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TECHNICAL REPORT

EVALUATION OF EPRI DRAFT REPORT NP-7065 - REVIEW OF NRC/INEL GATE VALVE TEST PROGRAM

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EXECUTIVE SUMMARY

This report documents an INEL evaluation of EPRI Draft Report NP-7065, "Review of NRC/INEL Gate Valve Test Program," (hereinafter referred to as the EPRI report). The EPRI report is critical of the NRC/INEL gate valve test program and is being used by some utilities as a rationale for discounting the applicability of the INEL gate valve test data. Our purpose in this review is to resolve the comments of the review team sponsored by EPRI and provide strong technical bases for areas of agreement and disagreement between the INEL and EPRI positions.

Areas of disagreement between EPRI and the NRC/INEL include predictable versus nonpredictable valve performance, motor-operator sizing equations, typicality of the test hardware, applicability of the Phase I and the Phase II test conditions, assessment of valve response as indicated in the measured stem force, and the validity of the NRC documents issued relating to valve testing.

The INEL tested 5-degree flexwedge gate valves. Selection of test valves was based on surveys of equipment installed in nuclear service. Not every variation produced by every valve manufacturer was tested; however, among the six valves with seven internal configurations, most of the design features (except the double-disc design mentioned in the EPRI report) of most of the wedge gate valves used in Generic Issue 87 nuclear service were tested. The majority of the valves that were tested exhibited nonpredictable performance because they were unable to close without damage when subjected to the design basis test loadings.

The EPRI report states that the manufacturers of the valves tested in the NRC/INEL program have produced valves with other design features. It further suggests that valves with other design features might perform differently than those tested in the NRC/INEL program. Test experience indicates that the design feature that has the greatest effect on whether internal damage occurs is body-guide to disc-guide clearance. Large clearances allow the disc to tip excessively during closure against high loads, resulting in damage to the guides, disc, and seats. The NRC/INEL test results, considered together with the results

of other similar test programs, indicate that most of the design variations the EPRI report refers to (single/double disc, thick/thin disc, hardfaced/nonhardfaced disc guide, etc.) have little effect on the capability of a valve to perform under Generic Issue 87 loads. These other similar test programs tested design variations not tested by NRC/INEL. The EPRI Marshall PORV and block valve test program performed after TMI resulted in about an even split between capable and noncapable valves. The double disc gate valve represented one of the noncapable valves. European testing prior to their development of new valve designs found similar problems. The threshold disc loading levels where current valve designs begin to perform nonpredictably are not known.

NRC/INEL testing has shown that the standard industry motor operator sizing equation used to determine the stem force requirements of a flexwedge gate valve is incomplete regardless of the disc area term or the disc factor used. This is because the standard industry equation puts all of the missing terms, including sliding friction, into an area-specific disc factor that serves as a multiplier. As such, we disagree with the disc factors that the EPRI report implies the industry can use in their MOV analyses. EPRI's NMAC equation is a more effective tool, but it, too, fails to account for the effects of fluid conditions, and it may estimate overly high loads for the motor operator if conservative disc (friction) factors are used.

The EPRI report questions whether the test conditions were applicable to Generic Issue 87 valves. The typicality of the test hardware was established prior to procurement by surveys of the hardware installed in nuclear plants; the test conditions, while not perfect in every case, provided representative Generic Issue 87 line break conditions for representative Generic Issue 87 valves. Although the blowdown conditions are not directly applicable to all safety-related valves, performance curves developed from a test program that includes blowdown conditions are applicable not only to Generic Issue 87 valves, but to other safety-related valves as well.

Reading the trace on a data plot of the measured stem force to draw inferences about valve response can at times appear to be more of an art than a science. For a predictable valve, that portion of the closure stroke that occurs just after flow isolation, when the disc is riding fully on the seats, is very well defined on a stem force trace and represents the maximum closing loading for such a valve. The sliding friction (INEL correlation or the EPRI-NMAC equation) or disc factor (industry equation) used to size a motor operator for a valve must be based on a correct identification of this point.

The INEL analyses of the Phase I and Phase II test results were not complete at the time of the EPRI review. At that time, we were trying to analyse the test results using standard industry equations. What we observed was a random variation in the analysis results when we solved for the disc factor. We were later able to correlate the randomness in the results to fluid subcooling and pressure effects. It was not until we quit trying to fit the data to the standard industry equation that we were able to make significant progress in the analysis of the test results.

The NRC documents reviewed in the EPRI report have some omissions in the description of circumstances, but after two years of additional analyses, the conclusions presented in the documents are still valid.

We hope that the analyses and results presented in this report will help the nuclear power industry resolve any confusion surrounding the NRC/INEL Gate Valve Research Program. We also hope the material presented in this report will provide additional insights for EPRI in their upcoming MOV Performance Prediction Program.

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ACKNOWLEDGMENTS

The authors would like to thank MPR Associates for providing a magnetic copy of the EPRI report. Having the EPRI report in this format allowed us to more easily and accurately reproduce the text for our paragraph by paragraph review, thus ensuring that there were no mistakes in our presentation of the content of the EPRI report. We would also like to thank EPRI for allowing us to reproduce the figures and tables from their report. With the figures and the tables from the EPRI report included, the reader can better understand the material being discussed. The applicable figures and tables (except the Section 4 material which has not been reproduced) follow each of the sections contained in Appendix A.

ABBREVIATIONS

ACRS	NRC's Advisory Committee on Reactor Safety
ANSI	Americal National Standards Institute
ASME	American Society of Mechanical Engineers
BWR	Boiling Water Reactor
EPRI	Electric Power Research Institute
GI	Generic Issue
GL	Generic Letter
HPCI	High Pressure Coolant Injection
INEL	Idaho National Engineering Laboratory
KWU	Kraftwerk Union AG (German architect-engineer)
MOV	Motor-operated valve
NMAC	Nuclear Maintenance Application Center
NRC	Nuclear Regulatory Commission
NRR	NRC Office of Nuclear Reactor Regulation
PORV	Power Operated Relief Valve
PWR	Pressurized Water Reactor
RCIC	Reactor Core Isolation Cooling
RES	NRC Office of Nuclear Regulatory Research
RWCU	Reactor Water Cleanup

EVALUATION OF EPRI DRAFT REPORT NP-7065 - REVIEW OF NRC/INEL GATE VALVE TEST PROGRAM

1. INTRODUCTION

For the past several years, the Idaho National Engineering Laboratory (INEL) has been performing motor-operated valve (MOV) research under the sponsorship of the U.S. Nuclear Regulatory Commission (NRC). The purpose of this research is to assess the capability of motor-operated gate valves commonly installed in boiling water reactor (BWR) high pressure coolant injection (HPCI) and reactor core isolation cooling (RCIC) steam supply lines and reactor water cleanup (RWCU) systems to close under postulated line break isolation conditions. The research included two full-scale qualification and line break flow isolation test programs using typical RWCU and HPCI gate valves. In response to the valve performance observed in the test programs, INEL and NRC raised several issues addressing potential problems for MOVs in these specific BWR systems and for nuclear power plant MOVs in general.

In response to the issues raised by the results of the NRC/INEL test programs, the Electric Power Research Institute (EPRI) sponsored a review of the INEL gate valve testing (hereinafter referred to as an EPRI effort). The results of the EPRI effort have been published in EPRI Report NP-7065 (Prepublication Copy), "Review of NRC/INEL Gate Valve Test Program," January 1991 (hereinafter referred to as the EPRI report). The EPRI report is critical of the NRC/INEL gate valve test program and is being used by some utilities as a rationale for discounting the applicability of the NRC/INEL test results.

At the request of the NRC Offices of Nuclear Reactor Regulation (NRR) and Nuclear Regulatory Research (RES), the INEL reviewed the EPRI report. The results of that review are presented in this INEL report. We evaluated the content of the EPRI report, addressed the conclusions, and responded to specific concerns expressed in the report, especially where problems or disagreements were apparent. Our purpose is to resolve the comments in the EPRI report and provide strong technical bases for areas of agreement and disagreement between the INEL and EPRI positions.

The EPRI report addresses three major subjects: (1) a review of early INEL publications of test results, (2) a report on the NRC-sponsored posttest valve inspection and measurement effort, and (3) recommendations for the EPRI MOV Performance Prediction Program. Our review is limited to the first subject. We accept the EPRI report's documentation of the posttest valve inspection and measurement effort as an accurate representation of what took place. The EPRI report's recommendations relative to the EPRI test program do not require our review in this format.

In Section 2 of this report, we present background information pertinent to an understanding of the subject. In Section 3, we extract the major technical issues contained in the EPRI report, organize them in a logical manner, and discuss each of them from the INEL viewpoint. Our conclusions of the review of the EPRI report are presented in Section 4. The various appendices provide supporting information for our review; of special note is Appendix A, which contains a paragraph by paragraph review of the EPRI report.

2. BACKGROUND INFORMATION

The INEL, under the sponsorship of the NRC Office of Nuclear Regulatory Research, is performing motor-operated valve research to contribute to the resolution of specific generic safety issues and to develop and improve industry mechanical equipment qualification, operation, and maintenance consensus standards. This effort includes a research program that qualified six full-scale motor-operated gate valves to ANSI/ASME B16.41 and then tested each at the design-basis conditions for containment isolation valves installed in BWR RWCU process lines and HPCI turbine steam supply lines. The valves were parametrically tested at pressures, temperatures, and flow conditions above, at, and below the worst-case conditions that could be experienced in the RWCU process lines and the HPCI turbine steam supply lines as a result of a downstream pipe break outside containment. One of the RWCU valves was also tested at saturated steam flow conditions to provide insights for the RCIC turbine steam supply line containment isolation valves, as part of the same generic issue.

The purpose of this testing was to provide technical input to the NRC effort regarding Generic Issue (GI)-87, "Failure of the HPCI Steam Line Without Isolation." GI-87 also applies to the RCIC and RWCU isolation valves. The test program has also provided information applicable to the implementation of Generic Letter (GL) 89-10, "Safety-Related Motor-Operated Valve Testing and Surveillance."

INEL has conducted two sets of experiments for the GI-87 research program. In Phase I, two full-scale RWCU valves, typical of those used in operating plants, were tested with high energy water. The test plan for Phase I was reviewed by the NRC, valve vendors, and NRC's Advisory Committee on Reactor Safety (ACRS). The results of the Phase I program were reported in NUREG/CR-5406, "BWR Reactor Water Cleanup System Flexible Wedge Gate Isolation Valve Qualification and High Energy Flow Interruption Test." The test results were unexpected; they challenged the validity of many gate valve design rules. As we analyzed these unexpected test results, we realized, in retrospect, that the test facility and instrumentation were marginal, the two-valve sample was small, and the data from one valve were less useful because the valve sustained damage as a result of the high flow loading. Because of these shortcomings, some experts in the industry did not accept the results as having general applicability. As a result, the NRC determined that a larger Phase II program was necessary. Both phases of the test program are more completely explained in Appendix B.

In the Phase II program, the NRC increased the number of valves to six, representative of those installed in both the HPCI and RWCU systems. The Phase II program benefitted from the lessons learned during the Phase I program and included tests on an RWCU valve that would be applicable to RCIC valves. The test plan for Phase II was reviewed by the NRC staff, EPRI, utilities, valve vendors, and diagnostic equipment vendors. The INEL developed its own advanced instrumentation and data acquisition system, and a different test facility with greater capacity was selected. However, we know from experience that it is impossible to anticipate every possible contingency. The EPRI report highlights some of the lessons we learned from the Phase II testing.

The results of the Phase II program (including the Phase I work) were presented to the public in (1) NRC Technical Report EGG-SSRE-8970, "Generic Issue-87 Flexible-Wedge Gate Valve Test Program Phase II Data Report," dated March 1, 1990, (2) "GI-87 Gate Valve Test Program Results Review and Issue Identification," presented at the Second NRC Valve Experts Review Group Meeting, Bethesda, MD, April 18, 1990, and (3) NUREG/CR-5558, "Generic Issue 87: Flexible Wedge Gate Valve Test Program, Phase II Results and Analysis." NUREG/CR-5558 was published at the same time as the EPRI report (January 1991) and was not included in their review.

In response to the INEL gate valve tests, the NRC has issued the following documents:

NRC Information Notice No. 89-88, "Recent NRC-Sponsored Testing of Motor-Operated Valves," December 26, 1989

NRC Information Notice No. 90-40, "Results of NRC-Sponsored Testing of Motor-Operated Valves," June 5, 1990

Generic Letter 89-10, Supplement 3, "Consideration of the Results of NRC-Sponsored Tests of Motor-Operated Valves," October 25, 1990.

To support licensee response to the issues raised in these documents, EPRI sponsored an independent review of the NRC/INEL Gate Valve Test program. The review was performed by MPR Associates with assistance from an industry inspection team and oversight from the EPRI MOV Performance Prediction Program Technical Advisory Group. The subject EPRI report documents the results of that review.

The technical issues extracted from the EPRI report fall into two major categories: the EPRI report expresses concern about the applicability of some of the NRC/INEL test program results, and many conclusions produced by the EPRI assessment of the data differ from the preliminary conclusions of the NRC and the INEL. It should be noted that the EPRI report was based on the very early gate valve work: the Phase I NUREG, the Phase II data report, and the April 18, 1990 NRC public meeting. The Phase I NUREG (NUREG/CR-5406) asked more questions than it answered. The Phase II data report (EGG-SSRE-8970) contained eight volumes of data traces without any analyses. The April 18th meeting was a general overview of the test results specific to GI-87 and some of the other interesting insights observed during the testing. We took great care at the April 18th meeting to point out that the analysis of the data had just begun and that we were only pointing out inconsistencies between observed test results and the industry precepts that were originally used to size valve operators in the plants. The purpose of the experts meeting was to review the results to date and to obtain input on further analysis. The EPRI-sponsored review of the NRC/INEL valve test results might have been more effective had it occurred later, after we had analyzed the Phase II data more thoroughly.

As stated in their report, the objectives of the EPRI review were to

1. *"Develop an understanding of the scope and applicability of the test results both for valves installed in the specific BWR systems under study and to industry MOVs in general."*

2. *"Document detailed information on the test valves, such that the test results and implications to specific valves could be evaluated."*

3. *"Document the principal results of the test program, including observed valve behavior."*

4. *"Develop lessons learned from these tests to better plan the EPRI MOV Performance Prediction Program."*

5. *"Identify, generally, gate valve design details which need to be properly addressed to obtain satisfactory performance under severe blowdown isolation conditions."*

EPRI's scope in this review was identified as

1. *"a detailed posttest inspection of the valves tested,"*

2. *"an assessment of the applicability of the valve designs tested to industry MOVs,"*

3. *"a limited assessment of the applicability of the conditions tested both to design basis conditions for the BWR systems under study and to design basis conditions for industry valves in general, and"*

4. *"a detailed review of the test data, using primarily published data plots, focusing on determination of the "apparent disk factor" implied by the data for all valve strokes performed with differential pressure and relating these results to the conditions tested and valve internal damage sustained."*

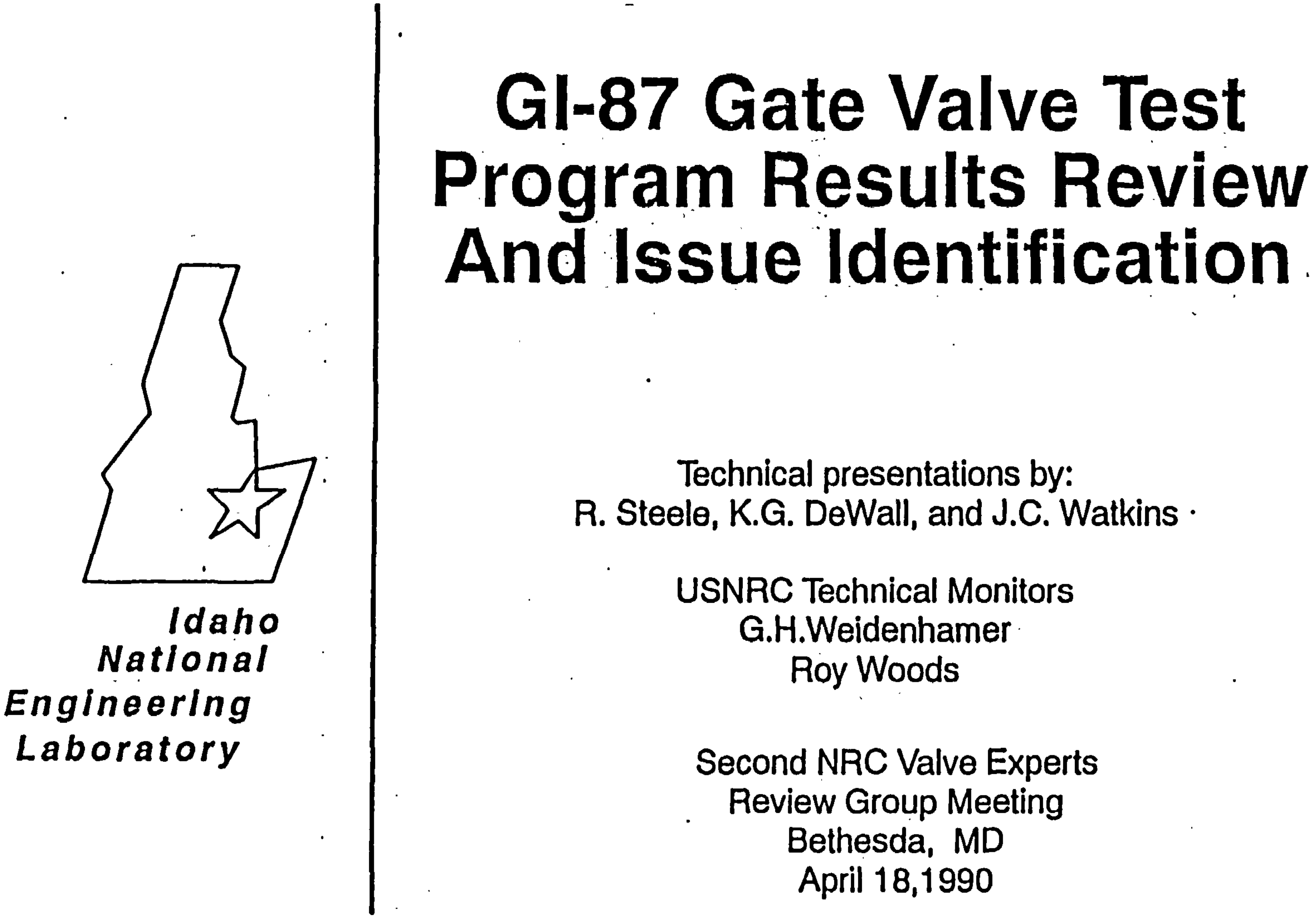
3. TECHNICAL ISSUES

3.1 Applicability of Results

The EPRI report expresses concern about the applicability of the test conditions, the test hardware, and the test results to a wide range of industry applications. The EPRI report does not review the additional subjects, e.g. electrical, training, or diagnostic testing portions of our published data. Instead, the review concentrates on the valve and thermal hydraulic portions of the NRC/INEL test programs.

Several statements in the EPRI report indicate that we were not careful enough in defining the applicability of the results of the early work. For example, the EPRI report states, *"It is expected that the potential for sustaining damage such as gouging/machining of valve internals and/or plastic deformation of valve internals is only significant under very high flow (blowdown) conditions where significant DP exists in mid-stroke. Specifically, such damage and the attendant high disk factors would* ***not*** *be expected for the vast majority of industry valves. Most industry valves are in pumped flow systems and, depending on the system frictional losses, would be expected to develop significant differential pressures only when the valve disk is on or very near the seats."* We have always tried to make it clear that our full scale testing applied specifically to that small percentage of BWR MOVs that have design basis requirements to close during blowdown conditions, and we have never stated otherwise.

At the time EPRI reviewed our work, the most conclusive INEL document was the April 18, 1990 NRC experts meeting handout. Figures 1 and 2 are the first two pages of that handout, and they clearly show that we intended to talk primarily about GI-87 at this meeting. Figure 3, the background page, brings up GL 89-10; however, Figures 4 and 5 show that only our seventh objective specifically discusses GL 89-10. This objective refers to correlating the data for in situ testing and extrapolation, which we have since accomplished (see Appendix C). The bulk of the thermal-hydraulic data presented, pertinent to the



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GI-87 Gate Valve Test Program Results Review And Issue Identification

Technical presentations by:
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Second NRC Valve Experts
Review Group Meeting
Bethesda, MD
April 18,1990

Figure 1. Page 1 of the INEL April 18, 1990 NRC Experts Meeting Handout

Purpose of the Presentation

- Provide the Review Group and the audience with a review of the work to date on the NRC GI-87 Gate Valve Test Program

M042 rs-0490-02

Figure 2. Page 2 of the INEL April 18, 1990 NRC Experts Meeting Handout

Background

- This presentation is based on the results and analysis of Phase I and Phase II qualification and high energy flow interruption gate valve tests performed to provide technical insights for the NRC effort regarding Generic Issue-87 (GI-87), "Failure of HPCI Steam Line Without Isolation."

- The results will also be applicable, in part, to the implementaion of Generic Letter 89-10 (GL-89-10), "Safety-Related Motor-Operated Valve Testing and Surveillance."

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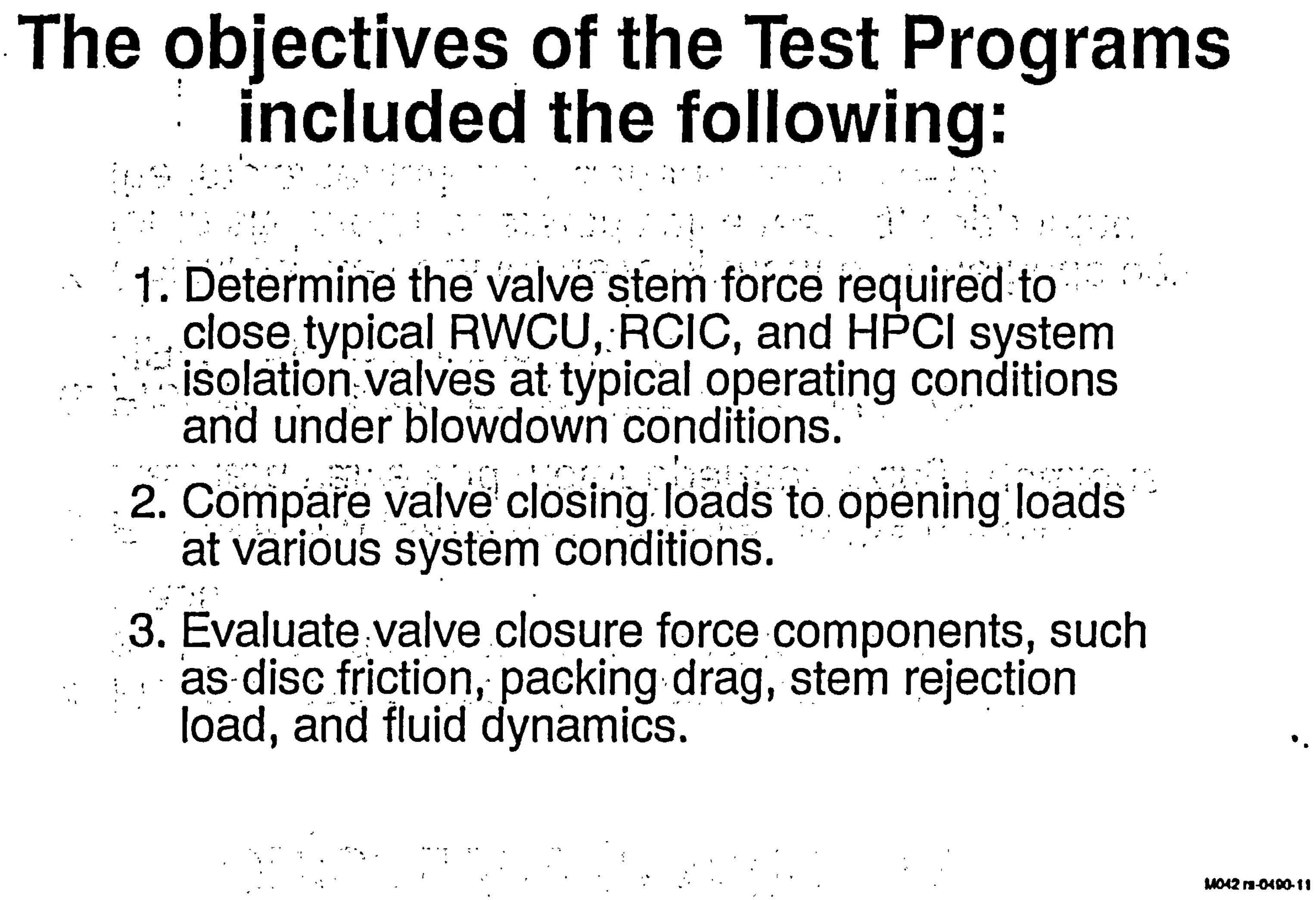
Figure 3. Background page from the INEL April 18, 1990 NRC Experts Meeting Handout



The objectives of the Test Programs included the following:

1. Determine the valve stem force required to close typical RWCU, RCIC, and HPCI system isolation valves at typical operating conditions and under blowdown conditions.
2. Compare valve closing loads to opening loads at various system conditions.
3. Evaluate valve closure force components, such as disc friction, packing drag, stem rejection load, and fluid dynamics.

M042 re-0490-11

Figure 4. Objectives listed in the INEL April 18, 1990 NRC Experts Meeting Handout.

Objectives (continued)

4. Measure the effects of temperature, pressure, and valve design on valve closing and opening loads.
5. Evaluate the terms and variables in the present standard valve and motor operator sizing equations.
6. Provide detailed information to assist in the NRC effort regarding GI-87.
7. Correlate the data for development of a methodology for in situ motor-operated valve testing, supporting the implementation of Generic Letter 89-10.

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Figure 5. Objectives listed in the INEL April 18, 1990 NRC Experts Meeting Handout.

EPRI review, was related to GI-87. We also mentioned that for the 10-in. valves we tested, the unseating loads were not the highest opening loads we encountered and that even our low flow data did not support the standard motor-operator sizing practices of the industry.

3.2 Applicability of Test Conditions

With regard to the applicability of the test conditions relative to both GI-87 and GL 89-10, two issues need to be recognized. First, it should be established that the GI-87 valves are a subset of the GL 89-10 valves, and they are specifically identified in Supplement 3 to the generic letter. Second, the additional concerns of GL 89-10, such as motor operator sizing, switch setting, and in-plant to design basis test extrapolation, cannot be ignored. Although the GI-87 blowdown test conditions do not apply directly to other valves designed for lower loads, the understanding of valve behavior provided by the GI-87 test results does address GL 89-10 concerns.

3.2.1 Valve Inlet Pressure. The EPRI report states, *"The DP versus stroke behavior for valves with blowdown design basis conditions in nuclear power plants would be dependent on the details of plant-unique piping configuration. The piping configuration is important because systems with high overall flow resistance would have more flow pressure losses in the system and less DP across the valve during mid-stroke. Less severe DP in mid-stroke is more favorable to valve performance, because the valve disk is not loaded as heavily while it is sliding on the guides and transitioning to the seat. The NRC/INEL test conditions were more severe in this regard, since system flow resistance was lower in the tests than in a typical BWR (see table below)."*

System	BWR Resistance and Basis	INEL Test Resistance and Basis
RWCU	32.9 (net K from reactor vessel to first isolation valve, based on 6" pipe)	1.6 (Phase 1) 2.7 (Phase 2) (net K from pressure tank to isolation valve, based on 6" pipe)
HPCI	1.5 (net K from reactor vessel to first isolation valve, based on 10" pipe)	0.6 (net K from pressure tank to isolation valve, based on 10" pipe)

The opposite was our concern: did we have too much line loss in the test loop to model the less complicated plant piping systems? Figure 6 is an isometric drawing of a Mark I RWCU supply line, Figure 7 is an isometric drawing of the Phase II 6-in. test loop, and Figure 8 provides the dimensions of the Phase II test loop. The test loop has about twice the line losses of a Mark I RWCU supply line. In contrast, Figure 9 is an isometric drawing of a much more complicated Mark II RWCU supply line, where the line losses have a greater effect on the pressure profile at the valve. It is easy to see that line losses in these systems vary significantly from plant to plant. To address the issue of line losses, we established, within facility limitations, the test target pressures at the valves. The parametric testing at higher and lower pressures provided an adequate range of pressure histories to account for any creditable line loss scenario.

Conclusion: The valve inlet test pressure conditions were applicable to the GI-87 valve subset. The parametric testing bounded the worst case conditions and was useful in developing a correlation (see Appendix C) that can be used once a utility has determined the design basis conditions for a given valve and determined that the valve design is predictable. (A predictable valve is defined as a valve that can close under design basis conditions without sustaining internal valve damage that would cause an unexpected increase in the stem force necessary to close the valve.)

