial loading. Half profiles for the inside and outside primary walls are shown.*

The stress profiles for unrestrained radial loading are shown in Figure 7. Here we notice that the outside primary wall profile is larger than the inside primary wall profile. This is due to nominal diameter contraction during axisymmetric loading. Figure 7 exemplifies again the necessity of using an axisymmetric model to represent the O-ring. While the difference between the inside and outside walls is minor for this particular restraining configuration it could be much more significant for a different type of loading.

Next up for attention are the restrained cases. Figure 8 gives the profile definition for restrained axial loading. Note that the profiles are symmetric about the x-z plane; however, they

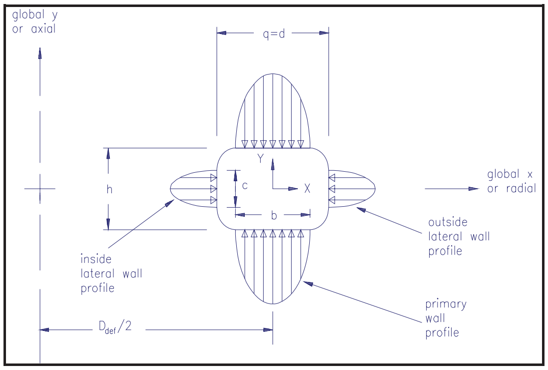

Figure 8 *Profile definition for restrained axial loading.*

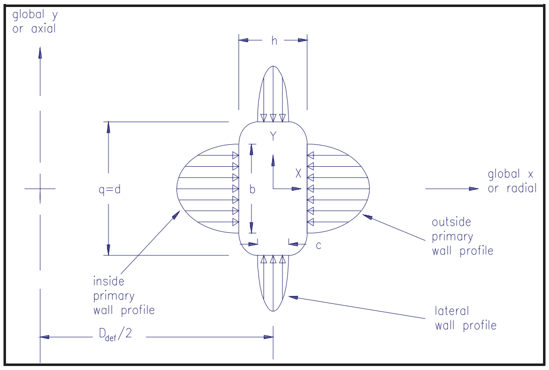

Figure 9 *Profile definition for restrained radial loading.*

are not symmetric about the y-z plane. The restrained radial profile definition can be seen in Figure 9. This profile is similar to the previous profile in that the symmetry planes are the same. However, the primary and lateral walls are different. Note the definitions for the contact widths *b* and *c* on the primary and lateral walls, respectively.

Figures 10 and 11 show the profiles for the primary and lateral walls, respectively, for the restrained axially loaded O-ring. The half profiles for the inside and outside lateral walls show that there is a difference between lateral wall profiles where axisymmetric loading is concerned. Here the peak value of S/E$_o$ is 17 percent larger for the primary wall than that for the lateral wall. Figures 10 and 11 show an interesting formation of significant compressive normal stresses at the O-ring surface that is in contact with the respective retaining walls. Molari (1973), using bidimensional photoelastic techniques, obtained similar profiles; however, the surface stresses did not show up in his work because they were masked by the physical boundary of the test apparatus.

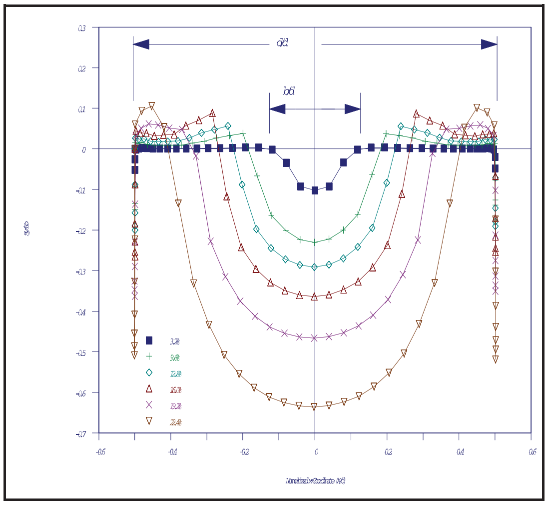

Figure 10 *Contact stress profile for primary wall of restrained axial loading.*

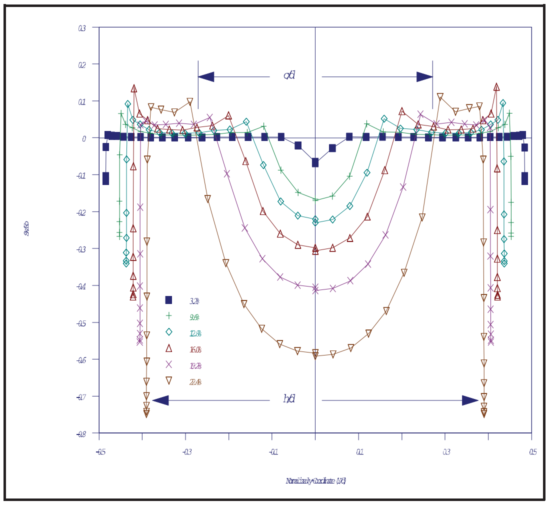

Figure 11 *Contact stress profile for inside and outside lateral walls for restrained axial loading.*

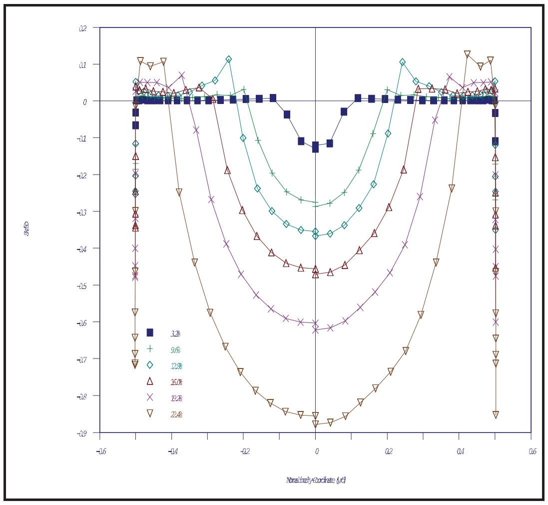

Figure 12 *Contact stress profile for inside and outside primary walls for restrained radial loading.*

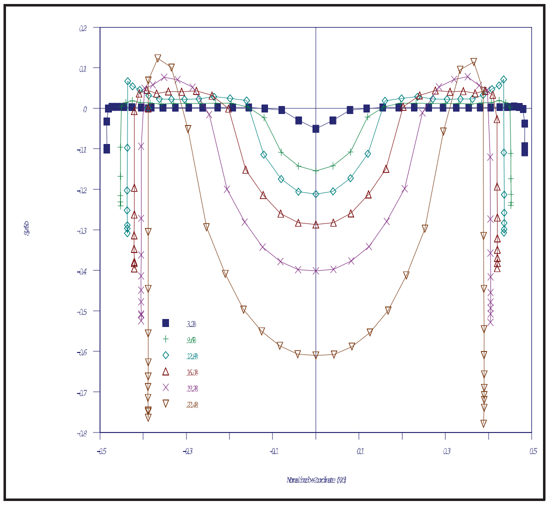

Figure 13 *Contact stress profile for lateral wall of restrained radial loading.*

Next we consider the case of restrained radial loading. Contact stress profiles for the primary and lateral walls are given in Figures 12 and 13, respectively. In Figure 12 a difference exists in the half profiles for the inside (left) and outside (right) primary walls. Peak contact stress values for the primary walls are about 34 percent greater than those for the lateral wall. Also here there are surface stresses at the retaining walls.

The final case under investigation is that for plane strain loading. Figure 14 shows the stress profile for unrestrained plane strain loading. Plane strain loading profiles for the restrained case are given in Figures 15 and 16. In this case there is symmetry about both the x-z and y-z planes. Hence, there is no need for a half profile plot of inside or outside walls. It can be seen by comparing the stress profiles from plain strain loading to all previous cases that there is a significant difference in the profiles, especially in radial loading and peak contact stresses. It is, therefore, concluded that plain strain conditions do not commonly describe O-ring compression.

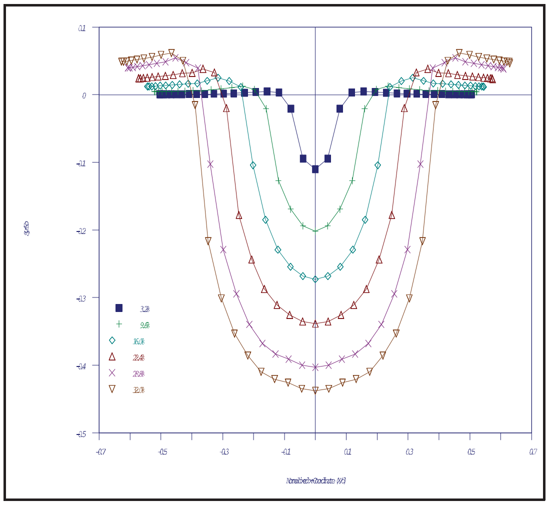

Figure 14 *Contact stress profile for unrestrained plane strain loading primary wall.*

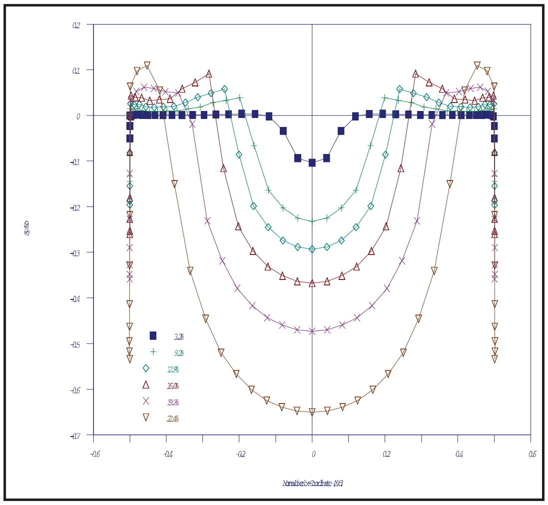

Figure 15 *Contact stress profile for restrained plane strain loading primary wall.*

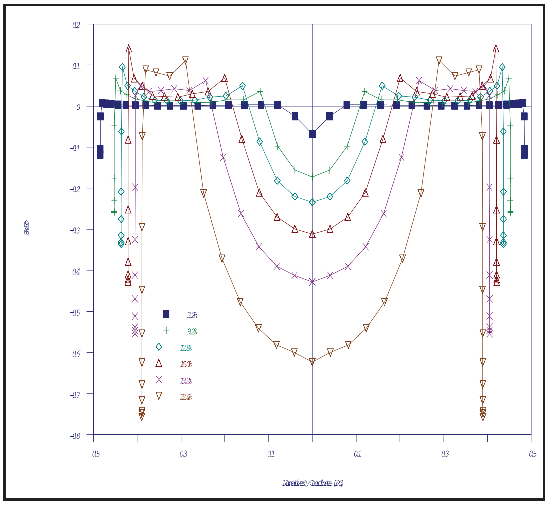

Figure 16 *Contact stress profile for plane strain loading lateral walls.*

PEAK CONTACT STRESS

Peak contact stress is of interest in order to estimate the ability of the O-ring to form a seal (Lindley, 1967). Figure 17 contains the compilation of peak contact stresses for unrestrained loadings, i.e., axial, radial, and plane strain. It can be seen that the primary wall peak contact stress response for radial loading is the greatest. This is followed by the stress response of the unlubricated axial loading, which is significantly greater than its lubricated correlative. Furthermore, we see that both Lindley's predictions underestimate the peak contact stress throughout the loading range with the exception of the plane strain case. The latter case agrees relatively well with the prediction Lindley derived from Hertzian theory (Eq. (2), but without the second correction term). Note that the empirically added correction term causes an overestimation of the peak contact stress for squeezes above 24 percent.

Lindley gives no prediction for the peak contact stress of a restrained O-ring. The comparison to Dragoni and Strozzi (1988) prediction can be seen in Figures 18 and 19. Their prediction agrees relatively well with the axial and plane strain results, but, underestimates the peak contact stress for radial loading. Where the lateral wall is concerned Strozzi's prediction underestimates the peak contact stress response for all cases. It is interesting that the lateral wall response for radial loading is less than the responses for both axial and plane strain cases. It seems from this comparison, that Strozzi's model is relatively accurate for predicting the peak contact stress for the primary wall of restrained axial and restrained plane strain cases, but it breaks down in radial loading and where the lateral wall is concerned.

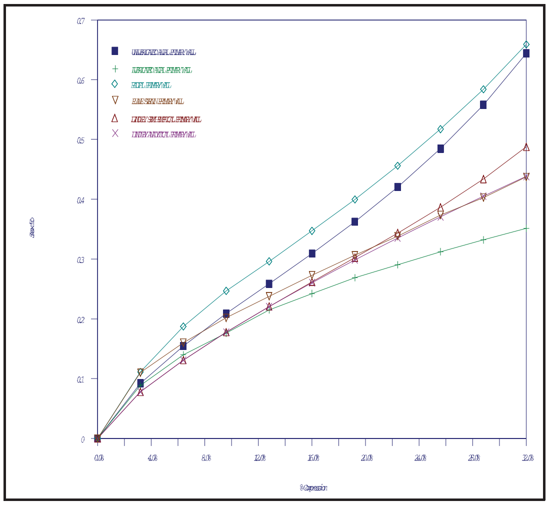

Figure 17 *Peak contact stress results for unrestrained loading.*

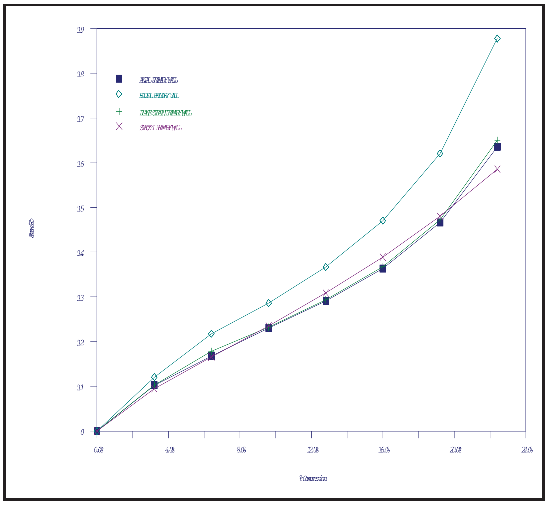

Figure 18 *Peak contact stress results for restrained loading primary wall.*

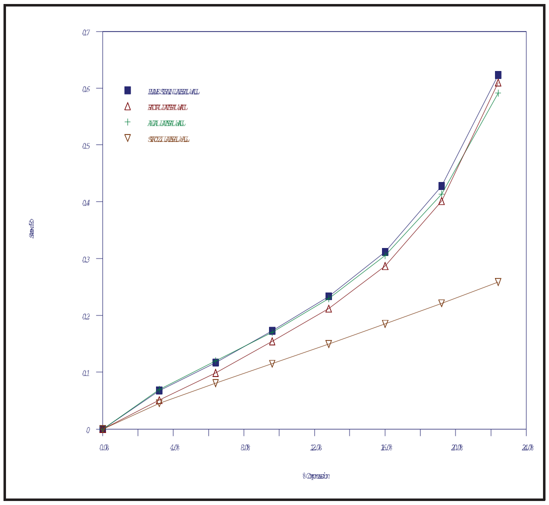

Figure 19 *Peak contact stress for restrained loading lateral wall.*

The lack of agreement to analytical work prompts the determination of the peak contact stress from the numerical data. This is accomplished by fitting a polynomial to the numerical results. Second and third order polynomials are proposed as follows:

$$\frac{S_{\max}}{E} = a\delta + b\delta^2 \tag{9}$$

$$\frac{S_{\max}}{E} = c\delta + d\delta^2 + e\delta^3 \tag{10}$$

where the coefficients are given in Table 1. While Eq. (10) produces an excellent fit, Eq. (9) may be used for simplicity with satisfactory results.

Table I *Least squares coefficients for the calculation of the peak contact stress*

Loading Case	a	b	c	d	e
Unrestrained lubricated axial primary wall	2.0572	-3.1417	2.6296	-8.8589	12.8391
Unrestrained unlubricated axial primary wall	2.0090	-0.2211	2.8383	-8.5051	18.6031
Unrestrained lubricated radial primary wall	2.4891	-1.5967	3.4591	-11.2857	21.7583
Unrestrained lubricated plane strain primary wall	2.2340	-2.8961	3.0373	-10.9192	18.0171
Restrained axial primary wall	1.9715	3.1502	3.8295	-23.0013	82.6963
Restrained axial lateral wall	1.0497	6.4631	2.6584	-16.1793	71.5999
Restrained radial primary wall	2.1587	6.7729	4.9363	-32.3232	123.630
Restrained radial lateral wall	0.5844	8.7930	2.3003	-15.3593	76.3744
Restrained plane strain primary wall	1.9933	3.2711	4.0499	-25.6765	91.5384
Restrained plane strain lateral wall	0.9400	7.5182	2.6698	-16.8290	76.9908

CONTACT WIDTH RESULTS

In Figure 3 the contact width, b, is defined as the length of the circumference of the O-ring, from a cross-sectional view, that makes contact with the compressing surface. This information is useful in calculating the total load required to compress the O-ring and in determining the contact stress profile when using Hertzian theory. Both Lindley (1967) and Wendt (1971) propose expressions which approximate the contact width as a function of compression for unrestrained loading, and Dragoni and Strozzi (1988) propose corresponding expressions for restrained loading. As illuminated in the introduction these were developed assuming plain strain conditions. This section compares results obtained in this research to those predicted by the other researchers.

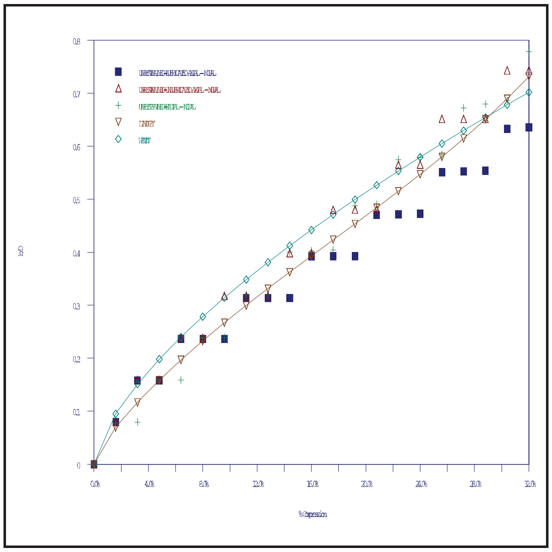

Figure 20 *Normalized contact width as a function of compression for unrestrained loading. Included are Lindley and Wendt's prediction as well as the results from nodal displacements.*

The error associated with the numerical results is significant when considering the technique used to obtain the contact width. In Figure 20 there are several data points with approximately identical values of b/d. This comes from the discrete points used to obtain the contact width. As the loading is applied, new nodes may or may not come into contact with the compressing surfaces. Several data points with the same value of b/d imply that no new nodes have come into contact during that portion of the loading sequence. Physically the contact width response is a continuous phenomenon. By discritizing the mesh we turn this response into a discrete phenomenon. Consequently the first data point, of those which have the same magnitude of b/d, is the most accurate. Therefore, the contact width shown is an underestimation of the actual contact width.

Contact width data, for the cases of unrestrained loading can be seen in Figure 20. The numerical results from the unlubricated axial and radial cases agree well with Wendt's prediction, Eq. (5), up to roughly 24 percent compression. Lindley's prediction, Eq. (1), underestimates the numerical contact width throughout the load range. For the lubricated axial load case Wendt's expression begins to overestimate the contact width at approximately 10 percent compression while Lindley's expression underestimates, at low compression, and over estimates it at higher compressions. From this we may conclude that Wendt's prediction is good for small compressions and that Lindley's prediction should generally not be used.

Now we turn to restrained loading while probing Strozzi's approach as outlined from Eq. (3) through Eq. (8). To do so a second order polynomial [similar to Eq. (3)] must first be fitted to the data obtained from the FE analysis of the three unrestrained loading results (lubricated and unlubricated axial loading, and radial loading). By extracting nodal displacements from the output it is possible to obtain the normalized deformed chord diameter. For the unlubricated-unrestrained axial loading case the fitted polynomial is

$$Q = 1 + 0.210\delta + 0.657\delta^2 \qquad (11)$$

For the lubricated-unrestrained axial loading case the polynomial obtained is

$$Q = 1 + 0.361\delta + 1.547\delta^2 \qquad (12)$$

and for the unrestrained radial loading case the polynomial obtained is

$$Q = 1 + 0.355\delta + 1.626\delta^2 \qquad (13)$$

The contact width results for restrained loading can be examined in Figures 21 and 22 for the primary wall and lateral walls, respectively. Looking at Figure 21 we see that the predictions

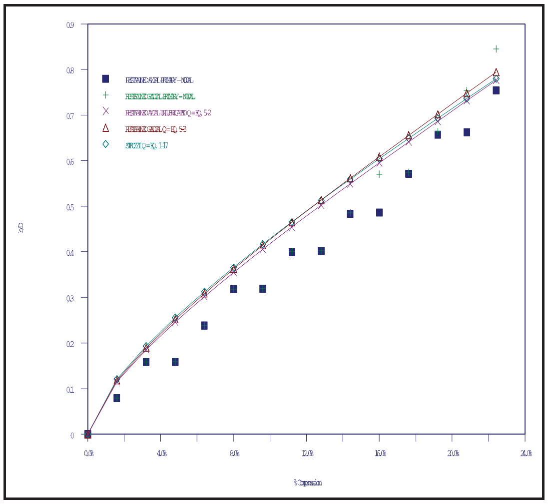

Figure 21 *Contact width as a function of compression for the primary wall of a restrained O-ring.*

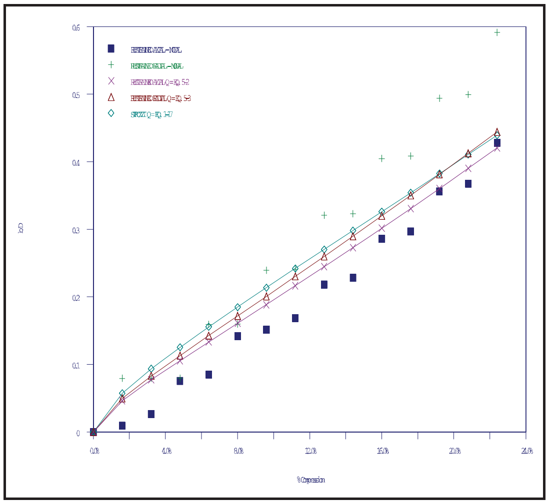

Figure 22 *Contact width as a function of compression for the lateral wall of a restrained O-ring.*

in the solid lines, using Eqs. (12) and (13) as well as Strozzi's Eq. (3), produce overestimates compared to the numerical nodal contact width at the primary wall for compressions below 19 percent. At the extreme compressions the normalized chord diameter technique underestimates the contact width of the primary wall of a restrained radially loaded O-ring. However, as mentioned above, these numerical data points underestimate the actual contact width. Therefore, the prediction may be considered to give a fairly accurate prediction of contact width.

In Figure 22 we see that Strozzi's technique is a closer approximation to the lateral wall contact width of a restrained axially loaded O-ring. But, the figure also shows that the technique is a gross underestimate of the lateral wall contact width for a restrained radially loaded O-ring. Without more experimental results it is hard to make a firm statement as to the accuracy of either Strozzi's approach or the current numerical approach. It can generally be said, however, that the numerical results underestimate the actual contact width and, therefore, the method Strozzi suggests is valid, with exception to the radially loaded case at the lateral wall.

CONCLUSIONS

Acquisition of the stress parameters requires more effort in the postprocessing phase of a finite element analysis, but compared to the extensive testing equipment required for experimental stress data acquisition, this methodology is far less expensive in terms of resources and time. Another feature that FEA has to offer is the ability to examine surface stress data that is otherwise hidden by the boundary of experimental apparatus.

The most profound finding of this work is the identification of a significant difference between the peak contact stress response of plane strain models and axisymmetric models of hyperelastic O-rings (see Figs. 17 through 19, and Table 1). This is particularly true for the case of unrestrained loading . The plane strain results obtained agreed well with those predicted by Wendt. However, Wendt's prediction of peak contact stress response greatly underestimated the response generated by axisymmetric loading. Results obtained from axisymmetric modeling of the lubricated-axially loaded O-ring also indicate that the plane strain assumption is not valid for prediction of the peak contact stress response for this particular case.

Contact width examinations performed in this work yield the most inconclusive results out of all the topics investigated. This is primarily because the mesh is finite at the perimeter and only discrete information about the contact width is available. Clearly better results can be obtained with a much refined mesh at the expense of computer time. Given the results for unlubricated-unrestrained axial loading reasonable agreement exists with Wendt's prediction for compressions up to 15 percent. Lindley's prediction underestimates the contact width response for all cases except lubricated-unrestrained axial loading.

Looking at the cases of restrained loading, only Strozzi offered an analytical technique of predicting contact width and stress. To conform with that technique the numerical results were fitted to produce expressions for the normalized chord diameter in Eqs. (11) - (13). However, the use of these equations, in the procedure outlined from Eq. (3) through Eq. (8), overestimates the contact width compared to numerical data obtained from the deformed nodal coordinates. Strozzi's prediction underestimates the lateral wall stress response for the axisymmetric axial and plane strain cases, yet it gives relatively good agreement to the axisymmetric radial case for compressions below 10 percent. For compressions above 10 percent Strozzi's prediction again underestimates the peak contact stress response.

Due to the lack of consistent agreement between the results obtained here and previous analytical work an alternate empirical procedure is proposed. The peak contact stresses can be determined using Eqs. (9) or (10) for the ten loading conditions listed in Table 1. According to Lindley (1967) these equations provide estimates of the maximum pressure an O-ring can seal.

ACKNOWLEDGMENT

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O-ring Seal Design Best Practices

12-15-12
Rev. 1

Table of Contents

1.0 O-RING SEALS – THEORY AND DESIGN PRACTICES

Theory:

An o-ring seal consists of an o-ring and a properly designed gland which applies a predictable deformation to the o-ring. The gland is basically a groove dimensioned to a certain height "H" and width "W" (Figure 1) to allow a fixed compression of the o-ring when the gland flanges make metal to metal contact. It is also oversized volumetrically such to allow accommodation of the o-ring as it flows under compression. Unlike gaskets which seal just by the resiliency of the material under mechanical compression of the joint, an o-ring can provide a seal both through the resiliency of the pre-compressed material and the pressure activation of the seal. The pre-compression of the o-ring applies a calculated mechanical contact stress or pressure at the o-ring contacting surfaces in the gland. As the o-ring seal is pressurized or "activated" the pressure on the o-ring further increases the contact stress on the o-ring contacting surfaces of the gland as the o-ring moves or "flows" toward the low pressure side. This means the pressure of the contained fluid transfers through the essentially incompressible o-ring material, and the contact stress rises with increasing pressure. As long as the pressure of the fluid does not exceed the contact stress of the o-ring, leakage should not occur.

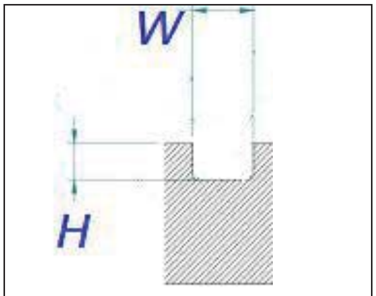


Figure 1 - O-Ring Groove Dimensions

At zero gauge pressure, only the pre-compressed resiliency of the o-ring provides the seal (see Figure 2). If the system pressure is in the range of 0 - 100 or even to 400 pounds per square inch (psi) it can be considered as low pressure (in this paper 400 psi or less is considered low pressure), and the seal is maintained predominantly by the pre-compression or "squeeze" on the o-ring and its resulting contact stress. As the pressure increases, the o-ring is forced to the low pressure side of the gland. This provides an additional increase in contact stress as the o-ring deforms to a "D" shape (see Figure 3) and the contact area of sealing under pressure increases to almost twice the original zero-pressure area. For this reason, an o-ring can easily seal a high pressure as long as it does not mechanically fail.

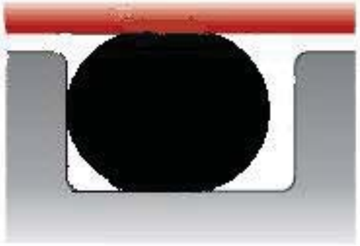


Figure 2 - O-ring un-pressurized

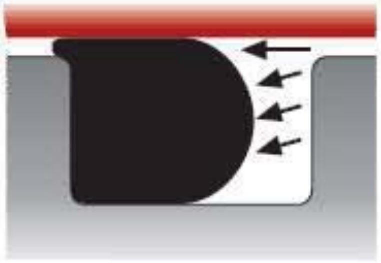


Figure 3 - O-ring with high pressure

Best Design Practices:

a. The flexible nature of o-ring materials accommodates imperfections and/or waviness in the gland parts. But it is still important to maintain a good surface finish of those mating parts. The following best practices are suggested: 32 micro-inch finish on the contact surfaces (top of gland and bottom or groove); 63 micro-inch finish on the sides of the groove; machined radii in bottom of groove of 1/32” (reference 2); holding waviness of groove bottom to less than 2% of o-ring thickness per 12” length of groove.

Figure 4 shows a poor surface finish and affect the tool mark direction. Such a finish can cause leaks.

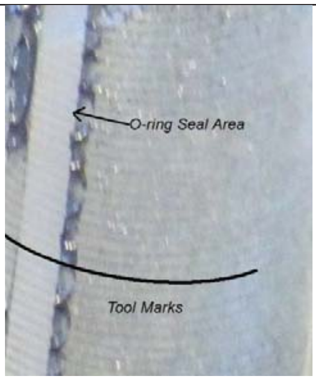


Figure 4 - Surface Finish Can Cause Leaks

b. As for o-ring compression or “squeeze” it is a result of three factors: the force to compress the o-ring, durometer, and cross section thickness. A 15-20% compression for dynamic (moving) applications (to mitigate wear) and 35-40% for static applications (reference 3) is generally suggested. Whereas, reference 2 (Parker) recommends 16% for dynamic applications and 30% for static. However, analysis and testing of the application will determine the ultimate compression. Compression % is defined as the deflection of the seal divided by the cross-section thickness (cord diameter) and the results times 100.

c. The rigidity of the gland closure and closure bolting spacing must be adequate to compress the o-ring without deflecting. Any deflection will reduce the design compression of the seal.

d. The area of the cross-section of the gland should be in the range of 15 to 40% greater than the area of the cross-section of the o-ring. A 75% fill is suggested which leaves 25% empty space in the gland groove (reference 2). However, it is very important that the installed o-ring contact the low pressure side of the gland groove (see Figure 1 in Appendix) such that the o-ring only has to move very little when pressurized or "activated".

e. For o-ring gland grooves that are non-circular, the groove turn radii in rectangular and square layout (i.e. the corners), must be large enough so the o-ring will not kink and such that the o-ring will fully contact the low pressure side of the groove (Figure 5 shows an example of too sharp of a corner in the o-ring groove). Otherwise, the small radius turn may impede any "activation" of the seal. For example, the radius in the corners of an o-ring groove layout is suggested to be at least 2 inches for a ¼" (0.275") nominal diameter o-ring stock, or 7 to 8 times the o-ring diameter. Fabricate the o-ring to snugly fit the low pressure side of the gland groove all the way around including the corner radii.

Figure 5 - Too Sharp of Corner

f. It is important not to stretch the o-ring since stretch affects seal compression by reducing cross section, which reduces the sealing potential of the o-ring. A stretch greater than 5% on the o-ring I.D. (equivalent ID in non-circular case) is not recommended because it can lead to a loss of seal compression (reference 3).

g. When sizing an o-ring, choose the largest cross-section thickness as practical. The larger the cross-section, the more effective the sealing and longer the life of the seal. However, with a dynamic application in which friction is a factor, a compromise will be required.

h. A 70 durometer (shore A) hardness should be used in the design whenever possible since it usually has the best combination of properties for most applications. It provides good conformability versus a mid-range contact stress capability (see Graph 1). It is also considered the standard o-ring hardness and is readily available from suppliers.

i. A lubricant compatible with the o-ring material should be applied to the o-ring as it is installed to decrease friction and assist in the "activation" of the seal under pressure.

j. O-ring re-use: reusing an o-ring in an assembly after some time in service is generally not recommended. Is the o-ring deformed, cracked, harder than when new, discolored, or less than clean? When in doubt, change out.

2.0 ANALYSIS OF O-RING SEAL DESIGNS

The maximum sealing capability of high pressure o-ring seal designs is dependent on seal "activation" as discussed earlier and is not solely dependent on the initial contact pressure as determined by the compression of the seal in its housing (groove). However for low pressure designs, an analysis of the contact stress makes it possible to better predict the success of the seal while assuming no "activation" of seal. Two methods are presented below:

Parker Method:
As an example referring to the "Parker O-ring Handbook, Figures 2-8" (reference 2) , below is an analysis of a ¼" o-ring design, Shore A durometer, with 20% compression:

For a 20% compression on a ¼ inch nominal o-ring, , the compression load per linear inch of the seal is at around 35 pounds from the Parker Figures. Referring to the paper "O-rings for Low Pressure Service", (reference 1), the contact area "b" per linear inch of seal is estimated by b=2.4x, where x is the deflection of the o-ring cross-section. Therefore, the contact area per inch is (2.4) (.20)(.275) = .132 square inch. The contact stress "S_{max}" per linear inch just from pre-compressed resiliency of the seal is 35 pounds divided by .132 square inches yielding 265 psi. This means, in theory with all things being perfect, the seal should not leak until the pressure exceeds 265 psig, as a minimum.

Lindly Method:
As an example using Lindly's analysis as referred to in reference 4, below is an analysis of a ¼" o-ring design, Shore A durometer, with 20% compression:

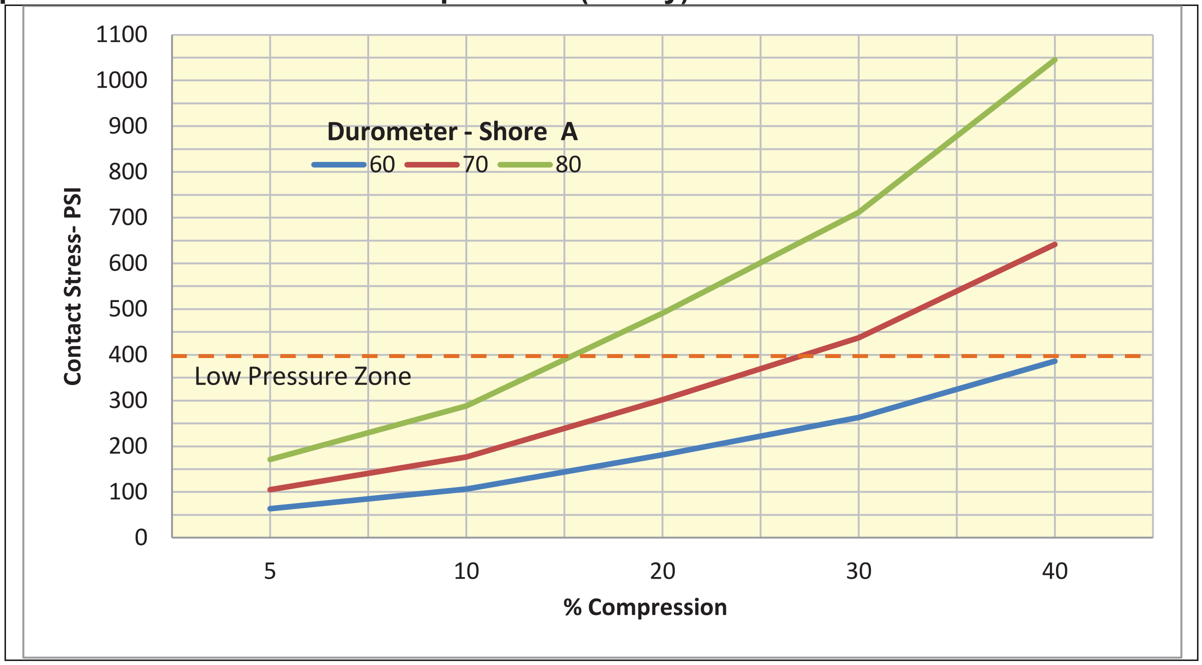
Lindly derived the equation below for predicting the contact stress "S_{max}" with respect to the modulus of elasticity "E" (E can be derived from Shore A durometer):

$S_{max}=E\ (0.849(1.25\delta^{1.5} + 50\delta^{6}))^{0.5}$
where: S_{max} = contact stress psi, δ = fractional compression, (20% = 0.2), E= modulus of elasticity (which can be found in reference 1, of E versus Shore A durometer; 60 = 630 psi, 70= 1,040 psi, 80 = 1,705 psi)

S_{max} is plotted in Graph 1 for Shore A durometer 60, 70, and 80. The Lindly Method gives a higher contact stress than the Parker, however, due to the simplicity of use, the Lindly Method is the preferred method.

Calculating contact stress is only a starting point in the seal design for determining the minimum required compression, however, with variables in the "less than perfect" sealing system, a margin above that is prudent, so it is suggested to follow the best practices in Section 1.0 in order to achieve a successful seal.

Graph 1 - Contact Stress vs. Compression (Lindly)



3.0 APPENDIX

References:

1. Hertz,D.L.,1979, "O-Rings for Low Pressure Service", Machine Design, 4/12/79, pp.94-98 (note, paper applies mainly to dynamic applications)
2. Parker Hannifin Corporation, O-Ring Handbook, Catalog ORD 5700A/US
3. Apple Rubber Products Inc.,www.applerubber.com
4. Green, Itzhak and English, Capel, “Stresses and Deformation of Compressed Elastomeric O-Ring Seals”

(TVA response to KEI data request 7-16-2020)

Lift check valves

Group	Component Id	Drawing No.	Seat contact diameter	Spring OD/Spring preload
32-2	1-CKV-32-293	TVDD9911X01-2	2 1/2"	***Design not available***
32-2	1-CKV-32-303			
32-2	1-CKV-32-313			
43-1	1-CKV-43-834	N89-180-1-MD-82013603		***Dwg. states 2-4 psid***
43-1	1-CKV-43-841			
43-1	1-CKV-43-883			
43-1	1-CKV-43-884			
61-1	1-CKV-61-533	W9825144		***Dwg. states a 5 psi spring installed on earlier valves; latest spring is a 10 psi cracking pressure - use conservative value since either valve could be installed.***
61-1	1-CKV-61-680			
61-1	1-CKV-61-692			
61-1	1-CKV-61-745			
62-4	1-CKV-62-639	7500001295 TVD-D-9556	1 3/8"	***Dwg. TVD-D-9556 states 4 psi cracking***
63-1	1-CKV-63-868	TVW1-30608GS-(2)	1"	***Spring part no. CatId is CWT472P, and PEG is reviewing doc for characteristics.***
67-1	1-CKV-67-575A	W9825144-MD-00403336	1"	***same as group 61-1***
67-1	1-CKV-67-575B			
67-1	1-CKV-67-575C			
67-1	1-CKV-67-575D			
67-3	1-CKV-67-585A	VTD-K085-0090		***Dwg. is TVW-D-30504-2(U1) and 7257697/TVW-D-30504-2 for U2 Same spring as group 63-1 w/ PEG searching.***
67-3	1-CKV-67-585B			
67-3	1-CKV-67-585C			
67-3	1-CKV-67-585D			
68-1	1-CKV-68-849	30508GLS-(2)	1 3/8"	***dwg. has 0.5 psi (max.) cracking pressure - note -NO SPRING - SOFT SEAT***

From: Neal Estep
To: Sandhya Shankar
Cc: Mital Mistry
Subject: FW: valve info request for LLRT design change
Date: Monday, August 3, 2020 6:22:17 AM

Sandhya,
Attached is some additional information for you piston/lift check valves.

Regards,
Neal

Neal Estep
Kalsi Engineering, Inc.
4410 Mint Hill Village Lane, Suite 201
Mint Hill, NC 28227
704-831-8950 - Charlotte Office/Direct
281-240-6500 - Main Switchboard
704-942-6773 - Mobile

Main Office:
745 Park Two Drive
Sugar Land, TX 77478

From: Cetta, William Frederick II <wfcetta5@tva.gov>
Sent: Monday, August 3, 2020 7:19 AM
To: Neal Estep <nestep@kalsi.com>
Cc: Ortiz, Jose J <jjortiz@tva.gov>; Gowin, Mark Allen <magowin@tva.gov>
Subject: FW: valve info request for LLRT design change

EXTERNAL EMAIL: Do not open attachments or click on links unless you know the content is safe.

See below for priority valve Flowserve information.

Thanks,
William Cetta
Design Engineer
Mechanical Design
Teleworking from home
865-335-1974 (Cell –primary contact)
423-365-1153 (Office)
TVA Watts Bar Nuclear
wfcetta5@tva.gov

From: Smith, John <JohSmith@Flowserve.com>
Sent: Friday, July 31, 2020 2:37 PM
To: Cetta, William Frederick II <wfcetta5@tva.gov>
Subject: RE: valve info request for LLRT design change

This is an EXTERNAL EMAIL from outside TVA. THINK BEFORE you CLICK links or OPEN attachments. If suspicious, please click the "Report Phishing" button located on the Outlook Toolbar at the top of your screen.

Bill,

- ***Group 63-1 Dwg. TVW1-30608GS-(2) for cracking pressure and seat contact diameter. Seat contact diameter was obtained from warehouse measurements. Cracking Pressure 2psi. Since this is a Soft seated valve it almost impossible to determine the seat contact: approx. 0.75 dia***
- ***Group 70-1 Dwg. 13-103681-001 for seat contact diameter. Since this is a Soft seated valve it almost impossible to determine the seat contact: Approx. 3.03 dia***

Best,

John C. Smith
Sales Engineer
Flowserve Corporation
johsmith@flowserve.com
919-271-6311

From: Cetta, William Frederick II <wfcetta5@tva.gov>
Sent: Tuesday, July 28, 2020 1:02 PM
To: Smith, John <JohSmith@Flowserve.com>
Cc: Ortiz, Jose J <jjortiz@tva.gov>; Gowin, Mark Allen <magowin@tva.gov>
Subject: [External] RE: valve info request for LLRT design change

CAUTION: This email originated from outside of Flowserve. Do not click links or open attachments unless you can confirm the sender and know the content is safe.

Hello John,

I was wondering on the status of the 2 priority items.

Attached is previous information I sent related to the 2 items.

Typically the cracking pressure is on a drawing, but the attached drawing ***TVW1-30608GS-(2)*** is missing this information. I am sending a PO of a spring for this valve we bought to assist.
Here are the high priority valves for Flowserve data:

- ***Group 63-1 Dwg. TVW1-30608GS-(2) for cracking pressure and seat contact diameter. Seat contact diameter was obtained from warehouse measurements.***
- ***Group 70-1 Dwg. 13-103681-001 for seat contact diameter.***

Thanks,
William Cetta
Design Engineer
Mechanical Design
Teleworking from home
865-335-1974 (Cell –primary contact)
423-365-1153 (Office)
TVA Watts Bar Nuclear
wfcetta5@tva.gov

From: Cetta, William Frederick II

From: Cetta, William Frederick II
To: Neal Estep; Ortiz, Jose J; Driskell, Charles Edmond
Cc: Sandhya Shankar; Mital Mistry; Gowin, Mark Allen
Subject: RE: Hard Seat of Soft Seat TVDD9911X01-2
Date: Sunday, August 16, 2020 1:42:30 PM
Attachments: Appendix A - Unit 1 Scope and Drawing List wfc cmnts.pdf
sys 32 chk vlv soft seat 55852.pdf
TVD-D-991X01-(2) mk no 47W555-25A.pdf
Appendix B - Unit 2 Scope and Drawing List wfc cmnts.pdf
WBN-TVD-D-9911-(2)-1-MD-86630 U2 w soft seat.pdf

Based on detail review, valves were confirmed to be soft seat as per previous direction.

We will add the change paper to the App A drawing list input information to supplement the U1 dwg. w/ no soft seat noted as a comment to Jose and Charlie.
U2 needs no change paper - We are changing the U2 drawing list App B to reflect the u2 drawing which has the soft seat on the drawing.

Also, I noticed for Unit 1 (Appendix A) specified drawing no. for group 32-2 applicable to 1-CKV-32-293 and -313 was not correct – it it should be TVDD9911-(2) and needs change paper since this dwg. version (U1) does not reflect the soft seat. Valve is same configuration as the u2 drawings – i.e. no new configuration. All are soft seat assemblies.

Jose/Charlie – The U1 group 32-2 check valves have 2 different drawings based on 2 different mark nos. per piping dwgs. and Maximo. Please correct the Appendix A prior to signing. (Reference old DCN no. 38814). Also, the App B group 32-2 drawing has a U2 w/ soft seat for these 3 valves (see attached – revise App B accordingly.

Thanks,

William Cetta
Design Engineer
Mechanical Design
Teleworking from home
865-335-1974 (Cell –primary contact)
423-365-1153 (Office)
TVA Watts Bar Nuclear
wfcetta5@tva.gov

From: Cetta, William Frederick II
Sent: Tuesday, August 04, 2020 2:17 PM
To: Neal Estep <nestep@kalsi.com>
Cc: Sandhya Shankar <SShankar@kalsi.com>; Mital Mistry <mcmistry@kalsi.com>; Gowin, Mark Allen <magowin@tva.gov>; Ortiz, Jose J <jjortiz@tva.gov>
Subject: RE: Hard Seat of Soft Seat TVDD9911X01-2

I am confident it is a soft seat - This is a case of change paper – I will send more supporting documentation.

Thanks,

William Cetta
Design Engineer
Mechanical Design
Teleworking from home
865-335-1974 (Cell –primary contact)
423-365-1153 (Office)
TVA Watts Bar Nuclear
wfcetta5@tva.gov

From: Neal Estep <nestep@kalsi.com>
Sent: Tuesday, August 04, 2020 2:13 PM
To: Cetta, William Frederick II <wfcetta5@tva.gov>
Cc: Sandhya Shankar <SShankar@kalsi.com>; Mital Mistry <mcmistry@kalsi.com>; Gowin, Mark Allen <magowin@tva.gov>
Subject: Hard Seat of Soft Seat TVDD9911X01-2

Bill,
I was wondering if you could verify that the Group 32-2 Kerotest check valves are **SOFT** seat. If so, could you please a suitable reference. The drawing TVD-D-9911-(2) shows a "soft seat option" in View "B", but drawing TVDD9911X01-2 only shows a **hard** seat.

The original spreadsheet we received from Jose for Unit 1 indicated they were soft seated, but the drawings are unclear.

Unit 1 list:

32-2	1-CKV-32-293	CONTROL AIR CNTMT CHECK	TVDD9911X01-2
32-2	1-CKV-32-303	ESSENT CNTL AIR CNTMT CHECK	TVDD9911X01-2
32-2	1-CKV-32-313	ESSENT CNTL AIR CNTMT CHECK	TVDD9911X01-2

Here is the Unit 2 list:

32-2	2-CKV-32-323	ESSENT CNTL AIR CNTMT CHECK	TVDD9911X01-2
32-2	2-CKV-32-333	ESSENT CNTL AIR CNTMT CHECK	TVDD9911X01-2
32-2	2-CKV-32-343	CONTROL AIR CNTMT CHECK	TVDD9911X01-2

Thanks,

Neal

Neal Estep
Kalsi Engineering, Inc.
4410 Mint Hill Village Lane, Suite 201
Mint Hill, NC 28227
704-831-8950 - Charlotte Office/Direct
281-240-6500 - Main Switchboard
704-942-6773 - Mobile

Main Office:
745 Park Two Drive
Sugar Land, TX 77478

Preparer By: Jose Ortiz
Reviewed By: Charles Driskell

Group	Component Id	Comp Description	ActuatorType	ValveType	Manufacturer	Valve Dwg / Vendor Manual
26-1	1-CKV-26-1260	REACTOR BLDG HPFP SUPPLY HDR CHECK	SA	CK	BORG-WARNER CORP.	421JBB1-002
26-1	1-CKV-26-1296	REACTOR COOLANT PUMP SPRINKLER HDR ISOL CHK	SA	CK	BORG-WARNER CORP.	421JBB1-002
26-2	1-FCV-26-240	REACTOR BLDG STANDPIPE ISOL	MO	GA	ANCHOR-DARLING	93-14978
26-2	1-FCV-26-243	REACTOR COOLANT PUMP SPRINKLER HDR ISOL	MO	GA	ANCHOR-DARLING	93-14978
32-1	1-BYV-32-288	CONTROL AIR 1-FCV-32-110 BYPASS	M	GL	K085/KEROTEST	99099X01S
32-1	1-BYV-32-298	ESSENT CONTROL AIR 1-FCV-32-80 BYPASS	M	GL	K085/KEROTEST	99099X01S
32-1	1-BYV-32-308	ESSENT CONTROL AIR 1-FCV-32-102 BYPASS	M	GL	K085/KEROTEST	99099X01S
32-2	1-CKV-32-293	CONTROL AIR CNTMT CHECK	SA	CK	K085/KEROTEST	TVD-D-9911-(2)
32-2	1-CKV-32-303	ESSENT CNTL AIR CNTMT CHECK	SA	CK	K085/KEROTEST	TVDD9911X01-(2)
32-2	1-CKV-32-313	ESSENT CNTL AIR CNTMT CHECK	SA	CK	K085/KEROTEST	TVD-D-9911-(2)
32-3	1-FCV-32-80	ESSENT CONTROL AIR TR A CNTMT ISOL	AO	GL	L170/LESLIE CO.	717543070D
32-3	1-FCV-32-102	ESSENT CONTROL AIR TR B CNTMT ISOL	AO	GL	L170/LESLIE CO.	717543070D
32-3	1-FCV-32-110	CONTROL AIR CNTMT ISOL	AO	GL	L170/LESLIE CO.	717543070D
43-1	1-CKV-43-834	PAS WASTE TO CNTMT SUMP CHECK	SA	CK	Circle Seals	N89-180
43-1	1-CKV-43-841	PAS WASTE TO CNTMT SUMP CHECK	SA	CK	Circle Seals	N89-180
43-1	1-CKV-43-883	PAS CONTAINMENT AIR RETURN CHECK	SA	CK	Circle Seals	N89-180
43-1	1-CKV-43-884	PAS CONTAINMENT AIR RETURN CHECK	SA	CK	Circle Seals	N89-180
43-3	1-FCV-43-202	LOCA H2 CNTMT MONITOR OUTLET ISOL	SO	GL	Target Rock	1015005-3-2
43-3	1-FCV-43-208	LOCA H2 CNTMT MONITOR OUTLET ISOL	SO	GL	Target Rock	1015005-3-2
43-3	1-FCV-43-434	LOCA H2 CNTMT MONITOR D/S SAMPLE ISOL	SO	GL	Target Rock	1015005-3-2
43-3	1-FCV-43-436	LOCA H2 CNTMT MONITOR D/S SAMPLE ISOL	SO	GL	Target Rock	1015005-3-2
43-3	1-FSV-43-307	PAS CONTAINMENT AIR RETURN ISOL	SO	GL	Target Rock	1015005-3-2
43-3	1-FSV-43-325	PAS CONTAINMENT AIR RETURN ISOL	SO	GL	Target Rock	1015005-3-2
52-1	1-ISV-52-500	PENETRATION 26B ILRT OUTSIDE	M	GL	Dragon Valve	13824
52-1	1-ISV-52-501	PENETRATION 26A ILRT OUTSIDE	M	GL	Dragon Valve	13824
52-1	1-ISV-52-502	PEN 96A INTERGRATED LE AK RATE TEST OUTSIDE	M	GL	Dragon Valve	13824
52-1	1-ISV-52-503	PEN 96B INTERGRATED LE AK RATE TEST OUTSIDE	M	GL	Dragon Valve	13824
52-1	1-ISV-52-504	PENETRATION 26B ILRT INSIDE	M	GL	Dragon Valve	13824
52-1	1-ISV-52-505	PENETRATION 26A ILRT INSIDE	M	GL	Dragon Valve	13824
52-1	1-ISV-52-506	PEN 96A INTERGRATED LE AK RATE TEST INSIDE	M	GL	Dragon Valve	13824
52-1	1-ISV-52-507	PEN 96B INTERGRATED LE AK RATE TEST INSIDE	M	GL	Dragon Valve	13824
61-1	1-CKV-61-533	GLYCOL SUPPLY HEADER BYPASS CHECK	SA	CK	A391/ANCHOR-DARLING	W9825144
61-1	1-CKV-61-680	GLYCOL RETURN HEADER BYPASS CHECK	SA	CK	A391/ANCHOR-DARLING	W9825144
61-1	1-CKV-61-692	GLYCOL COOLED FLOOR SUPPLY BYPASS CHECK	SA	CK	A391/ANCHOR-DARLING	W9825144
61-1	1-CKV-61-745	GLYCOL COOLED FLOOR RETURN BYPASS CHECK	SA	CK	A391/ANCHOR-DARLING	W9825144
62-3	1-FCV-62-61	CVCS SEAL WATER RETURN HEADER ISOL	MO	GA	W120/WESTINGHOUSE ELEC W120/WESTINGHOUSE ELEC	115 E001
62-3	1-FCV-62-63	CVCS SEAL WATER RETURN HEADER ISOL	MO	GA	W120/WESTINGHOUSE ELEC W120/WESTINGHOUSE ELEC	115 E001
62-4	1-CKV-62-639	CVCS SEAL WTR 1-FCV-62-61 EQL CHECK	SA	CK	K085/KEROTEST MANUFACTURING CORP.	7500001295 TVD-D-9556

REVISE
2 UNID
drawing
nos.