Reactor Water Cleanup High Energy Lines
Mark I

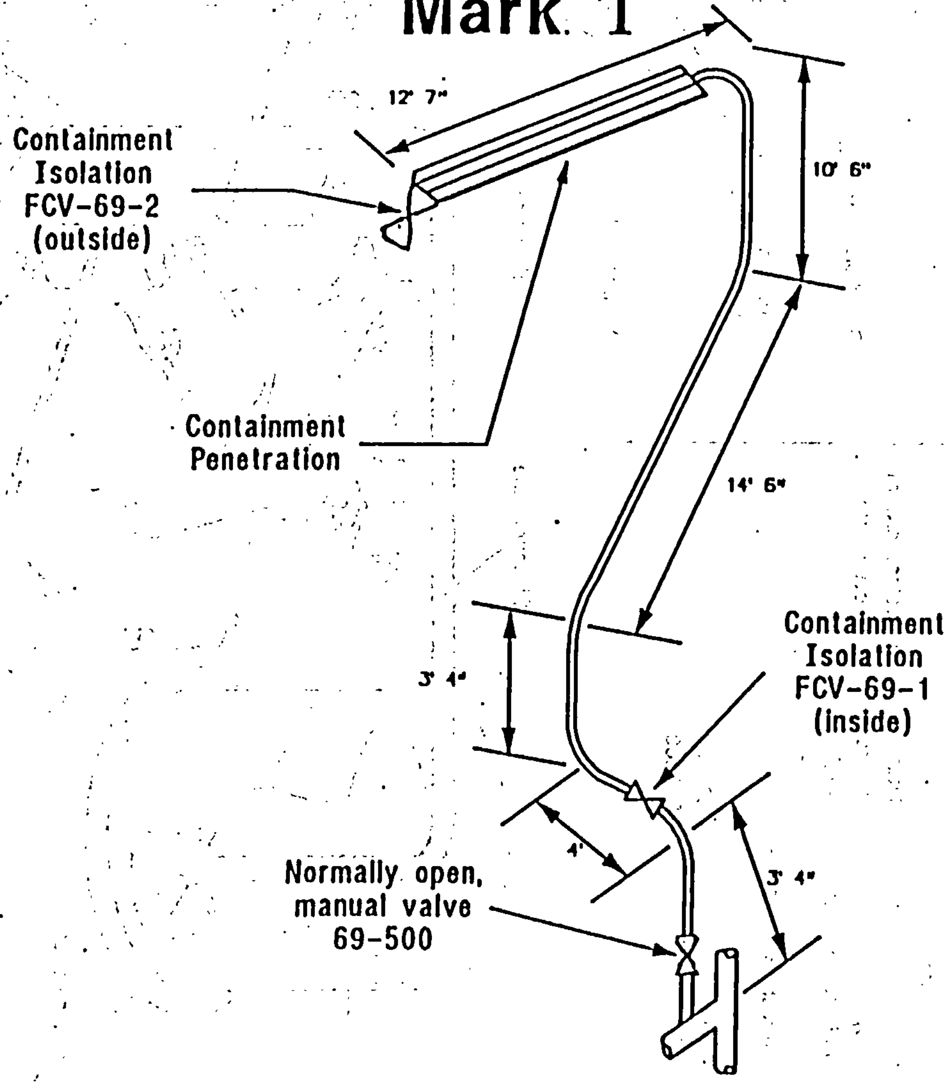

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Figure 6. Isometric drawing of a typical Mark I RWCU supply line.

SIEMENS

Valve Test Facility VPE

Design data

Design pressure	157 bar
Test fluids	Saturated steam , water , mixture
Mode of operation	Blowdown from an accumulator
Volume of accumulator	22 m³
Mass flow (Saturated steam at 85 bar)	approx. 200 kg / s
Connecting piping	
- Inlet	DN 250
- Outlet	DN 500

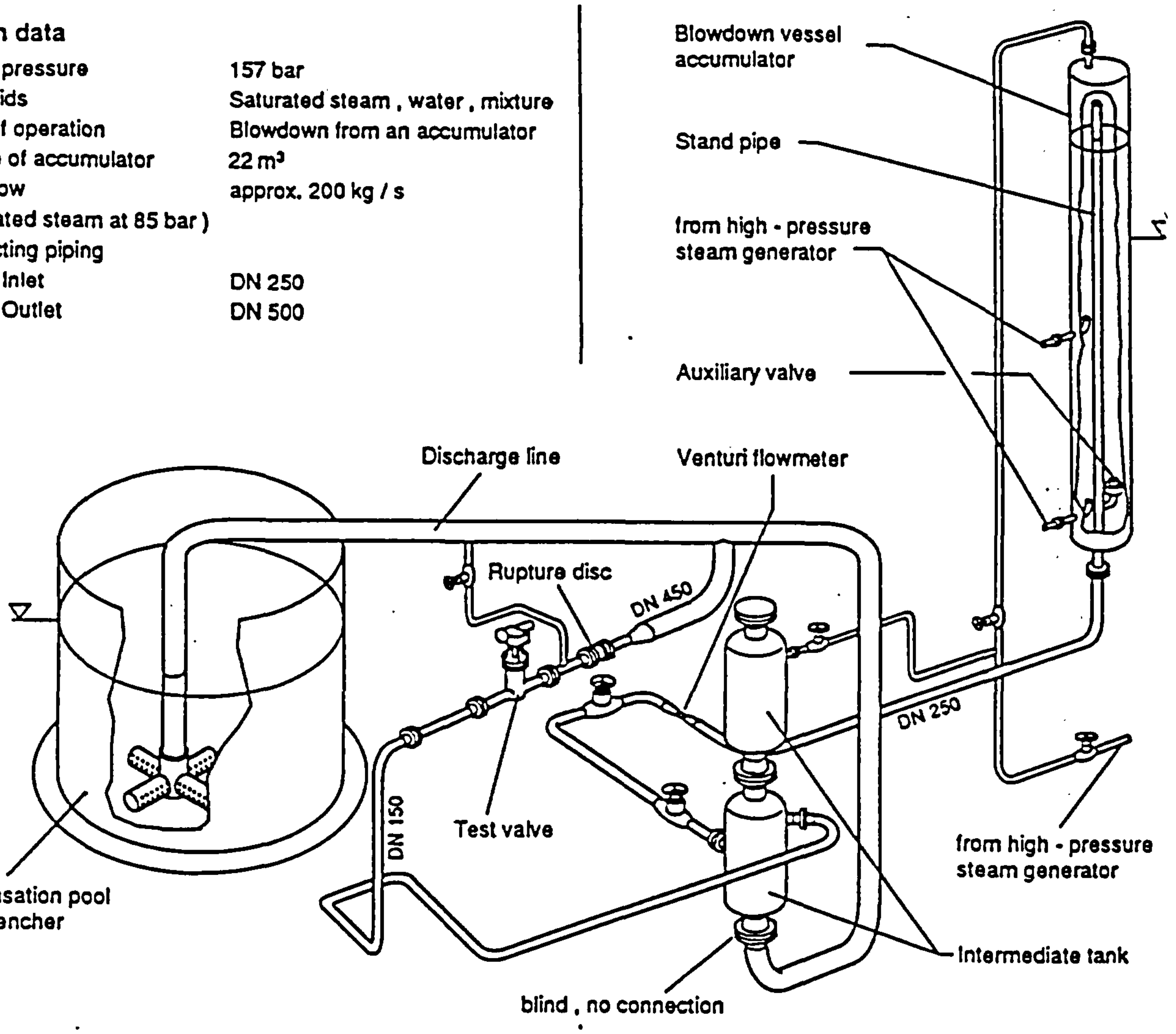

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Figure 7. Isometric drawing of the Phase II 6-in test loop.

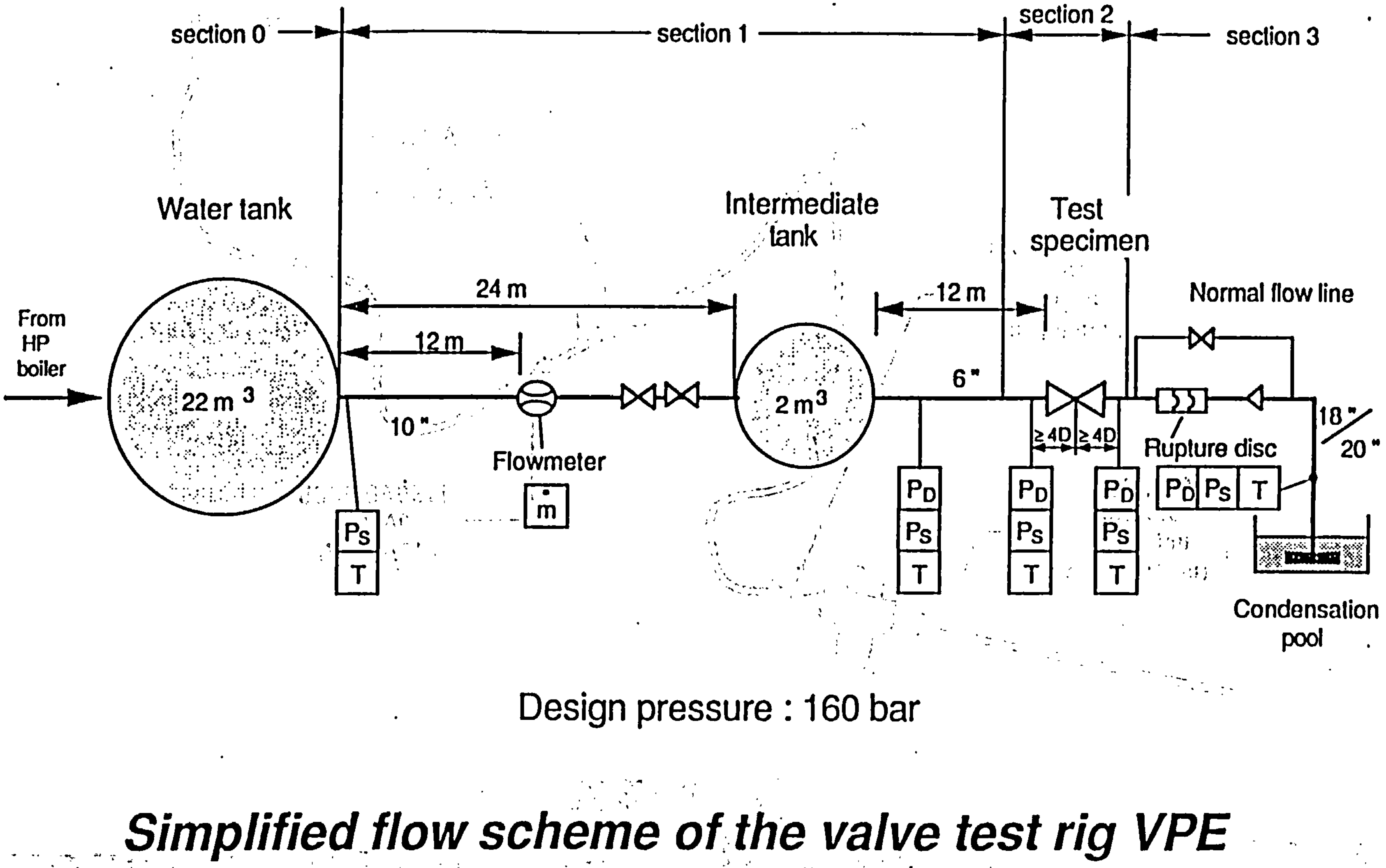


Figure 8. Schematic drawing of the Phase II 6-in test loop.

Reactor Water Cleanup High Energy Lines
Mark II

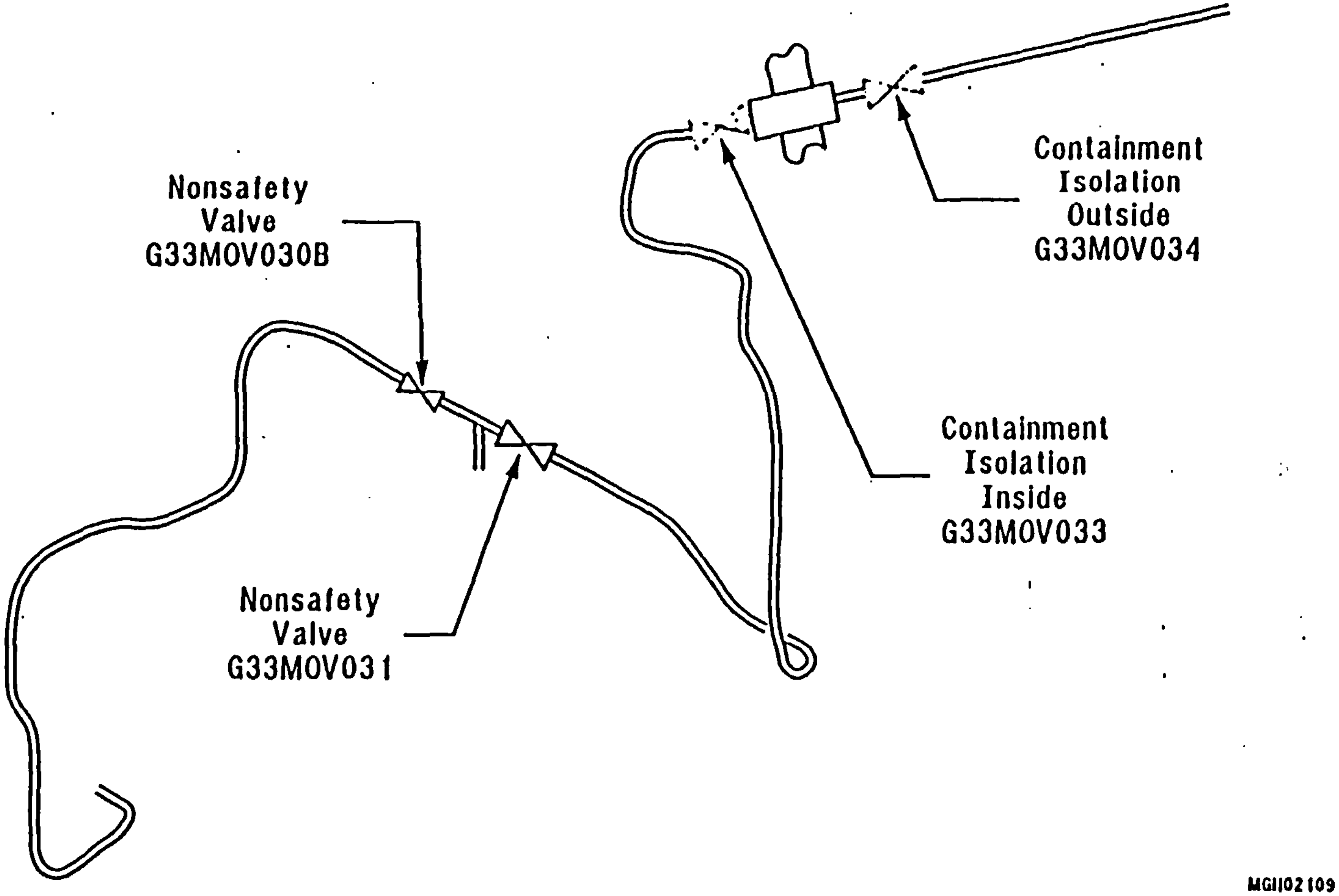


Figure 9. Isometric drawing of a typical Mark II RWCU supply line.

3.2.2 Multiple Closures. The EPRI report points out that GI-87 valves need to close only once at design basis conditions when it states *"MOVs in the RCIC, HPCI and RWCU systems are only required to isolate a break* *once*. *Because of the potential for valve damage under blowdown conditions, only the* *first* *blowdown isolation closure test for each valve design is considered potentially applicable to valves installed in these systems."* We agree, and we designed the research programs so that in every case (with the exception of Valve A), the first blowdown was the nominal design basis pressure and temperature test for the valve being tested. Four of the six valves tested in Phase II sustained internal damage due to high disc loadings during their design basis test. Thus, their performance is referred to as nonpredictable. A nonpredictable valve is defined as a valve that sustains internal valve damage, such as galling, machining of surfaces, or plastic deformation, during closure, such that the stem force reflects more than simple sliding friction. We performed the additional parametric tests primarily on the predictable valves, to obtain sufficient data to evaluate industry sizing methods and to evaluate valve performance under a range of loadings. The parametric tests were necessary, because it is not possible to define performance curves from a single data point.

The first blowdown test for Valve A in Phase I was not at the design basis conditions. Due to facility start-up problems, we tested Valve A at the design basis pressure but at less than design basis temperature (50°F subcooled instead of 10°F). The INEL test engineer made this decision to avoid losing a week of test facility time. We did not expect the results that we obtained from Valve A (the valve was damaged during the test), and in light of those results, it is easy to question the decision in hindsight.

Conclusion: For seven of the eight valves tested during Phase I and Phase II, the nominal design basis test was performed first to evaluate the ability of the valves to close once. The multiple closures after the initial design basis test were defined in the approved test plan and were applicable to the research program.

3.2.3 Blowdown Closure Tests. Several statements in the EPRI report indicate that the blowdown conditions simulated in tests performed by the INEL are not applicable to all safety-related valves in nuclear service. For example, the EPRI report states:

> "*Applicability of Blowdown Conditions to Overall Valve Population*"
>
> - *the NRC/INEL blowdown closure test conditions are directly applicable to a small portion of the MOV population - about 4% of BWR valves and none of PWR valves.*
> - *dependent on plant-unique configurations and "design-basis" interpretation, the NRC/INEL blowdown closure test conditions might be potentially applicable to additional valves (up to 15% for BWRs and 9% for PWRs).*
> - *the NRC/INEL blowdown opening conditions are not generally applicable to valve design basis conditions in nuclear power plants."*

Applicability of the blowdown test conditions to all of the safety related valves was never intended by any of the INEL reports. What we have learned for 5-degree flexible wedge gate valves is that when the on-the-seat normalized normal loading achieves a minimum threshold, the response of the valve becomes very repeatable (provided the valve does not experience damage). We have established this minimum threshold level at 400 lb_f/in^2. As such, if the normalized normal loading is above this threshold, the INEL correlation (see Appendix C) will bound the maximum valve stem loading from very low flows to blowdown conditions. The INEL correlation was developed from the results of our normal and low flow closure testing and our design basis blowdown closure testing. The development of the correlation is explained in Appendix C, which is a copy of our most recent paper presented at the Nineteenth Annual Water Reactor Safety Information Meeting. We are currently working with selected utilities to assess whether this correlation can be used with even lower test loadings, thereby encompassing nearly all 5-degree flexible wedge gate valves addressed by GL 89-10. Thus, in this indirect way, the NRC/INEL test results are applicable to valves other than GI-87 valves.

Conclusion: The blowdown tests provide data for the worst case loadings. To build complete valve performance curves, one must have the worst case loading as well as lesser loadings to determine if a relationship exists in the data and to establish the limits of that relationship. Although blowdown conditions are not directly applicable to all safety-related valves, performance curves developed from a test program that includes blowdown conditions are applicable to GL 89-10.

3.2.4 Blowdown Opening Tests. The EPRI report states that *"in general, nuclear power plant valves do not have to open against design basis blowdown opening conditions such as tested in these NRC/INEL tests. However, some valves need to open in systems where the flow rate may be significant as the valve opens, and there could be the potential for this type of behavior. Accordingly, to the extent this phenomenon is due to flow effects, it would need to be adequately accounted for in valve opening applications. For most nuclear power plant valves, which face opening conditions far less severe than the NRC/INEL blowdown conditions, this effect is not expected to be as strong as observed in the NRC/INEL tests."*

We performed normal flow openings, no flow openings, and maximum flow openings. The EPRI report expresses some concern about the value of the blowdown opening tests. We have never quoted a safety function for a valve to initiate blowdown flow, except perhaps for the PORV block valve. However, not all systems in a nuclear plant are pumped systems. Some are connected to large vessels where momentary to slightly more sustained high flows could be anticipated upon opening, depending on the downstream volume.

The results of these tests do show some interesting responses and yield insights into the phenomena affecting valve performance. Thus, the results of these tests became very useful to us in the overall analysis. In particular, we observed that the largest stem force did not always occur at unseating, as typically assumed by the industry. We do not yet know the point at which flow begins to be a significant contributor to opening loads. However, even the rapidly decaying flow forces observed during the large valve no-flow opening tests were sufficient to produce the largest stem forces after the valve was partially open. If such a response can so easily be obtained, we hesitate to term it *"unusual behavior"* as the EPRI report has. The INEL will continue to assess the results of the opening tests and will hopefully be able to better quantify valve opening response at a later date.

Conclusion: The blowdown opening tests provided very important information. The highest opening stem forces do not always occur during unseating, and the resultant flow during opening can have a significant effect on the stem force. We do not yet know the point at which flow becomes a factor in valve opening. These test results may be useful to licensees in determining the extent of bypass for the opening torque switch.

3.2.5 Normal Flow Tests. Regarding the NRC/INEL normal flow tests, the EPRI report states, *"the INEL normal flow conditions are quite unlike typical gate valve conditions in power plants. Although great care should be used in interpreting and applying results of these tests, it is expected that some data would be useful in valve evaluations. However, the evaluations described in Sections 5 and 6 show little or no meaningful information could be obtained at the point of flow "isolation" (due to very low DP) and that disk factors determined at other points (between isolation and seating for example) gave suspicious results (i.e., they were substantially out of agreement with other tests). Until these data are studied in more detail, it does not appear stem forces or disk factors determined from the data plots should be directly applied to nuclear power plant valves."*

We agree that not all of the tests provided useful information. However, the purpose of the normal flow tests was not simply to duplicate the normal flow conditions for a given valve in a plant, but instead to provide data that could be used to characterize valve behavior in general. In those normal flow tests where we were able to establish an on-the-seat normalized normal loading greater than 400 lb_f/in^2, the results contributed to the correlation shown in Figures 10 and 11. Since completing the correlation, we have been working with utilities that are performing differential pressure testing with proven diagnostic measurement equipment. We have been able to analyze some pumped low flow

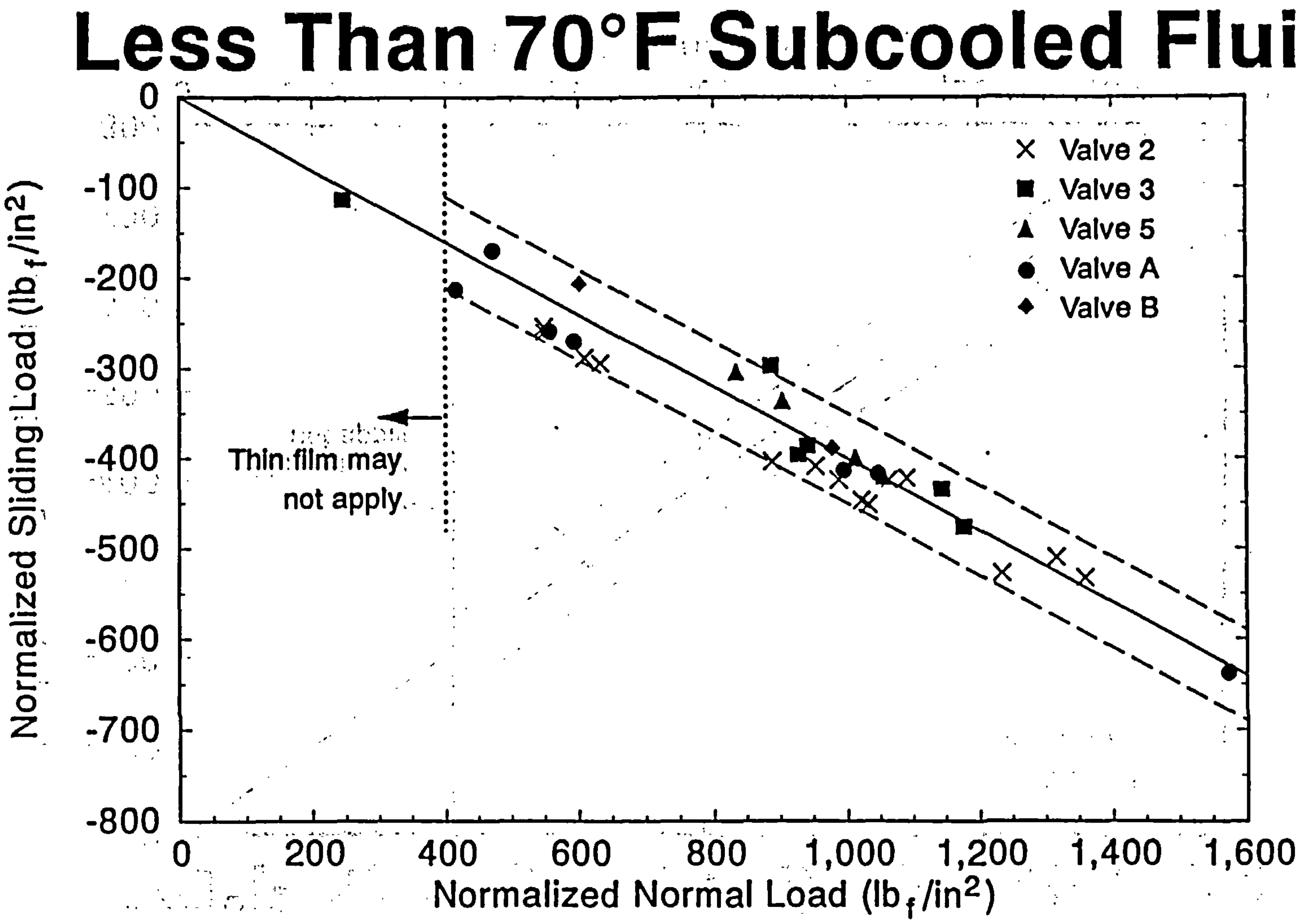


Figure 10. INEL correlation for tests with less than 70°F subcooled fluid.

M455 kgd-1091-22

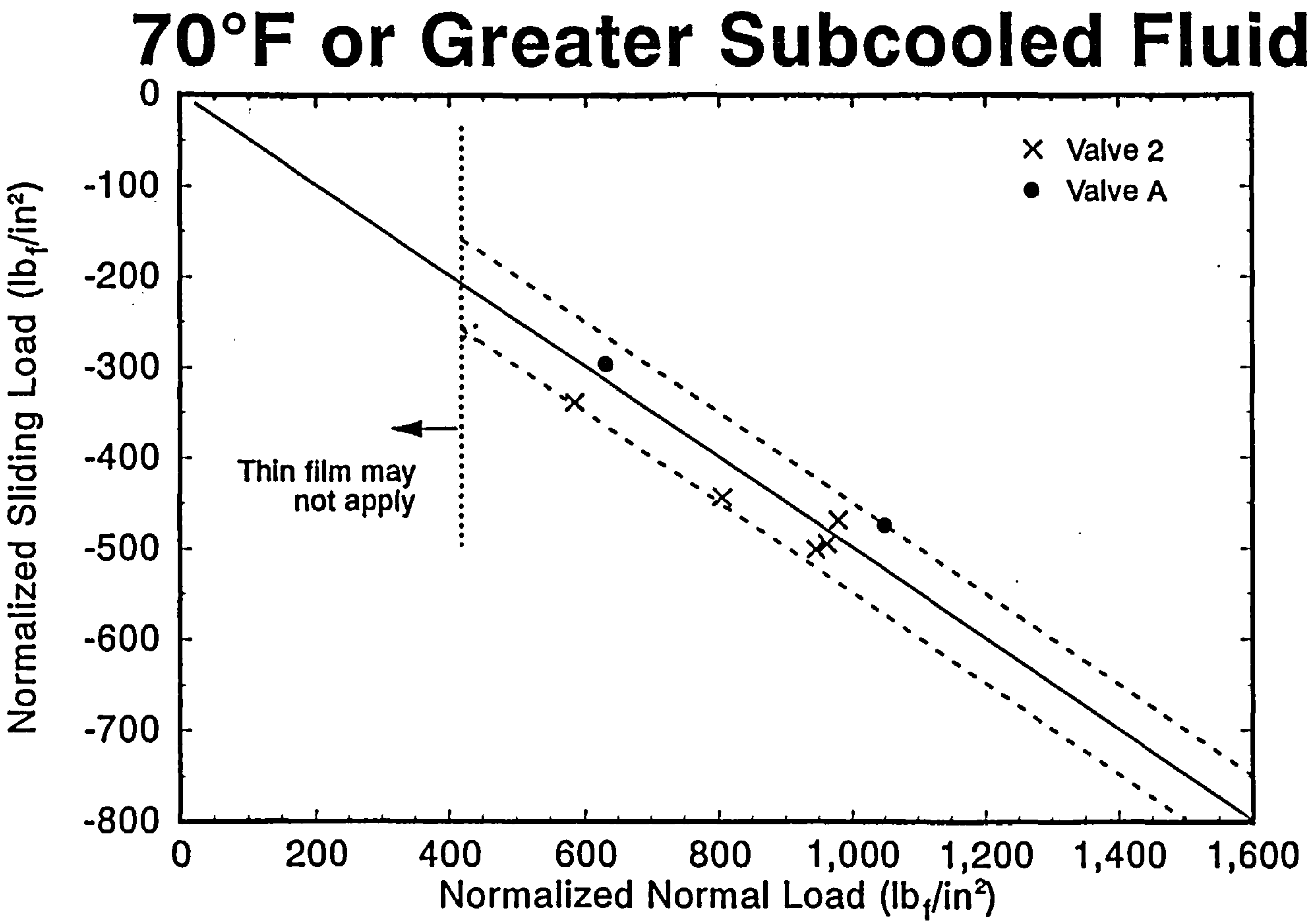


Figure 11. INEL correlation for tests with 70°F or greater subcooled fluid.

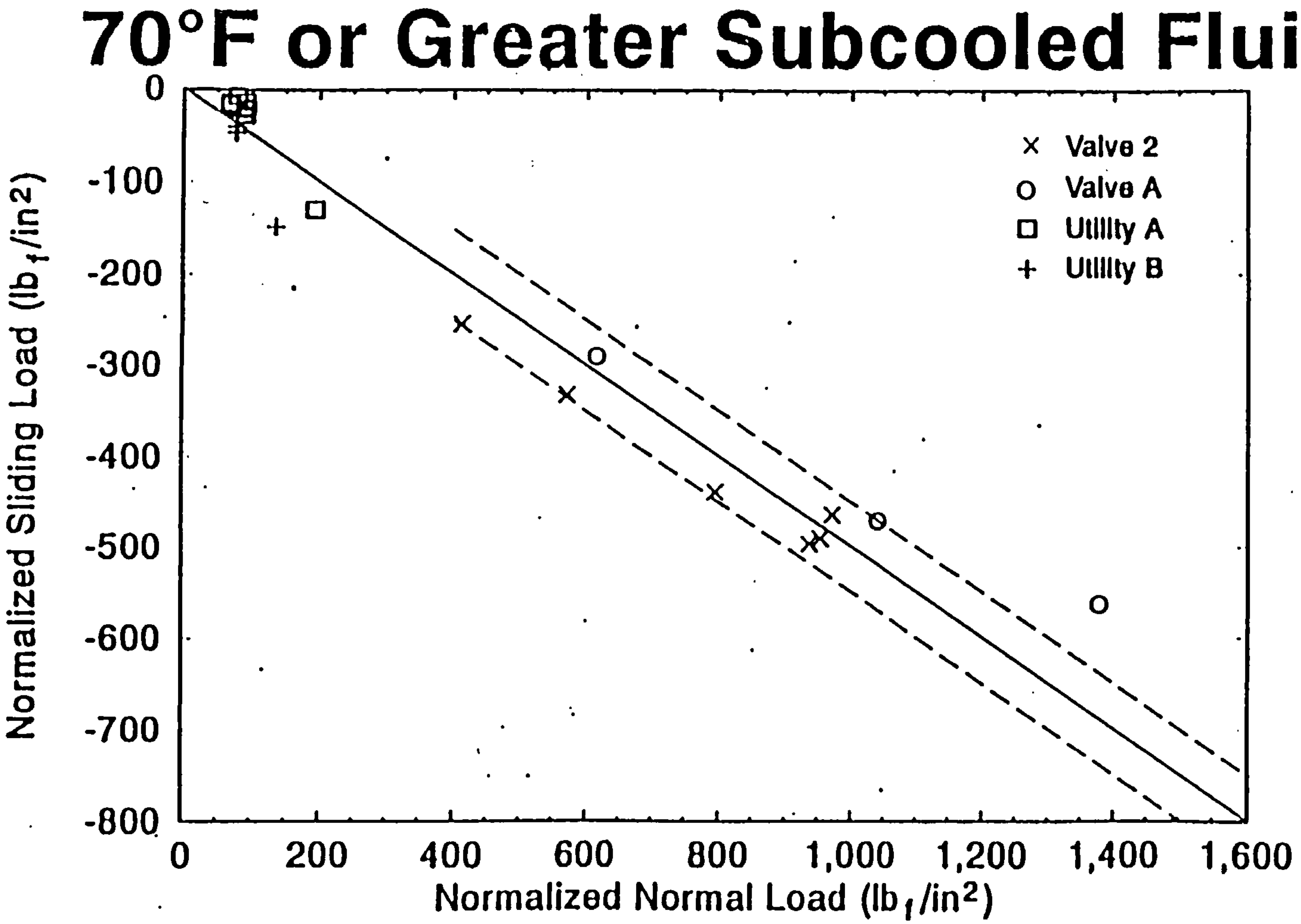
M455 kgw-1091-23b

differential pressure tests where the on-the-seat normalized normal loading did not reach the 400 lb_f/in^2 cutoff. One utility tested one 4-in., seven 8-in., and one 12-in. gate valve at pressures from 80 to 200 psig. A second utility tested four gate valves (one each at 3, 6, 10, and 12 in.) at pressures from 70 to 150 psig. All of the testing was done at fluid conditions greater than 70°F subcooled. Figure 12 shows the result of that analysis and how the valves fit the correlation.

Conclusion: We believe that when the results of our normal flow testing and the normal flow testing by others, with proven diagnostic measurement equipment, are properly used, they may be applicable for characterizing the response of predictable gate valves. Many valves cannot be design basis tested in situ. If a utility can determine that a valve design is predictable, low flow in situ testing could be used to validate that the valve is responding in a manner similar to valves tested by the INEL. If such a similarity can be shown, the INEL correlation can be used to bound the design basis loads for that particular valve.

3.2.6 No-Flow Tests. Regarding the NRC/INEL no-flow tests, the EPRI report states that *"the presence of an initially depressurized downstream volume actually permitted a brief period of flow -- much less than one second for cold conditions, about one second for hot water conditions (6" valves) and several seconds for steam conditions (10" valves). The longer duration for the hot conditions is attributed to the flashing two-phase flow or steam inrush flow as the valve initially opens and starts to pressurize the downstream volume. For 10" valves tested in steam, these "no flow" tests actually established several seconds of blowdown-like conditions. As discussed earlier, opening against blowdown flow is not a condition applicable to most gate valves in nuclear power plants, and thus 10" hot "no-flow" tests are not directly applicable to most industry MOVs."*

The leakage tests and the cold and hot cyclic no-flow tests were part of the ANSI/ASME B16.41 valve qualification tests. A no-flow test with a



M354 m 0691-14

Figure 12. INEL correlation and results from selected utility tests

pressurized fluid upstream of the valve will produce a momentary motion of the fluid when the valve is opened. This phenomenon will be more pronounced if the fluid is highly compressible. The term *"no flow"* is not an attempt to ignore this momentary phenomenon, but rather to distinguish these tests from tests with sustained forced flow. Note that during the no-flow tests, there was no flow at the discharge end of the test facility.

These tests were performed because the NRC wanted to be assured that the valves subjected to design basis flow interruption tests would have passed the nuclear valve qualification tests. The tests were applicable for what they were intended. The no-flow tests (and normal flow tests) performed before and after each blowdown were designed to represent possible in-plant performance tests and were performed to obtain data for possible extrapolation analysis. We were hoping to find something in the collected data that could indicate how the valves might perform at design basis blowdown conditions. To date we have not been able to predict valve performance using data from no-flow tests. The only major point we gained from this qualification data was the difference in response of the valves going from cold to hot cycling. The EPRI report suggests some possible reasons for this difference.

Conclusion: The ANSI/ASME B16.41 valve qualification tests demonstrated that most of the valves used in the INEL test program would have passed the standard qualification test used by the industry. The fact that some of the valves were damaged during design basis blowdown tests after having passed the standard qualification test has caused the ASME to take another look at the qualification standard.

3.2.7 Nitrogen Flow. The EPRI report points out that some of the Phase I tests had nitrogen flowing through the valves. This was an unfortunate facility problem. The EPRI report also points out that dry nitrogen might increase the friction factor of a valve. Flow of a nitrogen/steam mixture did occur, but not dry nitrogen flow. Our review of the video tapes of the Phase I blowdown tests clearly shows that water vapor was being discharged during all the tests, including those where nitrogen flow was involved. Figures 10 and 11 show all the on-the-seat sliding versus normal loads for the Phase I and Phase II valves (the friction factor is defined as the sliding load divided by the normal load, or the slope of the solid line on each of these figures). Two of the Valve A tests in Figure 10 (darkened circles) had nitrogen flow through the valve; these two data points lie near a normalized normal loading of 400 lb_f/in^2. As can be seen, the on-the-seat sliding versus normal loads for these Valve A tests line up well with those of all of the rest of the valves. This comparison indicates that the nitrogen/water vapor mixture did not affect the on-the-seat performance of the valves. This issue is discussed in depth in Section 3.4.6, and the thick film/thin film lubrication discussion in Appendix C provides further insight into the observed behavior.

Conclusion: Dry nitrogen flow did not occur. Where flow of a nitrogen/steam mixture occurred, the analysis of the on-the-seat performance of the valves shows that the presence of some nitrogen did not increase the friction between the disc and the seat. Even if the Phase I results with nitrogen flow were excluded, there would be no change in the conclusions presented to date.

3.3 Applicability of Test Hardware

3.3.1 Different Valve Designs. The EPRI report states that all of the tested valves, except Valve 1 in Phase II, are representative of valves in nuclear service. We discuss the exception in Section 3.3.2 of this report. The EPRI report also points out that the manufacturers have provided other designs to the power plants and suggests that these other designs may perform differently than those we tested. This statement might lead the reader to infer that other design variants might perform adequately. Most of the design variants listed in the EPRI report were tested as part of the INEL program. The major design variant that was not tested was the double disc gate valve; however, this design was tested by EPRI in an earlier program.

In that program, conducted in 1980, EPRI tested PORVs and block valves at the Duke Power Marshall Steam Station. The block valves were 3- and 4-in. gate valves tested at near blowdown conditions, with the PORV providing an orifice to full flow. The tests were basically uninstrumented, go/no-go tests. Two manufacturers, Velan and Anchor/Darling, were common between the EPRI/Marshall and the INEL tests. In the EPRI/Marshall test, the Velan flexwedge gate valve closed, but the Anchor/Darling double disc gate valve did not close with the originally sized operator, requiring a seat design change and a larger operator prior to retest. No public domain data are available to indicate why the Anchor/Darling valve failed, what stem force was required to close each valve, or how the results compare to industry calculations.

In addition to the NRC/INEL and EPRI/Marshall tests, full-scale design basis testing has been performed in Great Britain and Germany. In NRC Information Notice No. 90-72, "Testing of Parallel Disc Gate Valves in Europe," the NRC discusses the British and German experience in full-scale testing of parallel disc gate valves. That testing resulted in internal damage to the gate valves, including abrasion and galling of the disc and seat sliding surfaces. Because of this damage, significantly more stem force was required to close the valves than would be predicted using the standard industry equations. Their early parallel disc gate valve research provides results similar to the results of NRC/INEL testing. In later testing, after significant design changes, both the English and the Germans have developed predictable gate valve designs, albeit at a higher friction factor than is typically used in the U.S.

The EPRI report suggests that valves with different designs (machined and/or hardfaced guides, as-cast/machined and welded body guides, thinner/thicker discs) will perform differently than those tested in the NRC/INEL program. As for hardfacing, there was no difference in the NRC/INEL tests in the performance between Valve B with hardfaced disc guides and Valve 2 (same valve) with non-hardfaced disc guides. As for thinner discs, Valve 3, the Walworth valve, was a 600-lb class valve with a thin disc. The on-seat performance was the same as with the thick-disc valves. The as-cast body guides may have some effect on valve performance (higher frictions). We did not test every design variant of every manufacturer. However, the valves we tested represented most of the different variations in design possibilities, except for the double disc design noted. The one design feature that has the greatest effect on valve operability is body-guide/disc-guide clearance. Large clearances allow the disc to tip excessively during closure under high flow loads, resulting in damage to the disc, guides, and seats.

Conclusion: The valve designs tested in the NRC/INEL test program are typical of most flexwedge gate valves installed in GI-87 nuclear applications. There are no solid test results in the public domain to indicate that any of the other valve designs referred to in the EPRI report would perform any better than those tested in the test programs mentioned above. The INEL believes that any valve design should be tested before being placed in nuclear safety service.

3.3.2 Valve 1. Several statements in the EPRI report express concern about the representativeness of Valve 1. For example, the EPRI report states that *"Anchor/Darling indicates that Valve 1 is not representative of Anchor/Darling valves supplied to the nuclear industry. Specifically, the Valve 1 downstream disk hardfacing is thinner and the edge sharper than Anchor/Darling requires in their manufacturing process. These conditions are considered detrimental to valve performance. Valve 1 was refurbished between Phase 1 and Phase 2 of the NRC/INEL tests. The atypical condition of the disk hardfacing could have been the result of this refurbishment which was not performed by Anchor/Darling. Test results for Valve 1 are not considered applicable to typical Anchor/Darling valves meeting the manufacturer's hardfacing and manufacturing requirements."*

The EPRI report further states that *"After the Phase 1 test program, Valve A was refurbished to be used as Valve 1 in the Phase 2 test program. The refurbishment was performed by Crane Valve Services. Unfortunately, this refurbishment was not performed in accordance with the Crane nuclear Q/A program, and the available records are minimal. It is not possible to tell from the records what operations were carried out in the refurbishment."* The EPRI report concludes that *"Anchor/Darling has determined that Valve 1 is <u>not</u> representative of Anchor/Darling valves and that data from Valve 1 tests are <u>not</u> applicable to Anchor/Darling valves in nuclear power plants. The observed configuration of Valve 1 could have been the result of the disk face being machined down during refurbishment at Crane. Such a process could thin the existing Stellite layer* *and remove an existing bevel at the edge. Unfortunately, available documentation is not sufficient to evaluate this hypothesis, although it is plausible."*

It is important to note that both Phase II Anchor/Darling valve refurbishments (Valves 1 and 4) were performed by Crane-Aloyco. The EPRI report states that *"Valve 4 is an Anchor/Darling 10-inch flexible wedge gate valve with an ANSI class pressure rating of 900 lbs. This valve was fabricated by Anchor/Darling in 1982 for Hope Creek Unit 2, which was subsequently canceled. The figures and information in Section 4 and Appendix D of this report show the Valve 4 configuration. This valve had machined guide slots in the carbon-steel disk, cast guide rails in the carbon-steel body, and Stellite hardfacing on the disk and seat faces. Anchor/Darling indicates that Valve 4 is similar in design features to a large population of flexible wedge gate valves they have manufactured and supplied to nuclear power plants."*

The refurbishments were performed at Crane-Aloyco because Anchor/Darling proposed an unrealistic schedule to refurbish the valves. The work at Crane-Aloyco was performed through their engineering department at the suggestion of Crane-Aloyco. Standard shop work would not have assured us that original design features important to assessing valve performance would have been maintained. We are completely satisfied with the work done at Crane-Aloyco.

Figures 13 and 14 are photographs of the Valve A disc taken after the Phase I tests. These photographs show the condition of the seating surface and the sharp edge discussed later in this section. The valve was manufactured for the Phase I test program by Anchor/Darling, and to quote the EPRI report, *"Anchor/Darling indicates that Valve A is similar in design features to a large population of flexible wedge gate valves they have manufactured and supplied to nuclear power plants."* Valves supplied to nuclear power plants with similar design features to Valve A would therefore be expected to perform in a similar fashion when exposed to similar conditions. Valve A performed unpredictably in the Phase I test program due to internal damage caused by the flow loadings.

After the Phase I tests and in preparation for the Phase II program, Valve A was refurbished by Crane Valve Services, Crane-Aloyco, Inc. and

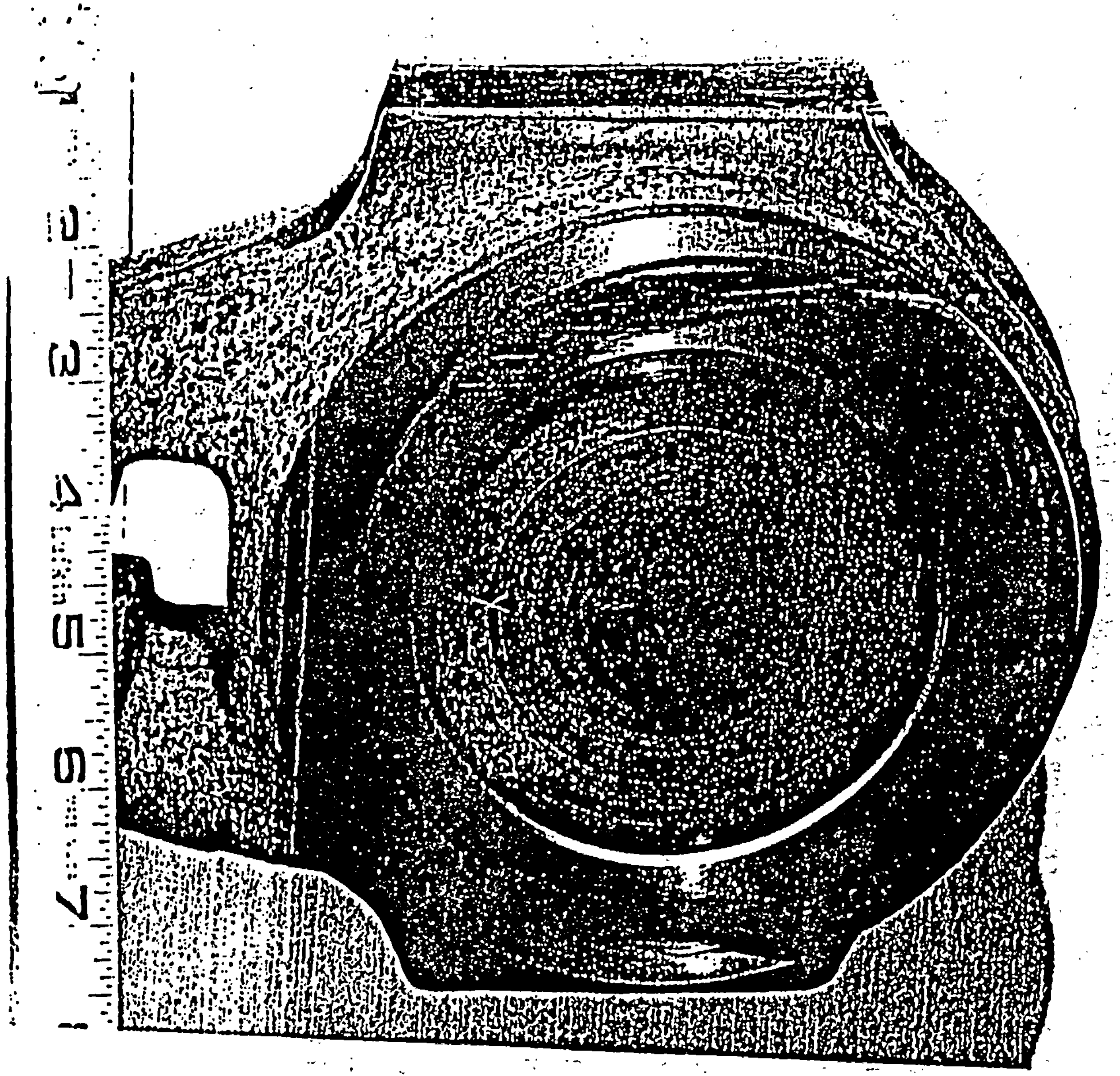


Figure 13. Photograph of the entire Valve A disc after the Phase I tests

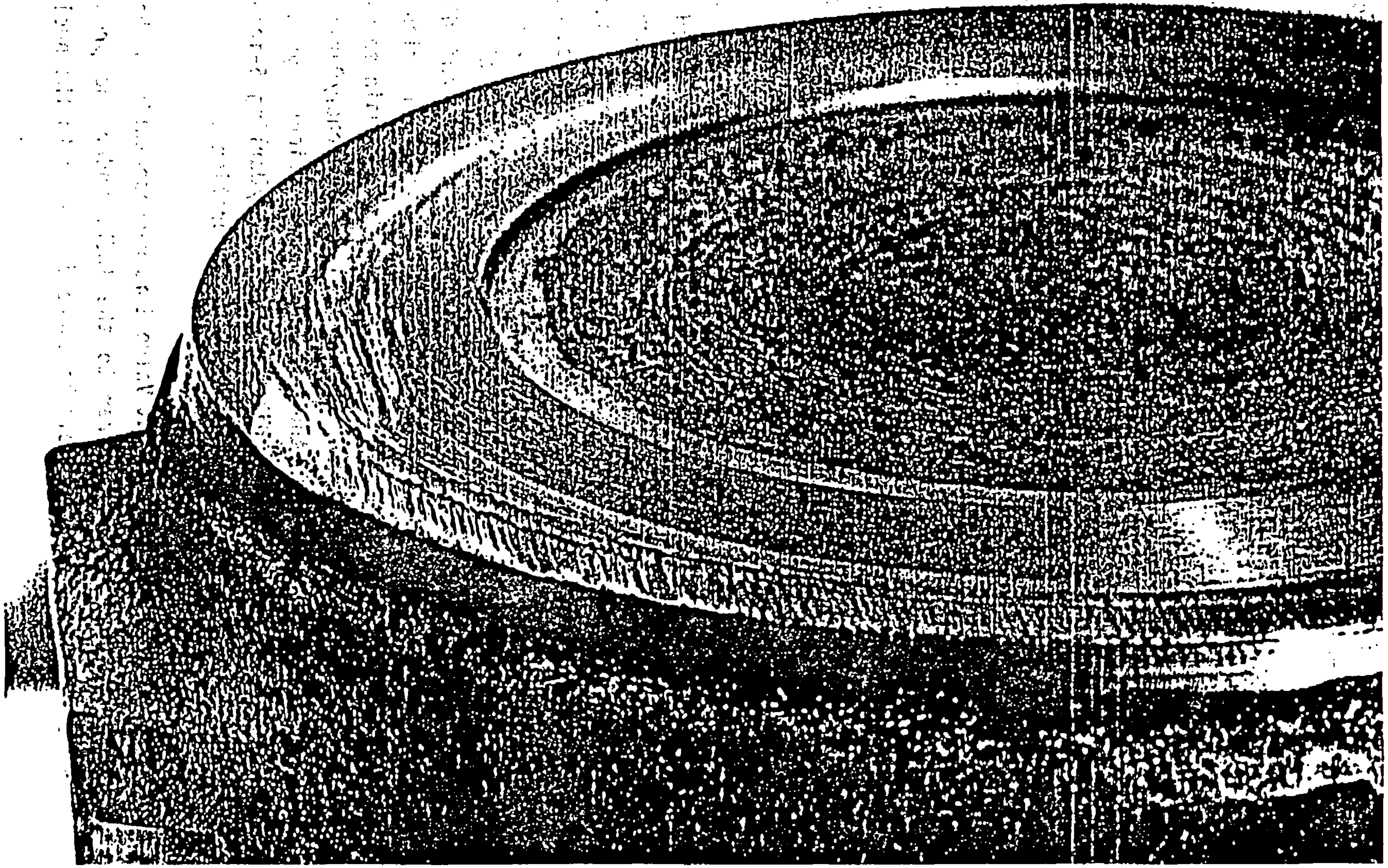


Figure 14. Closeup photograph of the Valve A disc after the Phase I tests

redesignated Valve 1 for Phase II. The work scope for this purchase order is correctly quoted in the EPRI report on page 3-3 as follows:

> *"Inspect Anchor/Darling valve - 6", 900 pound, Valve serial No. E-A345-1-1 and refurbish. In addition, manufacture a new stem nut for an SMB-0 Limitorque Motor Operator. Refurbishment will require disc and seat repair. The downstream disc face and body seat were previously damaged in testing."*

Numerous telephone discussions between INEL and Crane-Aloyco controlled the refurbishment process, which included repeated directions forbidding Crane-Aloyco from any work that was not previously agreed on. We were fully aware of how important it was that the work leave the original design features intact. Postwork conversations with Crane-Aloyco have assured INEL that no refurbishment work was performed other than that agreed to. Crane-Aloyco did not modify the undamaged upstream disc surface of Valve A, which became the downstream surface of Valve 1.

In the Phase II testing, Valve A was designated Valve 1 to help separate test results between the two test programs. The valve was installed in the system with its flow direction reversed from Phase I so that the downstream disc surface and valve body seat ring would be original Anchor/Darling surfaces. Reversing the flow direction through the valve does not impact the test results, as such valves have bidirectional application. The Anchor/Darling 6-in. valve was disassembled immediately after the Phase II testing to verify that the Crane refurbished surface was not downstream. As verified by INEL and NRC, the original Anchor/Darling surface was in the proper downstream orientation. Figure 15 is a photograph of the same surface after Phase II, again showing the sharp edge that the EPRI report identified as atypical of Anchor/Darling disc configurations. The photographs and the posttest verifications provide clear evidence that the downstream seat and disc on the Anchor/Darling 6-inch valve tested in Phase II were original Anchor/Darling configurations.

Conclusion: All of the evidence shows that Valve 1 is representative of hardware delivered by the manufacturer to the INEL, under the premise of being representative of their hardware delivered to the nuclear

Figure 15. Closeup photograph of the Valve 1 disc after the Phase II tests

industry. Posttest examinations showed that Valves 1 and 4 had exactly the same failure mechanisms when subjected to design basis flow.

3.3.3 Damaged Hardware. After the Phase I tests we were criticized for not performing valve inspections between tests and for further testing damaged hardware. Valve inspections between tests were considered for the Phase II test program, but we later decided against them because of cost. Experience had shown us that valve damage can be detected through a sensitive stem force measurement. Using such measurements during the Phase II testing, we were able to detect every occurrence of valve damage. This valve damage was subsequently confirmed during posttest inspections.

We might explain here in more detail why we did not perform inspections between tests during the Phase II testing. Our test program was primarily a hot test program. A large expenditure of time and resources went to heating the large volumes of water used to test these valves. These volumes could not be held at temperature for long periods of time because of the associated labor and energy costs. A hot water or steam test gets a valve very hot. Once a valve is heated, it needs 16 to 24 hrs to cool before an inspection could be performed. Such a delay is expensive. The INEL method of detecting valve damage worked, allowing the tests to be conducted with available funds.

Some valves were tested after damage was detected; we tested Valves 5 and 6 after damage was detected in the first blowdown closure of each. Further testing was performed because we believed that additional information supporting the objectives of the test program could be obtained, such as understanding the difference between mid-stroke performance and on-the-seat performance, and this was our last chance at testing the large valves during this test program. The additional information was useful in the development of the INEL stem force correlation, the analysis of marginally sized motors, and the analysis of predictable/nonpredictable valve behavior.

Conclusion: We used a sensitive stem force measurement to detect valve damage. Although damage occurred to valves 5 and 6, we continued to test them. The additional testing performed with these damaged valves provided some useful information. For all the predictable (undamaged) valves, the on-the-seat stem forces were the highest stem forces measured. Some of the nonpredictable valves, where high stem forces from guide damage occurred during the stroke, recovered once they reached the final seating part of the stroke. Properly used, these data can help us understand valve performance. Our biggest challenge for future testing will be determining which valves are nonpredictable and at what disc loadings they become nonpredictable.

3.4 Assessment of Test Results

The EPRI report's analyses of the INEL test data are based largely on two separate issues: identification of the position of the valve at which to assess performance, and the assessment of apparent disc factor. The following discussion first addresses these two issues, then addresses additional issues discussed in the EPRI report, such as an average disc factor, the linear contact stress model, anomalous valve behavior during closure strokes, and the effect of nitrogen flowing through a valve.

3.4.1 Identification of Valve Positions. The EPRI report identified four valve positions at which to assess valve response. These four positions were identified as zero stem position, flow isolation, wedging, and the position at which the maximum stem force occurred. We have evaluated each in light of our assessment of the test results, in light of how the EPRI report actually defines each position, and how each was used in the analyses of the INEL test data. The EPRI report states:

> *(1) "At zero stem position, as indicated by the "Valve Stem Position" data plot. INEL reported that, for Phase 2 testing, this position indicator was calibrated before testing so that it would read zero when the disk completely covered the flow area. Valve stem position information is not interpretable in this way for Phase 1 testing. Note that the interpretation of stem position is subject to hysteresis effects due to the stem/disk clearance (i.e., for a given stem position, the disk can be at either of two locations, depending*

> *on whether the stem is pushing or pulling the disk). Therefore, zero stem position may not always represent the instant that a "true" seal between disk and seat is made."*

We recognize that a slight hysteresis effect exists; however, our concern is more fundamental. For test repeatability purposes during the Phase II testing, we set each stem position indicator such that it read zero when the disc initially covered the visual flow area as viewed down the pipe and through the valve. At this point in the valve closure stroke, the flow is not isolated because the disc is not riding totally on the seats. The fluid is able to flow between the upstream seat and the disc, under the disc, and between the disc and the downstream seat. However, since the disc completely covers the visual flow area, the area term in the standard industry equation has reached its maximum. In its discussion on the effect of hysteresis, the EPRI report associates zero stem position with true flow isolation when it states that *"zero stem position may not always represent the instant that a "true" seal between disk and seat is made."* We have never stated that a zero stem position relates to actual flow isolation. In fact, we recognize that it does not. The INEL assessment of the Phase II test data used to develop the INEL correlation, as shown in Table 1, consistently shows stem positions at flow isolation not at our designated zero position, but instead somewhere between zero and final wedging. No useful information will be determined from the zero stem position, except that the area term in the standard industry equation is at its maximum.