Typical for group 32-2:
add change paper DCA-38814-08
to all 3 drawings

63-1	1-CKV-63-868	1-CKV-63-868 CONTAINMENT N2 HEADER CHECK	SA	CK	K085/KEROTEST MANUFACTURING CORP.	TVW1-30608GS-(2)
63-2	1-FCV-63-64	SIS ACCUM N2 HDR INLET VLV	AO	GL	F130/FISHER CONTROLS CO INC	54A0240
63-3	1-FCV-63-23	COLD LEG ACCUMULATOR FILL FROM SIP 1A-A ISV	AO	GL	F130/FISHER CONTROLS CO INC	54A0223
63-4	1-FCV-63-71	SIS CHECK VLV TEST LINE HOLDUP TANK ISOL	AO	GL	F130/FISHER CONTROLS CO INC	54A0237
63-5	1-FCV-63-84	SIS CHECK VLV LEAK TEST HOLDUP TANK ISOL	AO	GL	F130/FISHER CONTROLS CO INC	54A0237
67-1	1-CKV-67-575A	1-FCV-67-87 BYPASS CHECK	SA	CK	ANCHOR-DARLING	W9825144
67-1	1-CKV-67-575B	1-FCV-67-103 BYPASS CHECK	SA	CK	ANCHOR-DARLING	W9825144
67-1	1-CKV-67-575C	1-FCV-67-95 BYPASS CHECK	SA	CK	ANCHOR-DARLING	W9825144
67-1	1-CKV-67-575D	1-FCV-67-111 BYPASS CHECK	SA	CK	ANCHOR-DARLING	W9825144
67-2	1-CKV-67-580A	UPPER CNTMT VENT CLR 1A ERCW SUP HDR CHECK	SA	CK	A585/ATWOOD & MORRILL CO	14735-02
67-2	1-CKV-67-580B	UPPER CNTMT VENT CLR 1B ERCW SUP HDR CHECK	SA	CK	A585/ATWOOD & MORRILL CO	14735-02
67-2	1-CKV-67-580C	UPPER CNTMT VENT CLR 1C ERCW SUP HDR CHECK	SA	CK	A585/ATWOOD & MORRILL CO	14735-02
67-2	1-CKV-67-580D	UPPER CNTMT VENT CLR 1D ERCW SUP HDR CHECK	SA	CK	A585/ATWOOD & MORRILL CO	14735-02
67-3	1-CKV-67-585A	1-FCV-67-295 BYPASS CHECK	SA	CK	K085/KEROTEST	72576978
67-3	1-CKV-67-585B	1-FCV-67-297 BYPASS CHECK	SA	CK	K085/KEROTEST	72576978
67-3	1-CKV-67-585C	1-FCV-67-296 BYPASS CHECK	SA	CK	K085/KEROTEST	72576978
67-3	1-CKV-67-585D	1-FCV-67-298 BYPASS CHECK	SA	CK	K085/KEROTEST	72576978
67-5	1-FCV-67-130	UPPER CNTMT VENT CLR 1A ERCW SUP HDR ISOL	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491C
67-5	1-FCV-67-131	UPPER CNTMT VENT CLR 1A ERCW RET HDR ISOL	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491C
67-5	1-FCV-67-133	UPPER CNTMT VENT CLR 1C ERCW SUP HDR ISOL	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491C
67-5	1-FCV-67-134	UPPER CNTMT VENT CLR 1C ERCW RET HDR ISOL	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491C
67-5	1-FCV-67-138	UPPER CNTMT VENT CLR 1B ERCW SUP HDR ISOL	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491C
67-5	1-FCV-67-139	UPPER CNTMT VENT CLR 1B ERCW RET HDR ISOL	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491C
67-5	1-FCV-67-141	UPPER CNTMT VENT CLR 1D ERCW SUP HDR ISOL	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491C
67-5	1-FCV-67-142	UPPER CNTMT VENT CLR 1D ERCW RET HDR ISOL	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491C
67-5	1-FCV-67-295	UPPER CNTMT VENT CLR 1A ERCW RET ISOL	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491C
67-5	1-FCV-67-296	UPPER CNTMT VENT CLR 1C ERCW RET ISOL	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491C
67-5	1-FCV-67-297	UPPER CNTMT VENT CLR 1B ERCW RET ISOL	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491C
67-5	1-FCV-67-298	UPPER CNTMT VENT CLR 1D ERCW RET ISOL	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491C
68-1	1-CKV-68-849	PRESSURIZER RELIEF TANK N2 SUP HDR CHECK	SA	CK	Kerotest	30508GLS-(2)
68-3	1-FCV-68-307	PRESSURIZER RELIEF TANK GAS ANALYZER SUPPLY	AO	GL	C635/COPES-VULCAN, INC.	E-171555
68-3	1-FCV-68-308	PRESSURIZER RELIEF TANK GAS ANALYZER SUPPLY	AO	GL	C635/COPES-VULCAN, INC.	E-171555
70-1	1-CKV-70-679	RCP THERMAL BARRIER CCS SUP HDR CHECK	SA	CK	ATWOOD & MORRILL	14735-01
70-3	1-FCV-70-87	THERMAL BARRIER CCS RETURN	MO	GA	Walworth	SA2099-1
70-3	1-FCV-70-134	THERMAL BARRIER CCS SUPPLY	MO	GA	Walworth	SA-2117-3
70-4	1-FCV-70-90	THERMAL BARRIER CCS RETURN	MO	GA	Walworth	SA2099-1
77-2	1-FCV-77-127	RB SUMP DISCHARGE FLOW CONTROL	AO	PLG	Tufline / Xomox	NP1211C
77-2	1-FCV-77-128	RB SUMP DISCHARGE FLOW CONTROL	AO	PLG	Tufline / Xomox	NP1211C

81-1	1-CKV-81-502	PRIMARY WATER CNTMT HDR CHECK VLV	SA	CK	W120/WESTINGHOUSE ELEC CORP	934D174
90-1	1-FCV-90-110	CNTMT BLDG LOWER COMPT AIR RAD MON RETURN	AO	GL	K085/KEROTEST	TV-D9957X01AC
90-1	1-FCV-90-111	CNTMT BLDG LOWER COMPT AIR RAD MON RETURN	AO	GL	K085/KEROTEST	TV-D9957X01AC
90-1	1-FCV-90-116	CNTMT BLDG UPPER COMPT AIR RAD MON RETURN	AO	GL	K085/KEROTEST	TV-D9957X01AC
90-1	1-FCV-90-117	CNTMT BLDG UPPER COMPT AIR RAD MON RETURN	AO	GL	K085/KEROTEST	TV-D9957X01AC
Notes:						
1	t C11 (seat contact), C14 (control switch trip), and C16 (final/max seating thrust).					
unning load for spring to close. Indicate which are spring to close. If air to close the minimum regulator/supply pressure is also needed.						

Preparer By: Jose Ortiz
Reviewed By: Charles Driskell

Group	Component Id	Comp Description	System No	ActuatorType	ValveType	Manufacturer	Valve Dwg / Vendor Manual
26-1	2-CKV-26-1260	REACTOR BLDG HPFP SUPPLY HDR CHECK	026	SA	CK	BORG-WARNER CORP.	421JBB1-002
26-1	2-CKV-26-1296	REACTOR COOLANT PUMP SPRINKLER HDR ISOL CHK	026	SA	CK	BORG-WARNER CORP.	421JBB1-002
26-2	2-FCV-26-240	REACTOR BLDG STANDPIPE ISOL	026	MO	GA	ANCHOR-DARLING	93-14978
26-2	2-FCV-26-243	REACTOR COOLANT PUMP SPRINKLER HDR ISOL	026	MO	GA	ANCHOR-DARLING	93-14978
31-1	2-CKV-31-3378	INCORE INSTR RM AHU 2B CWS LEAK RATE CHECK	031	SA	CK	F990/FLOWSERVE CORPORATION	TVSW-30604GS
31-1	2-CKV-31-3392	INCORE INSTR RM AHU 2B CWR LEAK RATE CHECK	031	SA	CK	F990/FLOWSERVE CORPORATION	TVSW-30604GS
31-1	2-CKV-31-3407	INCORE INSTR RM AHU 2A CWS LEAK RATE CHECK	031	SA	CK	K085/KEROTEST MANUFACTURING CORP.	TVSW-30604GS
31-1	2-CKV-31-3421	INCORE INSTR RM AHU 2A CWR LEAK RATE CHECK	031	SA	CK	K085/KEROTEST MANUFACTURING CORP.	TVSW-30604GS
31-2	2-FCV-31-305	INCORE INSTR RM AHU 2A CWR ISOL	031	AO	GL	T340/TUFLINE DIV / XOMOX CORP	NP1071C
31-2	2-FCV-31-306	INCORE INSTR RM AHU 2A CWR ISOL	031	AO	GL	T340/TUFLINE DIV / XOMOX CORP	NP1071C
31-2	2-FCV-31-308	INCORE INSTR RM AHU 2A CWS ISOL	031	AO	GL	T340/TUFLINE DIV / XOMOX CORP	NP1071C
31-2	2-FCV-31-309	INCORE INSTR RM AHU 2A CWS ISOL	031	AO	GL	T340/TUFLINE DIV / XOMOX CORP	NP1071C
31-2	2-FCV-31-326	INCORE INSTR RM AHU 2B CWR ISOL	031	AO	GL	T340/TUFLINE DIV / XOMOX CORP	NP1071C
31-2	2-FCV-31-327	INCORE INSTR RM AHU 2B CWR ISOL	031	AO	GL	T340/TUFLINE DIV / XOMOX CORP	NP1071C
31-2	2-FCV-31-329	INCORE INSTR RM AHU 2B CWS ISOL	031	AO	GL	T340/TUFLINE DIV / XOMOX CORP	NP1071C
31-2	2-FCV-31-330	INCORE INSTR RM AHU 2B CWS ISOL	031	AO	GL	T340/TUFLINE DIV / XOMOX CORP	NP1071C
32-1	2-BYV-32-318	ESSENT CONTROL AIR 2-FCV-32-103 BYPASS	032	M	GL	K085/KEROTEST MANUFACTURING CORP.	TV-D-9909X01S-(2)
32-1	2-BYV-32-328	ESSENT CONTROL AIR 2-FCV-32-81 BYPASS	032	M	GL	K085/KEROTEST MANUFACTURING CORP.	TV-D-9909X01S-(2)
32-1	2-BYV-32-338	CONTROL AIR 2-FCV-32-111 BYPASS	032	M	GL	K085/KEROTEST MANUFACTURING CORP.	TV-D-9909X01S-(2)
32-2	2-CKV-32-323	ESSENT CNTL AIR CNTMT CHECK	032	SA	CK	K085/KEROTEST MANUFACTURING CORP.	TVD-D-9911-(2)-1-MD-86630 (U2)
32-2	2-CKV-32-333	ESSENT CNTL AIR CNTMT CHECK	032	SA	CK	K085/KEROTEST MANUFACTURING CORP.	TVD-D-9911-(2)-1-MD-86630 (U2))
32-2	2-CKV-32-343	CONTROL AIR CNTMT CHECK	032	SA	CK	K085/KEROTEST MANUFACTURING CORP.	TVD-D-9911-(2)-1-MD-86630 (U2)
32-3	2-FCV-32-81	ESSENT CONTROL AIR TR A CNTMT ISOL	032	AO	GL	L170/LESLIE CO.	717543070D
32-3	2-FCV-32-103	ESSENT CONTROL AIR TR B CNTMT ISOL	032	AO	GL	L170/LESLIE CO.	717543070D
32-3	2-FCV-32-111	CONTROL AIR CNTMT ISOL	032	AO	GL	L170/LESLIE CO.	717543070D
43-3	2-FCV-43-202	LOCA H2 CNTMT MONITOR OUTLET ISOL	043	SO	GL	Target Rock	82KK-003BB SH 1 & 2
43-3	2-FCV-43-434	LOCA H2 CNTMT MONITOR D/S SAMPLE ISOL	043	SO	GL	Target Rock	82KK-003BB SH 1 & 2
52-1	2-ISV-52-500	PENETRATION 26B ILRT OUTSIDE	052	M	GA	Dragon Valve	13824
52-1	2-ISV-52-501	PENETRATION 26A ILRT OUTSIDE	052	M	GA	Dragon Valve	13824
52-1	2-ISV-52-502	PEN 96A INTERGRATED LE AK RATE TEST OUTSIDE	052	M	GA	Dragon Valve	13824
52-1	2-ISV-52-503	PEN 96B INTERGRATED LE AK RATE TEST OUTSIDE	052	M	GA	Dragon Valve	13824
52-1	2-ISV-52-504	PENETRATION 26B ILRT INSIDE	052	M	GA	Dragon Valve	18437
52-1	2-ISV-52-505	PENETRATION 26A ILRT INSIDE	052	M	GA	Dragon Valve	13824
52-1	2-ISV-52-506	PEN 96A INTERGRATED LE AK RATE TEST INSIDE	052	M	GA	Dragon Valve	13824
52-1	2-ISV-52-507	PEN 96B INTERGRATED LE AK RATE TEST INSIDE	052	M	GA	Dragon Valve	13824
61-1	2-CKV-61-533	GLYCOL SUPPLY HEADER BYPASS CHECK	061	SA	CK	A391/ANCHOR-DARLING	W9825144
61-1	2-CKV-61-680	GLYCOL RETURN HEADER BYPASS CHECK	061	SA	CK	A391/ANCHOR-DARLING	W9825144
61-1	2-CKV-61-692	GLYCOL COOLED FLOOR SUPPLY BYPASS CHECK	061	SA	CK	A391/ANCHOR-DARLING	W9825144
61-1	2-CKV-61-745	GLYCOL COOLED FLOOR RETURN BYPASS CHECK	061	SA	CK	A391/ANCHOR-DARLING	W9825144

REVISE 3 drawings to reflect U2 dedicated drawing for soft seat.

62-3	2-FCV-62-61	CVCS SEAL WATER RETURN HEADER ISOL	062	MO	GA	W120/WESTINGHOUSE ELEC W120	115 E001
62-3	2-FCV-62-63	CVCS SEAL WATER RETURN HEADER ISOL	062	MO	GA	W120/WESTINGHOUSE ELEC W120	115 E001
62-4	2-CKV-62-639	CVCS SEAL WTR 2-FCV-62-61 EQL CHECK	062	SA	CK	K085/KEROTEST MANUFACTURING CORP.	TVD-D-9556
63-1	2-CKV-63-868	2-CKV-63-868 CONTAINMENT N2 HEADER CHECK	063	SA	CK	K085/KEROTEST MANUFACTURING CORP.	TVW1-30608GS-(2)
63-2	2-FCV-63-64	SIS ACCUM N2 HDR INLET VLV	063	AO	GL	F130/FISHER CONTROLS CO INC	54A0240
63-3	2-FCV-63-23	COLD LEG ACCUMULATOR FILL FROM SIP 1A-A ISV	063	AO	GL	F130/FISHER CONTROLS CO INC	54A0223
63-4	2-FCV-63-71	SIS CHECK VLV TEST LINE HOLDUP TANK ISOL	063	AO	GL	FISHER CONTROLS CO.	54A0237
63-4	2-FCV-63-84	SIS CHECK VLV LEAK TEST HOLDUP TANK ISOL	063	AO	GL	FISHER CONTROLS CO.	54A0237
67-1	2-CKV-67-575A	2-FCV-67-87 BYPASS CHECK	067	SA	CK	ANCHOR-DARLING	W9825144
67-1	2-CKV-67-575B	2-FCV-67-103 BYPASS CHECK	067	SA	CK	ANCHOR-DARLING	W9825144
67-1	2-CKV-67-575C	2-FCV-67-95 BYPASS CHECK	067	SA	CK	ANCHOR-DARLING	W9825144
67-1	2-CKV-67-575D	2-FCV-67-111 BYPASS CHECK	067	SA	CK	ANCHOR-DARLING	W9825144
67-2	2-CKV-67-580A	UPPER CNTMT VENT CLR 1A ERCW SUP HDR CHECK	067	SA	CK	A585/ATWOOD & MORRILL CO	14735-02
67-2	2-CKV-67-580B	UPPER CNTMT VENT CLR 2B ERCW SUP HDR CHECK	067	SA	CK	A585/ATWOOD & MORRILL CO	14735-02
67-2	2-CKV-67-580C	UPPER CNTMT VENT CLR 2C ERCW SUP HDR CHECK	067	SA	CK	A585/ATWOOD & MORRILL CO	14735-02
67-2	2-CKV-67-580D	UPPER CNTMT VENT CLR 2D ERCW SUP HDR CHECK	067	SA	CK	A585/ATWOOD & MORRILL CO	14735-02
67-3	2-CKV-67-585A	2-FCV-67-295 BYPASS CHECK	067	SA	CK	K085/KEROTEST	72576978
67-3	2-CKV-67-585B	2-FCV-67-297 BYPASS CHECK	067	SA	CK	K085/KEROTEST	72576978
67-3	2-CKV-67-585C	2-FCV-67-296 BYPASS CHECK	067	SA	CK	K085/KEROTEST	72576978
67-3	2-CKV-67-585D	2-FCV-67-298 BYPASS CHECK	067	SA	CK	K085/KEROTEST	72576978
67-6	2-FCV-67-130	UPPER CNTMT VENT CLR 1A ERCW SUP HDR ISOL	067	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491-C
67-6	2-FCV-67-131	UPPER CNTMT VENT CLR 1A ERCW RET HDR ISOL	067	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491-C
67-6	2-FCV-67-133	UPPER CNTMT VENT CLR 1C ERCW SUP HDR ISOL	067	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491-C
67-6	2-FCV-67-134	UPPER CNTMT VENT CLR 1C ERCW RET HDR ISOL	067	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491-C
67-6	2-FCV-67-138	UPPER CNTMT VENT CLR 1B ERCW SUP HDR ISOL	067	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491-C
67-6	2-FCV-67-139	UPPER CNTMT VENT CLR 1B ERCW RET HDR ISOL	067	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491-C
67-6	2-FCV-67-141	UPPER CNTMT VENT CLR 1D ERCW SUP HDR ISOL	067	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491-C
67-6	2-FCV-67-142	UPPER CNTMT VENT CLR 1D ERCW RET HDR ISOL	067	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491-C
67-6	2-FCV-67-295	UPPER CNTMT VENT CLR 2A ERCW RET ISOL	067	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491-C
67-6	2-FCV-67-296	UPPER CNTMT VENT CLR 2C ERCW RET ISOL	067	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491-C
67-6	2-FCV-67-297	UPPER CNTMT VENT CLR 2B ERCW RET ISOL	067	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491-C
67-6	2-FCV-67-298	UPPER CNTMT VENT CLR 2D ERCW RET ISOL	067	MO	PLG	T340/TUFLINE DIV / XOMOX CORP	NP3491-C
68-1	2-CKV-68-849	PRESSURIZER RELIEF TANK N2 SUP HDR CHECK	068	SA	CK	Kerotest	30508GLS-(2)
68-3	2-FCV-68-307	PRESSURIZER RELIEF TANK GAS ANALYZER SUPPLY	068	AO	GL	C635/COPES-VULCAN, INC.	E-171555
68-3	2-FCV-68-308	PRESSURIZER RELIEF TANK GAS ANALYZER SUPPLY	068	AO	GL	C635/COPES-VULCAN, INC.	E-171555
70-1	2-CKV-70-679	RCP THERMAL BARRIER CCS SUP HDR CHECK	070	SA	CK	Flowserve	13-103681-001
70-4	2-FCV-70-87	THERMAL BARRIER CCS RETURN	070	MO	GA	Walworth	SA-2099-1
70-5	2-FCV-70-134	THERMAL BARRIER CCS SUPPLY	070	MO	GA	Walworth	SA-2117-3

70-6	2-FCV-70-90	THERMAL BARRIER CCS RETURN	070	MO	GA	Walworth	09-57105-01
77-2	2-FCV-77-127	RB SUMP DISCHARGE FLOW CONTROL	077	AO	PLG	Tufline / Xomox	NP1211C
77-2	2-FCV-77-128	RB SUMP DISCHARGE FLOW CONTROL	077	AO	PLG	Tufline / Xomox	NP1211C
81-1	2-CKV-81-502	PRIMARY WATER CNTMT HDR CHECK VLV	081	SA	CK	W120/WESTINGHOUSE ELEC CORP	934D174
90-1	2-FCV-90-110	CNTMT BLDG LOWER COMPT AIR RAD MON RETURN	090	AO	GL	K085/KEROTEST	10-59621-01 sheets 1,2,3
90-1	2-FCV-90-111	CNTMT BLDG LOWER COMPT AIR RAD MON RETURN	090	AO	GL	K085/KEROTEST	10-59621-01 sheets 1,2,3
90-1	2-FCV-90-116	CNTMT BLDG UPPER COMPT AIR RAD MON RETURN	090	AO	GL	K085/KEROTEST	10-59621-01 sheets 1,2,3
90-1	2-FCV-90-117	CNTMT BLDG UPPER COMPT AIR RAD MON RETURN	090	AO	GL	K085/KEROTEST	10-59621-01 sheets 1,2,3

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ORIGINAL

DRAWING CHANGE AUTHORIZATION (DCA) 38814-A page 23

Note 1. : 47W406-73A is 47W406-73 with the substitution of a soft seat assembly [9911S-55-(1)] in lieu of the hard seat.

Note 2. : 47W555-25A is 47W555-25 with the substitution of a soft seat assembly [9911S-55-(1)] in lieu of the hard seat.

Note 3. : 47W560-48Ba is 47W560-48Ba with the substitution of a soft seat assembly [9913S-55-(1)] in lieu of the hard seat.

add

Drafter note: TVA revision 900 = vendor revision M.

Watts Bar Nuclear Plant Unit 1
Kerotest Drawing TVD-001 sht 1 of 2 Rev M
contract 83015

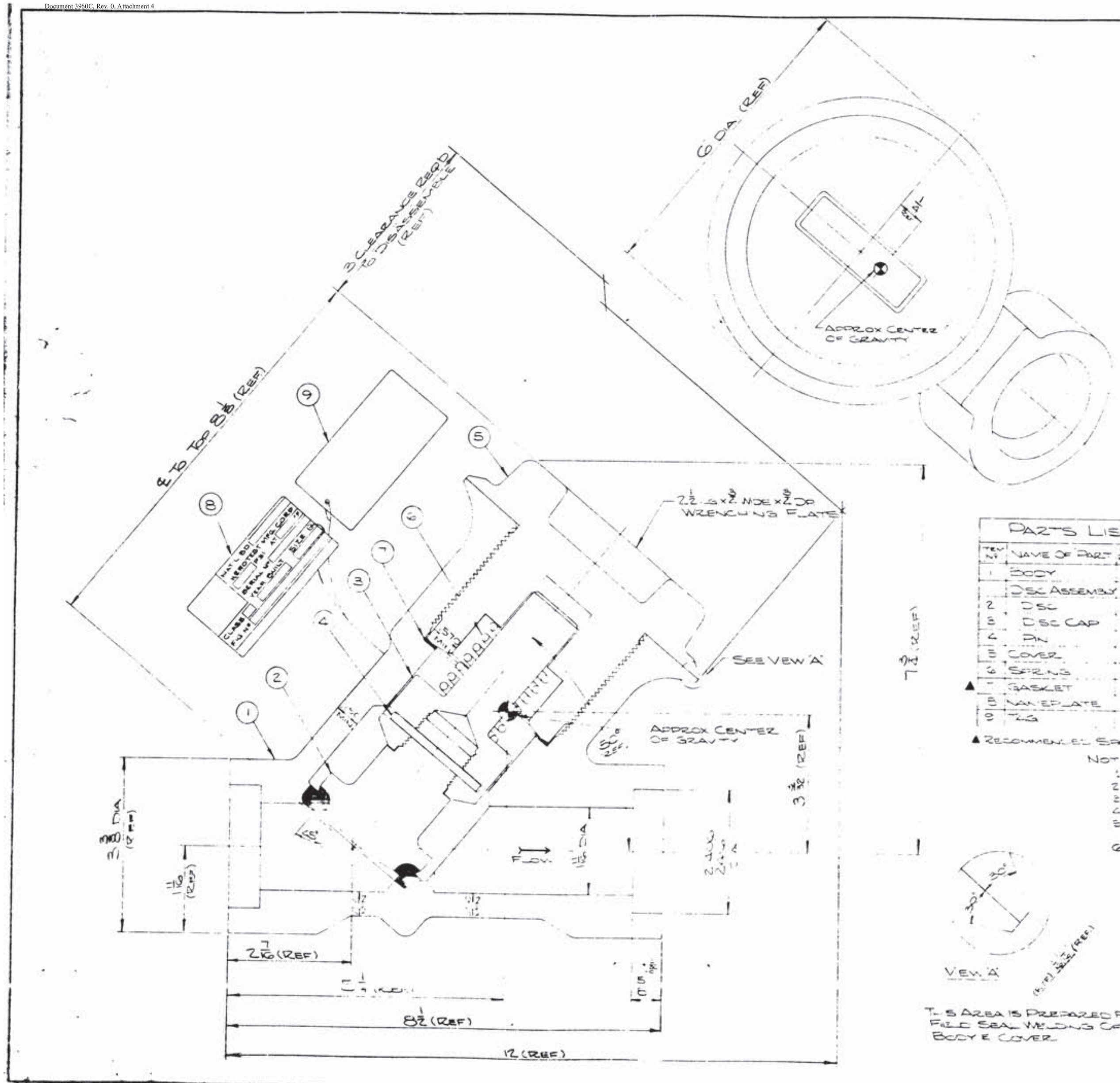
TITLE:
TVD Log

DCA - 38814 - 08

REV	TE	DV	REASON FOR CHANGE:
0	INIT DATE 5/13/96	INIT DWP DATE 5/13/96	Revise for soft seats.

Group 32-2

TOLERANCES UNL
OTHERWISE NOT
FRACTIONS ± 1/64
DECIMALS ± .005
ANGLES ± 1°
MACH FINISH



PARTS LIST

Item No	Name Of Part	No Req'd	Part No	Material	Remarks
1	Body	1	P-9911-1-(1)-Z	SA 182-Grade F316	*6 Hard Facing Mat'l
	Disc Assembly	1	99...55...Z		
2	Disc	1	99-1-3-(1)-Z	SA479 Type 316	*6 Hard Facing Mat'l
3	Disc Cap	1	5-99-5	ASTM A564 GR 630 Cond H1100	
4	Pin	1	A-22-5	ASTM A581 Type 303 Cond B	
5	Cover	1	P-9911-2-(1)-Z	SA 182-Grade F316	
6	Spring	1	A-9958 54	Inconel X750	
▲ 7	Gasket	1	A-99-63	ASTM A-- Type 304 (1/2 Hard)	
8	Nameplate	1	A-9924	18-8 Stainless Steel	
9	Tag	1	A-100 5-90	18-8 Stainless Steel	

▲ Recommended Spare Parts

Notes

1. Valve To Section III Of ASME Nuclear Code, Class (2)
2. Maximum Operating Temperature 650°F
3. Flow Coefficient Cv 60
4. Approx Weight 43 Lbs ± 10%
5. *6 Hard Facing On Seat Of Body & Face Of Disc To Be 3/32 Min
6. ASME Rating: Class 800

This Area Is Prepared For Field Seal Welding Of Body & Cover

Watts Bar Nuclear Plant - Units 1&2
Principal Piping System
TVA Contract No 74C38 83015
Dravo PO No (See Log TVD-001)
TVA Mark No (See Log TVD-001) Class B
ASME Class 2

TVA
Watts Bar
Contract No 74C38-83015
105
Valves
Checked
JUL 31
7-30-

2" Series 800
Y-Type Check Va
Date 7-2-
Scale Full
Kerotest
Pittsburgh, PA
VD-D-99

Manual No. 800-PC
Issued: March 31, 2004

INSTRUCTION MANUAL

for

½" thru 2" 800 lb. Piston Lift Check Valves with Resilient Seat Option

Flowserve Corporation
Flow Control Division
1900 S. Saunders Street
P.O. Box 1961
Raleigh, NC 27603

Phone: (919) 832-0525
FAX: (919) 831-3369

Table of Contents

Manual No. 800-PC

Revision Sheet

Revision	Date	Changes
-	03/31/2004	Original Issue

1.0 PHYSICAL DESCRIPTION AND OPERATION OF EQUIPMENT

1.1 Piston Check Valves (Figures 1 & 2 - See Section 11.0)

Piston Lift Check valves are generally used in applications where pressure drop through the valve is not critical, although Flowserve piston check valves have a relatively low pressure drop.

These small piston lift check valves include a return spring to facilitate closing. All Flowserve piston check valves have body guided discs to provide resistance to wear, thus, insuring a longer life. An equalizing hole is provided in the disc as a drain for condensate in steam valves.

A dual seat may be supplied which provides a hard surface for high differential pressure sealing and a resilient seat for sealing during low differential pressure.

These instructions are being furnished to the customer for use in the installation, operation and maintenance of the 800 pressure class series piston lift check valves.