> *(2) "At flow isolation (or unisolation). For closing strokes, isolation was generally identified as the point when downstream static pressure fell to zero. For opening strokes, isolation (or unisolation) was identified as the point when downstream pressure increased above zero. This method did not work for normal flow tests, where a downstream orifice was used to control flow and resulted in the downstream pressure remaining at a high level beyond valve closure, (i.e. the DP was small). Further, it appears dynamic pressure (which is measured with a tap facing the flow as opposed to a flush tap which is used to measure static pressure) may be a more sensitive indicator of true isolation. The exact determination of flow isolation should be studied more carefully in a long-term evaluation of the test data."*

Table 1. Phase II gate valve test data assessment

				Force (lb)			Pressure (psig)		
Valve	Test Number	Step	Stem Position	Stem	Normal	Sliding	Up	Delta	Subcooled Fluid (°F)
2	1	25	-7.34	12929	987	-424	959.6	948.5	11.5
2	1	26	-7.38	13578	1021	-447	1002.4	980.3	16.3
2	6b	18	-7.10	10477	571	-332	887.5	540.6	95.9
2	6b	25	-7.26	12173	888	-404	856.4	851.3	36.2
2	6b	26	-7.08	12453	953	-409	922.4	915.8	36.0
2	6b1	26	-7.22	13654	1031	-451	990.6	989.6	48.4
2	6a	18	-7.54	7880	413	-254	601.7	389.7	91.9
2	6a	25	-7.37	7859	550	-260	525.5	526.5	18.8
2	6a	26	-7.14	7703	548	-254	524.7	524.5	10.9
2	6a1	25	-7.07	8688	609	-288	585.7	582.8	42.5
2	6a1	26	-7.35	8866	633	-294	603.1	606.7	39.0
2	6c	13	-7.13	15626	952	-490	1414.6	907.9	124.4
2	6c	18	-7.08	15046	970	-464	1431.2	927.8	115.4
2	6c	25	-7.29	15798	1315	-510	1276.3	1268.3	47.0
2	6c	26	-7.39	16452	1359	-533	1317.7	1310.8	39.7
2	2	18	-7.46	16083	1234	-528	1215.7	1186.4	9.5
2	2	25	-7.06	13096	1091	-422	1056.1	1052.5	9.0
2	2	26	-7.12	13079	1063	-424	1027.6	1024.3	8.4
2	3	25	-7.10	12751	793	-438	746.4	753.2	371.7
2	3	26	-7.27	14512	936	-496	886.7	890.8	388.6
3	1	25	-7.13	4355	247	-113	1012.0	237.0	17.2
3	1	26	-7.30	8628	887	-298	856.1	861.0	5.9
3	1a	25	-7.17	10804	942	-386	915.1	909.1	7.5
3	1a	26	-7.33	11032	928	-396	894.4	893.8	7.1
3	5	25	-7.18	12235	1144	-435	1117.4	1106.8	7.3
3	5	26	-7.23	13281	1177	-477	1140.4	1136.2	11.0
5	1	25	-7.47	24756	904	-336	879.9	876.8	9.6
5	1	26	-7.28	22547	835	-304	813.0	810.9	6.9
5	1a	25	-7.21	30474	1055	-421	1026.3	1021.3	5.6
5	1a	26	-7.33	29045	1013	-400	985.7	981.2	7.7

Flow isolation is the most meaningful stem position at which to assess the response of a predictable valve as it closes. At flow isolation, the disc is riding fully on the valve body seats, and the upstream pressure, the bonnet pressure, and the under the disc pressures should equalize since there is no flow through the valve. The differential pressure should be close to its maximum, depending on how fast the downstream pressure decays, and the disc area term is still at its maximum. For a predictable valve, this is also the point where the stem force is the highest prior to wedging. We agree with the EPRI report that flow isolation is a position at which the performance of the valve should be assessed.

The EPRI report interprets flow isolation during a closure stroke as "*the point when downstream static pressure fell to zero.*" For opening strokes, "*isolation was identified as the point when downstream pressure increased above zero.*" The discussion recognizes the coarseness of this measurement and suggests that the "*dynamic pressure . . . may be a more sensitive indicator of true isolation.*" This definition of flow isolation, based on either a static or a dynamic downstream pressure, can be misleading. The downstream pressure is based on a number of phenomena and may not always be indicative of disc position. Phenomena which may adversely affect using the downstream pressure to identify disc position include leakage through the valve, the pressure and temperature of both the upstream and the downstream fluid, the net expansion of the fluid in the downstream piping, the resistance to flow in the downstream piping, and the ability of the instrumentation to detect small changes in pressure levels.

The flow isolation assessment performed by the INEL recognized these limitations and included a study to relate the position of the disc or stem to the valve body seats to more accurately identify true flow isolation. From this study, we realized that true flow isolation coincides with a very pronounced region in the stem force trace of a predictable valve. True flow isolation can also be observed in some of the pressure instrumentation, such as a convergence of the upstream, the bonnet, and the under the disc pressures or in the downstream dynamic pressure, provided the valve does not leak excessively. Note, however, that the usefulness of the pressure readings is limited by the sensitivity of the instrumentation.

By way of example, Figures 16 through 18 show the stem force, the upstream, bonnet, and under-the-disc pressure, and the downstream dynamic pressure histories for Valve 2 Test 1 Step 25. Also shown on each of these figures is the point identified as flow isolation as shown on Table 6-1 of the EPRI report and the point used by the INEL to assess the response of the valve.

What we observe is that at that point identified as flow isolation in the EPRI report, the upstream pressure is higher than either the bonnet or the under-the-disc pressure. This difference in the pressures indicates flow through the valve; the valve has not yet isolated the flow. Conversely, the point identified as flow isolation by the INEL is past the point where the pressures converge, reflecting a region on the stem force history where the stem force levels off just before wedging. After the pressures converge, the downstream dynamic pressure continues to decay and finally stabilize, as shown in Figure 18. The point identified in the EPRI report as flow isolation occurs before the downstream dynamic pressure falls to zero.

While it is true that downstream dynamic pressure is a better indication of flow isolation than downstream static pressure, we have found the plateau on the stem force trace (Figure 16) to be the best indicator of flow isolation, as confirmed by the convergence of the three valve pressures and by the decay of the downstream dynamic pressure. For predictable valves, this plateau represents the maximum force before wedging. The point identified in the EPRI report as flow isolation typically lies before this plateau rather than on it, thus yielding too low a value for the stem force necessary to achieve true flow isolation.

Most of the apparent disc factors presented in the EPRI report for flow isolation are too low, primarily because they are based on stem force values measured before isolation, when the disc was still riding on the guides. This issue is discussed in more detail in Section 3.4.2.

(3) "At wedging, as identified from the stem force plots. For closing strokes, wedging was identified as the instant just prior to the essentially vertical section of the stem force plot which corresponds to a rapid increase in stem force. For opening strokes,

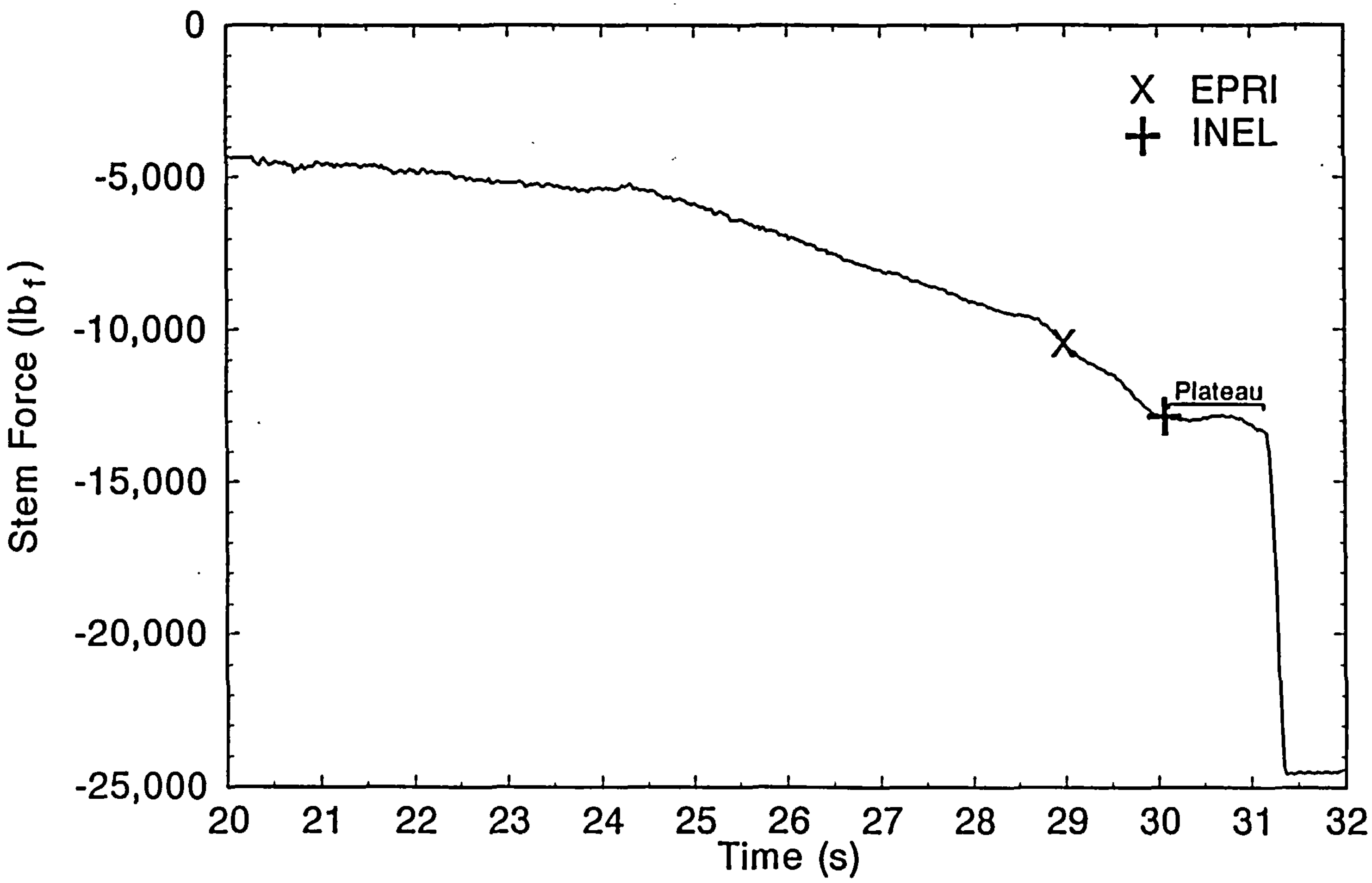


Figure 16. Stem force for Valve 2 during Step 25 of Test 1.

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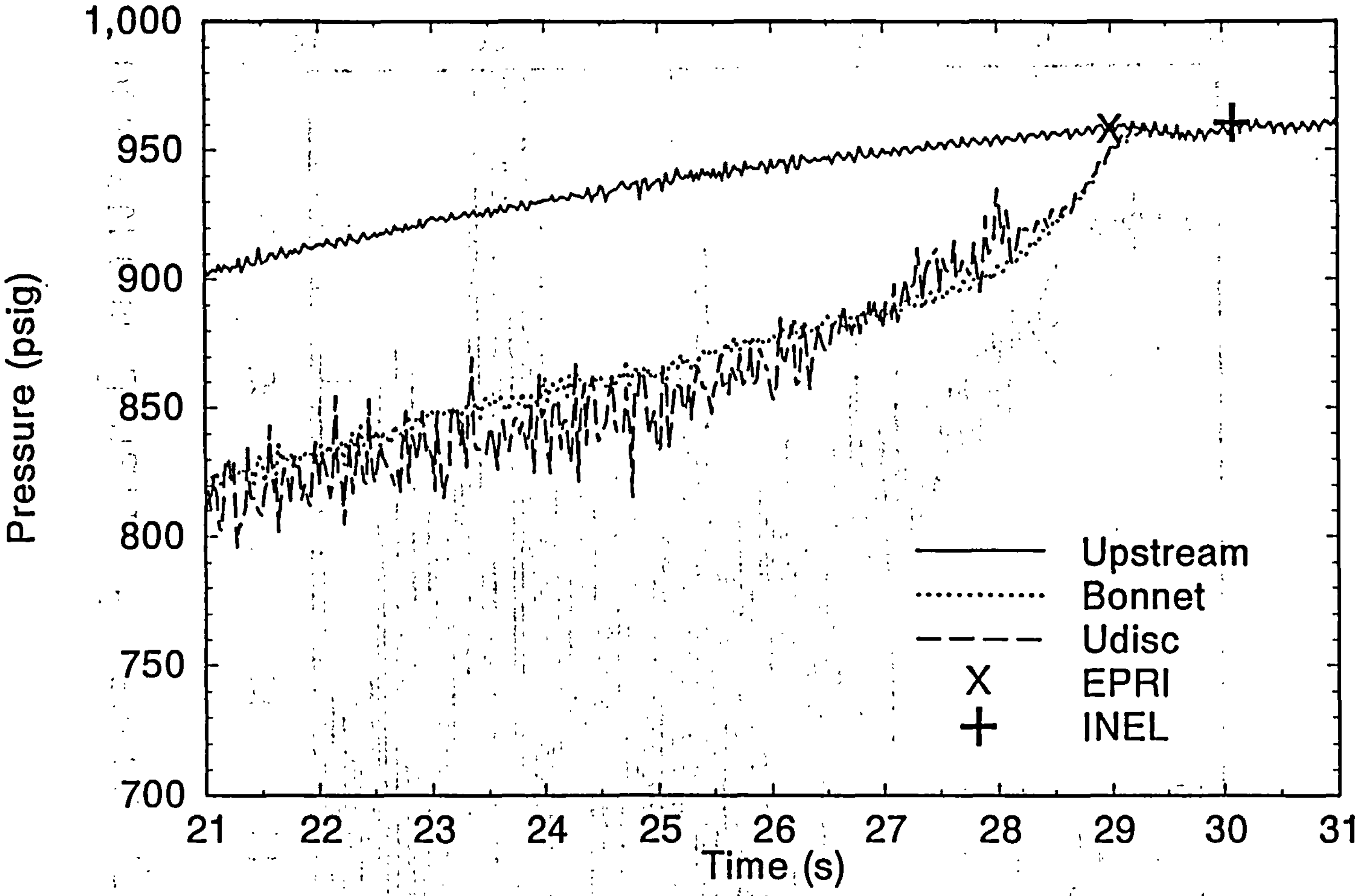

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Figure 17. Selected upstream pressures for Valve 2 during Step 25 of Test 1.

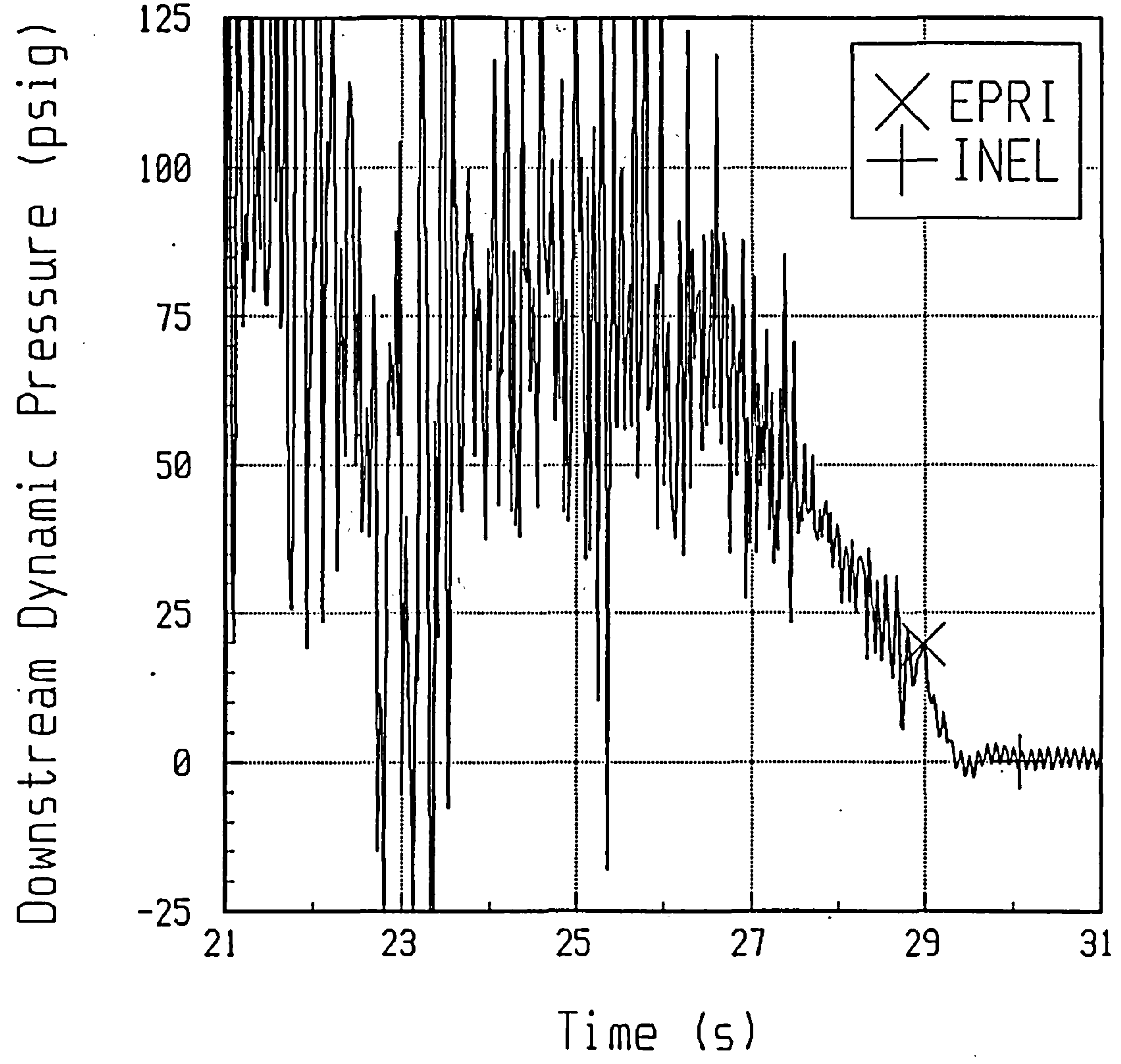

Figure 18. Downstream dynamic pressure for Valve 2 during Step 25 of Test 1.

> *wedging was identified by the plateau immediately after the initial "cracking" peak on the stem force plot."*

The EPRI report has defined the wedging position in the closing direction as *"the instant just prior to the essentially vertical section of the stem force plot which corresponds to a rapid increase in stem force."* Using such a definition to assess the stem force requirements of a gate valve should ensure that true flow isolation has occurred for a predictable valve. As such, this is an appropriate point in the valve closure stroke at which to assess valve performance.

However, as shown in Figure 6-4 and Table 6-1 of the EPRI report, the apparent disc factor for Valve 2 during Step 25 of Test 6B was calculated with a stem force (13,000 lb_f) that was <u>on</u> the *"essentially vertical section of the stem force plot,"* not just prior to it. While using a stem force on the vertical section will yield a higher (and thus a more conservative) apparent disc factor, we are more concerned with the care used in assessing the INEL test results. We have not determined whether this type of error occurred for any of the other wedging positions assessed in Table 6-1 of the EPRI report.

> *(4) "At maximum stem force (excluding cracking peak) regardless of disk position. This value is the highest stem force during the stroke. On some stem force plots, this coincided with one of the three points mentioned above. On others, there was a maximum stem force which occurred at a time other than isolation, wedging, or zero stem position indication."*

This point is applicable for assessment of predictable valves in the closing direction, assuming that the stem force just prior to wedging is used. For predictable valves, experience shows that the maximum stem force just prior to wedging occurs when the disc is riding fully on the seats, after true flow isolation has occurred. However, the analyst must use care to ensure that the results from nonpredictable valves do not bias the results. Information at the point the stem force maximizes is also useful in assessing the response of a valve opening against a flow load.

Conclusion: The valve positions specified by the EPRI report for evaluating the INEL test data are either incorrectly applied or else do not consistently provide useful information. For the closing direction, the stem force levels off shortly after'the disc begins riding on the seats and flow has been isolated. For predictable valves, this plateau is where the maximum load prior to wedging occurs. The sliding friction (INEL correlation or the EPRI-NMAC equation) or the disc factor (industry equation) used to size a valve must be based on a correct identification of this point and on the resulting loads. Other analyses may be interesting, but are not always useful.

3.4.2 Apparent Disc Factor. According to the EPRI report, the EPRI effort included *"a detailed review of the test data, using primarily published data plots, focusing on determination of the "apparent disk factor" implied by the data for all valve strokes performed with differential pressure and relating these results to the conditions tested and valve internal damage sustained."*

The EPRI review included calculation of apparent disc factors and presented the results as follows: *"Apparent disk factors (disk factor implied by measured DP and thrust using standard industry equation) required to achieve flow isolation on the first blowdown closure stroke of each test valve are shown below."*

Summary of First Blowdown Isolation Tests

Valve	Manufacturer	Size (in)	Test No.	Fluid	DP at Isolation (psi)	Apparent Disk Factor for Flow Isolation	Applicability to Similar Industry Valves*
A	Anchor/Darling	6	A-3-5	Nitrogen	510	0.63	Potentially Applicable
B	Velan	6	B-2-5	Hot Water	1000	0.35	Applicable
1	Anchor/Darling	6	1-1-25	Hot Water	870	Valve N/A (0.86)	Not Applicable
2	Velan	6	2-1-25	Hot Water	940	0.33	Applicable
3	Walworth	6	3-1-25	Hot Water	870	0.19	Applicable
4	Anchor/Darling	10	4-1-25	Steam	700	0.49	Applicable
5	Powell	10	5-1-25	Steam	880	0.44	Applicable
6	Velan	10	6-1-25	Steam	1000	0.42	Potentially Applicable

* *Indicates applicability of test result (apparent disk factor) to valves in systems requiring blowdown isolation. Test is considered applicable if both valve design details and test conditions are representative of some industry valves.*

The EPRI report also states that *"these data are considered potentially applicable only to similar valves installed in the BWR systems under study or other similar valves having as a design basis function the isolation of blowdown flows under the range of conditions tested."*

The apparent disc factors at flow isolation, as listed in the EPRI table shown above, are based on Table 6-1 of the EPRI report. Enough information is presented in Table 6-1 determine how these apparent disc factors were derived. Columns three, four, and eight of Table 6-1 contain generic valve information, whereas columns five, nine, and eleven contain test-specific information necessary to calculate the apparent disc factor at flow isolation, as listed in column thirteen of the table.

The INEL reassessed each test using the apparent disc factor equation presented in Section 5 of the EPRI report and recalculated the apparent disc factor using the INEL identification of the stem force necessary to isolate flow in each test (as explained in Section 3.4.1), the corresponding pressure and differential pressure at the time of flow isolation, and the packing drag measured during the test series. The results of these recalculations, and the data used, are presented in Table 2. As can be seen, there is a considerable difference between the apparent disc factors presented in the EPRI report and the apparent disc factors calculated by the INEL. Most of the EPRI report disc factors are significantly lower than the INEL disc factors.

Most of the difference is caused by the fact that the values for stem force used in the EPRI report analysis are too low; the EPRI report analysis does not correctly identify the point of true flow isolation. This issue is discussed at length in Section 3.4.1. The remaining difference is the result of revised estimates of the upstream pressure and the differential pressure at flow isolation. None of the difference is a product of the use of a smaller disc area term: in our reassessment of the EPRI calculations, we used the same disc area term that the EPRI calculation used, that is, the mean seat area, not the orifice area.

Based on the results of Table 6-1, the EPRI report states that the *"Disk/seat friction coefficients may be slightly higher than typically assumed values of 0.3. A value of 0.4 appears sufficient to cover friction phenomena based on the NRC/INEL tests."* Based on the recalculated results shown in Table 2, the disc factor typically exceeds 0.4, and recommendations to use a disc factor of 0.4 are not warranted.

A more fundamental concern, however, is the fact that the EPRI analysis uses the standard industry equation in its assessment of valve performance. In our early analyses of the NRC/INEL test results, we, too, tried to use the standard industry equation, and we found it inadequate.

We were initially puzzled by the scatter in the disc factor data produced in our early analyses of the NRC/INEL data. It became obvious that the range of

Table 2. Reassessment of the design basis tests

	Isolation Stem Force		Apparent Disc Factor		
Test Number	EPRI Tbl. 6-1	Actual Isolation	EPRI Tbl. 6-1	Actual Isolation	Notes
A-3-5	9000	5347	0.63	0.36	Nonpredictable
1-2-25	19500	22900	0.86	1.05	Nonpredictable[1]
B-2-5	12500	13833	0.35	0.43	
2-1-25	10400	12929	0.33	0.45	
2-2-25	9000	13096	0.23	0.40	
2-3-25	5200	12751	0.15	0.59	
2-6A-25	5300	7859	0.29	0.50	
2-6A1-25	6000	8688	0.29	0.50	
2-6B-25	8800	12173	0.31	0.48	
2-6B1-25	9200	13700	0.29	0.48	
2-6C-25	12200	15798	0.28	0.40	
3-1-25	5900	4355	0.19	0.48	
3-1A-25	7000	10804	0.23	0.43	
3-5-25	9100	12235	0.26	0.40	
4-1-25	23800	16100	0.49	0.30	Nonpredictable
5-1-25	28000	24756	0.44	0.39	Nonpredictable
5-1A-25	26500	30474	0.34	0.42	
6-1-25	28000	28200	0.42	0.41	Nonpredictable
6-1A-25	32000	29366	0.40	0.35	Nonpredictable
6-1B-25	19000	25233	0.26	0.36	Nonpredictable

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[1] Valve failed to close during the test.

the disc factor (from 0.40 to 0.59 for Valve 2, for example) was greater than could be reasonably attributed to random scatter. Our effort to discover a pattern to the scatter produced the results shown in Figures 19 and 20.

Figure 19 shows disc factor data for Valve 2 closing against four different fluid conditions, steam to cold water. In this particular figure, we used the valve orifice area for the disc area term as it represents the least conservative use of this term by the industry. For predictable valves, the plateau between isolation and wedging represents the highest stem force in the closing stroke prior to wedging. We selected the mid point of the plateau as being indicative of the stem force required to isolate flow through a valve. Figure 19 clearly shows that the disc factor varies with the degree of subcooling, with steam conditions producing the lowest disc factor and cold water producing the highest.

Figure 20 shows disc factor data for Valve 2 closing against three different pressures with the same degree of subcooling. A pattern in the data scatter is evident. Surprisingly, the disc factor is higher with lower pressures, and lower with higher pressures.

These results were unexpected, and the subsequent analysis performed by the INEL, as described in more detail in Appendix C, defined the force balance on the disc and a new correlation for assessing valve performance. During the development of the correlation, we discovered that the standard industry equation does not account for the pressure effects and fluid condition effects described above, and does not account for valve design characteristics that are acted upon by the differential pressure. One of these effects is the result of the angle of the downstream seat, which lies approximately 5 degrees from vertical. Appendix C presents a complete discussion of these effects.

Thus, what came out of the work was a realization that the standard industry equation is incomplete. Pressure effects and fluid subcooling effects are not accounted for, and some of the internal forces acting on the disc are missing, in effect causing these missing forces to be accounted for in the one component of the equation that is not specifically tied to a real quantity, the disc factor. In addition, we realized the definition of the disc area term is

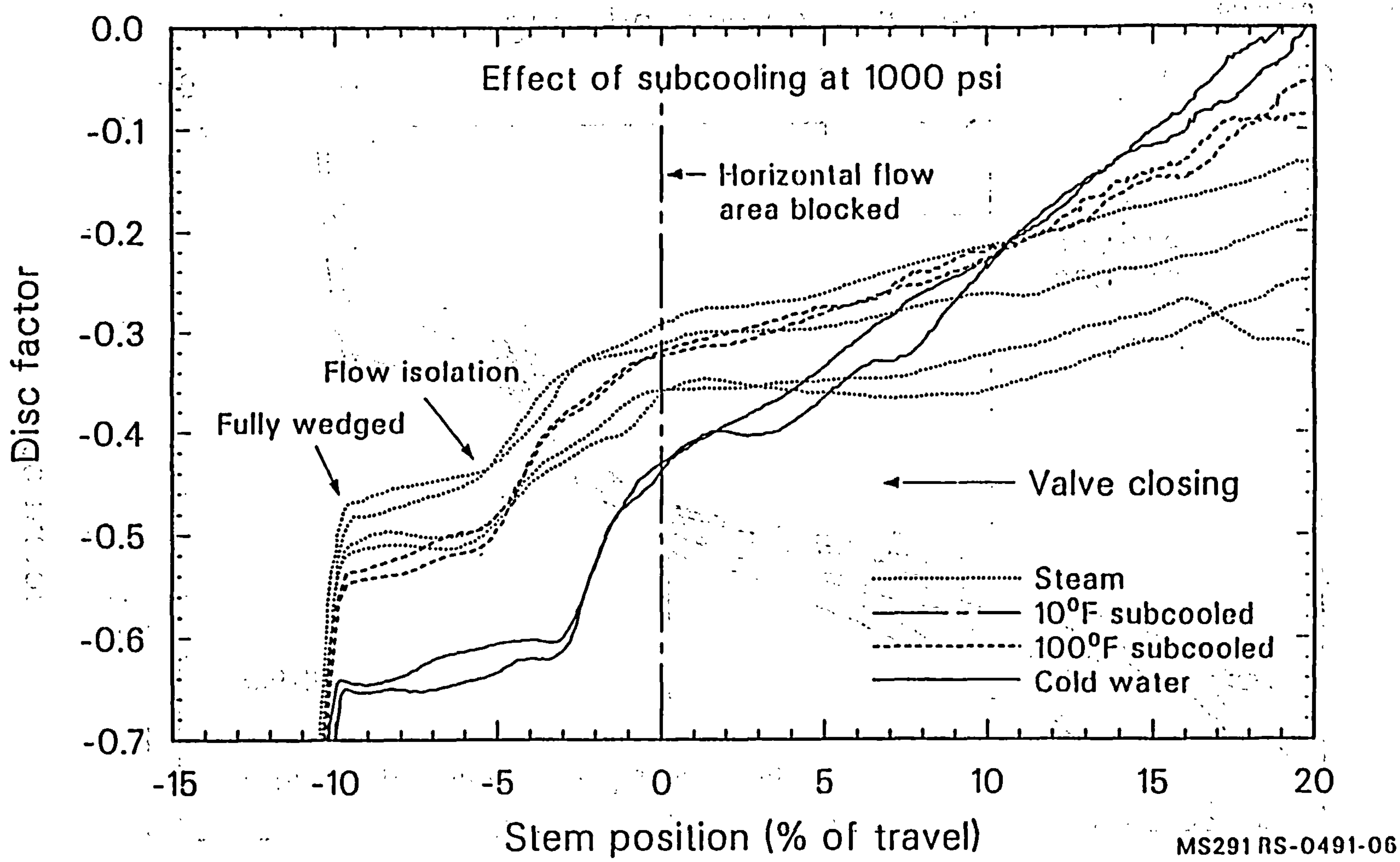

Figure 19. Disc factor for Valve 2 closing on line break flow, effect of subcooling at 1000 psig.