2.0 DESIGN CONDITIONS

N/A

3.0 OPERATING CONDITIONS

N/A

4.0 TEST CONDITIONS

4.1 Each valve covered by this manual has received the following hydrostatic tests:

4.1.1 Shell hydrostatic test at 1.5 times the 100°F pressure rating.

4.1.2 A seat leakage and disc closure test at 110% of the 100°F pressure rating.

4.0 TEST CONDITIONS (Continued)

4.2 Each valve, supplied with resilient seated discs, received the following hydrostatic tests:

4.2.1 A low-pressure water seat test at 50 psig for containment isolation valves.

5.0 OPERATING PRECAUTIONS AND LIMITATIONS

5.1 Maximum hydrostatic test pressure shall not exceed the values imposed by the ASME Code, Section III.

6.0 INSTALLATION INSTRUCTIONS

6.1 Lifting and Handling Requirements and Limitations

6.1.1 Good judgement should be exercised in selecting a lifting device that will safely support the unit's weight.

6.1.2 Remove the end covers.

6.1.3 Remove any blocks or heavy paper that might have been used to keep the disc from moving during shipment.

6.2 Installation

6.2.1 Although the valves have been shipped in a clean condition, prior to installing the valves, examine the lines and the valve ports for foreign matter and clean them thoroughly if they have been exposed to the elements. (BEFORE CLEANING IN THIS FASHION, CHECK AT THE SITE TO SEE IF A SPECIFIC CLEANING PROCEDURE SHOULD BE FOLLOWED.) Flush the valves out with water if possible; otherwise blow them out with air or steam.

In performing this cleaning procedure, the ports should be vertical to assure complete removal of all matter which might have accumulated during storage.

6.2.2 Ensure that there is no line sag at the point of installation. Eliminate any pipeline deviation by the proper use of pipeline hangers or similar device.

6.2 **Installation** (Continued)

6.2.3 Extreme caution should be taken when installing check valves. The arrow on the valve body indicates flow direction. Therefore, when installing a check valve, place it so that the flow of the incoming fluid will open the valve and return flow will close it. Check valves installed in reverse position will stop the flow in the normal flow direction. Valves should be installed in a horizontal run of pipe with the gasket retainer on top. Maximum deviation from the horizontal should be ± 15°.

6.2.4 The valves should then be blocked or slung into position with apparatus that is sufficient to hold the valve assembly weight while the valve is being welded into the line. WELDING SHOULD TAKE PLACE WITH THE DISC IN THE OPEN POSITION. This is particularly important for valves with soft seats. Welding the valve with the disc closed will damage the resilient seat material. This may require removal of the internals prior to welding.

6.2.5 Remove the end protectors and clean the ends with a solvent such as acetone in preparation to welding.

7.0 MAINTENANCE REQUIREMENTS

7.1 Preventative Maintenance

7.1.1 Check all bolts periodically to ensure tightness and to forestall possible leaks.

7.2 Recommended Spare Parts

7.2.1 Recommended spare parts are pressure seal gasket (030), bonnet (002), disc assembly (004 & 005, 245 & 306 if equipped with resilient seated disc) and spring (429). The recommended quantity is 1 set for every 10 valves.

7.2.2 For consolidating spare parts (See 7.2.1), use the following guidelines:

- ½" thru 1" Piston Check Valves

Recommended spare parts are interchangeable throughout this size range. Note that similar materials should be ordered for valve body type (i.e. carbon steel bonnet for carbon steel valve).

7.0 MAINTENANCE REQUIREMENTS (Continued)

- 1½" and 2" Reduced Port Piston Check Valves

Recommended spare parts are interchangeable throughout this size range. Note that similar materials should be ordered for valve body type (i.e. carbon steel bonnet for carbon steel valve).

- 2" Full Port Piston Check Valves

Recommended spare parts are only interchangeable with other 2" Full Port Piston Check Valves. Same material restrictions stated above apply.

7.3 Lubrication

7.2.1 A light coating of lubricant should also be applied to the bonnet retainer threads if and when the valve is reassembled.

8.0 PERIODIC INSERVICE TESTING RECOMMENDATIONS AND PROCEDURES

8.1 This is not required for piston check valves without external operators.

9.0 MAINTENANCE INSTRUCTIONS

9.1 Disassembly

WARNING
PRIOR TO PERFORMING DISASSEMBLY,
CLOSE OFF THE LINE PRESSURE TO
THE VALVE, AND RELEASE ALL
PRESSURE IN THE VALVE.

9.1.1 Remove the anti-rotation pin (258) and the bonnet capscrew (216). The gasket retainer (033) may now be unscrewed and removed. Now thread the bonnet capscrew (216) directly into bonnet (002) and pull bonnet capscrew (216) directly upward.

Care should be taken to pull evenly and straight upward as not to score the neck walls of the valve and bonnet edges.

9.0 MAINTENANCE INSTRUCTIONS (Continued)

Pulling of the capscrew (216) will remove the bonnet (002) and pressure seal gasket (030). Lift out the spring (429) and disc (004).

It may be necessary to insert a wire hook into the holes located in the side of the disc in order to lift the disc out of the valve.

9.1.2 After removal of the disc from the valve, care should be taken to protect the seating surface from damage. The disc should be placed in a clean area until it is ready for replacement. THE SLIGHTEST NICK OR SCRATCH ON SEATING SURFACE MAY PREVENT COMPLETE SHUTOFF AND NECESSITATE EXTENSIVE REWORK OR REPLACEMENT.

9.1.3 Resilient Seat Removal (if so equipped)

To disassemble disc/resilient seat assembly:

a) Remove retaining ring (245)

b) Unscrew disc (004) from disc skirt (005)

Note: For removal, disc skirt should be held by the relieved outside diameter containing the drainage hole rather than by the outside diameter guiding surfaces. A slot for a fitted screw driver is provided at the top of the disc to facilitate removal and to prevent damage to these critical surfaces.

c) Remove the resilient seat by carefully slipping it over the disc.

CAUTION
DO NOT EXPOSE THE RESILIENT SEAT TO ANY PETROLEUM BASED OILS OR GREASES OR OTHER CUTTING FLUIDS, LUBRICANTS, ETC. WHICH ARE HYDROCARBON BASED.

9.0 MAINTENANCE INSTRUCTIONS (Continued)

9.2 Refinishing Sealing Surfaces

Minor discontinuities in the seat sealing surface, which may cause leakage can, in many cases, be removed by lapping. Major defects such as cracks or deep gouges will generally require replacement of the part.

Minor discontinuities on the valve disc sealing surfaces may be removed by remachining the surface to remove a few thousandths of material. Major defects will generally require replacement of the part.

(NOTE: Lapping is a polishing process where a sealing surface is ground with an abrasive held in place by a special fixture. The abrasive is commonly found in paste form or bonded to a paper backing. Detailed instructions on the use of lapping abrasives and fixtures, normally supplied with such equipment, should be adhered to.)

In order to maintain seat tightness in piston check valves, the sealing surfaces on both the disc and seat ring must be kept within close tolerances. Flowserve does not recommend lapping the disc directly to the seat. A good seal is dependent on line contact. Direct contact lapping will result in excessive seat widths.

Lapping equipment for the series 800 piston lift check valve seat is available through Flowserve. Contact your nearest Flowserve representative for information.

9.3 Reassembly

9.3.1 First, all dirt, scale and foreign matter should be removed from inside the valve body and bonnet.

9.3.2 Before reassembling the valve, check the seating surfaces to determine that no scratches or minor imperfections are on the disc or seat ring. If any are evident - lap these surfaces until none are visible. (Reference Para. 9.2)

9.0 **MAINTENANCE INSTRUCTIONS** (Continued)

9.3.3 Resilient Seat Assembly (if so equipped)

a) Carefully place the resilient seat over the disc.

b) Reassembly of the balance of the assembly is the reverse of that described in 9.1.3.

c) Use nuclear grade thread lubricant on the threads, making sure that it does not come in contact with the resilient seat material.

d) The disc skirt (005) is to be screwed firmly against the disc (004) shoulder prior to installing the retaining ring (245).

9.3.4 Reassembly of the valve is accomplished by inserting the disc or disc assembly (004) and spring (429), followed by the bonnet (002) and pressure seal gasket (030). Use a nuclear grade thread lubricant on the threads, making sure that it does not come in contact with the resilient seat material. Then screw in the gasket retainer (033). The bonnet capscrew (216) is then threaded into the bonnet through the hole in the retainer (033). A maximum of 5 ft-lbs of torque should be exerted on the bonnet capscrew. Insert the anti-rotation pin (258) in hole in top of the body (001).

NOTE: Consolidation of graphite during initial system pressurization is normal and will often cause the bonnet capscrew to become finger tight or even loose.

9.3.5 Retorque the bonnet capscrew to 50 to 60 inch-lbs. when the system is initially pressurized to ensure that the bonnets will not move out of the sealed position when the pressure is relieved.

9.4 **Trouble Shooting**

A. Leakage Between the Disc (004) and Seat Ring (013)

This could be an indication that there is foreign matter on the seating surfaces.

Disassemble the valve and remove the source of the trouble. If no foreign matter is found, inspect the seating surfaces of the valve for signs of a scarred or damaged seat - in which case the seating surfaces of the Disc (004) and Seat Ring (013) should be lapped until no visible defects remain. (Refer to Para. 9.2)

10.0 STORAGE REQUIREMENTS

The valves have been shipped in the partially open position. Upon receipt of the valves at destination, the crates should be examined thoroughly for signs of mishandling or damage during shipment. With the valves strapped to the shipping skids, all bolting should be checked to ensure that the joints are secure. Bolting on occasion, may become loosened during shipment and handling.

The valves should then be stored in a sheltered area to protect them from the elements, dirt and foreign material. They should not be exposed to the atmosphere, uncrated or removed from the shipping skids except in a clean area just prior to installation.

If the valves are not to be installed within a short period of time after receipt, and will require long-term storage, the following should be adhered to:

(a) They should be stored in an upright position and where there is minimal temperature variations and the temperature does not drop below 50°F.

(b) In their storage condition, the valves should be wrapped in polyethylene to prevent accumulation of dust or foreign matter.

(c) A check-off tag should be affixed to each unit and should be dated and signed off by the inspector witnessing the inspection which is recommended at 6-month intervals.

The shelf life for resilient seat materials is 5 years.
The shelf life for gaskets is indefinite.

SECTION 11.0

REFERENCE DRAWINGS

FIGURE 1

PISTON CHECK VALVE WITH HARD SEATED DISC

PART NO	QTY	DESCRIPTION
001	1	BODY
002	1	BONNET
004	1	DISC
013	1	SEAT RING
030	1	PRESSURE SEAL GASKET
032	1	SPACER RING
034	1	BONNET RETAINER
216	1	BONNET CAPSCREW
258	1	ANTI-ROTATION PIN
260	1	WIRE
345	1	NAMEPLATE
346	1	IDENTIFICATION PLATE
429	1	SPRING

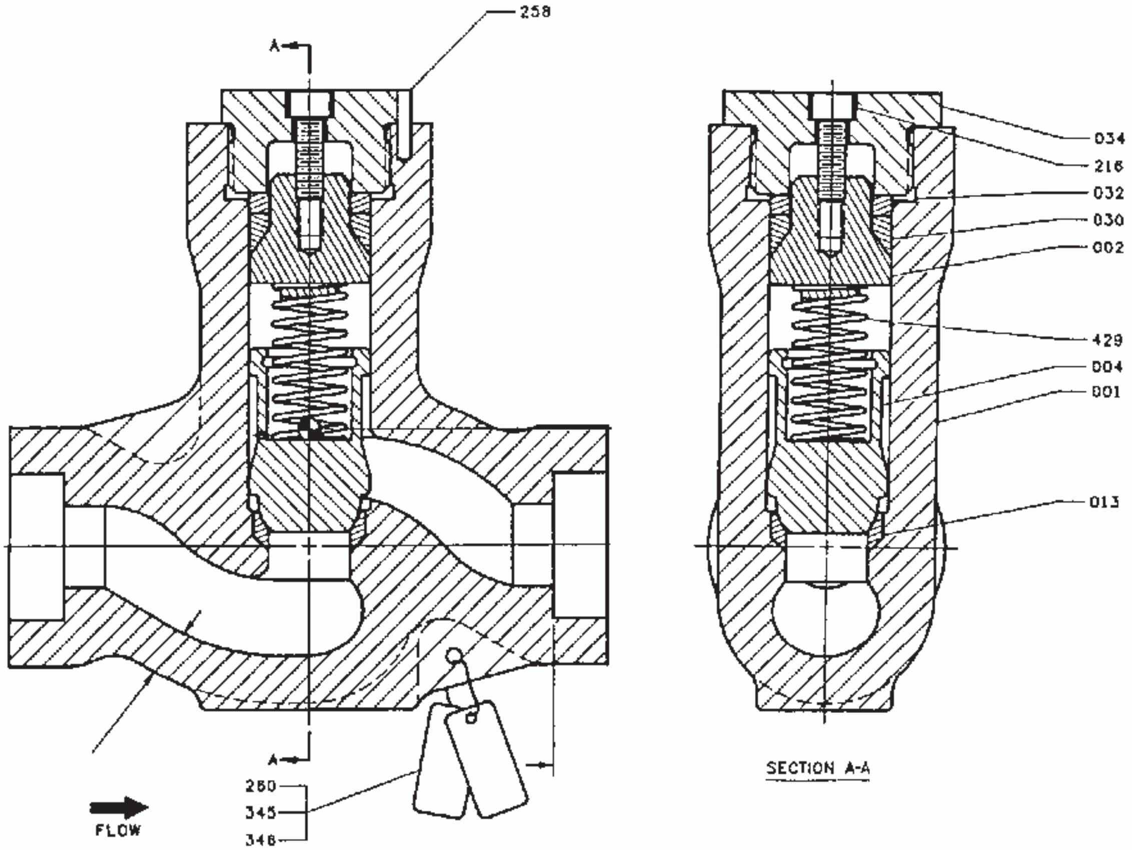
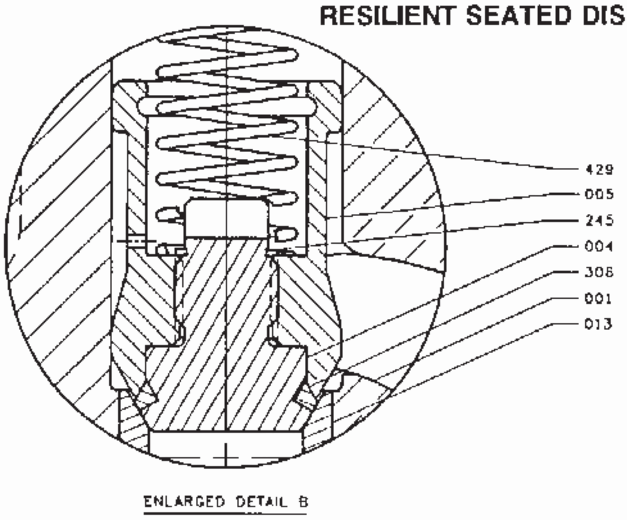


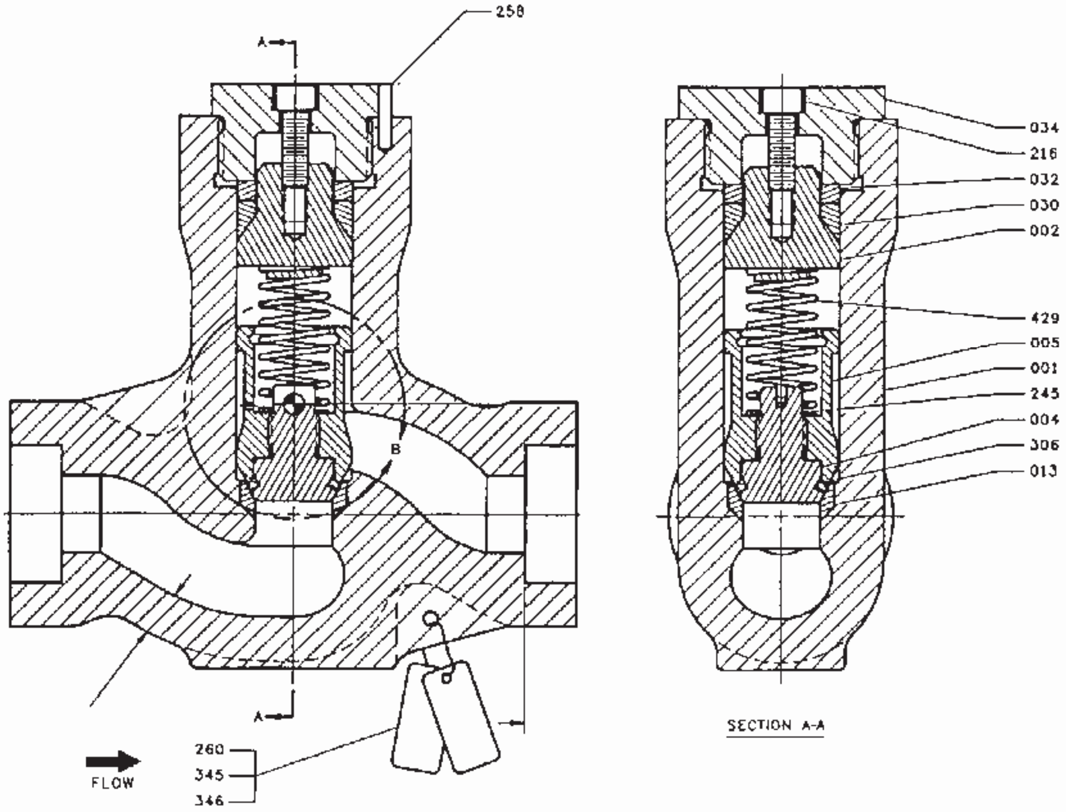
FIGURE 2

PISTON CHECK VALVE WITH RESILIENT SEATED DISC



ENLARGED DETAIL B

PART NO	QTY	DESCRIPTION
001	1	BODY
002	1	BONNET
004	1	DISC
005	1	DISC SKIRT
013	1	SEAT RING
030	1	PRESSURE SEAL GASKET
032	1	SPACER RING
034	1	BONNET RETAINER
216	1	BONNET CAPSCREW
245	1	RETAINING RING
258	1	ANTI-ROTATION PIN
260	1	WIRE
306	1	RESILIENT SEAT
345	1	NAMEPLATE
346	1	IDENTIFICATION PLATE
429	1	SPRING



SECTION A-A

Local Leak Rate Test Leakage Evaluation at Watts Bar for AOV Globe Valves

Document No. 3960C, Rev. 0, Attachment 5

Prepared for

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Revisions

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0	N/A	Initial release	All

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	Pages	**Rev**
Main Text	20	0
Appendix A	14	0
Appendix B	03	0
Total	37	

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1

OBJECTIVE AND SCOPE

1.1 OBJECTIVE

Kalsi Engineering, Inc. (KEI) has been contracted by Tennessee Valley Authority (TVA) to provide engineering services to evaluate the impact of local leak rate test (LLRT) pressures greater than the calculated peak containment internal pressure related to the design-basis loss-of-coolant accident (LOCA), Pa, for cases where greater test pressure tends to increase the sealing force. This work is being done in accordance with Purchase Order No. 6232543 [2][1].

The objective of this report is to determine the impact of the reduced LLRT pressure from DP_{test} to P_a on the seat leakage. All work performed under this project was done in accordance with the requirements of the KEI Quality Assurance Program [1], which meets the intent of 10CFR50 Appendix B requirements.

1.2 SCOPE

The scope of this attachment is LLRT air-operated globe valves. Component IDs and basic information are shown below in Table 1-1. All the valves are direct acting (extend to close) with a reverse acting (air to retract) actuator [7].

Table 1-1: Analysis Scope

Group	Component Id	Comp Description	Manufacturer/ Drawing No.
32-3	1-FCV-32-80 1-FCV-32-102 1-FCV-32-110 2-FCV-32-81 2-FCV-32-103 2-FCV-32-111	ESSENT CONTROL AIR TR A and B CNTMT ISOL; CONTROL AIR CNTMT ISOL	L170/LESLIE CO./ 717543070D
63-2	1,2-FCV-63-64	SIS ACCUM N2 HDR INLET VLV	F130/FISHER CONTROLS CO INC/ 54A0240

---

[1] The number in [] shows the reference documented in Section 6.

Group	Component Id	Comp Description	Manufacturer/ Drawing No.
63-3	1,2-FCV-63-23	COLD LEG ACCUMULATOR FILL FROM SIP 1A-A ISV	F130/FISHER CONTROLS CO INC/ 54A0223
63-4	1,2-FCV-63-71	SIS CHECK VLV TEST LINE HOLDUP TANK ISOL	F130/FISHER CONTROLS CO INC/ 54A0237
63-5	1,2-FCV-63-84	SIS CHECK VLV LEAK TEST HOLDUP TANK ISOL	F130/FISHER CONTROLS CO INC/ 54A0237
68-3	1,2-FCV-68-307 1,2-FCV-68-308	PRESSURIZER RELIEF TANK GAS ANALYZER SUPPLY	C635/COPES-VULCAN, INC./ E171555

1.3 HISTORICAL LEAKAGE

Reference 3 and Reference 8 provide the LLRT history for the Unit 1 and Unit 2 AOVs. Table 1-2, below, summarizes the results.

Table 1-2: Unit 1 and Unit 2 LLRT Leakage History

Group	Component Id	Leakage Results	Seat Type
32-3	1-FCV-32-80	Favorable history	Hard
	1-FCV-32-102	Favorable history	
	1-FCV-32-110	Favorable history	
	2-FCV-32-81	Favorable history	
	2-FCV-32-103	Favorable history	
	2-FCV-32-111	Unfavorable history	
63-2	1-FCV-63-64	Favorable history	Hard
	2-FCV-63-64	Favorable history	
63-3	1-FCV-63-23	Unfavorable history	Hard
	2-FCV-63-23	Favorable history	
63-4	1-FCV-63-71	Favorable history	Hard
	2-FCV-63-71	Favorable history	
63-5	1-FCV-63-84	Unfavorable history	Hard
	2-FCV-63-84	Favorable history	
68-3	1-FCV-68-307	Favorable history	Hard
	2-FCV-68-307	Favorable history	
	1-FCV-68-308	Favorable history	
	2-FCV-68-308	Favorable history	

2

METHODOLOGY

2.1 VARIABLES

Variable	Description	Units
A_o	Area based on mean seat diameter = $\frac{\pi}{4} \cdot D_m^2$	In^2
AR_{LB}	Lower benchset diaphragm area (EDA)	In^2
A_s	Stem area at packing = $\frac{\pi}{4} \cdot d_s^2$	In^2
D_m	Mean seat diameter	In
DP	Valve differential pressure	Psi
DP_{test}	Bounding LLRT test differential pressure	Psi
$DP_{test\_10\%}$	Test differential that will result in a 10% reduction in sealing load at P_a	Psi
ds	Stem diameter at packing	In
F_{DF}	Disc-to-cage/body friction force	Lb
F_{DP_DPtest}	DP force acting on sealing diameter @ DP_{test}	Lb
F_{DP_Pa}	DP force acting on sealing diameter @ P_a	Lb
F_{Dyn_DPtest}	Dynamic sealing force in stem axis direction @ DP_{test}	Lb
F_{Dyn_Pa}	Dynamic sealing force in stem axis direction @ P_a	Lb
F_{Pack}	Packing friction force	Lb
F_R	Maximum closed static friction load (includes packing and static seal friction)	Lb
F_{Static}	Static sealing force in stem axis direction	Lb
F_{SF}	Static seal friction	Lb
F_{S_DP}	Sealing load due to differential pressure	Lb
F_{S_DPtest}	Total sealing force in stem axis direction @ DP_{test}	Lb
F_{S_Pa}	Total sealing force in stem axis direction @ P_a	Lb
F_{SPL}	Minimum spring preload	Lb
F_W	Sealing force due to disc and stem weight	Lb
P_a	Calculated peak containment internal pressure related to the design-basis loss-of-coolant accident (LOCA)	Psig
R	Percentage reduction in sealing force due to the difference between P_a and DP_{test}	%
P_{LB}	Minimum lower benchset	Psig
R_{r_DPtest}	Sealing force normal to the seat @ DP_{test}	Lb

$R_{r\_DPtest\_Lin}$	Sealing force per linear inch normal to the seat @ DP_{test}	Lb/in
R_{r_Pa}	Sealing force normal to the seat @ P_a	Lb
$R_{r\_Pa\_Lin}$	Sealing force per linear inch normal to the seat @ P_a	Lb/in
$R_{r\_reduction}$	Reduction in normal sealing force due to the difference between pressures DP_{test} and P_a	Lb
$R_{r\_reduction\_Lin}$	Reduction in normal sealing force per linear inch due to the difference between pressures DP_{test} and P_a	Lb/in
W	Disc and stem weight	Lb
β	Stem angle from vertical	Deg.
θ	Seat angle from stem axis	Deg.
μ	Seat to disc friction coefficient	

2.2 GLOBE VALVE SEALING LOAD

During LLRT, sealing load includes 1) static force components and 2) dynamic force components due to differential pressure, DP. The subject valves are direct acting (extend to close) with a reverse acting (air to retract) actuator [7]. Therefore, at the closed position, the static force acting on the disc is equivalent to the spring preload minus packing/seal friction force. The dynamic force is proportional to the DP and the area over which the DP acts.

The approach for this analysis is to:

1. Determine the reduction in total sealing force due to changing the test DP from the current value, DP_{test}, to the calculated peak pressure, P_a.
2. Determine the value of DP_{test} required to achieve a 10% reduction in sealing force at P_a.

Figure 2-1: Force Components at Closed Position with Fluid Pressure Acting Above the Disc (Static and Dynamic)

2.2.1 Static Sealing Force Acting in Stem Axis Direction

The subject valves are direct acting (extend to close) with a reverse acting (air to retract) actuator [7]. Therefore, at the closed position, the static force, F_{Static}, acting on the disc is equivalent to the summation of spring preload and disc/stem weight minus packing/seal friction.

[redacted] [redacted]

[redacted]

[redacted]

TVA has provided the maximum closed static friction load, F_R, which includes packing and any other static friction. These valves do not have a seal between the disc and body/cage [10], therefore, F_{SF} is zero.

[redacted] (2)

2.2.2 Dynamic Sealing Force Acting in Stem Axis Direction due to Differential Pressure

The dynamic sealing force includes differential pressure force and disc-to-cage/body friction force:

[redacted] (3)

The DP sealing force at the closed position is:

[redacted] (4)

The disc-to-cage/body friction force, F_{DF} in Equation 3 is zero at the closed position.

2.2.3 Total Sealing Force and Seal Force Reduction

The total sealing force acting in the stem axis direction is given by Equation 5:

[redacted] (5)

Figure 2-2: Total Sealing Force Acting in the Stem Axis Direction (F_S) and Normal to the Seat (R_r) as mentioned in Reference 5

The total sealing force acting normal to the seat is given by Equation 6:

[redacted] (6)

The reduction in sealing force due to an LLRT test DP which is at a higher DP, DP_{test}, than the maximum peak pressure, Pa, is as follows:

[redacted] (7)

Therefore, the percentage reduction in sealing force due to testing at DP_{test} which is higher than P_a is determined as follows:

[redacted] (8)

Solving Equation 8 to determine the maximum allowable LLRT DP_{test} such that there is no greater than a 10% reduction is determined by the following equation:

[redacted] (9)

For each AOV in the scope of this analysis, the percentage reduction in sealing force, R, is determined using Equation 8 and the maximum LLRT test DP that results in a 10% reduction in sealing force is determined using Equation 9. A sample calculation is shown in Appendix B.

3

INPUTS

3.1 CALCULATION INPUTS

The following inputs are used in the sealing load calculations:

1. The input data for the analyses are documented in Table 3-1 were obtained from calculations, drawings, specifications, and other information provided by TVA. Some of these inputs are provided in Appendix A.
2. The maximum permissible LLRT test pressure, DP_{test}, is 1.1 x 15 = 16.5 psig [9, 11]. Calculated peak containment internal pressure related to the design-basis loss-of-coolant accident (LOCA), P_a, for Watts Bar is 9.36 psig [9]. For purposes of this analysis, a lower and more conservative value of 9 psig is used.
3. The disc and stem weight, W, will be negligible compared to the spring preload and therefore are excluded from the static sealing load component calculated in Equation 2. Since the weight term will generally provide additional closing force, this is a conservative.
4. The disc-to-seat coefficient of friction, μ, of 0.5 is used in Equation 7. The COF value does not affect the calculation of R (Equation 9) and $DP_{test\_10\%}$ (Equation 10).
5. Justified assumptions were made where data were not available. It is important to note that the results of this analysis may be significantly affected by changing key inputs. It will be necessary to perform an impact analysis if key data are changed in the future.