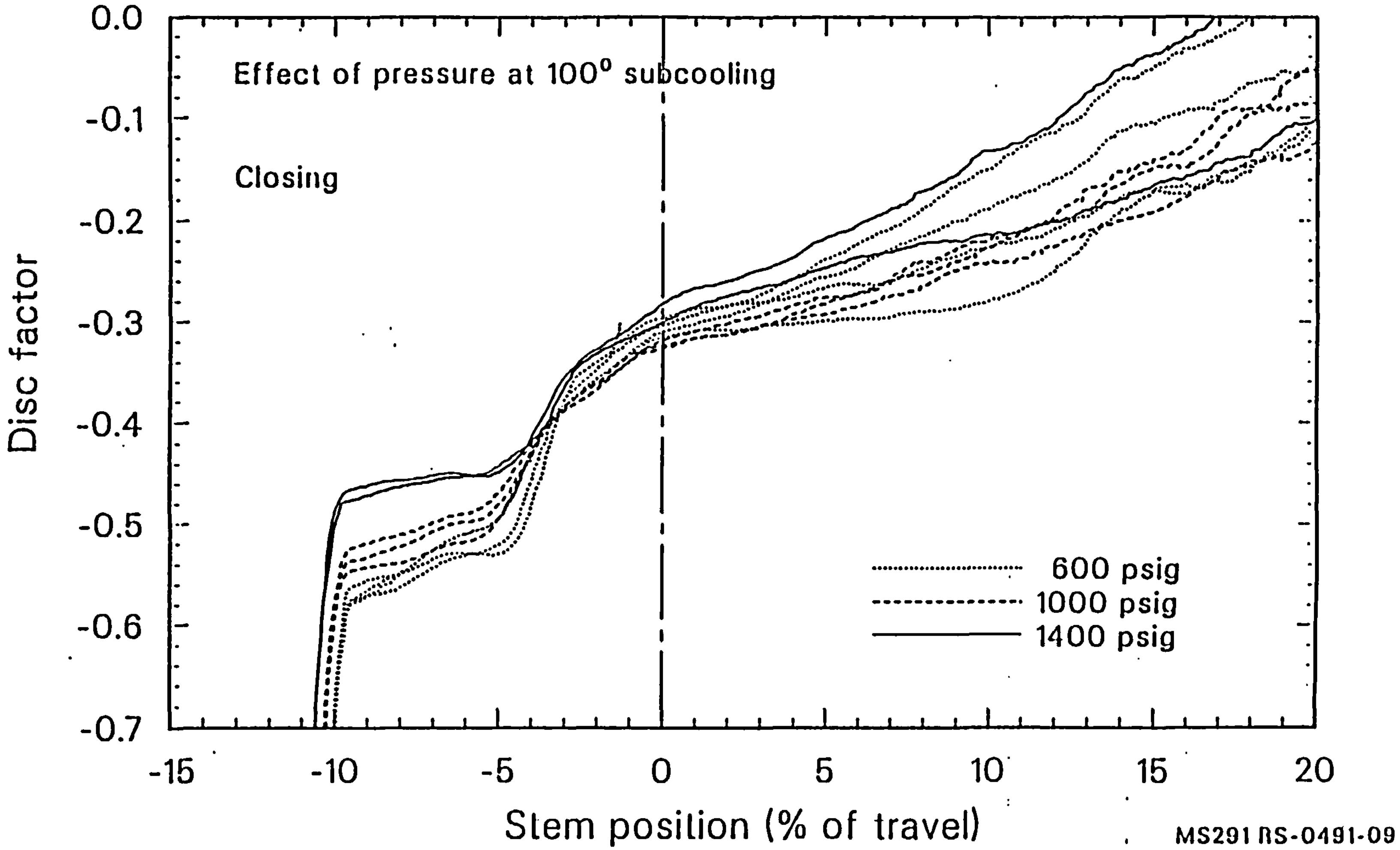

Figure 20. Disc factor for Valve 2 closing on line break flow, effect of pressure at 100°F subcooling.

not standardized; several definitions exist, making it even more difficult to develop results with wide applicability.

Using the standard industry equation, regardless of how the disc area term is defined, and solving for the disc factor will not result in a value for the sliding friction. The result is a disc factor that puts all of the terms missing in the standard industry equation, including sliding friction, into a multiplier. Assessing the NRC/INEL test results with the EPRI-NMAC equation would have provided results much closer to the results shown in Appendix C.

Conclusion: The disc factors derived by the EPRI report analyses are typically too low, mostly because the analysis incorrectly identified the point of flow isolation and consequently used too low a value for the stem force. The suggestion in the EPRI report that the industry use a disc factor of 0.4 in the standard industry equation cannot be supported irrespective of the disc area term used. The INEL is also concerned that the standard industry equation is incomplete. As such, we believe that the INEL correlation or like methodology should be used to estimate the maximum stem force requirements of a flexwedge gate valve whose operational characteristics are considered to be predictable at the valve's design basis pressure and temperature. We consider the INEL correlation to be a significant improvement over the standard industry equation and its use of a disc factor to account for margins and missing variables.

3.4.3 Average Disc Factor. The EPRI effort calculated the apparent disc factor for a number of the Phase I and Phase II closure strokes where the disc sliding on the seat <u>appeared</u> to be the dominant load phenomenon (rather than machining or shaping of surfaces). These are presented in Table 6-1 of the EPRI report, along with a summary of selected parameters during each test. EPRI describes its evaluation as follows: *"Based on evaluating all of the blowdown closure and opening strokes in this manner, average apparent disk factors due to sliding friction for each valve were determined. Table 6-3 summarizes the average disk factors for blowdown conditions when sliding of the disk on the seat is occurring. As shown in this table, the values are between 0.28 and 0.41 for* *closing strokes, and are between 0.25 and 0.40 for opening strokes, with the exception of Valve 2 at 0.47. If data for wedging of Valve 2 are considered, the average apparent disk factor is as high as 0.52; however, as mentioned previously, it appears additional surfaces were coming into play during wedging and the apparent disk factor does not necessarily represent true friction".*

We have not performed a detailed review of this table. As discussed in Section 3.4.2, the methodology used to determine the apparent disc factor is inadequate, and the analyses used a point incorrectly assumed to be flow isolation (see Section 3.4.1). Note also that the high disc factors for Valve 2 listed in Table 6-1 are from 100°F subcooled tests. As explained in Appendix C, subcooling greater than about 70°F can cause the disc factor to be high in analyses using the standard industry equation. Some of the high apparent disc factors for Valve 2 are more likely a product of fluid conditions effects than of additional surfaces coming into play.

We do not recommend the use of the standard industry equation either for operator sizing or for analysis of test data. However, if the standard equation is used, an average disc factor is less likely than a maximum disc factor to lead the analyst to a result that conservatively bounds the stem force requirements of a valve. The INEL assessment of the data from the closing tests, as presented in Appendix C, was not possible until we investigated all of the forces acting on the disc just prior to wedging. Rather than averaging the disc factor, we suggest that a follow-on analyses include:

(1) separately assess the opening and closing tests,

(2) use an equation that considers the effects of pressure and differential pressure on all components of the valve design and determine true sliding friction, not a disc factor,

(3) use only those test conditions representative of the disc actually sliding on the seats, and

(4) include the effects of fluid subcooling and fluid pressure.

Conclusion: Using the standard industry equation and averaging the resultant disc factors will continue to yield inconclusive results. Without a more rigorous assessment of the data, it is not possible to quantify phenomena that affect the ability of the disc to slide on the valve body seats.

3.4.4 Linear Contact Stress Model. In an effort to correlate the observed response of the valves tested, the EPRI report introduces a linear contact stress model and attempts to evaluate valve application severity and the effect it has on the apparent disc factor. The model plots the apparent disc factor for each valve tested against the linear contact stress. The EPRI report presents a series of eight figures, Figures 6-28 through 6-35, one for each valve tested in Phase I and Phase II. Each figure contains the results of both opening and closing strokes and testing using both blowdown and normal flow conditions. Based on this study, EPRI concludes that *"there appears to be no clear correlation of strokes overall or for a particular subset of strokes. It appears that linear stress, by itself, is not necessarily an adequate valve severity evaluation parameter for separating valves into "lightly loaded" and "heavily loaded" classes."*

The INEL assessment of the closing tests, as presented in Appendix C, concluded that a load dependent response does exist. This response was observed for both the Phase I and the Phase II closure testing. We suspect that the EPRI effort did not demonstrate a load dependent response because

(1) It used the standard industry equation (with a disc area based on the mean seat diameter), which does not accurately identify all the forces acting on the valve disc just prior to wedging and is thus incomplete; the EPRI-NMAC equation would have provided better results.

(2) Fluid subcooling and differential pressure phenomena are embedded in the results and cannot adequately be identified by solving for an apparent disc factor term only.

(3) For one of the valves, the EPRI effort uses a disc factor based on dimensions from the manufacturer's drawings for part of the assessment and a disc factor based on as-measured dimensions for another part, thereby obscuring any embedded trends.

(4) The EPRI report uses a linear stress correlation that is either not complete and not structured properly (currently based on the nominal valve diameter) to reveal the trends being sought.

(5) The apparent disc factor used for this study mixes isolation, wedging, and the maximum disc factor. The true trends available from the data may be obscured, since not all the values are based on true disc to seat sliding friction.

(6) Both opening and closing tests were assessed together. We have not assessed the results of the opening tests as yet, but the test results indicate that other phenomena are involved during opening and as such, combining opening and closing tests may not be appropriate.

Conclusion: The linear stress model used by EPRI does not provide the desired result. We believe the INEL methodology is more rigorous in assessing valve closing loads; this methodology does demonstrate a load and fluid phenomena dependency. The suggestions offered here might be useful to EPRI analysts in their effort to obtain useful results, both in understanding the NRC/INEL data and in evaluating the EPRI MOV Performance Prediction Program. It should also be noted that we are addressing only predictable valves; to date, nonpredictable valve performance has not been quantified by either the INEL or by EPRI.

3.4.5 Valve Anomalous Behavior During Closure. The EPRI report assesses the appearance of wear and damage to each valve tested by the INEL to determine whether the damage was responsible for any anomalous performance during the blowdown tests, and thus, whether the testing from that valve should be used to assess valve response in general. Identifiable wear and damage to the disc seat, body seats, disc guide, and body guides of each valve for the Phase II and to the Valve B disc from Phase I testing are described in Table 6-2 of the EPRI report, along with an assessment of whether the conditions noted could have caused anomalous behavior. Generally, they conclude that damage to the disc guide, the body guides, the disc seat, and the body seats directly affects whether a valve is considered to be predicable or nonpredictable. Such nonpredictable behavior can result in high stem forces and high apparent disc factors.

The EPRI report expresses concern that *"the inspection was carried out at the conclusion of the test program after numerous strokes had been performed on each valve. Because there were no inspections during the test sequence, it is not possible to precisely reconstruct the damage scenarios."* The apparent concern, among other things, is that we have used the test results of damaged valves and thereby biased the resultant disc factors. It was not our intent, during the INEL testing, to visually inspect the internals of each valve following each blowdown test. It was our intent to use our sensitive stem force measurement to provide insight to valve damage during the tests. We used this method to assess valve damage, and subsequent posttest inspections confirmed the relationship between an unusual stem force response and valve damage. Based on the posttest inspections and the stem force traces, we have made an assessment of each valve and any limitations in the resultant test data, as noted below.

The EPRI inspection team did not inspect the Phase I valves, as both had been refurbished for the Phase II testing. They were able to inspect the Valve B disc as it had been replaced prior to the Phase II testing. A complete inspection of the Phase I valves was performed by the INEL along with official record photographs of each valve's condition. The posttest inspection results of Valves A and B are the INEL's alone.

Valve A - This valve performed unpredictably during mid stroke, evidenced by damage to the disc and valve body guides. However, once the disc began riding on the valve body seats, the valve responded in a predictable manner (see Figure 21). We used selected Valve A test results in the development of the INEL correlation.

Valve B - This valve performed predictably during the Phase I testing, just as it did during the Phase II testing, even though a different disc was installed in the valve. The Phase I disc had hardfaced disc guides representative of later Velan valves. The Phase II disc had nonhardfaced guides representative of earlier Velan valves. There was no abnormal wear on Valve B. All Valve B results, except the 1400 psi parametric test which did not completely close, were used in the INEL correlation. The valve failed to seat during the 1400 psi test, not because of damage to the valve, but because the torque switch was not set high enough, even though it was set higher than what the manufacturer recommended. We observed that the motor operator suffered from what the industry has termed the rate of loading effect. This effect is one of the subjects of our 1991 research update to be published later this year.

Valve 1 - This valve was badly damaged and did not completely close during the initial design basis blowdown test sequence. No additional blowdown test sequences were performed with this valve. We did not use the results from this valve in developing the INEL correlation.

Valve 2 - This valve was cycled a number of times under blowdown conditions. As a result, more indications of disc to guide and seat wear were evident. However, there were no indications of abnormal or detrimental wear.

EPRI has identified disc to valve body wear due to rotation of the disc as one possible abnormality with this valve. This valve sustained by far the largest number of cycles under load. In light of the large number of valve cycles, we believe that the identified markings reflect normal wear for the test conditions the valve was subjected to.

The appearance of such wear on a valve is not surprising. None of the valves have any mechanism to prevent the disc from rotating relative to

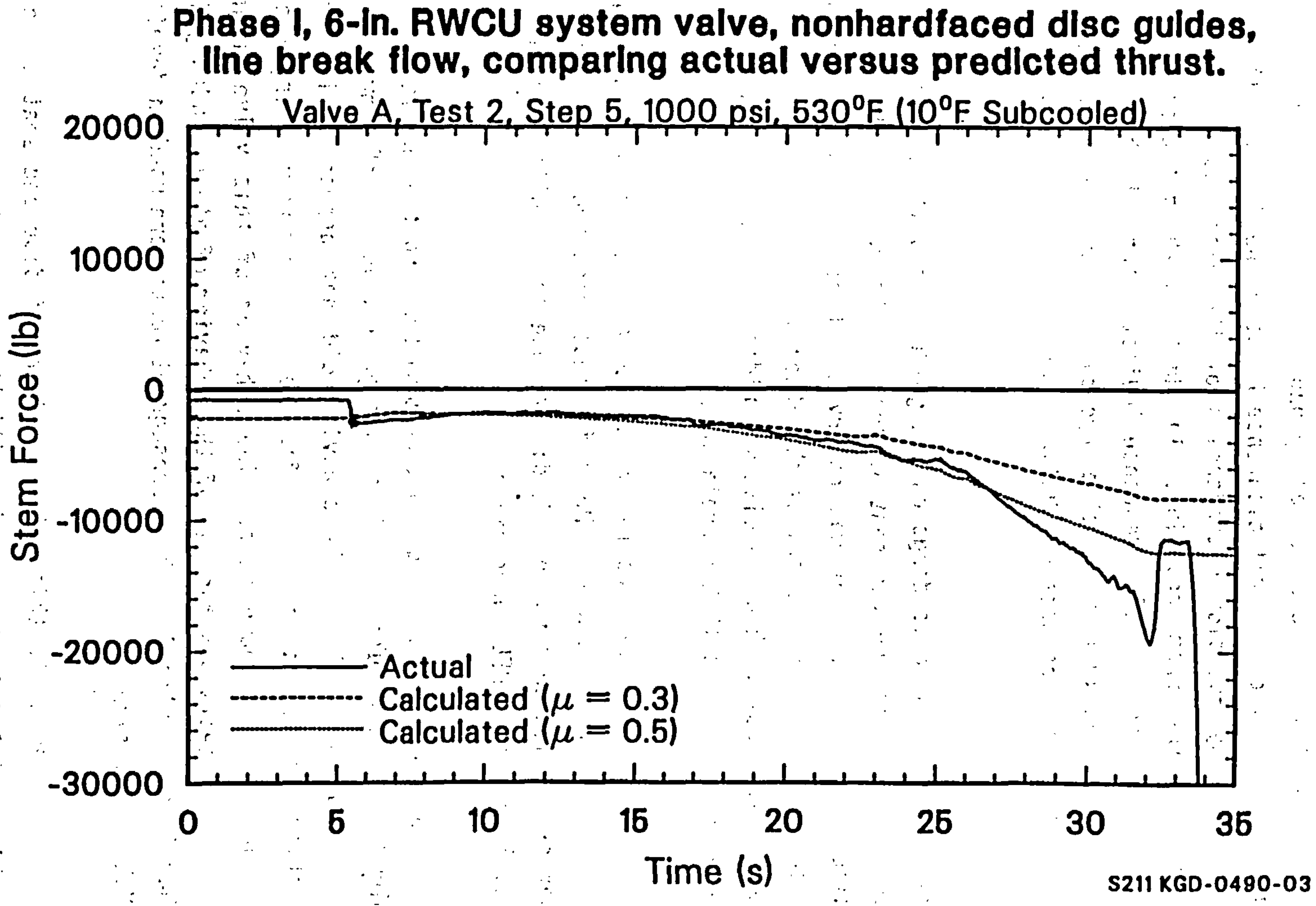

Figure 21. Stem force history of Valve A closing against 1000 psi, 10°F subcooled fluid at full flow conditions.

the pipe center line, other than resistance from the stem and by disc contact with the guides. We have no reason to suspect that any rotation of the disc in Valve 2 is more pronounced than in any other valve. In fact, the limited lateral clearance between the disc and the guide would minimize any rotational tendencies of the disc and prevent aggressive contact angles from occurring. In addition, the methodology employed by the INEL to assess valve response indicates that the behavior of Valve 2 during the testing was quite typical of the behavior of the other predictable valves tested. Valve 2 data were used in the development of the INEL correlation.

Valve 3 - The high loadings on the guide caused it to deform and allowed the disc to ride on the seat instead of the guides. As a result, more disc and body seat wear was observed. Otherwise, the valve responded predictably and was typical of the other predictable valves tested. Data from these tests, when the disc was riding on the seats, were used in the development of the INEL correlation.

Valve 4 - This valve was badly damaged during the initial design basis blowdown test sequence. No additional blowdown test sequences were performed with this valve. We did not use the results from this valve in developing the INEL correlation.

Valve 5 - The high loadings that occurred during the initial design basis blowdown test resulted in disc tippage and an interference between the disc and the seat. This behavior did not appear during subsequent testing, as the material interface had been removed during the initial design basis blowdown test. The behavior of this valve during those subsequent tests was typical of the behavior of other, undamaged valves. Therefore, results from those subsequent tests were used in developing the INEL correlation.

Valve 6 - Damage to this valve consisted of disc and seat damage, guide damage, and a bent guide. We initially attempted to use the results of design basis testing measured when the disc first started to ride on the seats, hoping to avoid the results of abnormal interferences between the bent guide and the disc and the seats. However, upon further assessment of the response of this valve during design basis blowdown testing, we decided not to use any of the results from this valve in developing the INEL correlation.

It should also be noted that the results of the posttest inspections were such that, had additional tests been in order, we would have continued to test Valves 2 and 3, which were the undamaged or minimally damaged valves on which we performed multiple test cycles. As we stated earlier in the report, we continued testing Valves 5 and 6 knowing they were damaged. Thus, we conclude that our damage detection methodology based on careful reading of the stem force trace was successful.

Conclusion: Having assessed the wear and damage of each of the Phase I and II valves, we believe that the sensitive stem force measurement used to assess valve damage was correct for our test program. Based on the damage each of these valves sustained and their respective stem force trace, we used most of the results of Valves A, 2, and 3, selected results from Valves B and 5, and none of the results from Valves 1, 4, and 6 in developing the INEL closing stem force correlation.

3.4.6 Nitrogen Flow Through Valves. The Phase I test loop at Wyle Laboratories in Huntsville, Alabama is shown in Figure 22. The water accumulator was a 450 ft^3 tank (3,366 gal) that discharged from the bottom. The nitrogen for the gas blanket entered through the top. The EPRI report expresses concern that a number of Phase I tests included nitrogen flow and states that *"a complete transition from water to nitrogen flow appeared to occur on the first blowdown stroke of Valve A (Test 3 Step 5)."*

Our assessment of Phase I Test 3 Step 5 indicates that Valve A closed on a nitrogen/steam mixture for the last two thirds of the blowdown stroke. Figures 23 and 24 show pressure traces for this test. Figure 23 shows the

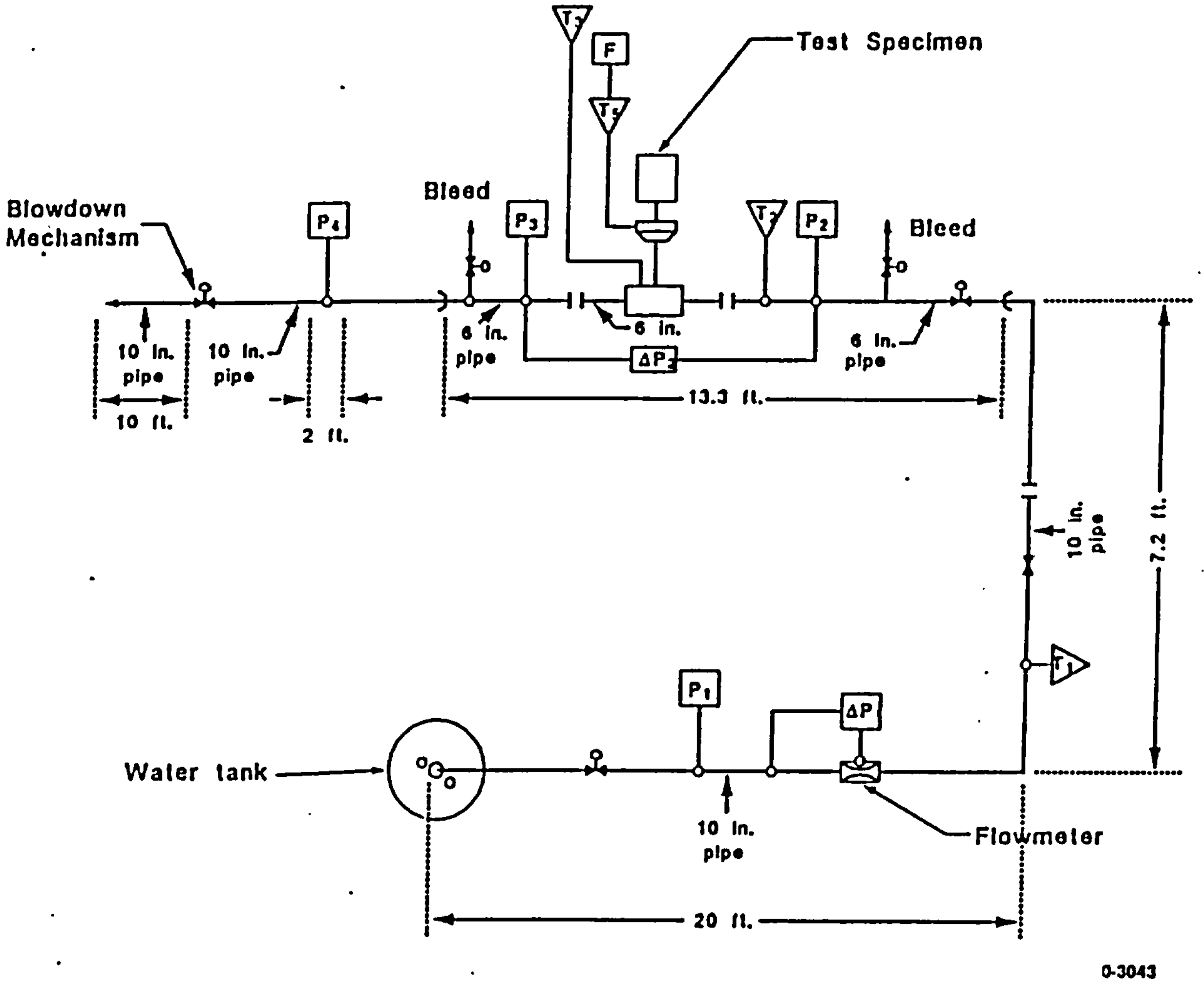

Figure 22. Schematic drawing of the Phase I test loop.

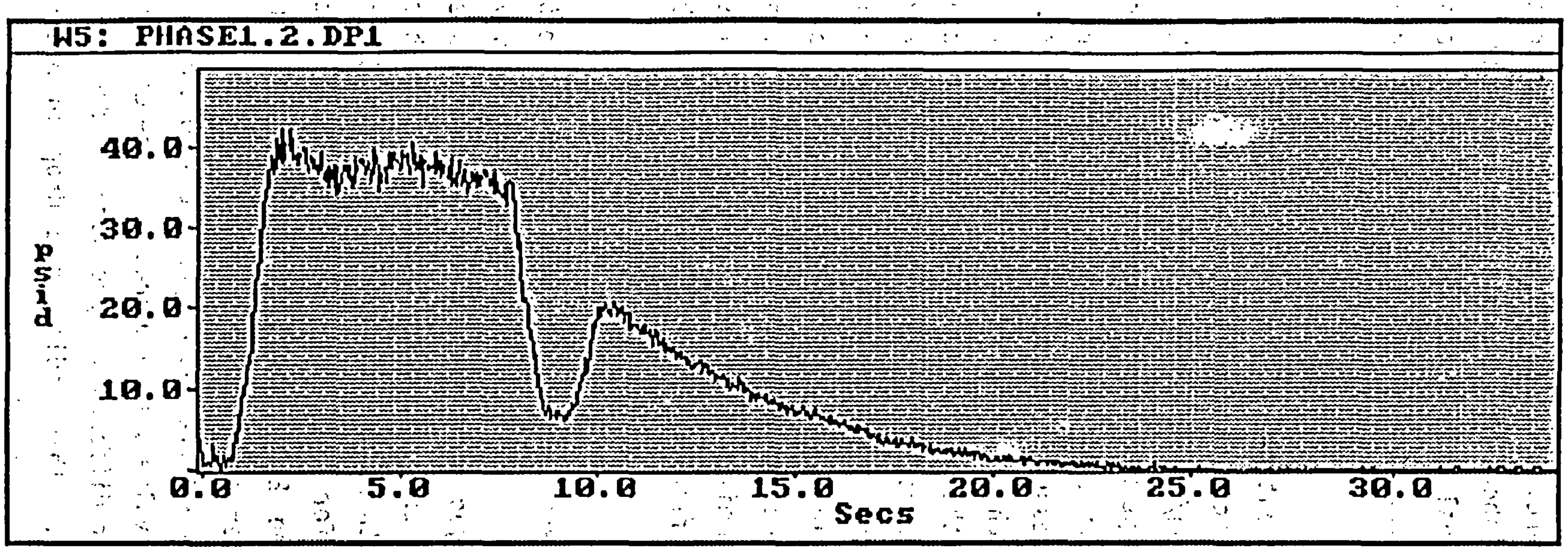

Figure 23. Flow meter differential pressure trace for Test 3 of Valve A, Phase I.