Table 3-1: Valve-Specific Input Data [8, 10]

Group ID	Component ID	Seat-to-Disc Material	Input Parameter					
			P_{LB}, psi	AR_{LB}, in^2	F_R, lbs	D_m[2], in	d_s, in	θ[3], deg.
32-3	1-FCV-32-80/ 2-FCV-32-81	Not Available	5.5	54.0	207	2.25	0.50	30
	1-FCV-32-102/ 2-FCV-32-103		5.5	54.0	207	2.25	0.50	30
	1-FCV-32-110/ 2-FCV-32-111		5.5	54.0	207	2.25	0.50	30

---

[2] D_m values for Groups 63-2, 63-3, 63-4, 63-5, and 68-3 are based on assumption provided in Section 4.

[3] θ values are scaled from the drawings.

Group ID	**Component ID**	**Seat-to-Disc Material**	**Input Parameter**					
			P_{LB}, psi	**AR_{LB}, in^2**	**F_R, lbs**	**D_m^2, in**	**d_s, in**	**θ^3, deg.**
63-2	1-FCV-63-64/ 2-FCV-63-64	Stellite-6/ Stellite-6	20.0	69.0	293	1.00	0.50	30
63-3	1-FCV-63-23/ 2-FCV-63-23	Stellite-6/ 316 SS	23.0	69.0	453	1.00	0.50	30
63-4	1-FCV-63-71/ 2-FCV-63-71	Stellite-6/ Stellite-6	23.0	69.0	240	0.75	0.50	30
63-5	1-FCV-63-84/ 2-FCV-63-84		23.0	69.0	410	0.75	0.50	30
68-3	1-FCV-68-307/ 2-FCV-68-307	316 SS/ 316 SS	16.0	17.0	111	0.38	0.31	30
	1-FCV-68-308/ 2-FCV-68-308		16.0	17.0	111	0.38	0.31	30

4

ASSUMPTIONS

Data that have not been formally verified are treated as assumptions. Where possible, the basis of the data has been noted. The following general assumptions were used in this analysis.

1. The mean seat diameters, D_m, for Groups 63-2, 63-3, 63-4, 63-5, and 68-3 are not available and are assumed to be equal to the nominal valve size. The higher mean seat diameter increases the percentage reduction in the sealing force at the design basis accident pressure, P_a. A sensitivity analysis showed that increasing the mean seat diameter by 20% has a negligible increase the percentage reduction in the sealing force. This assumption does not require a verification.
2. The seat contact band width, t, for Group 32-3 valves is assumed to be of 0.005 inches (see Section 5.3) which is a reasonable assumption for a globe valve. A lower seat contact band width will provide a conservative results. A sensitivity analysis showed that lowering the seat contact band width to 0.001 inches does not change the overall conclusion because the percentage increase in the leakage area, A_I, remains negligible. Therefore, this assumption does not require a verification.

5

RESULTS, RECOMMENDATIONS, AND CONCLUSIONS

5.1 SEAT LOAD RESULTS

The sealing load per linear inch for the applicable AOV Globe valves are shown in Table 5-1. The minimum recommended seat contact force value for metal seats is 100 lb/in per Reference 6. The seat contact force values exceed 100 lb/in except for Group 32-3 valves at DP_{test} and P_a.

Table 5-1: Seat Load Results

Group ID	Component ID	$R_{r\_DPtest\_Lin}$, lb/in	$R_{r\_Pa\_Lin}$, lb/in	$R_{r\_reduction\_Lin}$, lb/in
32-3	1-FCV-32-80/ 2-FCV-32-81	23.10	18.80	4.30
	1-FCV-32-102/ 2-FCV-32-103	23.10	18.80	4.30
	1-FCV-32-110/ 2-FCV-32-111	23.10	18.80	4.30
63-2	1-FCV-63-64/ 2-FCV-63-64	374.16	372.65	1.51
63-3	1-FCV-63-23/ 2-FCV-63-23	390.20	388.69	1.51
63-4	1-FCV-63-71/ 2-FCV-63-71	614.57	613.73	0.84
63-5	1-FCV-63-84/ 2-FCV-63-84	537.24	536.40	0.84
68-3	1-FCV-68-307/ 2-FCV-68-307	146.98	146.75	0.23
	1-FCV-68-308/ 2-FCV-68-308	146.98	146.75	0.23

5.2 SEAT LOAD REDUCTION AND MAXIMUM LLRT TEST PRESSURE FOR 10% SEAL LOAD REDUCTION

The sealing force percentage reduction due to a decrease in LLRT pressure from DP_{test} to P_a (16.5 psig to 9 psig) is shown in Table 5-2. Table 5-2 also includes the maximum LLRT test pressure, $DP_{test\_10\%}$, that ensures no greater than a 10% seal load reduction at P_a.

As can be seen that the seat load reduction for all the valves except for Group 32-3 are below 1%. The seat load is reduced by 18.61% for Group 32-3 valves when the pressure is reduced from DP_{test} to P_a (16.5 psig to 9 psig). The maximum test DP that results in 10% seat load reduction for Group 32-3 is 12.65 psig. Section 5.3 further discusses the effect of seat load reduction on seat leakage for Group 32-3 valves.

Table 5-2: Seat Load Reduction and Maximum DP_{test} for 10% Reduction in Seat Load

Group ID	Component ID	$R_{r\_DPtest\_Lin}$, lb/in	$R_{r\_reduction\_Lin}$, lb/in	R	$DP_{test\_10\%}$, psig
32-3	1-FCV-32-80/ 2-FCV-32-81	23.10	4.30	18.61	12.65
	1-FCV-32-102/ 2-FCV-32-103	23.10	4.30	18.61	12.65
	1-FCV-32-110/ 2-FCV-32-111	23.10	4.30	18.61	12.65
63-2	1-FCV-63-64/ 2-FCV-63-64	374.16	1.51	0.40	215.04
63-3	1-FCV-63-23/ 2-FCV-63-23	390.20	1.51	0.39	223.90
63-4	1-FCV-63-71/ 2-FCV-63-71	614.57	0.84	0.14	619.80
63-5	1-FCV-63-84/ 2-FCV-63-84	537.24	0.84	0.16	542.84
68-3	1-FCV-68-307/ 2-FCV-68-307	146.98	0.23	0.16	540.08
	1-FCV-68-308/ 2-FCV-68-308	146.98	0.23	0.16	540.08

5.3 EFFECT OF SEAT LOAD REDUCTION ON SEAT LEAKAGE FOR METAL SEATED VALVES

Unlike the soft-seated swing check valves, a tight sealing of a metal-seated valve requires yielding of one material into the surface "waviness" and surface roughness of the other to block direct leakage paths. Even, seemingly smooth machined surfaces have surface asperities as illustrated in

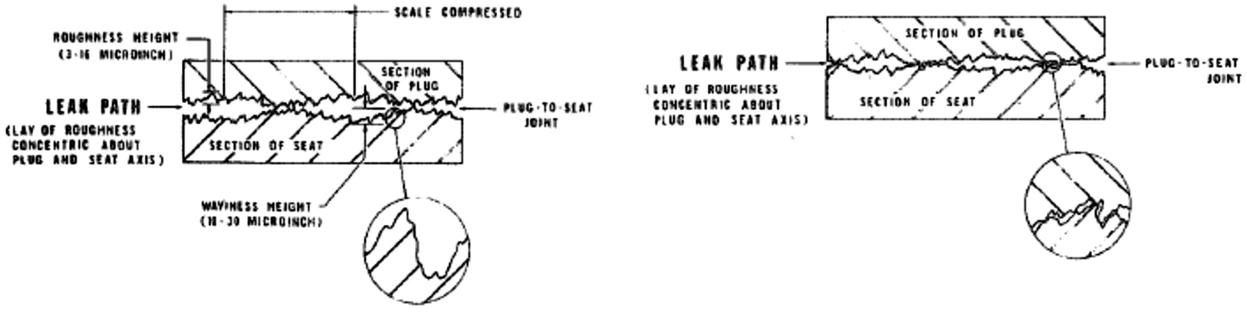
Figure 5-1. When the two surfaces contact each other, the surface asperities initially establish the contact. With an increasing load, the asperities initially deform elastically and then plastically. To ensure a reliable seal, the surface asperities within the contact band need to deform plastically over a reasonable amount of bandwidth. At low pressures, the seat load will not be sufficient to plastically yield the asperities on the contacting surfaces and therefore, the asperities will deform elastically. Due to the fact that these valves were providing a reliable sealing at DP_{test} pressure, the leak path at this pressure will have a very high flow resistance. Any reduction in the seat load will decrease the flow resistance by increasing the leakage flow area, A_I, [redacted]. For the subject valves, the seat load decreases with decreasing test differential pressure. The amount of seat load decrease is limited to the portion of seat load produced by differential pressure. Table 5-2 shows that the seat load reduction for all the valves are below 1% except for Group 32-3. The seat load is reduced by 18.61% for Group 32-3 valves when the pressure is reduced from the normal test DP_{test} to P_a (16.5 psig to 9 psig). The reduction in the seat load will reduce the leak path flow resistance by increasing the leakage flow area, A_I. A reduction in the flow resistance is equivalent to an increase in the leakage coefficient, C_L. Based on Equation 3-3 in Section 3.2 of the main report, the C_L can increase by 35% before the measured leakage at pressure P_a would increase from the measured leakage at DP_{test}.

A calculation is performed for Group 32-3 valves to determine the percentage increase in the leakage flow area, A_I, when the pressure is reduced from DP_{test} to P_a (16.5 psig to 9 psig). This calculation is performed based on the approach documented in Section 2.5 of Attachment 3 of this report. All the assumptions documented in Section 2.5.2 of Attachment 3 remains the same for the subject globe valves of Group 32-3 accept the assumption for the seat contact band width, t. The seat contact band width, t, for Group 32-3 valve is assumed to be of 0.005 inches which is a reasonable assumption. A lower seat contact band width will provide a conservative result. A sensitivity analysis showed that lowering the seat contact band width to 0.001 inches does not change the overall conclusion because the percentage increase in the leakage area, A_I, remains negligible. Therefore, this assumption does not require a verification. The mean seat diameter of Group 32-3 valves is 2.25 inches (Table 3-1).

Table 5-3: Percentage Increase in Leakage Flow Area Calculation for Group 32-3 Valves

Valve Group	**R_{r_DPtest}, lb**	**R_{r_Pa}, lb**	***These Variables are Defined in Attachment 3 of the Main Report***					
			[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	**A_I**
32-3	163.28	132.89	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	0.03

Table 5-3 shows that the calculated percentage increase in the leakage flow area, A_I, is very small and is not expected to increase the leakage coefficient, C_L, by 35% which is a threshold for the measured leakage at the lower pressure, P_a, to increase from the measured leakage at the higher pressure, DP_{test}.



(a) Under Light Seating Load

(b) Under Heavy Seating Load

Figure 5-1: Microscopic Flow Path Under Light and Heavy Seating Load [6]

5.4 NOTES/ RECOMMENDATIONS

The minimum recommended seat contact force value for metal seats is 100 lb/in per Reference 6. Per Table 5-1, the seat contact force values at 16.5 psig (DP_{test}) and 9.0 psig (P_a) pressures exceed 100 lb/in except for Group 32-3 valves. Although, the calculated seat load for Group 32-3 is below the recommended 100 lb/in at DP_{test}, the historical measured leakages for Group 32-3 (Unit 1) valves are below the acceptable value [3].

5.5 CONCLUSION

As can be seen from Table 5-2, the seat load reduction for all the valves except for Group 32-3 are below 1%. The seat load is reduced by 18.61% for Group 32-3 valves when the pressure is reduced from the normal test DP_{test} to P_a (16.5 psig to 9 psig). The maximum test DP that results in 10% seat load reduction for Group 32-3 is 12.65 psig. Per Section 5.3, to be at risk for increased leakage at a $P_a = 9.0$ psi, the reduction in the seat load would need to increase the leakage coefficient, C_L, by 35%. Based on the simplified but conservative calculation performed in Section 5.3, it is expected that the change in the leakage flow area, A_I, will be negligible (see Table 5-3) with the reduction in seat load. Therefore, it is expected that the leakage coefficient, C_L, will not increase by 35% which is a threshold for the measured leakage at the lower pressure, P_a, to increase from the measured leakage at the higher pressure, DPtest. Therefore, the seat load reduction of 18.61% for Group 32-3 valves is not expected to increase the leakage at pressure P_a.

Based on these results, seat leakage for all AOV Glove valves within the scope of this assessment is not expected to increase if tested at a lower differential pressure of 9.0 psig.

6

REFERENCES

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   b. Fisher Controls, Air Operated Control Valve, Type 667-SS-95, Size 1” Body 40 Actuator. Dual Spr., Dwg. No. 54A0223, Rev. 902, Dated: 11-01-88.
   c. Fisher Controls, Air Operated Control Valve, Type 667-SS-95, Size 1” Body 40 Actuator. Dual Spr., Dwg. No. 54A0240, Rev. 902, Dated: 11-01-88.
   d. Fisher Controls, Air Operated Control Valve, Type 667-SS-95, Size 3/4” Body 40 Actuator. Dual Spr., Dwg. No. 54A0237, Rev. D, Dated: 11-17-80.
   e. Copes-Vulcan, Inc., 3/8 Class 1500 ASME Valve Assembly Code Class-2, Dwg. No. E-171555, TVA Rev. 902, Dated: 9-18-91.

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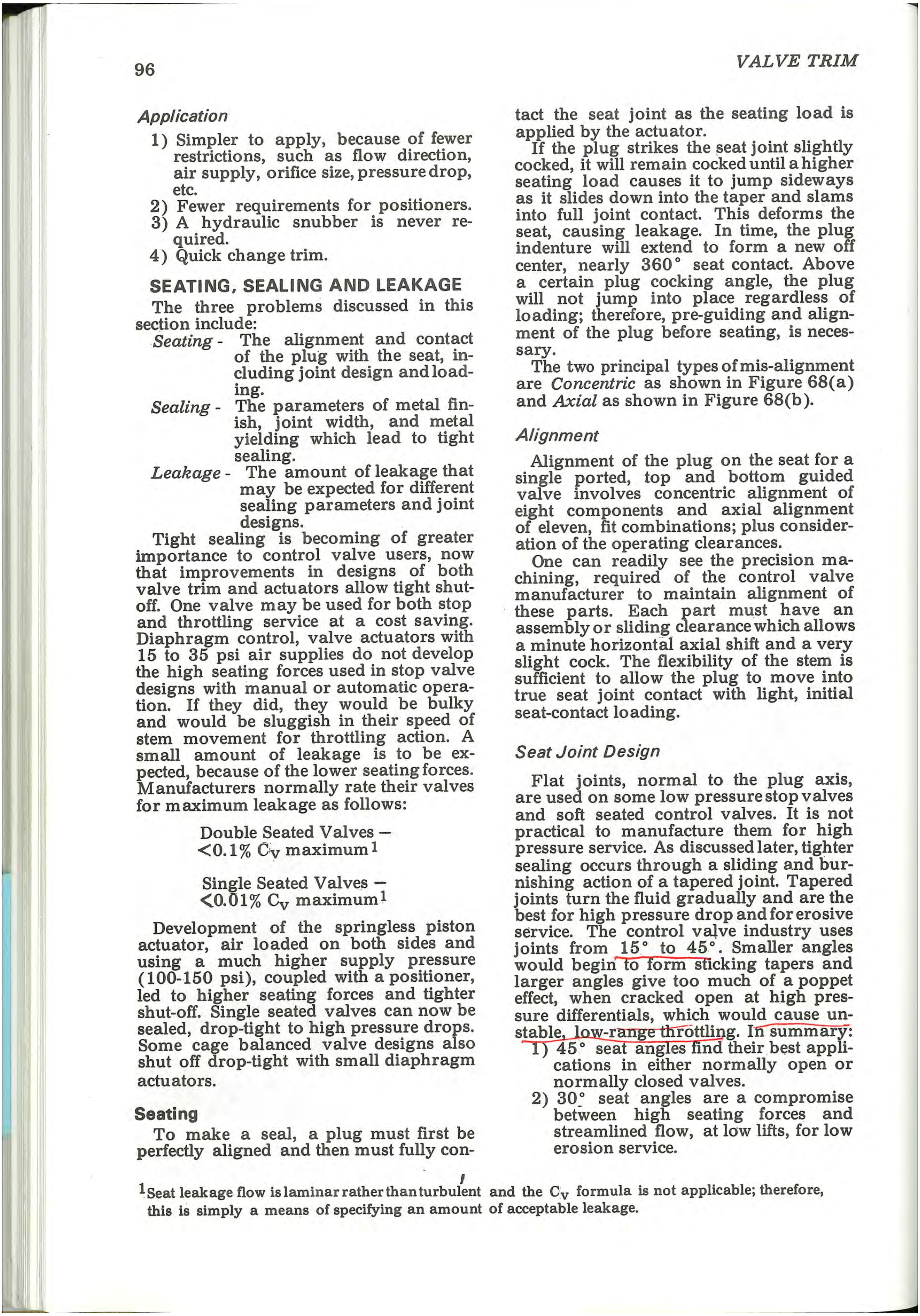
Appendix A

SUPPORTING DOCUMENTS



Application

1) Simpler to apply, because of fewer restrictions, such as flow direction, air supply, orifice size, pressure drop, etc.
2) Fewer requirements for positioners.
3) A hydraulic snubber is never required.
4) Quick change trim.

SEATING, SEALING AND LEAKAGE

The three problems discussed in this section include:

Seating - The alignment and contact of the plug with the seat, including joint design and loading.

Sealing - The parameters of metal finish, joint width, and metal yielding which lead to tight sealing.

Leakage - The amount of leakage that may be expected for different sealing parameters and joint designs.

Tight sealing is becoming of greater importance to control valve users, now that improvements in designs of both valve trim and actuators allow tight shut-off. One valve may be used for both stop and throttling service at a cost saving. Diaphragm control, valve actuators with 15 to 35 psi air supplies do not develop the high seating forces used in stop valve designs with manual or automatic operation. If they did, they would be bulky and would be sluggish in their speed of stem movement for throttling action. A small amount of leakage is to be expected, because of the lower seating forces. Manufacturers normally rate their valves for maximum leakage as follows:

Double Seated Valves —
$<0.1\%$ C_V maximum[1]

Single Seated Valves —
$<0.01\%$ C_V maximum[1]

Development of the springless piston actuator, air loaded on both sides and using a much higher supply pressure (100-150 psi), coupled with a positioner, led to higher seating forces and tighter shut-off. Single seated valves can now be sealed, drop-tight to high pressure drops. Some cage balanced valve designs also shut off drop-tight with small diaphragm actuators.

Seating

To make a seal, a plug must first be perfectly aligned and then must fully contact the seat joint as the seating load is applied by the actuator.

If the plug strikes the seat joint slightly cocked, it will remain cocked until a higher seating load causes it to jump sideways as it slides down into the taper and slams into full joint contact. This deforms the seat, causing leakage. In time, the plug indenture will extend to form a new off center, nearly 360° seat contact. Above a certain plug cocking angle, the plug will not jump into place regardless of loading; therefore, pre-guiding and alignment of the plug before seating, is necessary.

The two principal types of mis-alignment are *Concentric* as shown in Figure 68(a) and *Axial* as shown in Figure 68(b).

Alignment

Alignment of the plug on the seat for a single ported, top and bottom guided valve involves concentric alignment of eight components and axial alignment of eleven, fit combinations; plus consideration of the operating clearances.

One can readily see the precision machining, required of the control valve manufacturer to maintain alignment of these parts. Each part must have an assembly or sliding clearance which allows a minute horizontal axial shift and a very slight cock. The flexibility of the stem is sufficient to allow the plug to move into true seat joint contact with light, initial seat-contact loading.

Seat Joint Design

Flat joints, normal to the plug axis, are used on some low pressure stop valves and soft seated control valves. It is not practical to manufacture them for high pressure service. As discussed later, tighter sealing occurs through a sliding and burnishing action of a tapered joint. Tapered joints turn the fluid gradually and are the best for high pressure drop and for erosive service. The control valve industry uses joints from 15° to 45°. Smaller angles would begin to form sticking tapers and larger angles give too much of a poppet effect, when cracked open at high pressure differentials, which would cause unstable, low-range throttling. In summary:

1) 45° seat angles find their best applications in either normally open or normally closed valves.
2) 30° seat angles are a compromise between high seating forces and streamlined flow, at low lifts, for low erosion service.

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[1] Seat leakage flow is laminar rather than turbulent and the C_V formula is not applicable; therefore, this is simply a means of specifying an amount of acceptable leakage.

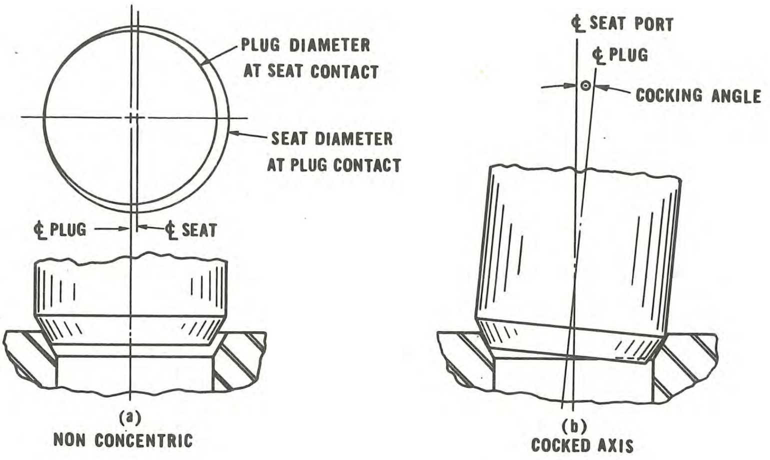


Figure 68. PLUG MISALIGNMENT WITH SEAT.

3) 15° seat angles are best applied to high pressure drop, erosive service.

Seat Joint Width

Seat joint width is a balance of adding length to the flow path to increase flow resistance vs. reduction of the seating force for a given actuator seating load. A certain minimum width is essential to establish a tight seal; however, the joint must have sufficient backup strength to support the compressive seating load and must be wide enough to prevent indention of the plug. Narrow joints are much tighter than wide joints, provided they exceed the minimum width requirements.

Seat Joint Loading

Seat joint loading is usually expressed as pounds of force per linear inch of mean seat joint circumference. Loading may vary from 25-600 lb./inch as given below:

1) 25 lb./in. - Low pressure drop service; leak-tight shut-off is not required; metal-to-metal joint.
2) 50 lb./in. - Moderate pressure drop service; slight leakage expected (0.1% C_V maximum).
3) 100 lb./in. - High pressure drop service; nearly drop-tight service (0.01% C_V maximum); will seal 3000 psi pressure drop on 0.015 in. width, 30° joint of 316 SS[1].
4) 300 lb./in. - Very high pressure drop service; drop-tight (will seal 6000 psi on 0.025 in. width, 20° joint of 440-C SS, hardness 55 R_C).
5) 600 lb./in. - Extremely high pressure service.

The apparent compressive seating stresses on joints described in items 3) and 4) above, are 13,000 psi and 35,000 psi respectively, which is well below the yield point of the given trim materials. These are the stresses normal to the joint. Elastomeric and plastic yielding is occuring at the high points of each surface making a tortuous flow path for leakage restriction. By contrast, stop-valve seat loading with hard-faced seats in steam service may be 50,000 psi, apparent stress, or four times a nominal control valve, seating load of 100 lb/linear inch for a diaphragm actuator.

eg. (Stellite vs Stellite)

To obtain the best circular seat-joint contact at low stem loading use:

1) Cage guided trim with the seat integral with the cage. Horizontal and axial alignment for seating involves

---

[1] 100 lbs/linear inch vertical seating force is equivalent to a force of 200 lbs/linear inch normal to a 30° joint (100 lb./sin 30°). The compressive seating stress is 200 lb/0.015 in.x 1 in.=13,300 psi.

only two parts in sliding contact. Alignment of regular trim must be transferred from the seat to the body, to the bonnet, to the guide, to the plug, and back to the seat.

2) Cage guided trim with the seat aligned by the cage.
3) A seat that is integral with body; or
4) Extend a thin flexible seat lip above the means of seat retention as shown in Figure 29.

A radial expandable, seat ring design is illustrated by Figure 69. In this design the seating angle creates a large radial component of force which expands the seat ring against the retaining collar. The spring-out action of the non-circular ring allows a near-perfect joint contact giving drop-tight shut-off in severe thermal cycle service. This design has been successfully used on pressure drops to 4,400 psi. The large flow, entrant passage also makes the valve suitable for erosive service.

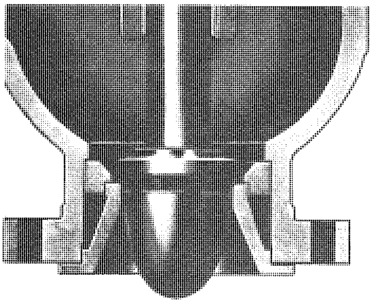


Figure 69. RADIALLY EXPANDABLE SEAT RING DESIGN.

Courtesy Conoflow Corporation

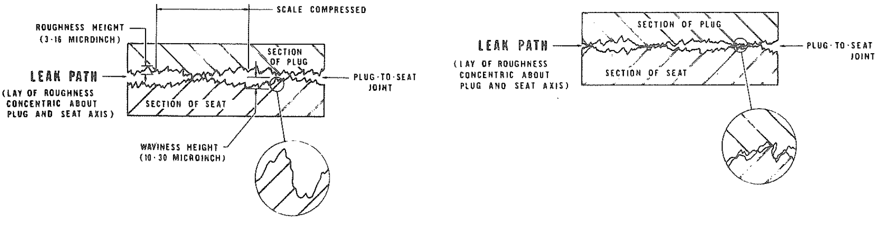
Trim Sealing

Tight sealing requires the yielding of one material into the surface "waviness" and surface roughness of the other, as illustrated by Figure 70, to block direct leakage paths; thus, making these paths long and tortuous. Compressive stresses are far below those that would yield the entire joint; therefore, the contact area is apparent. Actually, only the peaks of each surface are in contact and the concentration of force may then exceed the yield and will plastically deform the high spots on each valve closure. Additional closures require a higher seating load to achieve the same degree of tightness, until the wear particles are formed and conditions tend to stabilize.

Tapered joints provide for a sliding and burnishing action as contact is made and loading occurs. This gives a tighter initial seal than a perpendicular contact and the seal remains tighter with repeated closures.

The minimum width of a joint to seal gas to 1 x 10^{-7} cc/s/linear inch, maximum leakage, is 0.04 inch. Wider joints with the same surface finish and loading will not seal tighter. This width insures sufficient high point contact to form an adequate flow resistance path as shown by the graph of Figure 71.

Extra "super-finishing" of seat joints is unnecessary for tight sealing, because as the joint opens and closes, wear particles ball up on the surface, quickly returning it to a rougher finish. Also, some fluid contaminants tend to remain in the joint on closure and indent the surfaces. Excessive lapping generally either reduces seat tightness by increasing the actual contact area, thus, reducing the unit compressive seating stress provided by a fixed actuator seating force or it destroys the original surface geometry.



(a) Under Light Seating Load

(b) Under Heavy Seating Load

Figure 70. MATING OF SEAT JOINT SURFACES.

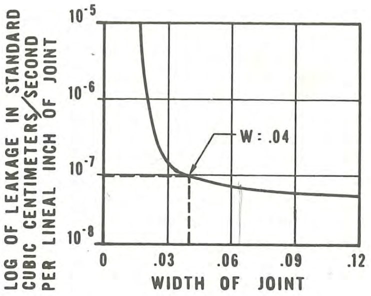


Figure 71. MINIMUM JOINT WIDTH FOR A TIGHT SEAL.