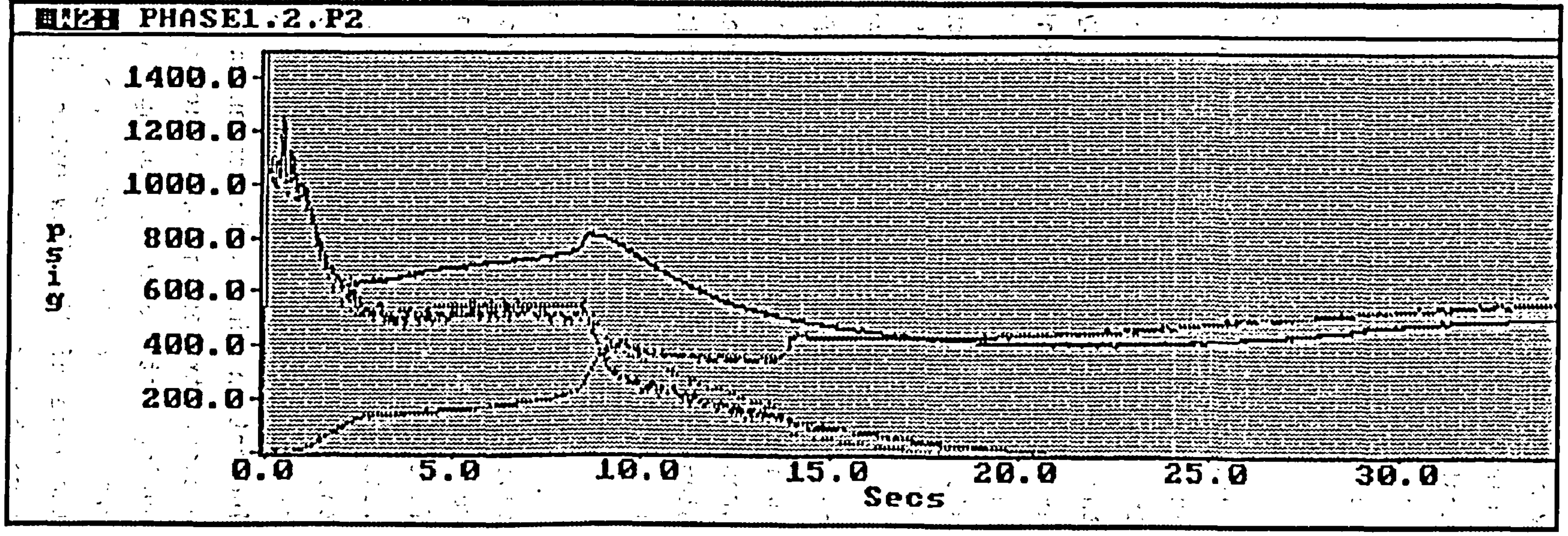

Figure 24. Pressure traces for Test 3 of Valve A, Phase I.

venturi flow meter differential pressure and, at 8 seconds, shows the disturbance pointed to in the EPRI report. Figure 24 shows that at this same time, the valve upstream static pressure increases, the valve differential pressure increases, the valve downstream static pressure decreases, and the exit pipe static pressure decreases.

The influence of nitrogen entrainment can be seen in a number of other instrument readings as well. Valve body accelerometers show dramatic increases in amplitude at the point where a nitrogen/steam mixture begins to pass through the test valve. Analysis of the video tape recordings shows a marked change in the visual shape and consistency of the exhaust, and an audible change in exitnoise can be heard. Differential pressure transducers at the venturi flow meter and test valve exhibit large changes in signal magnitude when a nitrogen/steam mixture passes; however, the flashing of the slightly subcooled water to steam and associated choke planes moving through the system can produce a similar effect. In addition, flow meter measurements were used to calculate an integrated flow for each test for comparison to the known accumulator volume. Collectively, the response of the instruments provide positive evidence that a transition from water to a nitrogen/steam mixture occurs at this point in Test 3 Step 5. In all cases where nitrogen flow was observed, all of the above indications were present.

The EPRI report identifies other tests where *"some nitrogen may have been passed through the blowdown pipe and test valve during the stroke without a complete transition from water to nitrogen occurring."* One of these tests is Test 2 for Valve A. Figures 25 and 26 show pressure traces for the Phase I Test 2 first blowdown stroke (compare with Figures 23 and 24). Figure 25 shows the flow meter differential pressure for this test and indicates a large disturbance at about 23.5 seconds. The EPRI report identifies this as an indication that nitrogen-entrained water was flowing. However, the other pressure traces, shown in Figure 26, show a different response than was observed during Test 3 Step 5. During Test 2, the valve upstream pressure, the downstream pressure, the exit pressure, and the valve differential pressure all decrease at the time of the flow meter disturbance. This indicates a drop in pressure throughout the system, consistent with water flashing to steam upstream of the

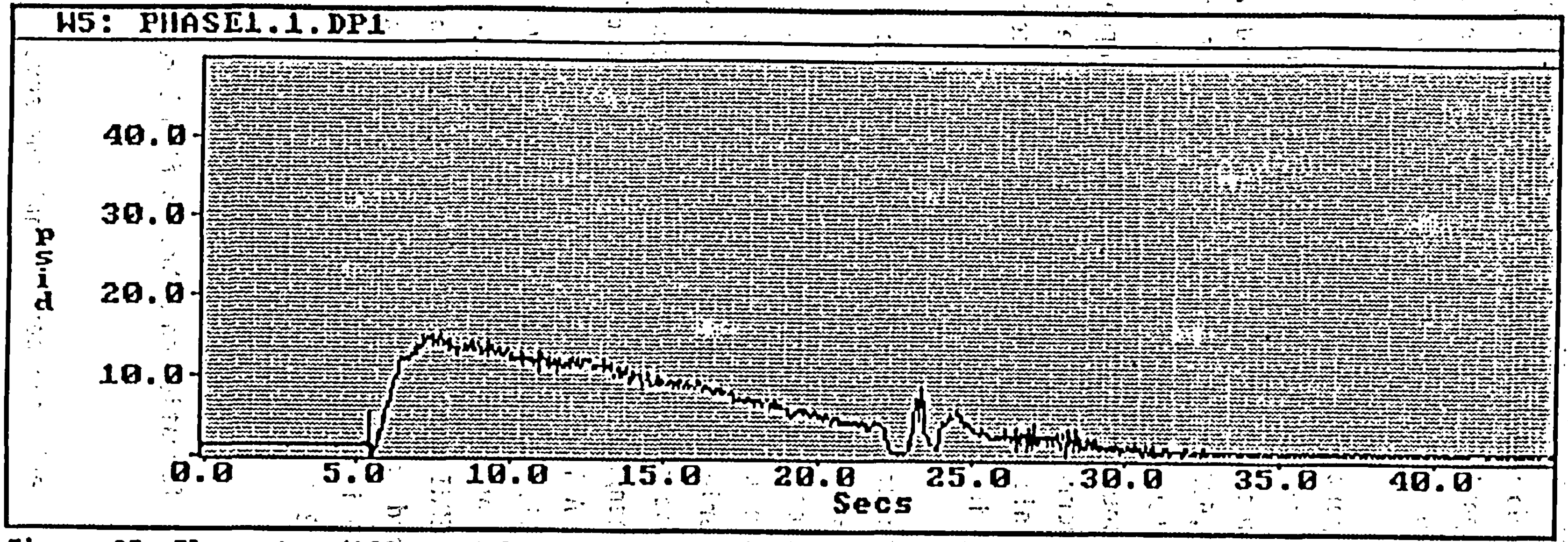

Figure 25. Flow meter differential pressure trace for Test 2 of Valve A, Phase I.

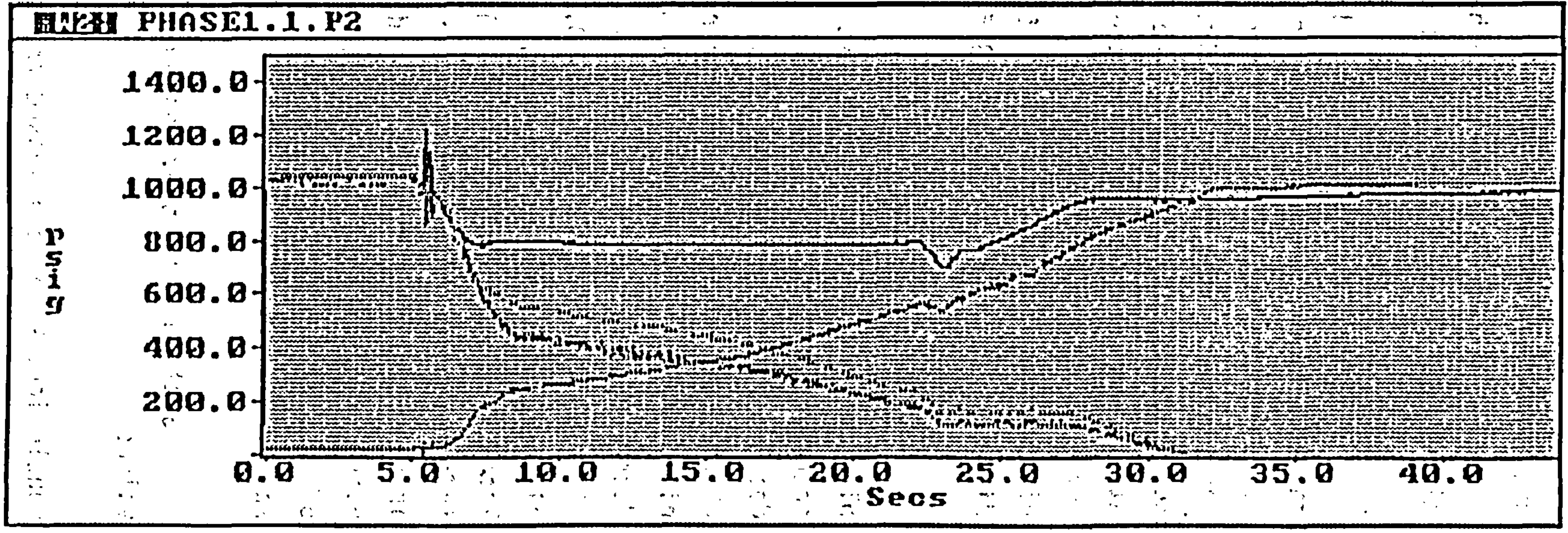

Figure 26. Pressure traces for Test 2 of Valve A, Phase I.

valve test section. The valve accelerometers do not show dramatic increases in amplitude as was observed in Test 3, nor do video tape recordings reveal the same trends. All of this taken together supports the conclusion that a water/steam mixture was present throughout the valve cycle with no nitrogen entrainment.

Fluid volume calculations also support this conclusion. During Test 2, the maximum flow (7,500 gpm) was measured at 15 psid (Figure 25), and the flow decreases somewhat linearly to zero 26 seconds later. The total consumed water inventory for Test 2 was approximately 1,625 gal, slightly less than half of the total accumulator inventory. The water level in the accumulator was over 8 feet at the end of the test. Flow rate was about 2000 gpm when the disruptionpointed out in the EPRI report occurred. This corresponds to an in-tank fluid velocity of about 0.09 ft per second. It is unlikely that nitrogen would enter the discharge with the water over 8 ft deep in the tank.

Our Phase I test plan was written to allow optional valve cycles under blowdown conditions when the test engineer determined that water remained in the accumulator after the primary blowdown closure. The primary blowdown closure was designated Step 5, and the optional stroke was identified as Step 6 (opening) and Step 7 (closing). Because of our inexperience with the Wyle test loop, we had nitrogen/steam flow during several of these valve strokes. From the analysis described above, we conclude that nitrogen/steam flow occurred in three of our Step 5 closures: Valve A Test 3, Valve A Test 6, and Valve B Test 5. We saw nitrogen/steam flow in four of our optional Step 6 and 7 strokes: Valve A Test 2, Valve A Test 7, Valve B Test 2, and Valve B Test 3. This matches the information given in Table 2-1 of the EPRI report. However, analysis of all instrumentation channels, as described above, shows that there was no nitrogen/steam flow for the tests listed in Table 2-2 of the EPRI report. All of the valve cycles listed in Table 2-2 of the EPRI report closed under water/steam flow.

Section 3.2.7 provides additional information on nitrogen flow through the valves.

Conclusion: We have assessed the Phase I tests and concur that the seven tests listed in Table 2-1 of the EPRI report included nitrogen (nitrogen entrainment in steam, not slugs of dry nitrogen). However, the eight tests listed in Table 2-2 of the EPRI report did not. Those tests had flow of water/steam mixture.

4. CONCLUSIONS

The most important question raised by the INEL testing is how to determine whether or not a valve will perform predictably. Although the EPRI report suggests that valves with different disc designs might perform differently, the INEL, EPRI Marshall, and European testing have all shown that a large number of the valves tested performed unpredictably. The threshold level where current valve designs begin to perform unpredictably needs to be determined and accounted for.

The industry's traditional stem force equation used to size motor operators is incomplete regardless of the disc area term or the disc factor used. This is because the disc factor includes other terms along with sliding friction. As such, we disagree with the suggested disc factors presented in the EPRI report and suggest that a more rigorous analysis approach be used.

The typicality of the test hardware and the test conditions, while not perfect in every case, provided representative Generic Issue 87 operating conditions for evaluating representative Generic Issue 87 valves. Although the EPRI report questions whether the test conditions were applicable to GI-87 valves, the research bounded the worst case conditions and has provided a correlation that can be used once the design basis conditions for a valve are known and the valve's predictable behavior established.

For a predictable valve, that portion of the closure stroke that occurs just after flow isolation, when the disc is riding fully on the seats, is very well defined on a stem force versus time trace and represents the maximum loading for such a valve. The sliding friction (INEL correlation or the EPRI-NMAC equation) or disc factor (industry equation) used to size a valve must be based on a correct calculation of this point. Determination of this point and the corresponding final stem force will help utilities evaluate performance margins and/or establish that the valve is representative of the valves tested by the INEL for predictable extrapolation purposes.

The NRC documents reviewed in Appendix A (Section 8) of this report have some omissions in the description of circumstances, but after two years of additional analyses, the conclusions presented in the documents are still valid.

APPENDIX A

PARAGRAPH BY PARAGRAPH REVIEW OF EPRI DRAFT REPORT NP-7065

This section of the report represents a paragraph by paragraph review of the Summary Section and Sections 1 through 8 of EPRI Draft Report NP-7065. The left hand column presents the original EPRI text as received from MPR Associates and all references to figures, tables or appendices pertain to the EPRI report. The right hand column presents the INEL evaluation of the EPRI text and all references to figures, tables or appendices pertain to this report unless otherwise stated. The applicable figures and tables follow each section (except the Section 4 material which has not been reproduced).

SUMMARY

Under NRC sponsorship, the Idaho National Engineering Laboratory (INEL) conducted a test program to assess the capability of motor-operated gate valves commonly installed in BWR HPCI, RCIC and RWCU systems to close under postulated blowdown isolation conditions. The results of the test program have been summarized by INEL[a] in test reports and presentations (References 1, 2 and 7). Based on the valve performance observed in the test program, several issues have been raised by INEL and NRC regarding potential implications to MOVs in these specific BWR systems and to nuclear power plant MOVs in general. However, utilization of the NRC/INEL data to assess these implications has been hindered by the absence of sufficient pre-and post-test hardware characterization and by a lack of detailed documentation on test facility configuration, instrumentation and measurement uncertainty.

This comment on the INEL test program is not valid. The NRC sponsored a one week, five man effort to assist EPRI in evaluating the posttest condition of the hardware. This EPRI report, criticizing the lack of posttest hardware characterization, contains the results of the NRC/EPRI evaluation. The pretest configuration was verified by the valve manufacturers; however, this information may be considered proprietary. EPRI has access to the same information we have. The test facility configurations have been published in each of our reports. Instrumentation accuracies have always been available upon request.

Appendix E contains a copy of the Wyle Laboratories instrumentation equipment sheet from the Phase I testing. The INEL load cells were calibrated before and after both test programs and their accuracies remained constant throughout, at 0.4% of full scale (40,000 lbs). The Phase II instrumentation is the same as we are currently using in the diagnostic test validation except for the pressure and temperature measurements.

We used a large number of various pressure transducers in Phase II. All were strain gage type and most were manufactured by Statham. All were calibrated by the INEL standards laboratory prior to testing. Overall pressure transducer accuracies were better than 2.0% of reading. Thermocouples were expendable items, and each valve required a different length thermocouple to properly place it in the flow stream. Thermocouple response time will influence accuracies (steady state versus transient). Steady state accuracies were ± 10°F.

In response to this need, EPRI sponsored an independent review of the NRC/INEL Gate Valve Test Program (Phases 1 and 2). The review was carried out by MPR Associates with assistance from an industry inspection team and with oversight from the EPRI MOV Performance Prediction Program Technical Advisory Group.

The objectives of the review were to:

- Develop an understanding of the scope and applicability of the test results both for valves installed in the specific BWR systems under study and to industry MOVs in general.
- Document detailed information on the test valves, such that the test results and implications to specific valves could be evaluated.
- Document the principal results of the test program, including observed valve performance.

Appendix E contains our end to end, 99% confidence level, data acquisition system and instrumentation accuracies for the diagnostic test system. There are two exceptions to this list. Torque spring position was measured by a MOVATS TMD, and on Valves 3, 4, 5, and 6 stem force was measured by General Physics load washers instead of stem-mounted load cells. Valves 1 and 2 had both the stem-mounted load cell and the load washers, with acceptable agreement between instruments. Additional information on the accuracy of the load washers can be obtained from the developer at Point Beach Nuclear Power Station.

Finally, the calibration lab at the INEL is continually audited by the U.S. government and outside agencies. It has recently been audited by Portland General Electric and Gulf States Utilities, and no problems were found.

- Develop lessons learned from these tests to better plan the EPRI MOV Performance Prediction Program.
- Identify, generally, gate valve design details which need to be properly addressed to obtain satisfactory performance under severe blowdown isolation conditions.

The scope of the review included:

- a detailed post-test inspection of the valves tested,
- an assessment of the applicability of the valve designs tested to industry MOVs,
- a limited assessment of the applicability of the conditions tested both to design basis conditions for the BWR systems under study and to design basis conditions for industry valves in general, and
- a detailed review of the test data, using primarily published data plots, focusing on determination of the "apparent disk factor" implied by the data for all valve strokes performed with differential pressure and relating these results to the conditions tested and valve internal damage sustained.

Overall, the INEL test program has provided a substantial quantity of MOV differential pressure test data. This information has allowed the development of insights on gate valve performance primarily under blowdown isolation conditions. However, because of the specific approach and conditions of these tests, their application to specific plant MOVs requires detailed and careful evaluation of the test configuration, test conditions and test results. The following summarizes key findings of this review.

APPLICABILITY OF NRC/INEL TEST CONDITIONS

Blowdown Closure Tests

- Blowdown closure tests are applicable to gate valves

We agree, blowdown test conditions are applicable only to valves that

having a design basis requirement to isolate under blowdown flow conditions. A small fraction (less than 5%) of safety-related MOVs in the nuclear industry are in this category.	have a design basis requirement to isolate under these conditions. The exact percentage of valves in this category is unknown to us.
- MOVs in the RCIC, HPCI and RWCU systems are only required to isolate a break <u>once</u>. Because of the potential for valve damage under blowdown conditions, only the <u>first</u> blowdown isolation closure test for each valve design is considered potentially applicable to valves installed in these systems.	The EPRI report points out that the GI-87 valves need to close against pipe break flow only once. We agree, and that is why we designed the test program so that in every case (with the exception of Valve A) the first blowdown was the design basis test for that valve. Four of the six valves in Phase II responded nonpredictably in their design basis tests. The following parametric tests were performed to provide information on performance across a wide range of pressures and fluid conditions.
- The first blowdown closure test performed on Valve A included nitrogen (rather than hot water) flow during the last 60% of the valve stroke. Several of the subsequent blowdown isolations for Valves A and B (Phase 1) showed evidence of some nitrogen passage during the tests. Nitrogen flow isolation is not a design condition of any industry MOV in a RCIC, HPCI or RWCU system.	We disagree with the number of Phase I tests The EPRI Report challenged because of nitrogen flow. The EPRI Report claims seven tests with dry nitrogen and eight with some nitrogen entrainment. Our analysis in Section 3.4.6 of this report shows that only three of the primary blowdown closure strokes for Phase I saw nitrogen entrainment. Four other tests saw no nitrogen entrainment during the primary closure but experienced nitrogen entrainment during the subsequent optional blowdown open/close strokes. Evidence does not support <u>dry</u> nitrogen flow during any Phase I test. We agree that nitrogen flow is not a design condition for HPCI, RCIC, or RWCU valves. However, when one analyzes on-the-seat valve performance using the INEL correlation, one finds no difference between steam and the steam/nitrogen mixture.
- In all blowdown tests, there was significant valve DP during mid-stroke, although there was considerable variation among the test valves in this regard. It appears large DP during mid-stroke is characteristic of blowdown conditions and not of normal flow conditions to which most MOVs are exposed. The mid-stroke DP affects	Section 3.2.1 contains a complete analysis of this EPRI comment. We agree that piping systems can influence the pressure seen at the valve. The Mark I System shown in 3.2.1 has less resistance than the test loops. The point should be to establish the design basis requirement for any

valve performance and susceptibility to damage. Typical BWR RWCU and HPCI systems have higher overall system flow resistances than the NRC/INEL 6" and 10" loops, respectively. Thus, valve DP during mid-stroke would be less in actual BWR systems compared to NRC/INEL tests, which would tend to make valve performance more favorable. Assessment of applicability of specific INEL tests to plant valves/systems requires a detailed comparison of the expected plant DP versus stroke behavior to that developed during the INEL test (beyond the scope of this effort).

valve and then calculate the line losses.

<u>Blowdown Opening Tests</u>

- Blowdown opening (unisolation of break flow) generally does not correspond to a design basis condition for industry MOVs. Some applicability may exist for a very limited number of MOVs, i.e., PORV block valves.

We have never quoted a safety function for a valve to initiate blowdown flow. The results of these tests do show some interesting responses and yield insights into the phenomena effecting valve performance. We do not know when flow begins to be a significant contributor to opening loads. The facts, however, remain: the highest stem forces do not always occur during unseating, and flow during opening can have a significant effect on opening stem forces.

<u>"Normal Flow" Closing and Opening Tests</u>

- Because of the test system configuration, the "normal flow" conditions in the NRC/INEL tests resulted in negligible differential pressures for 5 of the 8 valves tested (A, B, 4, 5 and 6). Data from these 5 tests would be applicable to those valves which operate under low differential pressures, but provide little insight into valve disk/seat friction under high DP.

It was not our intent to duplicate every possible DP condition in our test program, but rather to simulate a range of DP conditions and then develop, from the results, a workable understanding of valve behavior. It is true that the results from tests with very low DP were not as useful to us as some of the other results. However, those normal flow tests during which we were able to establish an on-the-seat normalized normal loading greater than 400 lb_f/in^2 contributed to the correlation shown in Figures 10 and 11 (Section 3.2.5). Since then we have been working with utilities that are performing differential pressure testing with proven diagnostic measurement equipment. We have analyzed some pumped low flow differential pressure tests where the on-the-seat

	normalized normal loading did not reach the 400 lb_f/in^2 cutoff. One utility tested one 4-in., seven 8-in., and one 12-in. gate valve at pressures of 80 to 200 psig. A second utility tested four gate valves (one each at 3, 6, 10, and 12 in.) at pressures of 70 to 150 psig. All of the testing was done at fluid conditions greater than 70°F subcooling. Figure 12 (Section 3) shows the result of that analysis. We believe that when the results of our testing are properly used to understand the response of a gate valve, they are applicable.
- Although moderate differential pressures were developed during tests of 3 of 8 valves (1, 2 and 3), an unusual behavior of DP with stroke observed during these tests makes assessment of these data extremely difficult. Further evaluation of these data is planned. Until more detailed assessment is performed, results of these tests should not be applied to MOVs in nuclear power plants.	For the reasons discussed above, we found these data, too, quite valuable.
- Quantitative information on flow rate in normal flow tests is not in the published NRC/INEL data. Hence, an evaluation of applicability of flow rates has not been performed.	Flow rate data for every test in Phase I was published in NUREG/CR-5406, Volume II, Data Report. Figure 2 of NUREG/CR-5406 is the flow rate versus DP calibration of the flow meter, and the fourth plot (DP1) for each test shows fluid flow versus time for that test. Phase II flow rates were published in Phase II data report, EGG-SSRE-8970, for those tests with flow rates within the calibrated range of the KWU flowmeters.
"No-Flow" Opening Tests	
- Tests performed ostensibly under "no-flow" conditions actually resulted in a brief period of flow as the valve opened. Some useful information on disk friction is obtained from these tests prior to flow initiation. In addition, the "no-flow" tests performed on the 6-inch valves under both hot and cold water conditions resulted in DP versus stroke behavior similar to that expected for typical power plant pumped flow systems. Hence, it appears these data are potentially applicable to a wide range of applications. Also, these tests provide a basis for comparing performance between blowdown	The leakage and the cold and hot cyclic no-flow tests were part of the ANSI B16.41 valve qualification tests. The NRC wanted to be assured that the valves subjected to design basis flow interruption tests would have passed the nuclear valve qualification tests. The tests were applicable for what they were intended. The no-flow tests (and normal flow tests) performed prior to and after each blowdown were designed to represent possible in plant performance tests and were performed to obtain data for possible extrapolation analysis. We were hoping to find something in the

conditions and milder conditions. However, hot "no-flow" tests performed on 10-inch valves developed blowdown-like conditions for the first few seconds of the stroke. Therefore, these tests would have very limited potential applicability, i.e., only to valves required to open against blowdown flow conditions.

APPLICABILITY OF NRC/INEL TEST VALVES

INEL tested two 6-inch flexible wedge gate valves (Valves A and B) in the Phase 1 program. INEL tested three 6-inch flexible wedge gate valves (Valves 1, 2 and 3) and three 10-inch flexible wedge gate valves (Valves 4, 5 and 6) in the Phase 2 program. Valves A and B were refurbished and re-used as Valves 1 and 2 in Phase 2. Based on inspections of Valves 1 through 6 and discussion with the manufacturers:

- Anchor/Darling indicates that Valve 1 is not representative of Anchor/Darling valves supplied to the nuclear industry. Specifically, the Valve 1 downstream disk hardfacing is thinner and the edge sharper than Anchor/Darling requires in their manufacturing process. These conditions are considered detrimental to valve performance. Valve 1 was refurbished between Phase 1 and Phase 2 of the NRC/INEL tests. The atypical condition of the disk hardfacing could have been the result of this refurbishment which was not performed by Anchor/Darling. Test results for Valve 1 are not considered applicable to typical Anchor/Darling valves meeting the manufacturer's hardfacing and manufacturing requirements.

collected data that could indicate how the valves would perform at design basis blowdown conditions. To date we have not been able to predict valve performance using no-flow data.

The EPRI Report suggest that our designation of these tests as no-flow tests is a misnomer. Our use of this term was based on the fact that during these tests, there was no flow at the discharge end of the test facility.

Valve 1 was manufactured for the test program by Anchor/Darling and originally tested as Valve A in Phase I. As the EPRI report states, **"Anchor/Darling indicates that Valve A is similar in design features to a large population of flexible wedge gate valves they have manufactured and supplied to nuclear power plants."** After the Phase I tests and in preparation for the Phase II program, Valve A was refurbished by Crane Valve Services, Crane-Aloyco, Inc.

In the Phase II testing, Valve A was designated Valve 1 to help separate test results between the two test programs. The valve was installed in the system with flow direction reversed from Phase I so that the downstream disc surface and valve body seat ring were original Anchor/Darling surfaces. Thus, the performance of Valve 1 is

	representative of hardware delivered by the manufacturer to the INEL, under the premise of being representative of their hardware delivered to the nuclear industry. A more complete discussion of this issue is presented in Section 3.3.2 of this report.
- All other valves tested (A, B, 2, 3, 4, 5 and 6) appear to be representative of <u>some</u> gate valves produced by the respective manufacturers. Specifically, they are representative of valves with the same design features. However, gate valves with <u>different</u> design features have been provided in significant quantity to nuclear power plants, particularly by Anchor/Darling (manufacturer of Valves A and 4) and Velan (manufacturer of Valves B, 2 and 6). The NRC/INEL test valve designs are not the same as these other valve designs.	Together, the six valve designs tested by the INEL are representative of most flex wedge gate valves used in nuclear power plants. The EPRI report points out that the manufacturers have provided other designs to the power plants and suggests that these other designs may perform differently than those we tested. Experience from NRC/INEL testing and from other similar testing indicates otherwise. Section 3.3.1 presents a complete discussion of this issue.
- Detailed applicability of test valve results to nuclear power plant valves is dependent on internal valve dimensions. Dimensions are available for Valves 1 through 6 from the industry inspection effort. Detailed dimensions are available for Valves A and B for those surfaces which were not reworked between Phases 1 and 2; dimensions for surfaces which were reworked are available only as nominal dimensions from manufacturer drawings. This limitation hinders the use of these data.	More is known about the dimensions of the Phase I and II valves than is known about most of the valves in nuclear power plants. The valve designs are representative of actual nuclear power plant hardware delivered by these manufacturers.
- Because all of the valves were damaged to some extent during the test sequence, at some point the configuration was no longer applicable to nuclear power plant valves. Because mid-test inspections were not carried out, it cannot be known precisely when this point occurred.	Valve inspections between tests were considered for the Phase II test, but we later decided against them because of cost factors. Experience had shown us that valve damage can be detected through a sensitive stem thrust measurement. Using this method during the Phase II testing, we were able to detect every occurrence of valve damage.

OBSERVED VALVE PERFORMANCE UNDER BLOWDOWN CLOSURE CONDITIONS

Apparent disk factors (disk factor implied by measured DP and thrust	The disc factors derived by the EPRI analyses are typically too low.

using standard industry equation) required to achieve flow isolation on the first blowdown closure stroke of each test valve are shown below.