(Leakage rates for 14.7 psi Δ P helium on a flat circular joint.)

Consolidated graph taken from Reference No. 48.

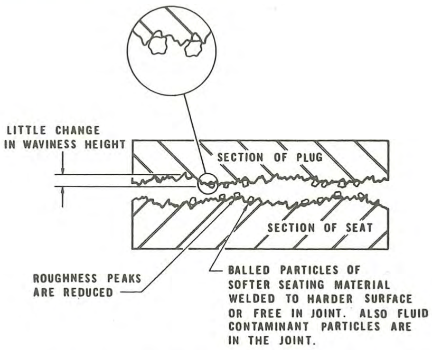


Figure 72. JOINT SURFACE AFTER REPEATED CLOSURES.

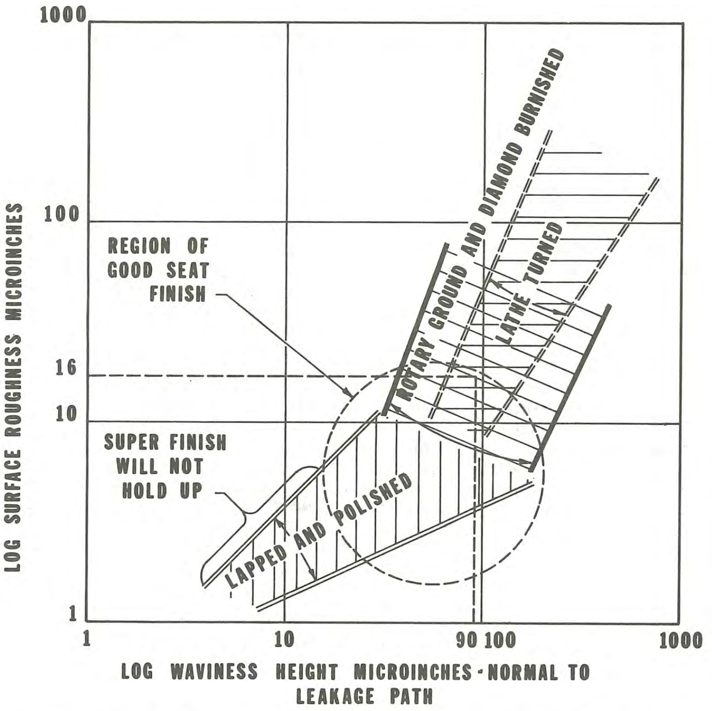


Figure 73. DEGREE OF SEAT JOINT FINISH VS. METHOD OBTAINING FINISH.

Chart presented in "Investigation of Leakage and Sealing Parameters", Paul Bauer, ITT Research Institute, Technical Report AFRPL-TF-65-153, August, 1965.

The following comparison illustrates the relative seating force to obtain same degree of tightness vs. the seat joint finishing method (concentric lay of finishing pattern). Refer to Figures 72 and 73.

Finishing Method	*Relative Seating Force*
diamond burnished (after grinding)	1.0
lathe turned	1.3
ground	2.5
lapped (excessive) (90% of apparent area of) (contact actually mated)	2.9

Trim Leakage

Definitions Relative to Trim Leakage:

Drop tight, to be meaningful, must be specified in terms of the maximum allowed number of drops per unit of time (drops/minute, cc/hour or no visible drop).

Bubble tight, to gas, should be specified as the maximum allowed number of bubbles of a given size per minute (usually 1/8 in. diameter).

Zero leakage is defined as 1 x10^{-8} cc/s or about 0.3 cc/year (helium leak rate at standard conditions). Zero leakage is often specified in critical service and requires very careful joint design, material selection, finish control, and sufficient seating force on narrow joints. It is practical only for small valves, at extra cost, and may last for only a few closing cycles.

Stop valve maximum leakage rates are given in the Valve Manufacturers Standardization Society, SP-61 as:

1) Water tests at ΔP = Body CWP rating (10 cc/hour/inch of valve pipe size or about 3/drops/minute).
2) Air tests at ΔP=80 psi (0.1 SCFM/inch of valve pipe size).

Leakage Specifications, to be meaningful and allow comparison, should include test fluid, temperature, pressure, pressure drop, seating force and duration of test.

Control Valve Leakage

Properly designed control valves can achieve stop valve tightness and maintain it throughout a long service life before trim replacement; particularly with cage guided, balanced trim having elastomer plug-to-cage seals. The control valve, however, is expected to throttle and often shuts off much more frequently than stop valves. For example, some dump valves may have from 4000 to 7000 opening and closing cycles per day, handling high pressure and erosive fluids at 1000 to 4000 psi pressure drop. Few stop valves could match this performance and remain tight.

It is customary to expect a slight degree of leakage and, in general control valve service applications, this has presented few problems. Specified permissible leakage should be based on process considerations (hazards resulting from leakage after emergency shut off, etc.). Tight shut off should be specified only when necessary, because a higher quality more expensive valve is required.

Liquid Leakage is to a great extent affected by surface tension and the particular fluid wetting the joint surface, before the new fluid attempts to enter. For precise leak testing, the joint and body should be free of all traces of oil, which would preferentially wet the metal joint surfaces. Water leakage rates of an oil-free joint are higher. Oil clinging to the roughness, blocks some leakage paths, causing a higher capillary displacement pressure to establish flow of the test fluid.

Seat Leakage Specifications

Single Seated Globe Valves

A maximim allowable leakage of 0.01% of Rated C_V is often based on the nominal or catalog listed actuator size for the given valve tested with 50psi of air across the seat joint.

Double Seated Globe Valves

These valves are specified to have a maximum leakage rate of 0.5% to 0.1% of rated C_V depending upon quality purchased. They are tested with 50 psi of air across the seat joint. See ISA standard 39.1.

Extra Tight Shut Off for Single Seated Globe Valves

A water test is often conducted at the differential pressure rating assigned to the valve by the manufacturer and which is based upon actuator size, air loading, spring force and direction of leakage across the plug (either over or under the plug). Maximum leakage may be specified as 0.0005 cubic centimeters of water per minute per inch of valve seat orifice diameter (not pipe size of valve end) per psi pressure drop. Example: A valve having a 4 inch seat orifice and tested to 2000 psi differential pressure would have a maximum water leakage rate of 4cc/minute. Leakage may be checked with a gas instead of a liquid. The maximum allowable rate is often specified at 6 x 10^{-7} cubic centimeters per second per inch of seat diameter.

Soft Seats in Globe Valves

These may be leak tested in accordance with SAMA Standard#PMC23.2c. Under this standard valve actuators are sized to provide a minimum stem force of 150 pounds per inch of seat diameter over and above the plug unbalance force created by the maximum rated differential pressure. The test pressure using air is the maximum rated differential pressure or 300psi, whichever is the *least*, but not to exceed the maximum operating pressure at ambient temperature.

Elastomer Lined Butterfly Valves

These are often tested with 50psi of air as a minimum, or maximum differential operating pressure across the disc. With the downstream side of the disc covered with water, the maximum allowable leakage rate may be specified at one bubble of air in ten seconds, per inch of vane diameter.

Elastomer Sealed Ball and Plug Valves

They are usually bubble tight to their rated differential pressure. Metal seated valves have relatively high leak rates compared to globe style valves. One exception is a rotary cam type plug valve with leakage rates comparable with globe valves.

Theoretical Leakage Formula

The equation relating the fluid properties, flow path geometry, and flow rate is:

$$Q_o = \frac{\pi (p_1^2 - p_2^2) \bar{h}^3}{12 \mu p_o \ln r_o / r_i} \quad \text{(See [1])}$$

where:

$\bar{h}$ = uniform channel clearance[2]
p_o = pressure at standard conditions
p_2 = exit fluid pressure
p_1 = inlet fluid pressure
Q_o = volume rate of flow at standard conditions
r_o, r_i = outside and inside radii of joint sealing area
μ = absolute viscosity

When the terms are rearranged, the uniform channel clearance is:

$$\bar{h} = \sqrt[3]{\frac{12 p_o \mu \ln r_o / r_i \, Q_o}{\pi (p_2^2 - p_1^2)}}$$

for gases the leakage formula becomes

$$Q_o = \left[\frac{\pi h^3 (r_o + r_i)(p_1^2 - p_2^2)}{12 \mu (r_o - r_i) p_o} \right] X \left[1 + \frac{12.76 \ \epsilon p_o \cdot \lambda o)}{(p_1 + p_2) h} \right]$$

λo = molecular mean free path at standard conditions.
ϵ = correction factor, 0.9 for a single gas and 0.66 for a mixture.

The problem is that the leakage test gives no indication of whether the leak path is one large scratch or the sum of leakage through millions of tiny tortorous paths. Refinishing the joint may eliminate the first cause, but the condition may already be at the practical limit of seal tightness for the latter.

Type Of Gas Flow Through Seat Joint Leakage Pattern

The following is a summary of characteristics for various leak conditions.

Plug Position	*Type of Flow*	*Minimum Restricting Dimension in Leakage Path*
cracked open	nozzle flow	> 0.005 in.
seating load build up zone	turbulent channel flow	0.0005 to 0.005 in.
valve seated and leakage begins	laminar flow	0.0001 to 0.0005 in.
joint surface waviness, then roughness provides leak paths as deformation begins	transition flow (molecular and laminar)	0.000001 to 0.0001 in.
elastic and plastic yielding of joint has closed large paths	molecular flow	< 0.000001 in.

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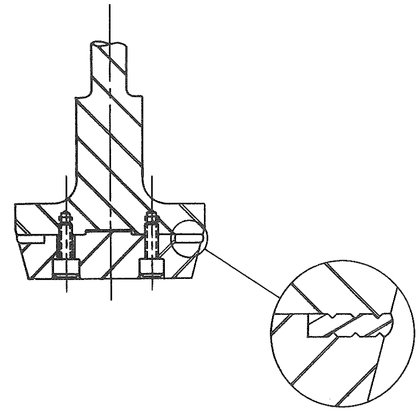
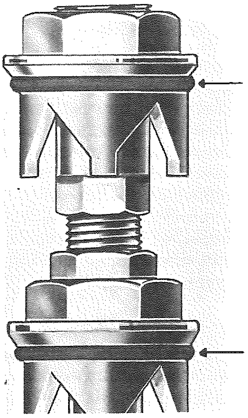
[1] Taken from Reference 50, the formula applies to a flat seat joint.

[2] This is the theoretical separation of two truly plane surfaces to give an equivalent rate of leakage caused by channels, imperfections, etc.

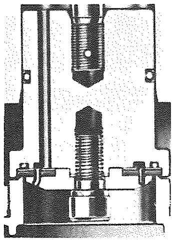


(a) Nylon seal retained in plug.



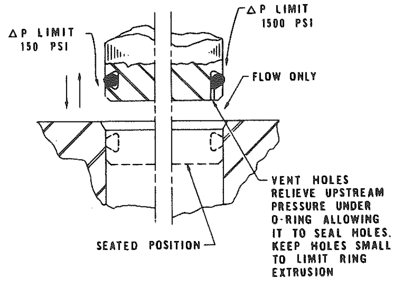
(d) Lightly restrained O-rings for low pressure drop, installed on double V-port plug.

Courtesy Fisher Controls Company

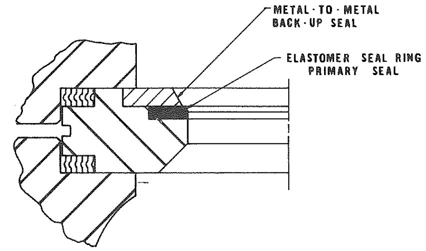


(b) TFE seal in plug of cage guided, balanced valve.

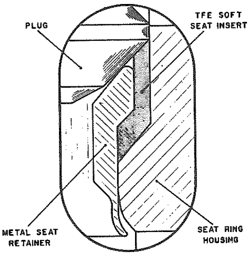
Courtesy Fisher Controls Company



(e) O-ring in dove-tail groove for higher pressure drop. Vent holes relieve pressure under O-ring retaining it in the groove as the seat joint cracks open. Holes are small to prevent seal extrusion.



(c) Elastomer seal in seat ring of split body valve.



(f) Soft seat design used in boiler feedwater pump recirculation anticavitation low noise valve.

Handles fluids to 475° F and 6000 psig inlet pressure.

Courtesy of Masoneilan International, Inc.

Figure 74. SOFT SEAT RETENTION.

When sealing to the point of achieving molecular flow, the lighter, smaller and higher velocity molecules, such as helium and hydrogen, will have the highest leakage rates.

Determination of Seat Leakage Rate

Determining the Seat Leakage Rate is not as simple as it may appear. Fluids are subject to thermal expansion and contraction during tests and air may go in or out of solution, causing volume changes in the downstream measuring system.

For accurate testing, maintain the valves and the fluids at an equal temperature and air dissolved in water at equilibrium conditions.

Helium leak detection requires a clean background with large amounts of fresh air for maximum sensitivity.

The following is a summary of the sensitivity of various test methods, given in cc/s at atmospheric conditions.

air bubbles in water (also air and soap bubbles)	1 x 10^{-3} to 1 x 10^{-4} cc/s
thermal detectors	1 x 10^{-4} cc/s
halogen detectors	1 x 10^{-5} cc/s
mass spectrometer using "sniffer" (helium leak pick up probe)	1 x 10^{-6} to 1 x 10^{-8} cc/s

Soft Seating

Resilient composition sealing materials are used to obtain bubble tight sealing with a small actuator force. Compressive seating stresses are such, that the material is elastically deformed into the surface roughness of the mating metal part, to block all leak paths. The permeability of the material, to the fluid, is the source of a very minor leakage.

Materials which are too soft, or that tend to cold-flow (creep) under load, may be stiffened with fillers such as glass. When used in thin sections, and adequately retained, the cold-flow or permanent-set problems may be eliminated.

Seals must be carefully restrained against rupture and blow-out by differential pressure. Several designs of soft-seat retention are illustrated by Figure 74. The bonding of seats to metal parts is an aid, but not a total solution, because bonds are subject to thermal shock cracking and to degradation. Sufficient pressure drop will rupture the bonding material.

A secondary advantage of soft sealing is that the seal, once compressed, is free to re-expand and to follow seat distortion as the pressure drop loading increases. To do this, the sealing material should have a rapid recovery rate upon removal of the load. This action will occur only at resilient temperatures.

Hard materials such as nylon, in thin sections carefully restrained, can handle pressure drops of several thousand psi; whereas, TFE materials are readily abraded.

Soft seals are useful for sealing where contaminants or solid material are trapped in the closed joint. Material as hard as 60D in a raised-seal beadform is capable of sealing 0.01 in. particles, bubble-tight, to 1500 psi pressure drop.

The softer the seal, the better its abrasive resistance, up to the point where it is damaged by pressure drop forces.

Large volume, high pressure blowdown systems are necessary to adequately test elastomer seals and retention means for pressure drop strength. Elastomers, under high loading, tend to act as a fluid and extrusion may occur unless the load is limited or unless a metal-to-metal stop is used. Some joint designs allow soft sealing first, followed by a metal-to-metal closure as a secondary seal in case of soft seal rupture.

The material properties to be considered in the selection of a soft seat are:

1) Fluid compatibility including, swelling, loss of hardness, permeability, degradation;
2) Hardness;
3) Permanent set;
4) Rate of recovery upon removal of load;
5) Tensile and compressive strength;
6) Distortion before rupture;
7) Modulus of elasticity.

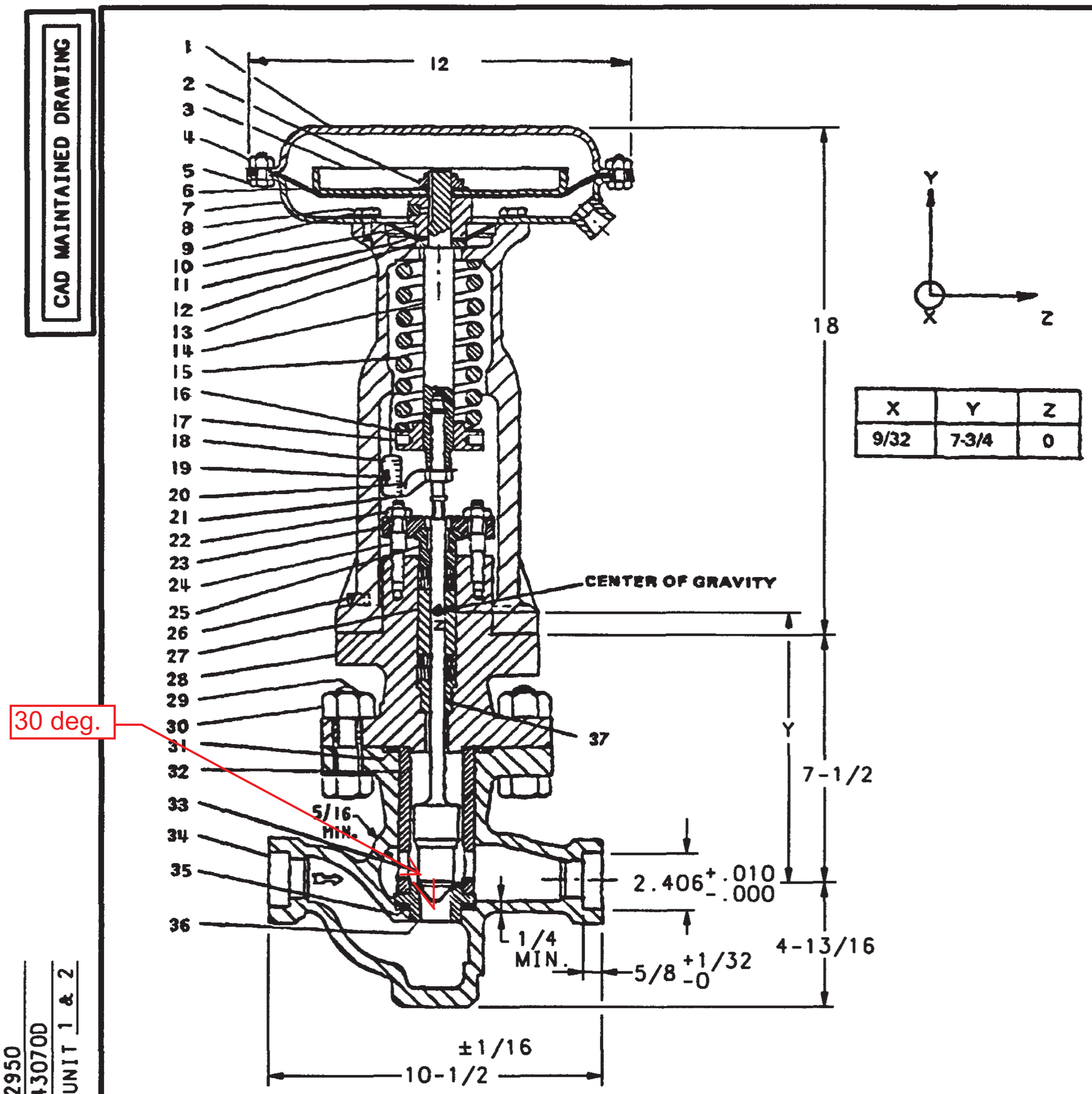
Rarely do the physical properties given for sealing materials relate to the actual conditions of loading and strain in valve seals. There is no substitute for thermal and blow-down testing as the means to prove material, seal configuration and joint design.

SEAT ATTACHMENT AND SEALING TO BODY

Seat attachment and sealing to the body is a major consideration of valve sealing, equal in importance to joint seal, bonnet seal, and stem seal. Lack of seat-to-body sealing gives a continuous leak, often blamed on the seat-to-plug joint. In high pressure and/or steam service, leakage behind the seal will actually erode through

CAD MAINTAINED DRAWING

PROJECT WATTS BAR
CONTRACT 78-822950
DRAWING NO. 717543070D
SHEET 3 REV. 901 UNIT 1 & 2



X	Y	Z
9/32	7-3/4	0

TRAVEL IS 7/8"
APPROX. NET WT.
148 LBS

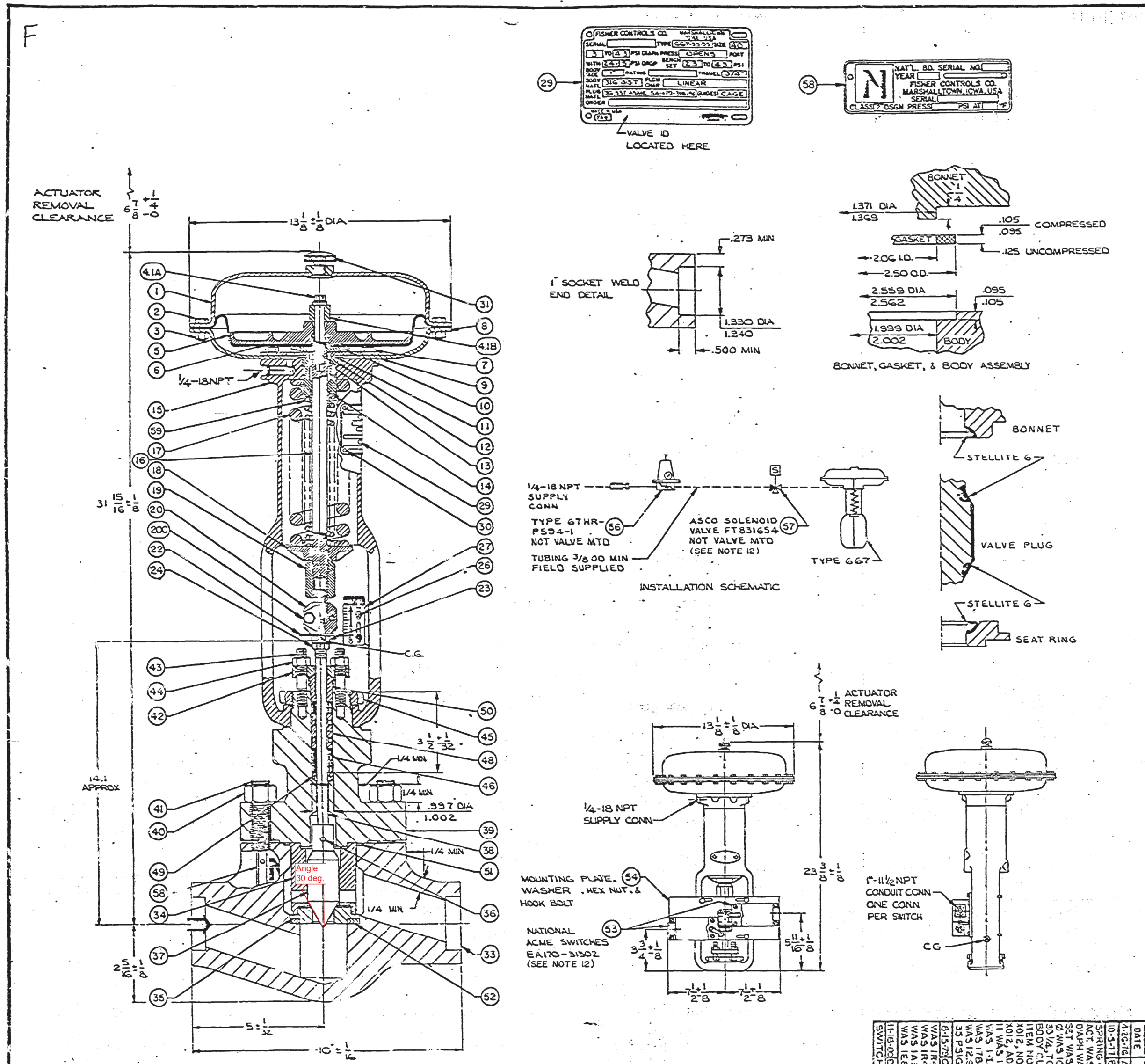
REV	CHANGE REF	PREPARER	CHECKER	APPROVED	DATE
901	ADMIN	TDK	JEW/ESJ	JKa	10-27-05
DRAWING ENHANCED FOR LEGIBILITY (REDRAWN). TOOK TVA REVISION CONTROL OF MD DRAWING PER ADMIN (T71050826804).					

APPROVED
This approval does not relieve the Contractor from any part of his responsibility for the correctness of design, details and dimensions.
TENNESSEE VALLEY AUTHORITY
Date: FEB 16, 1983

DIAPHRAGM CONTROL VALVE
2" CLASS DDOSX
150# S.W.E.

LESLIE®
CO.
PARSIPPANY
NEW JERSEY

SIZE -	CK'D R.S.	DATE 11/16/78	717543070D	REV. 901
DWN MJ	APP'D TJ	DATE 11/17/78		
REVISIONS BY TVA-TVA 900=VENDOR R4			SHEET 3 OF 12	



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1	1	2E681428992	DIAPHRAGM CASE, UPPER	STEEL	AISI 1010 ZN PL-IRIDITE
2	16	1E760324052	CAP SCREW 3/8-24 x 7/8	STEEL	SAE GR 5 CD PL
3	16	1A346324122	HEX NUT 3/8-24	STEEL	ASTM A307 GR B CD PL
41A	1	1U865328992	CAP SCREW 1/2-20 x 2 3/4	CARBON STEEL	COMMERCIAL STEEL
41B	1	1R927624092	SPACER	STEEL	AISI 12L14 COLD DRAWN
*5	1	2E669902202	DIAPHRAGM	BUNA N	MOLDED CN NYLON FABRIC
6	1	3E880519042	UPPER DIAPHRAGM PLATE	CAST IRON	ASTM A48 CL 30
7	8	1A344324052	CAP SCREW 3/8-16 x 1	STEEL	SAE GR 5 CD CS ZN PL
8	1	2E692625062	DIAPHRAGM CASE, LOWER	STEEL	AISI 1010 ZN PL, IRIDITE
*9	1	1E801204022	GASKET, SPECIAL	ASBESTOS	
10	1	1E682744022	LOWER DIAPHRAGM PLATE	ZINC	ASTM B86 AL41A, IRIDITE
11	1	15A7937X012	SEAL BUSHING RETAINER	STEEL	NON WELD/FMS 20813
12	1	15A2556X012	SEAL BUSHING	BRASS	ASTM B16 1-2H
*13	1	1C415706992	O-RING 1 3/8 x 1 5/8 x 1/8	BUNA N	
*14	2	1D237506992	O-RING 3/4 x 1 x 1/8	BUNA N	
15	1	32A3817X012	YOKE	STEEL	ASME SA-216-WCB
16	1	1E820924222	ACTUATOR STEM	STEEL	AISI 12L14 CHR PL
17	1	15A2553X012	ACTUATOR SPRING, RATE, 1635 LBS/IN	STEEL	AISI 5160H CD PL
18	1	15A2555X012	LOWER SPRING SEAT	316 SST	ASME SA-479-316
19	1	1E821024102	SPRING ADJUSTOR	STEEL	AISI 12L14 CD PL
20	1	1J8033000A2	STEM CONNECTOR	416 SST	ASTM A582-416
20C	2	1C379124052	CAP SCREW 5/16-18 x 1 1/8	STEEL	SAE GR 5 CD PL
22	1	1E807538992	TRAVEL INDICATOR	430 SST	ASTM A240-430
23	1	1A413224122	HEX NUT, 1/2-20	STEEL	ASTM A307 GR B CD PL
24	1	1A353724122	HEX NUT, JAM 1/2-20	STEEL	ASTM A307 GR B CD PL
26	2	1E793238992	MACHINE SCREW, NO. 8 x 5/8	18-8 SST	COMMERCIAL PART
27	1	1E808138992	TRAVEL SCALE	18-8 SST	
29	1	1K225738992	NAMEPLATE	18-8 SST	
30	6	1A368228982	DRIVE SCREW NO. 2 x 3/16	18-8 SST	COMMERCIAL PART
31	1	1E8955000A2	VENT	ASSEMBLY	ZINC ASTM 238 AG40A, IRIDITE
33	1	31A8884X012	VALVE BODY	316 SST	ASME SA-182-F316
34	1	2N2882X0022	CAGE	17-4PH SST	ASME SA-564 GR 630 HT H1100
*35	1	15A2552X012	SEAT RING	316 SST	ASME SA-479-316/STELL 6 SEAT
*36	1	1B827035072	GROOVE PIN	316 SST	ASME SA-479-316
*37	1	15A2557X012	VALVE PLUG	316 SST	ASME SA-479-316/STELL 6 SEATS & GUIDE
*38	1	1K586835162	VALVE STEM, 1/2 DIA	316 SST	ASTM A276-316 COND B
39	1	21A8899X012	BONNET	316 SST	ASME SA-182-F316/STELL 6 BACKSEAT
40	8	1A3760X0052	HEX NUT, 5/8-11	410 SST	ASME SA-194-6
41	8	1P9264X0012	STUD, 5/8-11 x 3 1/4	SST	ASME SA-453-660 COND B
42	1	1F380335072	PACKING FLANGE	316 SST	ASME SA-479-316
43	2	1E944435222	STUD, 7/16-14 x 2 1/2	316 SST	ASME SA-193-CLASS 2-B8M/STRAIN HARDENED
44	2	1E944535252	HEX NUT, 7/16-14	316 SST	ASME SA-194-8M
45	1	1E807423062	YOKE LOCKNUT	STEEL	ASTM A235-A
*46	6	1E3190X0172	PACKING RING, 1/2 x 1" x 1/4	ASBESTOS-GRAPHITE	CRANE 2-CR-J
48	2	1J562335072	LANTERN RING	316 SST	ASME SA-479-316
49	1	1J873235042	PACKING BOX RING	304 SST	ASME SA-479-304
50	1	12A3720X012	PACKING FOLLOWER	304 SST	ASME SA-479-304
*51	1	1L122099322	BONNET GASKET, 2 1/16 x 2 1/2 x .125	316L SST & ASBESTOS	
*52	1	1N297999442	SEAT RING GASKET, 1 5/16 x 1 13/16 x .175	INCONEL & GRAPHITE	INCONEL ALLOY 600 & GTB GRAPHITE LAMINATE
53	2	EA170-31302	NATIONAL ACME SWITCH (SEE NOTE 12)	ASSEMBLY	
54			SWITCH MTG. PARTS		
	1	36A0378X012	MTG. PLATE	CARBON STEEL	COMMERCIAL STEEL
	3	1A375324122	HEX NUT 3/8-16	STEEL	ASTM A307 GR B CD PL
	3	12A3792X012	HOOK BOLT 3/8-16 x 4 3/4	STEEL	AISI 12L14
	3	10716328982	WASHER 7/16 x 1 x 3/32	STEEL	AISI 1010 CD PL
56	1	TYPE 67HR-P594-1	FILTER REGULATOR	ASSEMBLY	
57	1	FT831654	ASCO SOLENOID VALVE (SEE NOTE 12)	ASSEMBLY	
58	1	12A0542X012	NAMEPLATE, NUCLEAR	18-8 SST	
59	1	15A2554X012	ACTUATOR SPRING, RATE 221 LBS/IN	STEEL	AISI 9254 CD PL

APPROVED
This approval does not relieve the Contractor from any part of his responsibility for the correctness of design, details and dimensions.
DATE MAY 26 1982
T.V.A. NUCLEAR ENGR BRANCH
by: CHIEF NUCLEAR ENGINEER
Iss'd by Ltr. W-4691

TENNESSEE VALLEY AUTHORITY
PLANT: WATTS BAR NUCLEAR PLANT
UNITS: 1 & 2 IDENT NO. 1-IA78RD
STATUS: CERTIFIED FOR CONSTRUCTION
CERTIFICATION LTR. NO. WAT-D-4866
AUTHORITY: J. L. TAIN
ENGR. LTR. NO. EP/SA-36512

PROJECT WBN DATE MAY 24 '82
CONTRACT 71C62-54114-1 FILE
DRAWING NO. 54A0223
SHEET – REV 902 UNIT 1 & 2

R1
R2

NOTES:

1. MAXIMUM C_v 8 AT .750" STROKE.
2. OPERATING TEMPERATURE: 650°F
3. AIR PRESSURE IN THE DIAPHRAGM CHAMBER IS NOT TO EXCEED 50 PSIG TO PREVENT COMPONENT DAMAGE.
4. APPROXIMATE TOTAL VALVE WEIGHT: 131 LBS ± 10%
5. RECOMMENDED SPARE PARTS ARE MARKED WITH AN ASTERISK (*) ON THE BILL OF MATERIAL.
6. 4 RINGS OF PACKING ARE TO BE UNDER THE LANTERN RING AND 2 ABOVE.
7. REQUIRED AIR FOR SHUT OFF OF MAIN SEAT: 0 PSIG.
8. REQUIRED AIR FOR BACKSEAT: 43 PSIG.
9. MINIMUM REQUIRED WALL THICKNESS: BODY-1/4 BONNET-1/4
10. PRESSURE RATING: ASME SECTION III CLASS 2, 1500 LB
11. EFFECTIVE DIAPHRAGM AREA: 69 SQ. IN.
12. FOR CURRENT MODEL NUMBER SEE TVA INSTRUMENT TABULATIONS, 47B601 – SERIES.

APPROVED
This approval does not relieve the Contractor from any part of his responsibility for the correctness of design, details and dimensions.
DATE JUN 14 1983
T.V.A. NUCLEAR ENGR BRANCH
by: CHIEF NUCLEAR ENGINEER
Iss'd by Ltr. W-5077

EXCEPTION "A"

DATE		REVISIONS
4-26-76	A	FIRST DRAWN
10-5-77	B	ADDED DUAL SPRING CONSTR TO ACT., ACT. WAS SIZE 45, AIR TO DIAPH WAS 6 TO 35, BENCH SET WAS 23 TO 35, CASING Ø WAS 16, ACT. HT WAS 30 1/4, TOP OF ACT. TO BODY CL WAS 38 13/16, ITEM NO. 33 WAS 12A4020 X012, NO. 37 WAS 12A4019 X012, ADDED NO. 59, NOTE 11 WAS 105 SQ IN., TAG WAS 1-IA78RE, TOTAL WT WAS 178, CG WAS 18.1, CV WAS 12.9, NOTE 8 WAS 35 PSIG
8-15-79	C	FIND NO. 41A WAS 1R408928992, 4.2B WAS 1R409524092, 7 WAS 1A3684240052, 11 WAS 1E801337022.
11-18-80	D	REVISED SWITCH MTG BKT.

CUSTOMER
P.O. NO.
TAG NO. 1-IA78RD.
SERIAL NO.
OUR NO
DIMENSIONS CERTIFIED CORRECT DATE 10-27-77 BY
Q

FISHER Controls
MARSHALLTOWN, IOWA
CODE 225861

AIR OPERATED CONTROL VALVE

TYPE 667-SS-55
SIZE 1" BODY
40 ACTUATOR, DUAL SPR

DWN JCW 4-26-76
CHKD RLD 5-27-76
APVD FJL 5-28-76
SCALE NONE

D JLM 11-18-80
C JLM 8-15-79
B SHULTZ 10-5-77
REVISIONS

REF DOT
ITEM 8
4-34371

DWG NO 54A0223
REV. 902

RELEASE TO MFG
PRELIMINARY PRINT UNLESS SIGNED
DATE ____ BY ____

REV NO.	CHANGE REF	DATE	DFTR	CHKR	DSGN	RVWR	1 APPD	2 APPD	3 APPD	ISSD
902	EXCEPTION "A"	11-1-88	AKJ		AKJ	MAC	DLH		RM	H6016
	ADDED Q TO TITLE BLOCK PER EXCEPTION "A"									

REV NO.	ECN/FCR	DATE	DRWN	DSGN	CHKD	RVWD	APPD	ISSD		
901	6173	3-10-86	JBC	MJL	HRE		EC	JCS		
	REVISED MATERIALS LIST PER ECN 6173 (U1 & U2).									

REVISIONS BY TVA TVA 900 = VENDOR REV D

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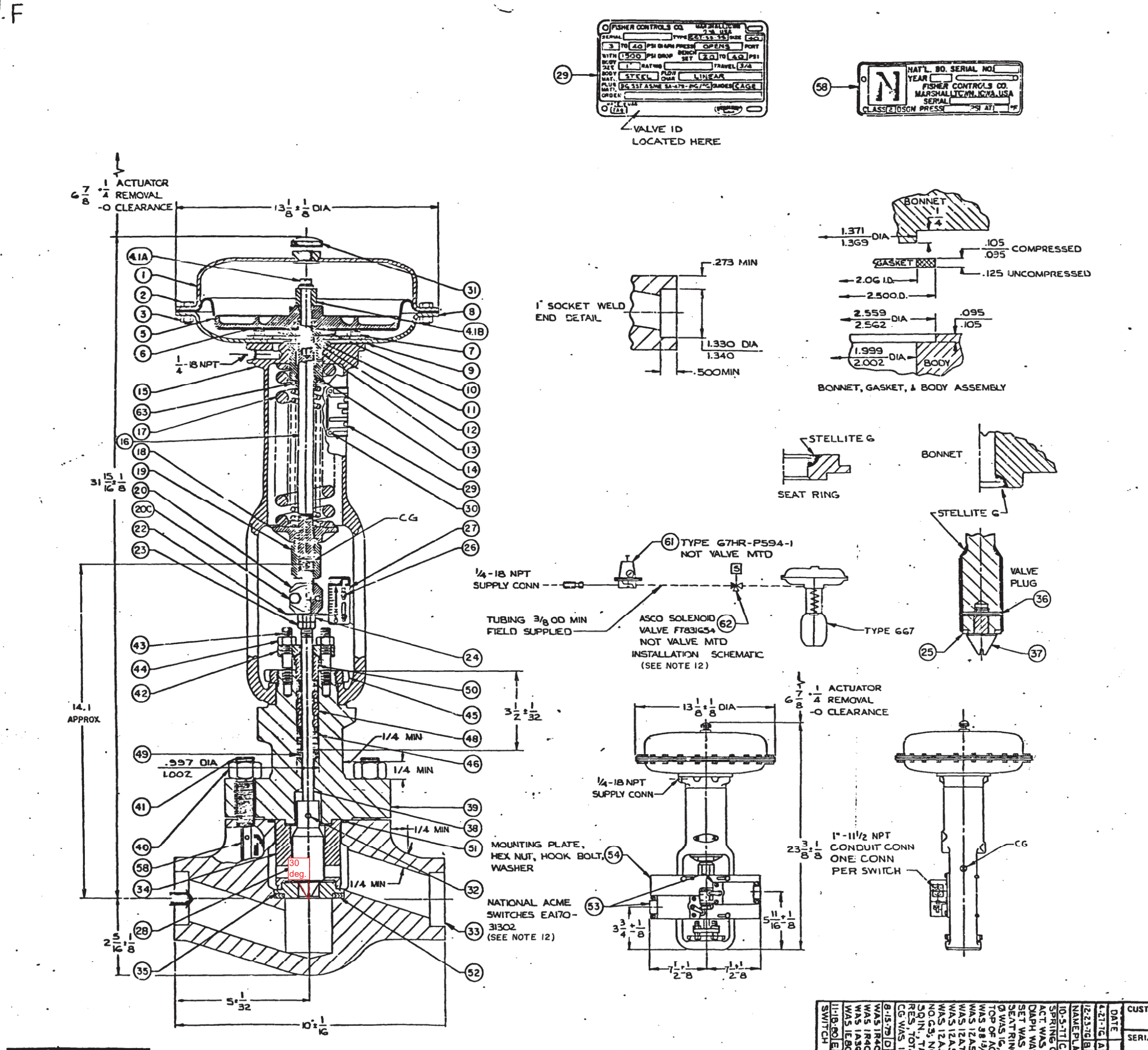

RND NO	NO. RECD.	PART NUMBER	DESCRIPTION	MATERIAL	MATERIAL SPECS
1	1	2E681428992	DIAPHRAGM CASE, UPPER	STEEL	AISI 1010 ZN PL-IRIDITE
2	16	1E760224052	CAP SCREW 3/8-24 x 7/8	STEEL	SAE GR 5 CD PL
3	16	1A346524122	HEX NUT 3/8-24	STEEL	ASTM A307 GR B CD PL
4 1A	1	1U865928992	CAP SCREW 1/2-20 x 2 3/4	CARBON STEEL	COMMERCIAL STEEL
4 1B	1	1R927624092	SPACER	STEEL	AISI 12L14 COLD DRAWN
*5	1	2E663902202	DIAPHRAGM	BUNA N	MOLDED ON NYLON FABRIC
6	1	3E880513042	UPPER DIAPHRAGM PLATE	CAST IRON	ASTM A48 CL 30
7	6	1A344924052	CAP SCREW 3/8-16 x 1	STEEL	SAE GR 5 CD OR ZN PL
8	1	2E682625062	DIAPHRAGM CASE, LOWER	STEEL	AISI 1010 ZN PL, IRIDITE
*9	1	1E801204022	GASKET, SPECIAL	ASBESTOS	
10	1	1E682744022	LOWER DIAPHRAGM PLATE	ZINC	ASTM B86 AC41A IRIDITE
11	1	15A7937X012	SEAL BUSHING RETAINER	STEEL	NON WELD/FMS 2C813
12	1	15A2556X012	SEAL BUSHING	BRASS	ASTM B16 1 2H
*13	1	1C415706992	O-RING 1 3/8 x 1 5/8 x 1/8	BUNA N	
*14	2	1D237506992	O-RING 3/4 x 1 x 1/8	BUNA N	
15	1	32A3817X012	YOKE	STEEL	ASME SA-216-WCB
16	1	1E820924222	ACTUATOR STEM	STEEL	AISI 12L14 CHR PL
17	1	15A2553X012	ACTUATOR SPRING RATE 1635 LBS IN	STEEL	AISI 5160H CD PL
18	1	15A2555X012	LOWER SPRING SEAT	316 SST	ASME SA-479-316
19	1	1E821024102	SPRING ADJUSTOR	STEEL	AISI 12L14 CD PL
20	1	1J8033C00A2	STEM CONNECTOR	416 SST	ASTM A582-416
20C	2	1C379124052	CAP SCREW 5/16-18 x 1 1/8	STEEL	SAE GR 5 CD PL
22	1	1E807528992	TRAVEL INDICATOR	430 SST	ASTM A240-430
23	1	1A353724122	HEX NUT, JAM 1/2-20	STEEL	ASTM A307 GR B CD PL
24	1	1A413224122	HEX NUT, 1/2-20	STEEL	ASTM A307 GR B CD PL
*25	1	1P6961X0012	VALVE PLUG DISC	POLYIMIDE RESIN	VESPEL SP-1
26	2	1E793228992	MACHINE SCREW NO 6 x 5/8	18-8 SST	COMMERCIAL PART
27	1	1E308138992	TRAVEL INDICATOR SCALE	18-8 SST	
*28	1	15A2559X012	VALVE PLUG POST	316 SST	ASME SA-479-316 STELLITE 6 BACKSEAT & GUIDE
29	1	1K325738392	NAMEPLATE	18-8 SST	
30	6	1A368228982	DRIVE SCREW NO 2 x 3/16	18-8 SST	COMMERCIAL PART
31	1	1E89550G0A2	VENT	ASSEMBLY	ZINC, ASTM B86 AG40A, IRIDITE
*32	1	1B627035072	GROOVE PIN	316 SST	ASME SA-479-316
33	1	31A8884X022	VALVE BODY	STEEL	ASME SA-105 GR II
34	1	2N2862X0022	CAGE	17-4PH SST	ASME SA-564 GR 630 HT H1100
*35	1	11A8838X012	SEAT RING	316 SST	ASME SA-479-316, STELLITE 6 SEAT
*36	1	1B599435072	GROOVE PIN	316 SST	ASME SA-479-316
*37	1	15A2559X012	VALVE PLUG TIP	316 SST	ASME SA-479-316
*38	1	1K586835162	VALVE STEM, 1/2 DIA	316 SST	ASTM A276-316 COND B
39	1	21A8899X022	BONNET	STEEL	ASME SA-105 GR II STELLITE 6 BACKSEAT
40	8	1P9264X0022	HEX NUT, 5/8-11	STEEL	ASME SA-194-2H
41	8	1A376024072	STUD 5/8-11 x 3 1/4	STEEL ALLOY	ASME SA-193-B7
42	1	1E943724102	PACKING FLANGE	STEEL	AISI 12L14 CD PL
43	2	1E944131032	STUD, 5/16-18 x 1 7/8	STEEL ALLOY	ASME SA-193-B7 CD PL
44	2	1E944024112	HEX NUT, 5/16-18	STEEL	ASME SA-194-2H CD PL
45	1	1E793023062	YOKE LOCKNUT	STEEL	ASTM A235-A
*46	6	1E3190X0172	PACKING RING, 1/2 x 1" x 1/4	ASBESTOS-GRAPHITE	CRANE 2-CR-J
48	2	1J962335072	LANTERN RING	316 SST	ASME SA-479-316
49	1	1J873235042	PACKING BOX RING	304 SST	ASME SA-479-304
50	1	12A3720X012	PACKING FOLLOWER	304 SST	ASME SA-479-304
*51	1	1L122099322	BONNET GASKET 2 1/16 x 2 1/2 x .125	316L SST & ASBESTOS	
*52	1	1N297999442	SEAT RING GASKET 1 5/16 x 1 13/16 x .175	INCONEL & GRAPHITE	INCONEL ALLOY 600 & GTB GRAPHITE LAMINATE
53	2	EA170-31302	NATIONAL ACME SWITCH (SEE NOTE 12)	ASSEMBLY	
54			SWITCH MTG. PARTS		
	1	36A0978X012	MTG PLATE	CARBON STEEL	COMMERCIAL STEEL
	3	1A375324122	HEX NUT 3/8-16	STEEL	ASTM A307 GR B CD PL
	3	12A3792X012	HOOK BOLT 3/8-16 x 4 3/4	STEEL	AISI 12L14
	3	1D716328982	WASHER 7/16 x 1" x 3/32	STEEL	AISI 1010 CD PL
58	1	12A0542X012	NAMEPLATE, NUCLEAR	18-8 SST	
61	1	TYPE 67HR-P594-1	FILTER REGULATOR	ASSEMBLY	
62	1	FT831654	ASCO SOLENOID VALVE (SEE NOTE 12)	ASSEMBLY	
63	1	15A2554X012	ACTUATOR SPRING, RATE 221 LBS IN	STEEL	AISI 9254 CD PL

~~APPROVED~~
~~This approval does not relieve the Contractor from any part of his responsibility for the correctness of design, details and dimensions.~~
~~DATE MAR 30 1982~~
~~T.V.A. NUCLEAR ENGR BRANCH~~
~~by: CHIEF NUCLEAR ENGINEER~~
~~Rec'd by Ltr. W-4641~~

TENNESSEE VALLEY AUTHORITY
PLANT: WATTS BAR NUCLEAR PLANT
UNITS: 1 & 2 IDENT NO. 1-IA68RDS
STATUS: CERTIFIED FOR CONSTRUCTION
CERTIFICATION LTR. NO. WAT-D-4866
AUTHORITY: J. L. TAIN
ENGR. LTR. NO. EP/SA-36511

PROJECT WBN DATE MAY 24 '82
CONTRACT 71C62-54114-1 FILE N3M-2-51C
DRAWING NO. 54A0240
SHEET — REV 902 UNIT 1 & 2

MF
R1
R2

NOTES:
1. MAXIMUM C_v 8 AT .750" STROKE
2. OPERATING TEMPERATURE: 200°F
3. AIR PRESSURE IN THE DIAPHRAGM CHAMBER IS NOT TO EXCEED 50 PSIG TO PREVENT COMPONENT DAMAGE.
4. APPROXIMATE TOTAL VALVE WEIGHT: 131 LBS ± 10%
5. RECOMMENDED SPARE PARTS ARE MARKED WITH AN ASTERISK (*) ON THE BILL OF MATERIAL.
6. 4 RINGS OF PACKING ARE TO BE UNDER THE LANTERN RING AND 2 ABOVE.
7. REQUIRED AIR PRESSURE FOR SHUT OFF OF MAIN SEAT: 0 PSIG
8. REQUIRED AIR PRESSURE FOR BACKSEAT: 30 PSIG
9. MINIMUM REQUIRED WALL THICKNESS: BODY-1/4 BONNET-1/4
10. PRESSURE RATING: ASME SECTION III, CLASS 2-1500LB
11. EFFECTIVE DIAPHRAGM AREA: 69 SQ. IN
12. FOR CURRENT MODEL NUMBER SEE TVA INSTRUMENT TABULATION, 47B601-SERIES.

APPROVED
This approval does not relieve the Contractor from any part of his responsibility for the correctness of design, details and dimensions.
DATE JUN 14 1983
T.V.A. NUCLEAR ENGR BRANCH
by: CHIEF NUCLEAR ENGINEER
Rec'd by Ltr. W-5077

EXCEPTION "A"

DATE		REVISIONS
4-27-76	A	FIRST DRAWN
12-23-76	B	PSI DROP ON NAMEPLATE WAS 2400
10-5-77	C	ADDED DUAL SPRING CONSTR TO ACT, ACT. WAS SIZE 45, AIR TO DIAPH WAS 3 TO 30, BENCH SET WAS 22 TO 30, ADDED SEATRING DETAIL, CASING Ø WAS 16, ACT. HT WAS 30¼ TOP OF ACT. TO BODY CL WAS 38 13/16, ITEM NO. 25 WAS 12A5248X012, NO. 28 WAS 12A7037X012, NO. 35 WAS 12A5346X012, NO. 37 WAS 12A5317X012, ADDED NO. 63; NOTE 11 WAS 105 SQIN., TAG WAS 1-IA68 RES, TOTAL WT WAS 178, CG WAS 19.5, Cv WAS 12.9
8-15-79	D	FIND NO. 4.1A WAS 1R408928992, 4.1B WAS 1R409524092, 7 WAS 1A368424052, 11 WAS 1E801337022.
11-18-80	E	REVISED SWITCH MTG BKT

CUSTOMER
P.O. NO.
TAG NO. 1-IA68RDS
SERIAL NO.
OUR NO.
DIMENSIONS CERTIFIED CORRECT
DATE 10-27-77 BY L Witte
Q

FISHER Controls
MARSHALLTOWN, IOWA
CODE 325081

AIR OPERATED CONTROL VALVE

DWN JCW 4-27-76
CHKD RLD 5-27-76
APVD FJL 5-28-76
SCALE NONE

D JLM 8-15-79
C SHULTZ 10-5-77
E WITTE 11-18-80
REVISIONS

REF D09
ITEM 10
4-34371

TYPE 667-SS-95
SIZE 1" BODY
40 ACTUATOR, DUAL SPR

DWG NO 54A0240
REV. 902

RELEASE TO MFG
PRELIMINARY PRINT
UNLESS SIGNED
DATE ______ BY ______

REV NO.	CHANGE REF	DATE	DFTR	CHKR	DSGN	RVWR	1 APPD	2 APPD	3 APPD	ISSD
902	EXCEPTION "A"	11-1-88	AKJ		AKJ	MAC			RM	
	ADDED Q TO TITLE BLOCK PER EXCEPTION "A"									
901	6173	3-10-86	GBC		HRE		EC	JCS		
	REVISED MATERIALS LIST PER ECN 6173 (U1 & U2).									
REV NO	ECN/FCR	DATE	DRWN	DSGN	CHKD	RVWD	APPD	ISSD		

REVISIONS BY TVA   TVA 900 = VENDOR REV E

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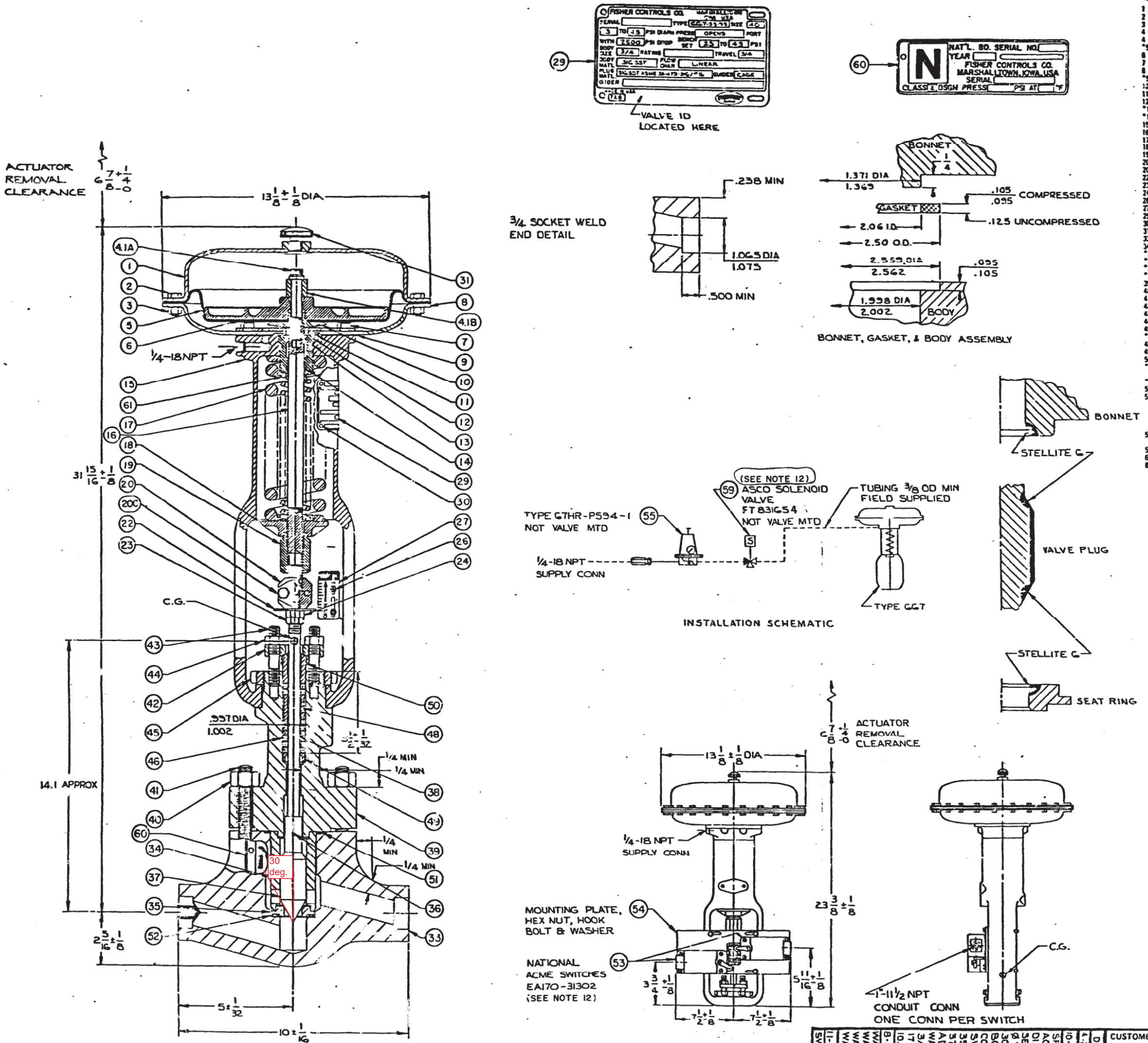