Section 3.4.2 of this report addresses this issue.

Summary of First Blowdown Isolation Tests

Valve	Manufacturer	Size (in)	Test No.	Fluid	DP at Isolation (psi)	Apparent Disk Factor for Flow Isolation	Applicability to Similar Industry Valves*
A	Anchor/Darling	6	A-3-5	Nitrogen	510	0.63	Potentially Applicable
B	Velan	6	B-2-5	Hot Water	1000	0.35	Applicable
1	Anchor/Darling	6	1-1-25	Hot Water	870	Valve N/A (0.86)	Not Applicable
2	Velan	6	2-1-25	Hot Water	940	0.33	Applicable
3	Walworth	6	3-1-25	Hot Water	870	0.19	Applicable
4	Anchor/Darling	10	4-1-25	Steam	700	0.49	Applicable
5	Powell	10	5-1-25	Steam	880	0.44	Applicable
6	Velan	10	6-1-25	Steam	1000	0.42	Potentially Applicable

* Indicates applicability of test result (apparent disk factor) to valves in systems requiring blowdown isolation. Test is considered applicable if both valve design details and test conditions are representative of some industry valves.

These data are considered potentially applicable <u>only</u> to similar valves installed in the BWR systems under study or other similar valves having as a design basis function the isolation of blowdown flows under the range of conditions tested.

We do not consider the information contained in this table to be valid; the stem position chosen by EPRI for flow isolation was in error. Section 3.4.3 explains our position on this issue. Also, the apparent disc factors are based on the mean seat diameter, which is not always used by industry.

	The EPRI report attempts to limit the applicability of the INEL testing to specific valves in specific systems under specific conditions. The INEL test program was designed to test a representative sample of valves to produce data that would contribute to an understanding of valve performance. Our assessment of these data has resulted in a correlation that can be used to bound the closing stem thrust of a predictable 5-degree flexible wedge gate valve. This correlation is applicable to a wide range of conditions and systems. Provisions are included for determining whether a given valve is typical of the valves tested by the INEL and whether the INEL correlation can be used for that valve.
As previously discussed, the internal dimensions of Valve 1 are not typical of valves supplied by the manufacturer and as a result the disk factor implied by the data is not considered applicable to industry valves.	Section 3.3.2 of this report addresses this issue.
Similarly, review of the data and observed damage for Valve 6 indicates that significant deformation of the body guide rails apparently occurred on the first hot cycle "no flow" opening test (at 1200 psi). This stroke had blowdown-like conditions for the first few seconds, which is unlike typical non-blowdown nuclear power plant systems. It appears the brief blowdown-like conditions may have caused the damage. Therefore, it appears all blowdown closure strokes for this valve were performed with pre-existing damage and, as a result, the direct applicability of the disk factor implied by the data to industry valves is unknown. Although the direct applicability of the blowdown closure test is unknown, it would be expected that a blowdown closure stroke would have bent undamaged body guides in a similar manner as did the opening test, potentially resulting in similar valve performance as shown in the table for Valve 6.	Damage to this valve consisted primarily of bent guides (abnormal seating behavior) and damaged seats, guides, and disc (nonpredictable mid-stroke behavior). We initially attempted to use the results of design basis testing from that portion of the stroke where the disc first started to ride on the seats, hoping to avoid the influence of the nonpredictable behavior and yet avoid the results of abnormal interferences caused by bent guides. However, upon further assessment of the response of this valve during design basis blowdown testing, we decided not to use any of the results from this valve in developing the INEL correlation. Note, however, that the fact that the valve experienced damage when subjected to its design basis conditions is a significant result.

Further, the test conditions for Valve A on the first blowdown closure stroke were atypical (N_2 versus water) of those for industry valves, and as a result, the direct applicability of the disk factor implied by the data to industry valves is unknown. Although the effect of nitrogen flow is unknown, the presence of gas versus liquid flow would not nominally be expected to significantly affect disk tilting and resulting gouging/machining. Therefore, the performance for Valve A shown in the table is considered potentially representative of performance under water flow conditions.

With the exception of the qualifiers discussed above, the disk factors shown above should be taken as an indication of performance which can potentially occur for similar valve designs and blowdown closure conditions. It should be noted that disk factors for valves which sustained substantial internal damage (Valves A, 1, 4, 6 and to a limited extent 5) might be expected to vary considerably from the values indicated.

GENERAL OBSERVATIONS

Effect of Stroke History

On all valves, apparent disk factors increased from an initial low level (0.1 to 0.2) to a higher stable "plateau" level (above 0.3) when the valve was first stroked at elevated temperature. Some data also indicated an increase in disk factor with repeated strokes at cold temperatures. Potential causes for this behavior include:

- removal of residual machining oil from valve internal surfaces,
- removal of an oxide layer on valve internal surfaces,

Section 3.4.6 addresses the issue of nitrogen flow.

As discussed in detail in Sections 3.4.1 and 3.4.2 of this report, the INEL disagrees with the disc factors recommended by EPRI in their report. In particular, the disc factors listed for flow isolation were taken from a valve position prior to isolation, and thus they are not conservative. The mean seat area was not generally used for calculating stem force when the valve operators were originally sized, and the standard industry equation is incomplete.

and

- mechanical wear (microscopic or macroscopic) of valve internal surfaces.

In the NRC/INEL tests, disk factor in cold tests performed after hot tests remained at the stable level. Hence, information on valve performance at hot conditions could be obtained from cold tests performed after exposure to hot conditions. This is contrary to NRC and INEL conclusions which indicate valves need to be tested at temperature to obtain meaningful performance information.	Although some information can be obtained from cold tests, to date we know of no way to determine if a valve is predictable except by testing at design basis conditions. The normal flow testing we performed would not have told us that four of the six valves tested in Phase II would respond nonpredictably during their design basis tests. As for sliding friction, we still see a temperature dependence for valve performance. Through further analysis we have determined that valves should be tested at conditions which produce similar sliding surface lubrication (i.e., thin-film lubrication). Fluid subcooling is an important parameter in this behavior. See Appendix C for additional information.

Behavior Beyond Sliding Friction

During blowdown testing of some valves (A, 1, 4, 6 and to a limited extent 5) significant internal damage occurred indicating that the disk was not sliding on the guide/seat surfaces. Instead, the disk tilted in the direction of flow and aggressively engaged body guide rails and seats, resulting in gouging and machining. Valves sustaining such damage generally had higher apparent disk factors which are not considered representative of those expected under sliding friction conditions.	We agree that stem forces required to close nonpredictable valves are not representative of stem forces required to close predictable valves.
In addition, the body guides in Valve 6 were bent in the direction of flow. It appears this bending first occurred during a "hot cycle" no-flow opening test. As previously mentioned, blowdown-like conditions existed for the first few seconds of this test and may have caused the damage.	We agree that the Valve 6 body guides were bent during the first hot cycle DP opening test. The portion of the guides that bent corresponds with the last 8% of the valve closure cycle. Because of this, Valve 6 did not exhibit the normal closing plateau in the force trace when

This damage resulted in pinching of the disk on subsequent tests which would not be indicative of sliding behavior. This damage is attributed to the lack of sufficient structural support for the lower portion of the body guides in this particular valve design.

It is expected that the potential for sustaining damage such as gouging/machining of valve internals and/or plastic deformation of valve internals is only significant under very high flow (blowdown) conditions where significant DP exists in mid-stroke. Specifically, such damage and the attendant high disk factors would not be expected for the vast majority of industry valves. Most industry valves are in pumped flow systems and, depending on the system frictional losses, would be expected to develop significant differential pressures only when the valve disk is on or very near the seats.

Sliding Friction Behavior

All tests were reviewed to identify periods of the test during which sliding friction was the predominant behavior. Apparent disk factors for sliding friction generally were in the 0.1 to 0.4 range. Sliding friction is representative of the behavior expected for most industry valves, i.e., valves in pumped flow systems. This result is generally consistent with industry practice.

The only significant exception to this result was Valve 2 which had a significantly higher apparent disk factor (0.5 to 0.6) when the disk was in the region between isolation and wedging, both on opening and closing. This result is attributed to the involvement of additional surfaces (disk

sliding on the seat as seen in all other Phase I and II valves. For this reason we were unable to use Valve 6 data in the INEL stem force correlation. The other 92% of each Valve 6 stroke is not influenced by the bent guides, and that information is applicable for analysis of nonpredictable behavior and high mid-stroke loads during blowdown opening cycles.

The damage noted in these valves occurred during design basis blowdown testing. The severity of the loadings contributed to the damage. However, we currently have no way to assess a given loading or to determine whether valve damage will occur without testing the valve at its design basis conditions. We have never suggested that all industry valves include blowdown conditions in their design bases.

As discussed previously, we take exception with the methods used in the EPRI report to evaluate apparent disc factors. The range quoted (0.1 to 0.4) is not supported by the data, and the use of mean seat diameter was not the common practice in operator sizing. See Section 3.4.2 for additional information.

Using appropriate analytical methods, Valve B and 2 test data provide on-the-seat disc friction values similar to the other valves' on-the-seat disc friction. See Appendix C for the analysis method. The discussion of Valve 2 in Section 3.4.5 addresses the possible effects of lateral

slot lateral contact with body guide) in this region. Indications of similar performance were also observed on Valve 8. However, disk factors were only slightly above 0.4.	disc rotation.
Apparent disk factors for sliding friction conditions in blowdown tests showed good agreement with those in simpler "no-flow" opening tests. This result indicates that as long as anomalous behavior (beyond friction) is avoided, valve performance can be predicted or extrapolated across a range of differential pressure conditions.	We agree with this concept, but only under our stated constraints and using an appropriate analytical method. Data supports extrapolation of performance for predictable, 5-degree flexible wedge gate valves, in the closing direction, using the INEL correlation. We know of no data available to justify extending this concept to other valve designs.

Thrust Increase during Blowdown Opening

After initial unwedging and for a significant period afterward (1-10 secs) an increase in required stem thrust was observed on some blowdown opening tests. This behavior is generally attributed to a reduction in pressure below the disk due to high flow "Bernoulli" effects. In at least one case (Valve 6), such behavior was potentially the result of previously sustained valve damage (bent body guide).	We believe this phrase should read "after initial unseating" not "unwedging." After unwedging we see a period where the disc is sliding on the seat and flow is still isolated. Only after unseating do we see an increase in stem force caused by the high flow pressure loadings. Valve 6 behavior during blowdown opening is not the result of the bent body guide. The bent guides would cause high stem forces after hammer blow due to the pinching of the guides. The stem forces would gradually decrease until the disc passed from the bent portion of the guides. Instead we see a large increase in stem force at unseating and the onset of flow. The blowdown opening data for Valve 6 is not the result, even partially, of bent body guides.
As previously discussed, with the possible exception of PORV block valves, blowdown opening is not a design basis requirement for industry MOVs.	We agree.

PERSPECTIVE ON NRC/INEL CONCLUSIONS

In general, although the results of this test program do have potential implications for specific valves in specific systems, some of the NRC and INEL conclusions documented to date imply data applicability beyond what is warranted. A detailed perspective on each NRC and INEL conclusion is presented in Section 8.

After two years of additional in-depth data analysis with extensive peer review, we still find that almost all of the conclusions stated in the NRC/INEL documents quoted in Section 8 of the EPRI report are correct. See our comments in Section 8 for exceptions.

RECOMMENDED FURTHER INEL TEST PROGRAM EVALUATION

Further investigation is recommended in the following areas:

- INEL digital data should be examined to:
  - confirm values obtained from plots,
  - further assess details of "normal flow" tests
  - further assess test system and flow effects on valve performance.
- A detailed measurement accuracy evaluation should be obtained from INEL.
- Details on instrument calibration methods and frequency should be obtained from INEL.
- Detailed valve dimensions from the inspection should be used to develop and evaluate a model for predicting disk/guide/seat interaction and potential for damaging behavior.
- A correlation of measured surface roughness and iron content values with observed valve performance should be made.

Comment on this section is beyond the scope of this review.

LESSONS LEARNED FOR EPRI MOV PERFORMANCE PREDICTION PROGRAM

Based on this review of the NRC/INEL data and the valve inspection activities, several insights were gained which should be considered in the EPRI MOV Performance Prediction Program as follows:

Comment on the EPRI MOV Performance Prediction Program is beyond the scope of this review.

- Test hardware (valves and operators) should be extensively characterized prior to testing. Information should be obtained and documented according to procedures, and should include dimensional measurements, photographs, and performance information such as motor characteristics, spring pack stiffness, etc.
- The hardware vendors should be involved with the test program to lend immediate information on valve set up, performance, dimensional characteristics, inspection interpretations, etc.
- Flow loop testing should generally progress from less severe to more severe conditions.
- Valves should be internally inspected between strokes to check for damage.
- Flow loops for testing should cover conditions typical of nuclear power plant systems containing applicable MOVs. Further, the systems should have configurational and operational flexibility so that ranges of parameters (e.g., flow, pressure) can be covered in the tests.
- The MOV performance prediction methodology should incorporate insight on valve performance gained from the NRC/INEL tests.
- Separate effects elements for friction testing should investigate the stroke/temperature history effect and the effect of iron content.
- Separate effects analyses and flow loop tests to cover flow effects (Bernoulli effect) on valve stem force should be included.
- Testing to reproduce and explain the NRC/INEL Valve 2 behavior (unusually high disk factor near wedged position) is warranted.

KEY VALVE DESIGN CHARACTERISTICS

Several aspects of valve design which appear to be important to achieving optimal and repeatable valve performance under severe blowdown isolation

Comment on this section is beyond the scope of this review. However, we caution the reader that not all of these statements are fully supported conditions were qualitatively identified through this review. by data.

- Disk-to-Guide Clearance (fore, aft and lateral)

  These clearances should be large enough to eliminate the potential for binding (observed particularly in the lateral direction in the NRC/INEL tests) yet not so large as to allow significant disk tilting in the direction of flow.

- Guide Slot and Guide Rail Surface Finish

  A smooth flat surface appears to be favorable. As-cast, unmachined surfaces appear to aggravate the severity of internal valve damage.

- Edge Configuration of Disk Guide Slots, Disk and Body Hardfacing on Seats

  Sharp edges appear to increase the potential for gouging/machining of internal surfaces. Rounded or beveled edges appear to be more favorable.

- Body Guide Rail Length

  Guide rails should be of sufficient length to allow a smooth transition of the disk from guide to seat without significant disk tilting.

- Disk Guide Slot Length

  Disk guide slots should be long enough to adequately constrain disk tilting and provide adequate load bearing area.

- Body Guide Rail Support.

  Guide rails should be adequately supported throughout their length to minimize the potential for plastic deformation in the direction of flow.

- Guide Slot and Rail Hardfacing

  Hardfacing of body guide and disk slots would appear to be beneficial although sufficient data was not obtained from this program to fully evaluate this aspect.

- Hardfacing Iron Content.

  Iron dilution from base metal into the hardfacing material may degrade the hardfacing's friction and wear properties. Hardfacing procedures which require application of several layers of hardfacing to the disk and body seat base metal and control of hardfacing thickness during subsequent machining should minimize the potential for significant iron dilution.

Section 1

INTRODUCTION

BACKGROUND

Two phases of testing of motor operated gate valves have been performed by Idaho National Engineering Laboratory (INEL) under the sponsorship of the United States Nuclear Regulatory Commission (NRC). Phase 1 testing was performed during 1988 on two 6-inch valves (referred to as Valves A & B) intended to represent typical BWR Reactor Water Clean-up (RWCU) supply line isolation valves. Phase 2 testing was performed during 1989 on six valves -- three 6-inch valves (referred to as Valves 1, 2 and 3) and three 10-inch valves (referred to as Valves 4, 5 and 6). These valves were intended to represent typical BWR RWCU, High Pressure Coolant Injection (HPCI) steam supply and Reactor Core Isolation Cooling (RCIC) steam supply isolation valves. The NRC/INEL tests covered high energy blowdown flow conditions (intended to simulate pipe break conditions) and selected lower flow conditions.

INEL and NRC have published conclusions and recommendations based on the results of these tests. These conclusions and recommendations (and their appropriate source documents) are described in this report. The most significant conclusions made by NRC and INEL are that the gate valves which were tested required stem forces greater than predicted by existing industry sizing equations, and that some of the valves showed unexpected behavior which is attributed to valve internal damage. These conclusions are based strongly on the observed results under the severe blowdown conditions. Based on these tests, NRC has indicated concerns with MOV performance in nuclear power plants.

No INEL comments are appropriate for this section.

This report presents results of a short-term, EPRI-led effort to independently evaluate the NRC/INEL tests. The objectives of this effort are discussed below.

OBJECTIVES

The objectives of this effort are as follows:

- Develop an independent understanding of the scope, results and implications of the NRC/INEL tests so that utilities (particularly BWR's) can effectively deal with NRC concerns.

- Develop information needed to help interpret and explain MOV performance in the NRC/INEL tests, so that the implications to specific valves in nuclear power plant systems can be evaluated.

- Identify areas where detailed evaluation of the NRC/INEL data should be pursued.

- Identify needed and desired elements of the EPRI MOV Performance Prediction Program based on NRC/INEL test results.

- Identify, generally, valve design features which need to be properly addressed to obtain satisfactory performance under severe blowdown isolation conditions.

Because of the short-term nature of this effort, the scope was limited, as described below.

SCOPE OF EFFORT

The scope of this effort included:

- Evaluation of the applicability of the NRC/INEL blowdown test conditions to design basis conditions of valves in nuclear power plants.

- Scoping evaluation of NRC/INEL data (using published data plots), with particular emphasis on determining "apparent disk factor"[1] for all valve strokes performed with differential pressure (DP) and relating these results to the test conditions.

- Inspection of NRC/INEL Phase 2 valves to obtain valve configuration and other information to support evaluating the test results and their applicability to nuclear power plant valves.

- Evaluation of likely causes for observed valve behavior.

- General assessment of implications for the EPRI MOV Performance Prediction Program.

Because of the short-term nature of this task, it was not possible to completely resolve the technical issues in these areas. In many places this report identifies additional questions or areas where more detailed evaluation is required.

ORGANIZATION OF REPORT

Section 2 presents a discussion of the applicability of test conditions used in NRC/INEL tests to the design basis conditions of valves in nuclear power plants. This section incorporates work presented to the NRC in March 1990 (Reference 3). Section 3 discusses the applicability of the valves used in the NRC/INEL tests to valves in nuclear power plants.

Section 4 describes the activities covered in the inspection of the NRC/INEL valves and the results from the inspection. Section 5 describes the methods and data used in the review of NRC/INEL data and the approach used in the analysis of the data. Section 6 discusses the evaluation of valve performance in the NRC/INEL tests based on the test data review and inspection results. Section 7 discusses recommendations for future efforts as a result of the findings of this work. Section 8 presents a discussion of insights this effort has yielded on existing NRC and INEL conclusions.

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1. Apparent disk factor is the disk factor determined from the data using the standard industry gate valve thrust equation. See Section 5.

Section 2

APPLICABILITY OF TEST CONDITIONS USED IN NRC/INEL TESTS

TYPES OF TEST CONDITIONS

In general, there were three types of test conditions used for valve strokes with differential pressure (DP) in the NRC/INEL tests. These are described in the table below.

Type	General Procedure	DP Behavior
No Flow (Open strokes only)	Upstream side pressurized and downstream depressurized; valve opened.	DP rapidly dissipated as downstream volume pressurized.
Normal Flow (Close and open strokes)	Flow established using pump (Phase 1) or orifice (Phase 2); valve stroked closed then opened.	DP increased as valve closed and then dissipated as valve opened. In most cases this DP was very small at all times.
Blowdown (Close and open strokes)	Flow established using quick-opening device; valve stroked closed and then partially opened and re-closed.	DP increased as valve closed and then decreased as valve opened. In all cases this DP was substantial throughout the stroke.

Figures 2-1 through 2-4 show sample time histories of selected valve strokes. Each figure includes a curve of upstream pressure, valve differential pressure and stem position. These graphs were constructed using digital data files provided by INEL.

- Figure 2-1 shows data for a no-flow stroke (6-inch valve with hot water conditions).
- Figure 2-2 shows data for a blowdown closure stroke (10-inch valve with steam conditions).

- Figure 2-3 shows data for a closure/opening cycle under normal steam flow conditions for a 10-inch valve.
- Figure 2-4 shows data for a closure/opening cycle under normal hot water flow conditions for a six-inch valve.

The valve DP behavior throughout the stroke differs considerably between these selected strokes. To permit the data from several valve strokes to be effectively compared, normalized DP (DP/upstream pressure) versus normalized stroke position (% open) was plotted. Figures 2-5, 2-6 and 2-7 show comparisons of several valve strokes under no-flow, normal flow and blowdown conditions, respectively. Once again, these data are from digital data files provided by INEL, except for data for Valves A and B on Figure 2-7, which are taken from data plots from Reference 1. Each graph also includes a curve representing the DP/stroke behavior for a typical MOV in a six-inch, cold water pumped system in a nuclear power plant, based on data from Toledo Edison. The applicability of each type of INEL test condition to design basis conditions for valves in nuclear power plants is discussed separately below.

We are not surprised at the differences in DP behavior shown in Figures 2-1 through 2-4. However, we are concerned about the use of **"normalized DP (DP/upstream pressure)."** The pressure under the disc acts on the valve stem through the valve disc to produce the stem rejection load (piston effect), one differential pressure (upstream and downstream disc surfaces) loads the disc producing disc drag, and another differential pressure (top and bottom disc surfaces) provides additional rejection type loads. These differential pressure forces produce the primary loadings on a valve irrespective of whether the flow has been isolated. The DP used by the EPRI report is simply the difference between the upstream and downstream pressure measurements. As such, the ratio of DP divided by upstream pressure does not represent real valve loading, nor does it represent all the components that load a valve. Comparisons of this ratio between tests does not even provide insight on test severity. Consider, for example, that a low-pressure test with an upstream pressure of 75 psig and a differential pressure of 60 psid has a normalized DP of 0.8, while a high-pressure test with an upstream pressure of 1500 psig and a differential pressure of 600 psid has a normalized DP of 0.4.

In the no flow test (Figure 2-1) and low flow tests (Figures 2-3 and 2-4), upstream pressure remains essentially constant for the complete valve cycle. Here the EPRI report normalized DP can be thought of as merely expressing DP as a percentage of initial pressure. Packing drag and stem rejection forces are significant in low flow applications; these are not represented by normalized DP. Where upstream pressure holds constant, normalized DP may be proportional to the forces acting on the

APPLICABILITY OF BLOWDOWN CONDITIONS

The blowdown test conditions used in the NRC/INEL tests were first evaluated to determine what type of conditions were achieved and how this would compare to design basis blowdown conditions in nuclear power plants. Then, the blowdown test conditions were compared to the population of nuclear power plant valves to determine the overall applicability of these types of flow conditions. These evaluations are discussed below.

Range of Blowdown Conditions

Figure 2-7 shows normalized DP vs. stroke behavior for blowdowns of four

disc, but not related to the total stem force.

In blowdown tests (Figure 2-2), upstream pressure drops with flow and may not fully recover to its pretest value, even at closure. With the upstream, bonnet, and under disc pressure changing independently, the normalized DP is not proportional to disc forces. Packing drag and stem rejection forces are once again not represented, although they are less significant in blowdown tests. The actual ratio of DP to upstream pressure can be affected by many conditions, including upstream pressure, flow rate, flow medium (water or steam), flow restriction (upstream or downstream of the valve), subcooling (with the possibility of flashing), direction of valve actuation (opening or closing), and rate of valve actuation. Comparisons of such ratios, such as those shown in EPRI's Figures 2-5 through 2-7, are not useful indicators of DP behavior unless it is known that all those conditions are the same for the tests being compared. Even then, it is unlikely that such ratios will provide the analyst any useful information.

Normalized DP is not a valid method for evaluating valve loading, and

	of the 6-inch valves (A, B, 1, and 2) and for one of the 10-inch valves (4). The conditions were similar for the 10-inch valves, so it is only necessary to show one curve. As shown, however, there was quite a variation of conditions for the 6-inch valves. Important points gathered from this evaluation are summarized below.	comparisons between tests based on normalized DP are not appropriate as discussed above.
1.	Blowdown conditions for 10-inch valves were the most severe in terms of the differential pressure loading during mid-stroke. Specifically the DP was about 60% of the upstream pressure as the valve started to close, increased to over 80% of upstream pressure as the valve closed halfway and then to 100% of upstream pressure at flow isolation. These conditions would be expected to more strongly load the guide surfaces (i.e., during mid-stroke) in comparison to most of the 6-inch valve strokes.	The 10-inch valves are representative of HPCI steam supply isolation valves. DP during stroke is representative of GI-87 type closures. Valve 2 (6-inch) was tested with steam (GI-87 RCIC application) and produced similar DP loadings. The DP and stroke relationship of valves in a steam environment is expected to differ from valves in hot water with flashing environments.
2.	The conditions for the first blowdown stroke of Valve A were much more erratic and more severe during midstroke than other blowdown strokes for six-inch valves. As discussed more extensively below, it appears this blowdown had nitrogen flow for a significant portion of the valve stroke. The passage of the water/nitrogen front and subsequent nitrogen flow are believed to have caused the particular DP behavior.	Discussion of nitrogen flow during the first blowdown test using Valve A is presented in Section 3.4.6 of this report. During this test, upstream pressure started at 1000 psig but dropped severely during the valve closure. The normalized DP ratio shows what appears to be very high loading, when in fact final upstream pressures and maximum DPs were only on the order of 400 psi. Here again, normalized DP does not represent real valve loading.
3.	Blowdown conditions for 6-inch valves, even when tested in the same loop, showed considerable differences. For example, Valves 1 and 2 showed significantly different behavior during mid-stroke (Figure 2-7). Although some of this behavior may be attributable to valve flow resistance differences, it appears more likely there were differences in the way the test facility operated. Valve 3, although not shown, started off with a DP	Figure 2-7 in the EPRI report actually shows that without a significant loss in upstream pressure, Valves 1 (A) and 2 (B) show different but very reproducible behavior between Phases I and II. Note how the Valve 1 and A traces lie almost on top of one another. The same is true for Valve 2 and B. Recall that Phase I and II used different test facilities with completely different piping configurations. The EPRI report's argument for a difference in how the facilities operated as the cause of the

behavior similar to Valve 2 and then suddenly "switched" during mid-stroke to a behavior similar to Valve 1. The root cause for the different behaviors is not known.

In summary, a wide range of DP versus stroke behavior is observed in the NRC/INEL valve tests. The DP versus stroke behavior can significantly influence valve performance because it affects how strongly the disk is loaded while it is still sliding on the guides and transitioning to the seat. The DP versus stroke behavior for valves with blowdown design basis conditions in nuclear power plants would be dependent on the details of plant-unique piping configuration. The piping configuration is important because systems with high overall flow resistance would have more flow pressure losses in the system and less DP across the valve during mid-stroke. Less severe DP in mid-stroke is more favorable to valve performance, because the valve disk is not loaded as heavily while it is sliding on the guides and transitioning to the seat. The NRC/INEL test conditions were more severe in this regard, since system flow resistance was lower in the tests than in a typical BWR (see table below).

System	BWR Resistance and Basis	INEL Test Resistance and Basis
RWCU	32.9 (net K from reactor vessel to first isolation valve, based on 6" pipe)	1.6 (Phase 1) 2.7 (Phase 2) (net K from pressure tank to isolation valve, based on 6" pipe)
HPCI	1.5 (net K from reactor vessel to first isolation valve, based on 10" pipe)	0.6 (net K from pressure tank to isolation valve, based on 10" pipe)

difference between valve responses is not supported by the data.

As previously discussed, normalized DP is not a valid method for evaluating valve loading, and comparisons between tests based on normalized DP are not appropriate.

As discussed in Section 3.2.1, a Mark I RWCU supply line would typically have only half the line losses of the Phase II test loop. Conditions for a Mark I would therefore be more severe. A Mark II RWCU supply line would have greater line losses.

Nitrogen Flow through Valves

In Phase 1 tests, an accumulator with a nitrogen overpressure was used

We disagree with EPRI's conclusion that flow through any of the Phase I to provide the blowdown flow. In some of the blowdown isolation strokes, it appears the flow was entirely nitrogen during the latter part of the stroke. In others, it appears there may have been significant nitrogen entrainment. These conclusions were inferred from the data plots, as discussed below.

A complete transition from water to nitrogen flow appeared to occur on the first blowdown stroke of Valve A (Test 3 Step 5). Figure 2-8 shows the DP across the upstream flowmeter and across the test valve. At a time of about 8 seconds, the flowmeter DP drops sharply. After about one second, it rises again. If a water/nitrogen interface passed through the system, the flowmeter at the upstream end of the system would first show a sharp drop as the fluid density dropped. Then, as the water slug in the system was accelerated and ejected from the system, the DP would increase, first gradually (during acceleration) and then sharply (at ejection). This behavior is seen on the flowmeter DP plot in Figure 2-8. At the test valve location, which is further downstream, DP would be expected to increase as the water slug was accelerated, drop as the nitrogen arrived at the valve and then increase as the slug cleared. This is consistent with the observed behavior, although the times are not as sharply defined. This could be due to a blending of nitrogen and water as it flowed downstream. Nonetheless, it appears that after about 10 to 14 seconds, when the valve was about 30-45% closed, only nitrogen was flowing through the valve. The valve stem force plot, also shown in Figure 2-8, shows that substantial forces developed only in the last one-half of the valve stroke, i.e., when nitrogen flow was occurring.