FIND NO.	NO. RECD	PART NUMBER	DESCRIPTION	MATERIAL	MATERIAL SPECS
1	1	2E881428992	DIAPHRAGM CASE, UPPER	STEEL	AISI 1010 ZN PL-IRIDITE
2	16	1E780324052	CAP SCREW 3/8-24 x 7/8	STEEL	SAE GR 5 CD PL
3	16	1A348524122	HEX NUT 3/8-24	STEEL	ASTM A307 GR B CD PL
4 1A	1	1U865928992	CAP SCREW 1/2-20 x 2 3/4	CARBON STEEL	COMMERCIAL STEEL
4 1B	1	1R927624092	SPACER	STEEL	AISI 12L14 COLD DRAWN
*5	1	2E663902202	DIAPHRAGM	BUNA N	MOLDED ON NYLON FABRIC
6	1	3E387519042	UPPER DIAPHRAGM PLATE	CAST IRON	ASTM A48 CL 30
7	6	1A344924052	CAP SCREW 3/8-16 x1	STEEL	SAE GR 5 CD CR ZN PL
8	1	2E882825082	DIAPHRAGM CASE, LOWER	STEEL	AISI 1010 ZN PL, IRIDITE
*9	1	1E801204022	GASKET, SPECIAL	ASBESTOS	
10	1	1E882744022	LOWER DIAPHRAGM PLATE	ZINC	ASTM B86 AC41A, IRIDITE
11	1	15A7937X012	SEAL BUSHING RETAINER	STEEL	RON WELD/FMS 20B13
12	1	15A2558X012	SEAL BUSHING	BRASS	ASTM B16 1/2H
*13	1	1C415706992	O-RING 1 3/8 x 1 5/8 x 1/8	BUNA N	
*14	2	1J237506992	O-RING 3/4 x 1 x 1/8	BUNA N	
15	1	32A3817X012	YOKE	STEEL	ASME SA-216-WCB
16	1	1E220924222	ACTUATOR STEM	STEEL	AISI 12L14 CHR PL
17	1	15A2553X012	ACTUATOR SPRING, RATE 1835 LBS./IN	STEEL	AISI 5160H CD PL
18	1	15A2555X012	LOWER SPRING SEAT	316 SST	ASME SA-479-316
19	1	1E621024102	SPRING ADJUSTOR	STEEL	AISI 12L14 CD PL
20	1	1J8033000*2	STEM CONNECTOR	416 SST	ASTM A582-416
20C	2	1C379124052	CAP SCREW 5/16-18 x 1 1/8	STEEL	SAE GR 5 CD PL
22	1	1E807538992	TRAVEL INDICATOR	430 SST	ASTM A240-430
23	1	1A353724122	HEX NUT, JAM 1/2-20	STEEL	ASTM A307 GR B CD PL
24	1	1A413224122	HEX NUT, 1/2-20	STEEL	ASTM A307 GR B CD PL
26	2	1E793238992	MACHINE SCREW, NO. 6 x 5/8	18-8 SST	COMMERCIAL PART
27	1	1E808138992	TRAVEL SCALE	18-8 SST	
29	1	1K325738992	NAMEPLATE	18-8 SST	
30	6	1A368228982	DRIVE SCREW NO. 2 x 3/16	18-8 SST	COMMERCIAL PART
31	1	1E8955000A2	VENT	ASSEMBLY	ZINC ASTM B86 AG40A, IRIDITE
33	1	31A8885X012	VALVE BODY	316 SST	ASME SA-182-F316
34	1	2N2882X0022	CAGE	17-4PH SST	ASME SA-564 GR 630 HT H1100
*35	1	15A2552X012	SEAT RING	316 SST	ASME SA-479-316/STELL 6 SEAT
*36	1	1B827035072	GROOVE PIN	316 SST	ASME SA-479-316
*37	1	15A2557X012	VALVE PLUG	316 SST	ASME SA-479-316/STELL 6 SEATS & GUIDE
*38	1	1K586835162	VALVE STEM, 1/2 DIA	316 SST	ASTM A276-316 COND B
39	1	21A8899X012	BONNET	316 SST	ASME SA-182-F316/STELL 6 BACKSEAT
40	8	1A3760X0052	HEX NUT, 5/8-11	410 SST	ASME SA-194-6
41	8	1P9264X0012	STUD, 5/8-11 x 3 1/4	SST	ASME SA-453-660 COND B
42	1	1F380335072	PACKING FLANGE	316 SST	ASME SA-479-316
43	2	1E944435222	STUD, 7/16-14 x 2 1/2	316 SST	ASME SA-193-CLASS 2-B8M/STRAIN HARDENED
44	2	1E944535252	HEX NUT, 7/16-14	316 SST	ASME SA-194-8M
45	1	1E807423082	YOKE LOCKNUT	STEEL	ASTM A235-A
*46	6	1E3190X0172	PACKING RING, 1/2 x 1" x 1/4	ASBESTOS-GRAPHITE	CRANE 2-CR-J
48	2	1J982335072	LANTERN RING	316 SST	ASME SA-479-316
49	1	1J873235042	PACKING BOX RING	304 SST	ASME SA-479-304
50	1	12A3720X012	PACKING FOLLOWER	304 SST	ASME SA-479-304
*51	1	1L122099322	BONNET GASKET, 2 1/16 x 2 1/2 x .125	316L SST & ASBESTOS	
*52	1	1N297999442	SEAT RING GASKET, 1 5/16 x 1 13/16 x .175	INCONEL & GRAPHITE	INCONEL ALLOY 600 & GTB GRAPHITE LAMINATE
53	2	EA170-31302	NATIONAL ACME SWITCH (SEE NOTE 12)	ASSEMBLY	
54			SWITCH MTG. PARTS		
	1	36A0978X012	MTG. PLATE	CARBON STEEL	COMMERCIAL STEEL
	3	1A375324122	HEX NUT 3/8-16	STEEL	ASTM A307 GR B CD PL
	3	12A3792X012	HOOK BOLT 3/8-16 x 4 3/4	STEEL	AISI 12L14
	3	10718328982	WASHER 7/16 x 1 x 3/32	STEEL	AISI 1010 CD PL
55	1	TYPE 67HR-P594-1	FILTER REGULATOR	ASSEMBLY	
59	1	FT831654	ASCO SOLENOID VALVE (SEE NOTE 12)	ASSEMBLY	
60	1	12A0542X012	NAMEPLATE, NUCLEAR	18-8 SST	
61	1	15A2554X012	ACTUATOR SPRING, RATE, 221 LBS/IN	STEEL	AISI 9254 CD PL

~~APPROVED~~
~~This approval does not relieve the Contractor from any part of his responsibility for the correctness of design, details and dimensions.~~
~~DATE MAY 26 1982~~
~~T.V.A. NUCLEAR ENG BRANCH~~
~~By: CHIEF NUCLEAR ENGINEER~~
~~Ans'd by Ltr.# W-4591~~

TENNESSEE VALLEY AUTHORITY
PLANT: WATTS BAR NUCLEAR PLANT
UNITS: 1 & 2 IDENT NO. 3/4-IA78RD
STATUS: CERTIFIED FOR CONSTRUCTION
CERTIFICATION LTR. NO. WAT-D-4866
AUTHORITY: J. L. TAIN
ENGR. LTR. NO. EP/SA-36511

PROJECT WBN DATE MAY 26 '82
CONTRACT 71C62-54114-1 FILE N3M-2-51C
DRAWING NO. 54A0237
SHEET – REV 902 UNIT 1&2

R1
R2

NOTES:
1. MAXIMUM C_v 6 AT .750" STROKE
2. OPERATING TEMPERATURE: 650°F
3. AIR PRESSURE IN THE DIAPHRAGM CHAMBER IS NOT TO EXCEED 50 PSIG TO PREVENT COMPONENT DAMAGE.
4. APPROXIMATE TOTAL VALVE WEIGHT: 131 LBS ± 10%
5. RECOMMENDED SPARE PARTS ARE MARKED WITH AN ASTERISK (*) ON THE BILL OF MATERIAL.
6. 4 RINGS OF PACKING ARE TO BE UNDER THE LANTERN RING AND 2 ABOVE.
7. REQUIRED AIR PRESSURE FOR SHUT OFF OF MAIN SEAT: 0 PSIG
8. REQUIRED AIR PRESSURE FOR BACKSEAT: 43 PSIG
9. MINIMUM REQUIRED WALL THICKNESS: BODY – 1/4, BONNET – 1/4
10. PRESSURE RATING: ASME SECTION III, CLASS 2 - 1500 LB
11. EFFECTIVE DIAPHRAGM AREA: 69 SQ. IN
12. FOR CURRENT MODEL NUMBER, SEE TVA INSTRUMENT TABULATIONS, 47B601 SERIES.

APPROVED
This approval does not relieve the Contractor from any part of his responsibility for the correctness of design, details and dimensions.
DATE JUN 14 1983
T.V.A. NUCLEAR ENG BRANCH
By: CHIEF NUCLEAR ENGINEER
Ans'd by Ltr.# W-5077

EXCEPTION "A"

DATE		REVISIONS
4-26-76	A	FIRST DRAWN
10-14-77	B	ADDED DUAL SPRING CONSTR TO ACT. ACT. WAS SIZE 45, AIR TO DIAPH WAS 6 TO 40, BENCH SET WAS 29 TO 40, CASING Ø WAS 16, ACT. HT WAS 30 1/4, TOP OF ACT. TO BODY CL WAS 38 13/16, CORRECTED HT DIM. OF SWITCH CONN, ITEM NO. 35 WAS 12A4020X012, NO. 37 WAS 12A4019X012, ADDED NO. 61, NOTE 11 WAS 105 SQ IN, TAG WAS 3/4-IA78RE, WT WAS 178, CG WAS 18.1, CV WAS 10.4, NOTE 8 WAS 40 PSIG
8-15-79	C	FIND NO. 4.1A WAS 1R4089 28992, 4.1B WAS 1R4099 24092, 7 WAS 1A3684 24052, 11 WAS 1E801337022
11-17-80	D	REVISED SWITCH MTG BKT

CUSTOMER
P.O. NO.
TAG NO. 3/4-IA78RD
Q
SERIAL NO.
OUR NO.
DIMENSIONS CERTIFIED CORRECT
DATE 10-27-77 BY

FISHER Controls
MARSHALLTOWN, IOWA
CODE 33388

AIR OPERATED CONTROL VALVE

TYPE 667-SS-95
SIZE 3/4 BODY
40 ACTUATOR, DUAL SPR

DWN JCW 4-27-76
CHKD RLD 5-27-76
APVD FJL 5-28-76
SCALE NONE

D JLM 11-17-80
C JLM 8-15-79
B SHULTZ 10-14-77
REVISIONS

REF DZ8
ITEM 3C
4-34371

DWG NO 54A0237
REV D

TVA 902

NOT SUITABLE FOR MICROFILM
3-10-86 A.H

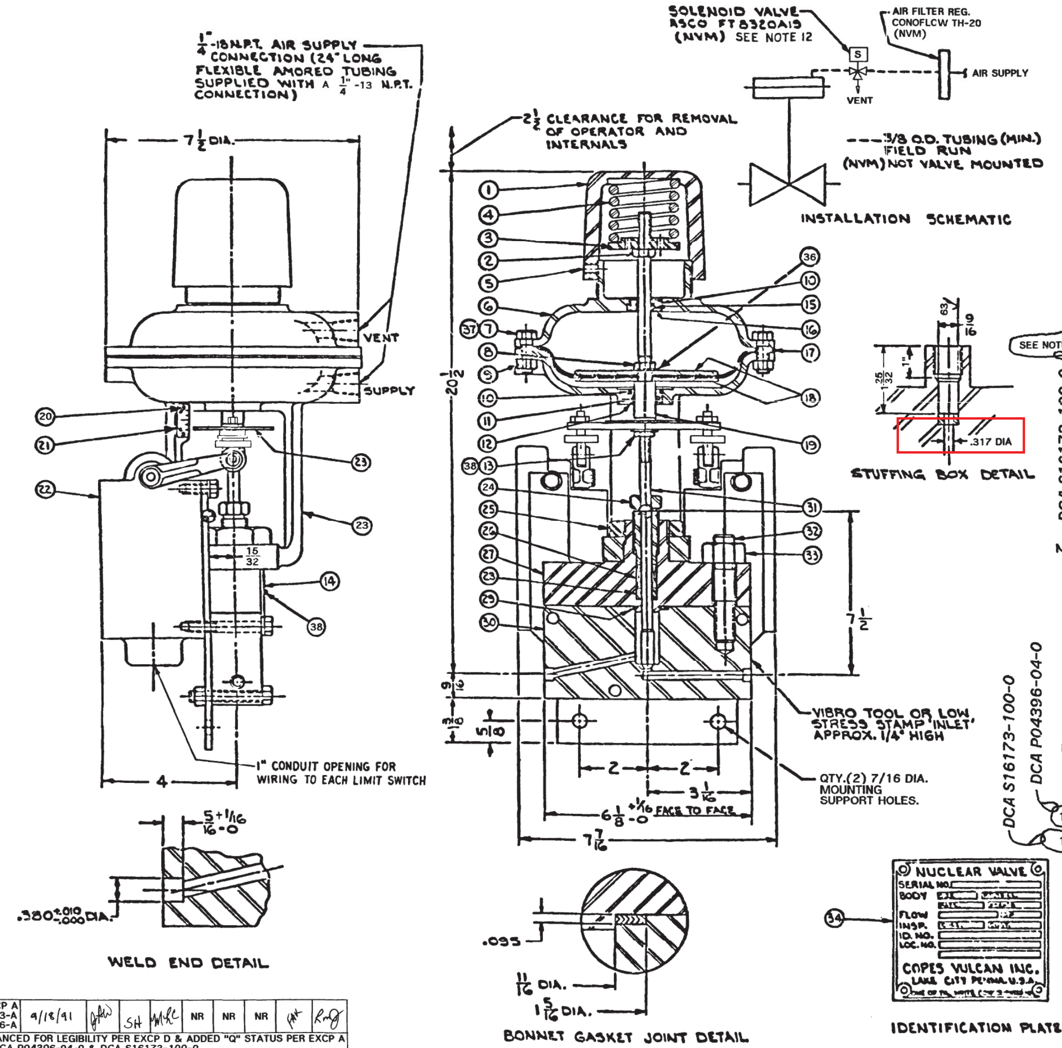
RELEASE TO MFG
PRELIMINARY PRINT
UNLESS SIGNED
DATE ______ BY ______

REV NO.	CHANGE REF	DATE	DFTR	CHKR	DSGN	RVWR	1 APPD	2 APPD	3 APPD	ISSD
902	EXCEPTION "A"	11-1-88	AKJ	JTH	AKJ	MAC	BAH		RM	HBB/c
	ADDED Q TO TITLE BLOCK PER EXCEPTION "A"									
901	6173	3-10-86	JBC	MAZ	HRE	GLD	EC/LR	JCS/LD		
	REVISED MATERIALS LIST PER ECN 6173 (U1 & U2).									

REV NO	ECN/FCR	DATE	DRWN	DSGN	CHKD	RVWD	APPD	ISSD

REVISIONS BY TVA TVA 900 = VENDOR REV D

TENNESSEE VALLEY AUTHORITY
PLANT: WATTS BAR NUCLEAR PLANT
UNITS: 1 & 2 IDENT NO. 3/8-TA78RL
STATUS: CERTIFIED FOR CONSTRUCTION
CERTIFICATION LTR. NO. WAT-D-5040
AUTHORITY: J. L. TAIN
ENGR. LTR. NO. EP/SA-37660



INSTALLATION SCHEMATIC

STUFFING BOX DETAIL

WELD END DETAIL

BONNET GASKET JOINT DETAIL

IDENTIFICATION PLATE

SEE NOTES

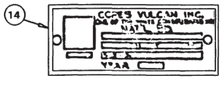
DCA S16173-100-0

DCA P04396-04-0

LIST OF MATERIALS								
	ITEM NO.	NO. REQ	PART NO.	PART CODE	DESCRIPTION	MAT'L.	MATERIAL SPECIFICATIONS	REMARKS
	1	1	167296		CAP, SPRING	C.STEEL	ASME-SA216,GR.WC3	
	2	1	167297		LOCKNUT	STEEL	COM'L	
	3	1	167298		HOLDER, SPRING	STEEL	COM'L.	
	4	1	167299		SPRING (375#/IN.)	STEEL	COM'L.	CADMIUM PLATED
	5		167300		SET SCREW & PLUG	C.STEEL	COM'L.	
	6	1	167301		CASING, UPPER	C.STEEL	ASME-SA216,GR.WC3	
	7	5	167302		BOLT, CLAMPING	STEEL	COM'L.	
	8	1	167303		LOCKNUT	CARB.STL	COM'L.	
	9	6	167304		NUT	STEEL	COM'L.	
*	10	2	167305		'O' RING	BUNA'N'	COM'L.	
*	11	1	167306		'O' RING	BUNA'N'	COM'L.	
*	12	1	167307		BUSHING, YOKE	DELRIN AF	COM'L.	
	13	1	167308		LOCKNUT. STEM	STEEL	COM'L.	CADMIUM PLATED
	14	1	147888	M	'N' STAMP PLATE	CRES.	COM'L., TYPE 302	
*	15	1	167309		'O' RING	BUNA'N'	COM'L.	
*	16	1	167310		BUSHING, CASING	DELRIN AF	COM'L.	
*	17	1	167311		DIAPHRAGM	NEOPRENE	COM'L.	17 SQ.IN. EFFECTIVE AREA
	18	2	167312		BUTTON	C.STEEL	COM'L.	
	19	1	167313		STEM, UPPER	CRES.	COM'L.	
	20	2	167314		SCREW	STEEL	COM'L.	CADMIUM PLATED
	21	1	167315		SCALE, INDICATOR	CRES.	COM'L.	
	22	1	167316	L	LIMIT SWITCH ACC.KIT		SEE NOTE 12	NAMCO EA17011302
	23	1	167317		INDICATOR	STEEL	COM'L.	CADMIUM PLATED
	24	1	167318	S	PACKING FOLLOWER	CRES.	ASTM-A479,TYPE 410	
	25	1	167319		LOCKNUT, YOKE	STEEL	COM'L.	CADMIUM PLATED
*	26	5	167320		PACKING RING	ASB.	COM'L.	CRANE 2CRJ-01, 9/16×3/16×1/8
	27	1	167321	M	BONNET	CRES.	ASME-SA182,GR.F-316	
	28	1	167322	S	GUIDE BUSHING	CRES.	ASTM-A479,TYPE 410	
*	29	1	167323		GASKET	ASB.SST.	COM'L.	1 1/4"O.D.x3/4"I.D.x.125THK
	30	1	167324	L	VALVE BODY	CRES.	ASME-SA182,GR.F-316	
*	31	1	167325	M	PLUG/STEM	CRES.	ASTM-A276,TYPE 316	COND.B (STEM-3/16 DIA.)
	32	2	149226	S	STUD		SEE NOTE-4	5/8-11 UNC × 3" LONG
	33	2	148181	M	NUT		SEE NOTE-4	5/8-11 UNC
	34	1	147887	M	IDENTIFICATION PLATE	CRES	COM'L. TYPE 302	
	35	1	167330		CASING & YOKE	C.STEEL	ASME-SA216,GR.WC2	
	36	1	169459		WASHER	STEEL	COM'L	
	37	1	169460		BOLT, CLAMPING	STEEL	COM'L	
	38	1	59404		LOCK WASHER	STEEL	COM'L	CADMIUM PLATED
	39	1	64341		DRIVE SCREW	STEEL	COM'L	CADMIUM PLATED

NOTES:

1. FOR MINIMUM Cv OF .5 , STROKE 3/4 INCH.
2. MAXIMUM TEMPERATURE 650°F.
3. AIR PRESSURE IN DIAPHRAGM MUST NOT EXCEED 50 P.S.I.G. TO PREVENT COMPONENT DAMAGE.
4. STUD MAT'L.-CRES, ASME-SA453 GR. 660
   NUT MAT'L.- CRES, ASME-SA193, GR. 8-6 (AND OTHER REQ'MTS. AS SPECIFIED IN ASME-SA194).
5. RECOMMENDED SPARE PARTS ARE MARKED WITH AN ASTERISK (*) ON THE BILL OF MATERIAL.
6. REQUIRED AIR PRESSURE INPUT TO BEGIN LIFT OF PLUG FROM MAIN SEAT = 16 P.S.I.G.
7. REQUIRED AIR PRESSURE INPUT TO SHUT OFF BACKSEAT = 48 P.S.I.G.
8. REQUIRED AIR TO OPERATE = 48 P.S.I.G.
9. MINIMUM WALL 3/16 (A.N.S.I. B16.5-1968)
10. ALL DIMENSIONS ARE IN INCHES AND ARE REFERENCE UNLESS OTHERWISE SPECIFIED BY TOLERANCE.
11. IDENTIFICATION PLATE TO BE WIRED OR CHAINED TO OPERATOR YOKE.
12. FOR CURRENT MODEL NUMBER SEE TVA INSTRUMENT TABULATIONS 47B601-SERIES. (UNLESS OTHERWISE NOTED IN TABLE A.)
13. ASCO SOLENOID MODEL NO. FT8320A19 IS MOUNTABLE IN ANY POSITION.
14. VALVE PACKING MAY BE REPLACED IN ACCORDANCE WITH 47A400-32 DRAWING SERIES.



'N' STAMP PLATE

mF
R902

902	EXCP D,EXCP A DCN S-16173-A DCN P-04396-A	9/18/91		SH		NR	NR	NR		
DRAWING ENHANCED FOR LEGIBILITY PER EXCP D & ADDED "Q" STATUS PER EXCP A REVISED PER DCA P04396-04-0 & DCA S16173-100-0										
REV NO.	CHANGE REF	DATE	DFTR	CHKR	DSGN	RVWR	1 APPD	2 APPD	3 APPD	ISSD
901	6173	3 10 86	JBC							
REVISED MATERIALS LIST PER ECN 6173 (U1 & U2).										
REV NO.	ECN/FCR	DATE	DRWN	DSGN	CHKD	RVWD	APPD	ISSD		
REVISIONS BY TVA		TVA 900 = VENDOR REV 2								

REV. 2 CENTER OF GRAVITY WAS 5/8 & 7/8 WAS 14 & DRY WT. WAS 50 LBS. D.F. 12-29-80

NO.	DATE	REVISIONS	BY	CHK.
1	3-3-78	REVISED AIR PRESSURE, NOTES 3, 6, 7 & 8; ITEM 2 NOW UNDER ITEM 3 & ADDED ITEM 39.	J. K.	JTP

PROJECT WBN DATE SEP 24 1982
CONTRACT 71C62-54114-1 FILE: N3M-2-51C
DRAWING # E-171555
SHEET ___ REV. 902 UNIT 1 & 2

TVA I.D.	MODEL NO.	CONTRACT	ORIENT. REQ,MT
1-FSV-68-307	206-381-3RF	85629-2	VERT & UPRIGHT ± 45°
1-FSV-68-308	NPX831654E	827551	ANY POSITION

DCA P04396-04-0

APPROVED
This approval does not relieve the Contractor from any part of his responsibility for the correctness of design, details, and dimensions.
TENNESSEE VALLEY AUTHORITY
Date NOV 9 1982
TVA NUCLEAR ENGR BRANCH
BY CHIEF NUCLEAR ENGINEER
ANS'D BY LTR# W-4770

VALVE IDENT: 3/8-TA78RL
DRY WT.: 45 LBS. APPROX.
OPER. MODE: REVERSE ACTING

COPES-VULCAN, INC.
LAKE CITY (ERIE CO.) PA. U.S.A.

3/8 CLASS 1500 ASME
VALVE ASSEMBLY
CODE CLASS - 2

Q

EXCP A

DFTSMN D.L.M. DATE
CHECKED DATE
APP'D. DATE
CSCN. DATE
MFG. DATE
DATE

PART CODE G
SCALE NTS DWG NO. E-171555 REV.2
R902

Appendix B

SAMPLE CALCULATION

Valve ID	**1-FCV-32-80/2-FCV-32-81**		
Generic Inputs			
Description	**Variable**	**Value**	**Units**
Bounding LLRT test differential pressure	DP_{test}	16.5	psig
Lower bounding maximum peak pressure	P_a	9	psig
Valve Specific Inputs			
Description	**Variable**	**Value**	**Units**
Minimum lower benchset	P_{LB}	5.5	psig
Lower benchset diaphragm area (EDA)	AR_{LB}	54	in^2
Maximum closed running load (includes packing and static seal friction)	F_R	207	lb
Mean seat diameter	D_m	2.25	in
Stem diameter at packing	d_S	0.5	in
Disc and stem weight	W	0	lb
Stem angle from vertical	β	0	degrees
Seat angle from stem axis	θ	30	degrees
Seat to disc friction coefficient	μ	0.5	
Calculations			
Description	**Variable**	**Value**	**Units**
Area based on mean seat diameter	A_O	3.976	in^2
Stem area at packing	A_S	0.196	in^2
Minimum spring preload	F_{SPL}	297	lb
Sealing force due to disk and stem weight	F_W	0	lb
DP force acting on sealing diameter @ DP_{test}	F_{DP_DPtest}	62.37	lb
DP force acting on sealing diameter @ P_a	F_{DP_Pa}	34.02	lb
Static sealing force in stem axis direcion	F_{Static}	90	lb
Dynamic sealing force in stem axis direction @ DP_{test}	F_{Dyn_DPtest}	62.37	lb
Dynamic sealing force in stem axis direction @ P_a	F_{Dyn_Pa}	34.02	lb
Total sealing force in stem axis direction @ DP_{test}	F_{S_DPtest}	152.37	lb
Total sealing force in stem axis direction @ P_a	F_{S_Pa}	124.02	lb
Sealing force normal to the seat @ DP_{test}	R_{r_DPtest}	163.3	lb
Sealing force per linear inch normal to the seat @ DP_{test}	$R_{r\_Dptest\_Lin}$	23.1	lb/in
Sealing force normal to the seat @ P_a	R_{r_Pa}	132.92	lb
Sealing force per linear inch normal to the seat @ P_a	$R_{r\_Pa\_Lin}$	18.8	lb/in
Reduction in normal sealing force due to the difference between pressures DP_{test} and P_a	$R_{r\_reduction}$	30.38	lb
Reduction in normal sealing force per linear inch due to the difference between pressures DP_{test} and P_a	$R_{r\_reduction\_Lin}$	4.3	lb/in
Percentage reduction in sealing force due to the difference between P_a and DP_{test}	R	18.61	%
Test differential that will result in a 10% reduction in sealing load at P_a	$DP_{test\_10\%}$	12.65	psig

Percentage Increase in Leakage Area Calculation for the Valve Group 32-3

Enclosure 5

Kalsi Engineering Affidavit

APPLICATION FOR ORDER APPROVING LICENSE TRANSFER AND CONFORMING LICENSE AMENDMENT

10 CFR 2.390 AFFIDAVIT
Affidavit of Manmohan S. Kalsi

I, Manmohan S. Kalsi, President and Officer of Kalsi Engineering, Inc., do hereby affirm and state:

1. I am authorized to execute this affidavit on behalf of Kalsi Engineering, Inc. (KEI).
2. KEI requests that Report 3960C and Attachments, which are labeled "Proprietary and Confidential" per 10 CFR 2.390 (b)(1)(i)(A), be withheld from public disclosure under the provisions of 10 CFR 2.390(a)(4). Another version of this report marked "Non-Proprietary" has been provided for public records.
3. Report 3960C and Attachments contains confidential information, the disclosure of which would adversely affect KEI.
4. This information has been held in confidence by KEI. To the extent that KEI has shared this information with others, it has done so on a confidential basis.
5. KEI customarily holds such information in confidence since the information is not available to the public to the best of our knowledge and belief.
6. Public disclosure of this information would cause substantial harm to KEI's business opportunities because such information has significant commercial value to KEI and its disclosure could adversely affect these opportunities by making it available to our competitors.

Manmohan S. Kalsi Sep 15, 2020.

Manmohan S. Kalsi
President, Kalsi Engineering, Inc.

NANCY A. RICHEY
Notary Public, State of Texas
Comm. Expires 03-26-2024
Notary ID 124872147

Subscribed and sworn before me,
A Notary Public

This 15th day of September, 2020.

Nancy Richey