While the presence of dry nitrogen can result in higher friction factors on valve parts, the effects of nitrogen flow versus saturated water flow are not known for these tests. Table 2-1 identifies the valve blowdown strokes from Phase 1 where it appears nitrogen flow replaced water flow

valves was ever entirely nitrogen. Nitrogen entrainment did occur in seven out of 24 full flow strokes.

Section 3.4.6 of this report discusses our analysis to determine when nitrogen flow occurred. Dry nitrogen flow did not occur during any of the Phase I tests.

The tests identified in Table 2-1 experienced nitrogen entrainment, not dry nitrogen flow.

at some point in the stroke, and the approximate stroke position where this took place. The information in this table is based on data interpretation as discussed above.

In other strokes of the Phase 1 testing, it appears some nitrogen may have been passed through the blowdown pipe and test valve during the stroke without a complete transition from water to nitrogen occurring. Figure 2-9 shows the flowmeter DP and valve DP for the second blowdown stroke of Valve A (Test 2 Step 5). At a time of about 22 seconds, a significant disruption on the flowmeter DP is seen. The DP drops to zero, remains there for about one second, and then oscillates sharply. A slug of nitrogen being passed at about the same velocity as water would give rise to a temporary low flowmeter DP. The disturbance is seen slightly later at the valve (23-26 sec) as a somewhat attenuated DP variation. This behavior began when the valve was about 60% closed and seemed to settle out as the valve went to the fully closed position. The stem thrust trace for this valve is also shown on Figure 2-9. Significant stem force increase occurred during the last 35% of the stroke, i.e., when nitrogen flow was occurring.

The effects of passing slugs of nitrogen through the system on valve performance are not known for these tests. Table 2-2 identifies the valve blowdown strokes from Phase 1 where it appears nitrogen slugs may have been passed through the system, and the approximate stroke position where this took place. The information in this table is based on data interpretation as discussed above.

Overall, the presence of nitrogen (continuous or in slugs) does not appear to be directly applicable to blowdown isolation design basis conditions for valves in nuclear power plants.

In the test referred to here (Valve A, Test 2, Step 5), only one half of the water volume in the accumulator was consumed. We see no way that slugs of nitrogen could pass down through approximately eight feet of standing water to enter the piping system. Video recordings and other system instrumentation support the conclusion that no nitrogen flow occurred during this test.

All of the tests identified in Table 2-2 closed on water flashing to steam (water/steam slug flow) without nitrogen entrainment.

Section 3.2.7 of this report discusses the effect of nitrogen and water vapor mixture on the valve's on-the-seat performance. Valve A's on-the-seat data are included in our Figures 10 and 11. The Valve A data line up well with data from all the rest of the Phase I and II valves. Note

Applicability of Blowdown Conditions to Overall Valve Population

Two methods were used to evaluate applicability of blowdown conditions: a valve loading severity evaluation and a condition-similarity evaluation.

Valve Loading Severity. The valve loading severity evaluation examined the contact force and contact stress between the valve disk and seat as indicative of loading severity. This approach was studied because many valve applications involve smaller valves and/or lower differential pressures than the INEL tests; both of these parameter effects lead to lower contact forces and stresses and would be intuitively expected to yield improved sliding interaction. Contact force is defined as

Contact force = (DP) x (A)

where A = nominal area = $\pi D^2/4$ where D is the nominal valve diameter.

Because of lack of detailed information about valve-specific seat contact widths, contact stress was evaluated in accordance with a "linear stress" parameter.

Linear stress = (DP) x (A)/(C)

where C = nominal circumference = πD. This parameter is the force per unit length of circumference between disk and seat.

During 1989, an MOV population data base was established by MPR for EPRI

also that there is nothing in the EPRI reports' Figure 2-8 to indicate that nitrogen entrainment had any effect on the measured stem force.

This analysis using nominal valve diameter contradicts the EPRI methods used in Section 5, where mean seat diameter is used. We agree with the use of mean seat diameter and question the use here of nominal diameter. Several valves of the same nominal size can have widely varying mean seat diameters.

It may be true for the EPRI data base that valve-specific seat information is unavailable. However, the information is available for the NRC/INEL valves. The EPRI report contains the results of the NRC/EPRI posttest characterization of the Phase I and II test hardware, including the valve-specific seat information.

We agree that the Phase I and II blowdown conditions are applicable to (see, for example, Reference 4). The data base covered about 10% of the safety related MOV's in U. S. nuclear power plants, or over 1500 valves. This data base was evaluated to select all of the gate valves for which the design basis DP was known, which provided a sample of 404 valves. These 404 valves represent 44% of the 913 gate valves in the database. Figures 2-10 and 2-11 show this population in terms of contact load and linear stress, respectively. Also shown on these graphs are the RWCU and HPCI steam isolation valve conditions based on the 6" and 10" valve conditions used in the NRC/INEL tests. These graphs show that the majority of gate valves operate with much lower contact forces and stresses than existed for the NRC/INEL test conditions. Hence, it was concluded that the conditions covered in the NRC/INEL blowdown tests, expressed in terms of contact load and stress, apply to only a small fraction of the valves in nuclear power plants.

Condition Similarity. One of the unique features of a blowdown condition is that substantial DP across the valve exists throughout the valve stroke (see Figure 2-7). For most valve applications, which do not cover blowdown conditions, DP is relatively small except near or at the closed position of the stroke. These conditions are judged to be more favorable to reliable valve performance since the valve will not be heavily loaded while the disk is sliding on the guides or transitioning to the seat ring. Accordingly, a brief study of the number of gate valves which would be expected to face blowdown isolation conditions within their design basis was carried out. This was done by reviewing system drawings and talking to cognizant utility system engineers. The results are presented in Table 2-3. From these results, it is concluded that:

- the NRC/INEL blowdown closure test conditions are directly applicable to a small portion of the MOV population - about 4% of BWR valves and none of PWR valves.
- dependent on plant-unique configurations and "design-basis" interpretation, the NRC/INEL blowdown closure test conditions

GI-87 valves. The application of blowdown conditions to all of the safety-related valves in all of the plants was never intended or stated in any of our reports or presentations.

might be potentially applicable to additional valves (up to 15% for BWRs and 9% for PWRs).

- the NRC/INEL blowdown opening conditions are not generally applicable to valve design basis conditions in nuclear power plants.

APPLICABILITY OF NORMAL FLOW CONDITIONS

Because of the testing method used in the NRC/INEL tests, unique differential pressure behavior was observed during the normal flow valve strokes. Basically, two types of behavior were observed, which are called "Very Low DP Behavior" and "Changing DP Behavior with Hysteresis" in this report. These behaviors and their direct applicability are discussed below.

Very Low DP Behavior

Normal flow tests for Valves A, B, 4, 5 and 6 in the NRC/INEL tests were carried out in such a way that the valve DP was very small (<100 psi) throughout the test. This occurred because a low-head pump was used for Valves A and B and a large downstream accumulator volume (which didn't significantly depressurize as the valve was stroked closed and then open) existed for Valves 4, 5 and 6. Under these conditions, the system configuration, stroke time and hold time (between closing and opening strokes) influenced the DP. Detailed comparison to nuclear power plant systems was beyond the scope of this effort. As a result of the low DP in these tests, no useful disk factor information was obtained from these strokes (see Sections 5 and 6). These tests show that for valve conditions where DP is a negligible load compared to packing and piston effect loads, the valve can be stroked to full seat contact with the stem load remaining at essentially the running load. This favorable

We have never quoted a safety function for a valve to initiate blowdown flow, except perhaps for the PORV block valve.

As shown in Section 3.2.5 of this report, much of the low DP data were useful in that they helped provide an understanding of valve performance.

conclusion may apply to some systems in nuclear power plants. For most motor operated gate valves in nuclear power plants, the DP builds up in the last portion of the closing stroke, usually to a value which is not negligible in terms of overall valve load. Accordingly, the conditions for normal flow strokes for Valves A, B, 4, 5 and 6 in the NRC/INEL tests are not applicable to most nuclear power plant valves. Furthermore these tests do not provide useful quantitative information on valve performance.

Changing DP Behavior with Hysteresis

Normal flow tests for Valves 1, 2 and 3 achieved moderate DPs (several hundred psi) but did so in a unique time history fashion. Specifically, during closure strokes, the DP started to build just before the flow isolated and then continued to build as the disk moved to wedging (hard seat contact). After the disk seated and valve motion stopped, DP continued to build. As the opening stroke started, DP continued to build slightly as the disk moved off the seat and then rapidly dissipated as the flow area was opened (see Figure 2-6). This behavior, which was different opening than closing (hysteresis), was due to the presence of a moderate size accumulator volume downstream of the test valve.[1] Under these conditions, DP is sensitive to system configuration, stroke time and hold time (between close and open strokes). This type of behavior may be applicable to some nuclear power plant systems. However, this type of DP condition would not be expected in typical nuclear power plant MOV gate valve applications, which are typically in pumped systems. Based on discussions with utility personnel and review of limited utility data, we find that typically the DP is constant at its maximum value (not changing) while the disk moves from isolation to hard seat, and that there is very little hysteresis. Accordingly, the INEL normal flow conditions are quite unlike typical gate valve conditions in power

Hysteresis describes "the phenomenon exhibited by a system in which the reaction of a system to changes is dependent upon its past reactions to change." Whether the DP behavior of the NRC/INEL piping system is attributed to hysteresis or to some other characteristic is not important.

It was not our intention to precisely duplicate specific in-plant conditions during the NRC/INEL tests, but rather to obtain data that could be used to characterize valve behavior in general. Thus, what is important here is the actual DP at the valve for a specific point in the valve cycle. As discussed in Section 3.2.5 of this report, the data from these tests provide useful information with regard to a valve's on-the-seat performance.

plants. Although great care should be used in interpreting and applying results of these tests, it is expected that some data would be useful in valve evaluations. However, the evaluations described in Sections 5 and 6 show little or no meaningful information could be obtained at the point of flow "isolation" (due to very low DP) and that disk factors determined at other points (between isolation and seating for example) gave suspicious results (i.e., they were substantially out of agreement with other tests). Until these data are studied in more detail, it does not appear stem forces or disk factors determined from the data plots should be directly applied to nuclear power plant valves.

APPLICABILITY OF NO-FLOW CONDITIONS

Tests with "no-flow" conditions covered opening strokes only. In these tests, the presence of an initially depressurized downstream volume actually permitted a brief period of flow -- much less than one second for cold conditions, about one second for hot water conditions (6" valves) and several seconds for steam conditions (10" valves). The longer duration for the hot conditions is attributed to the flashing two-phase flow or steam inrush flow as the valve initially opens and starts to pressurize the downstream volume. For 10" valves tested in steam, these "no flow" tests actually established several seconds of blowdown-like conditions. As discussed earlier, opening against blowdown flow is not a condition applicable to most gate valves in nuclear power plants, and thus 10" hot "no-flow" tests are not directly applicable to most industry MOVs.

The condition of a very brief initial period of flow followed by a prolonged period of no-flow during the opening stroke may be applicable to some MOVs but is not the same as the design basis conditions of most safety-related MOV's in nuclear power plants. Typically valves have the

The leakage and the cold and hot cyclic no-flow tests were part of the ANSI/ASME B16.41 valve qualification tests. The tests were applicable for what they were intended. Section 3.2.6 provides additional information on this issue.

greatest flow when the valve is full open. Even though the test condition is not directly applicable to typical valve design basis conditions, the DP profile for cold tests and for 6" valve hot tests somewhat resembles that for opening a typical valve in a pumped system (Figure 2-5). Accordingly, these tests provide data which may be potentially applicable to gate valves under a wide range of conditions, since the loading on the disk as a function of stroke position is similar. This result also suggests that a simplified in-plant test method in which the valve is opened after the upstream has been pressurized with a hydro pump may provide meaningful information for many valves.

Table 2-1

PHASE 1 BLOWDOWN CLOSURE STROKES WHERE NITROGEN FLOW APPARENTLY REPLACED WATER FLOW

Valve/Test/Step	% Closed at Nitrogen Flow Initiation
A-3-5	28
A-2-7	30
A-6-5	2
A-7-7	55
B-2-7	48
B-3-7	70
B-5-5	59

Table 2-2

PHASE 1 BLOWDOWN CLOSURE STROKES WITH APPARENT PARTIAL NITROGEN ENTRAINMENT

Valve/Test/Step	% Closed at Nitrogen Flow Initiation
A-2-5	59
A-5-5	62
A-9-5	14
A-10-7	93
A-11-5	10
B-2-5	10
B-3-5	52
B-4-7	72

Table 2-3

SUMMARY OF GATE VALVES EXPOSED TO BLOWDOWN ISOLATION CONDITIONS WITHIN DESIGN BASIS

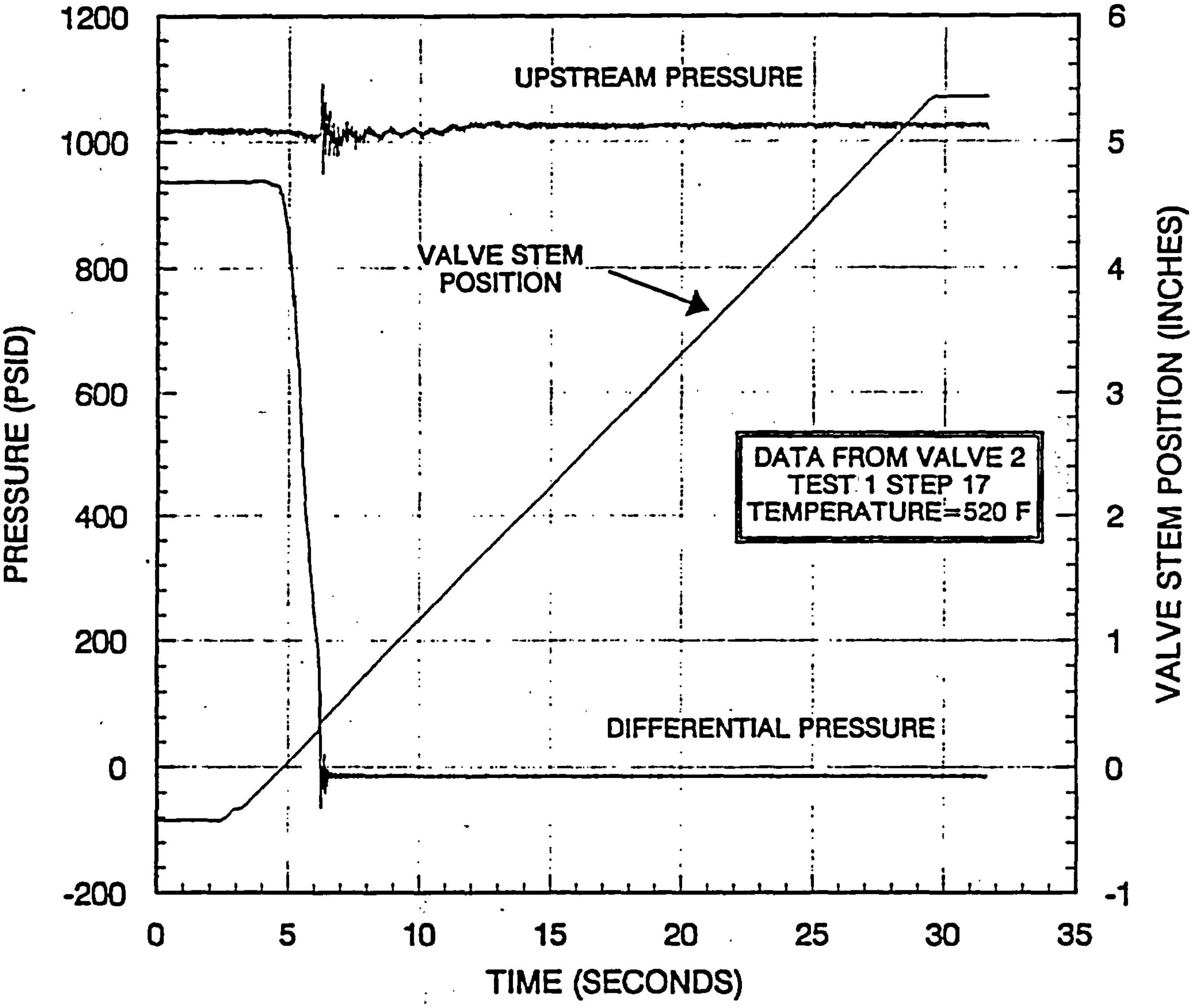
CRITERIA*

1. Motor-Operated
2. Gate Valve
3. High Energy Blowdown Isolation Within Design Basis Function

* An applicable valve had to meet all three criteria.

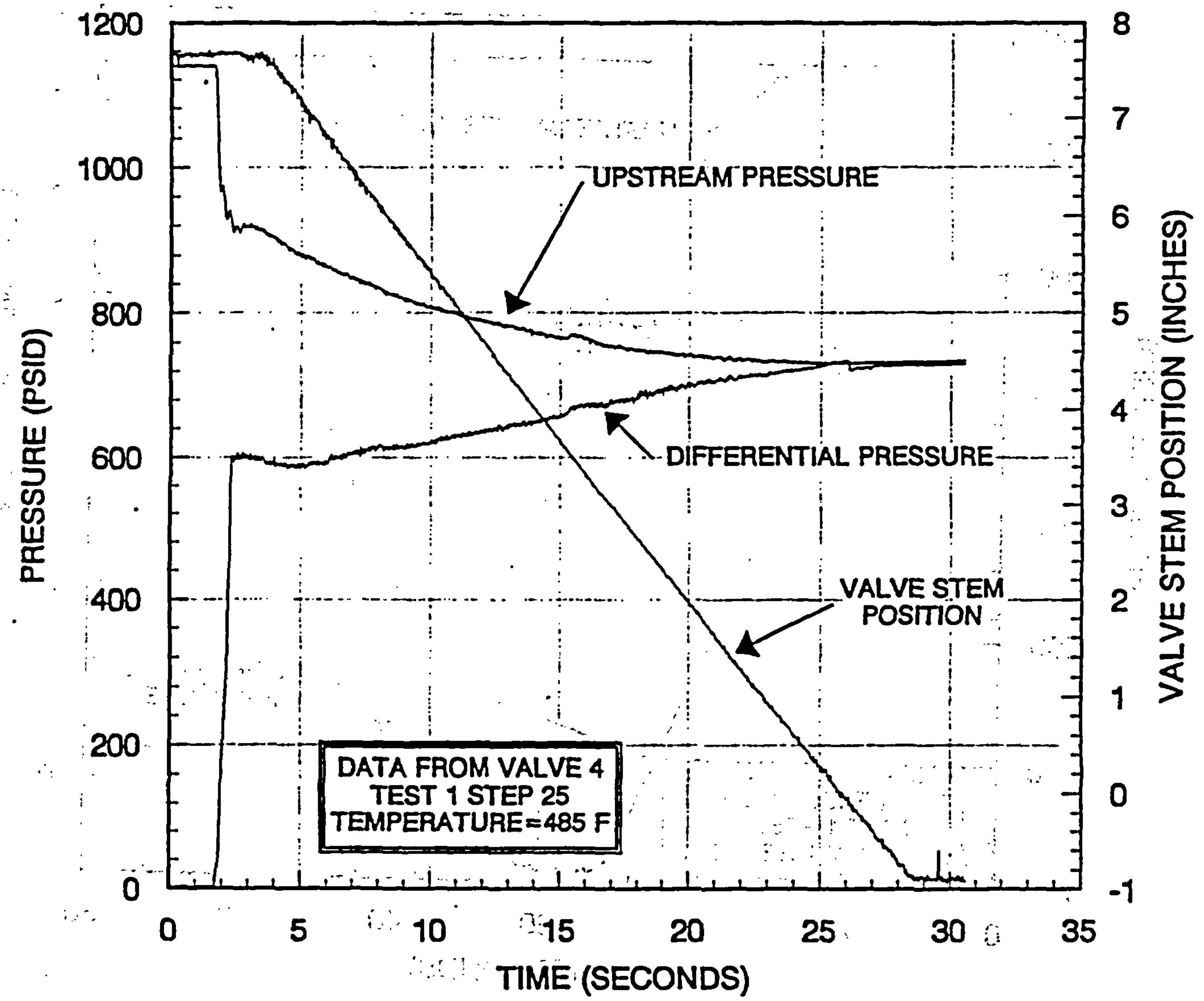
Reactor Type	Minimum Extent of Applicability	Possible Additions to Applicability (May be beyond Design Basis)
BWR	6 valves/unit (about 4% of MOVs) These are lines connected to the primary system and penetrating containment, with normally open MOV's and no check valves.	Up to 20 valves/unit (about 15% of MOVs) These are lines connected to the primary system and penetrating containment, but MOVs are normally <u>closed</u> or there are check valves.
PWR Primary System	0 valves/unit In many units, no MOV isolation on primary system required <u>within design basis</u>. Isolation capability may be implied or desired on some valves.	2 to 3 valves/unit (2% of MOVs) PORV block valves, let- down line MOVs on some units.
PWR Secondary System	0 valves/unit Nominally, no MOV isolation on secondary side required <u>within design basis</u>. Isolation capability may be implied or desired on some valves.	Up to 10 valves/unit (7% of MOVs) Lines with check valves (e.g. feed lines) or lines attached to main steam pipes.

1.We have requested, but not been provided with, drawings and detailed information to allow this "system effect" to be independently calculated.

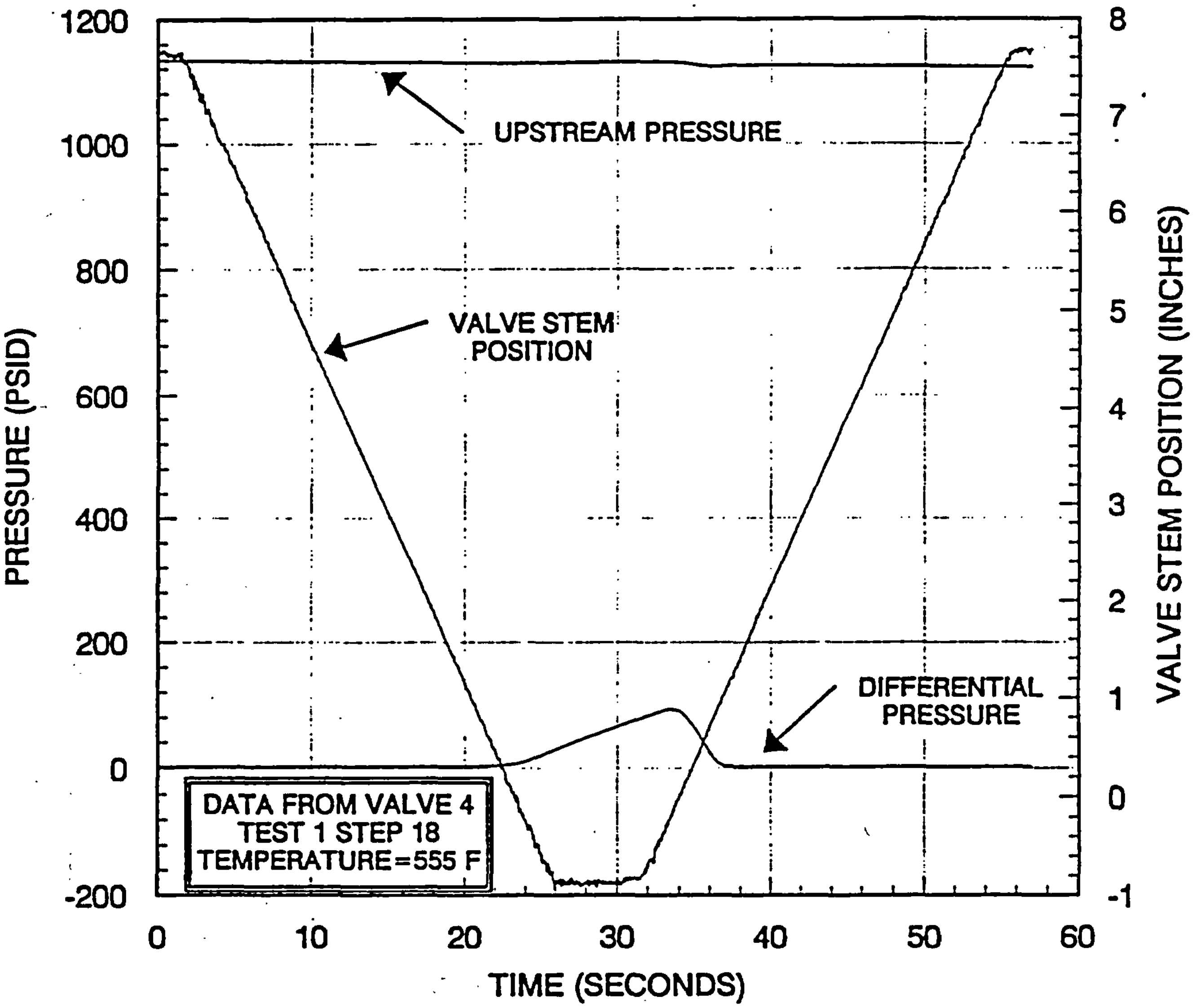


PRESSURE, DP, AND POSITION HISTORIES FOR NO-FLOW OPENING TEST

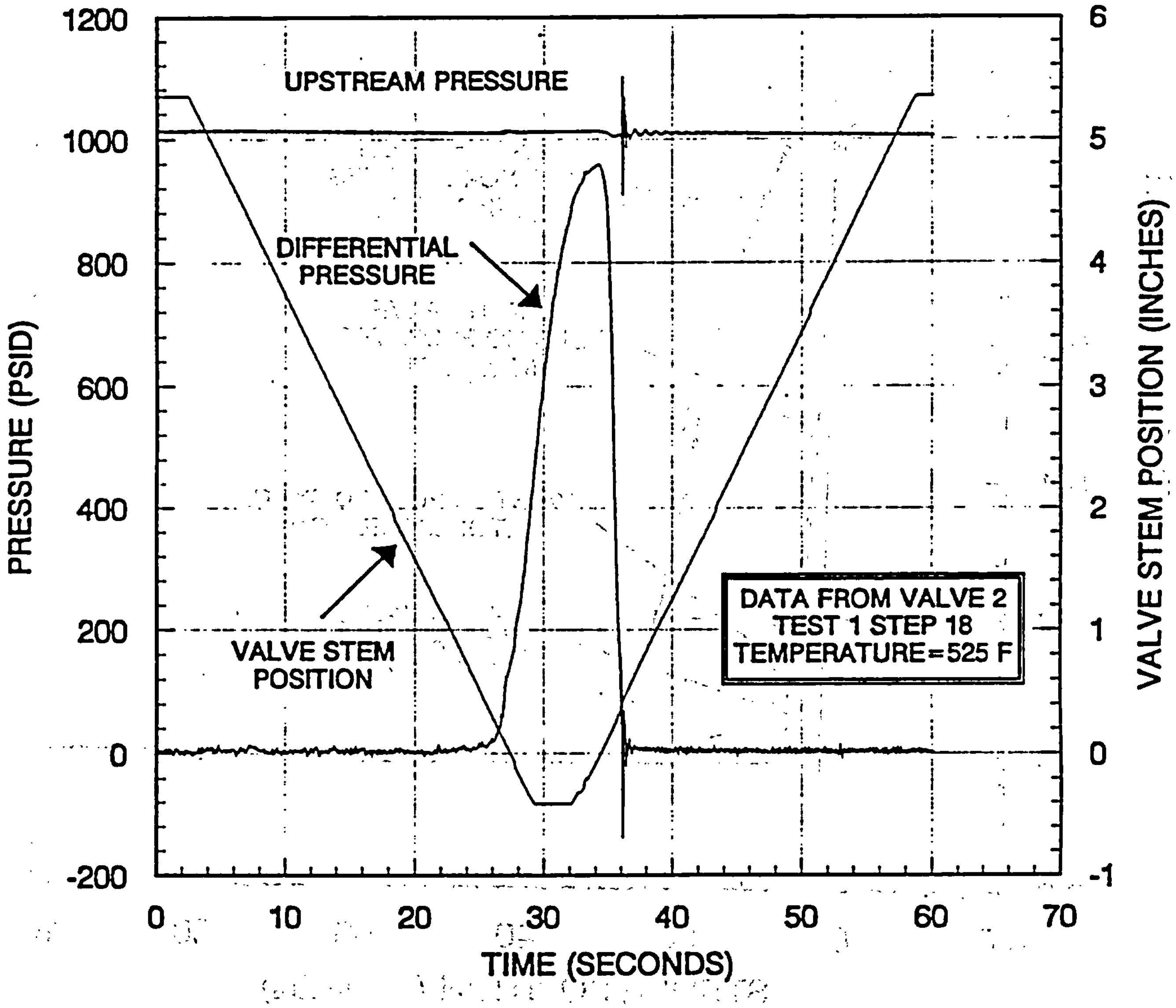
FIGURE 2-1



PRESSURE, DP, AND POSITION HISTORIES
FOR BLOWDOWN CLOSING TEST
FIGURE 2-2

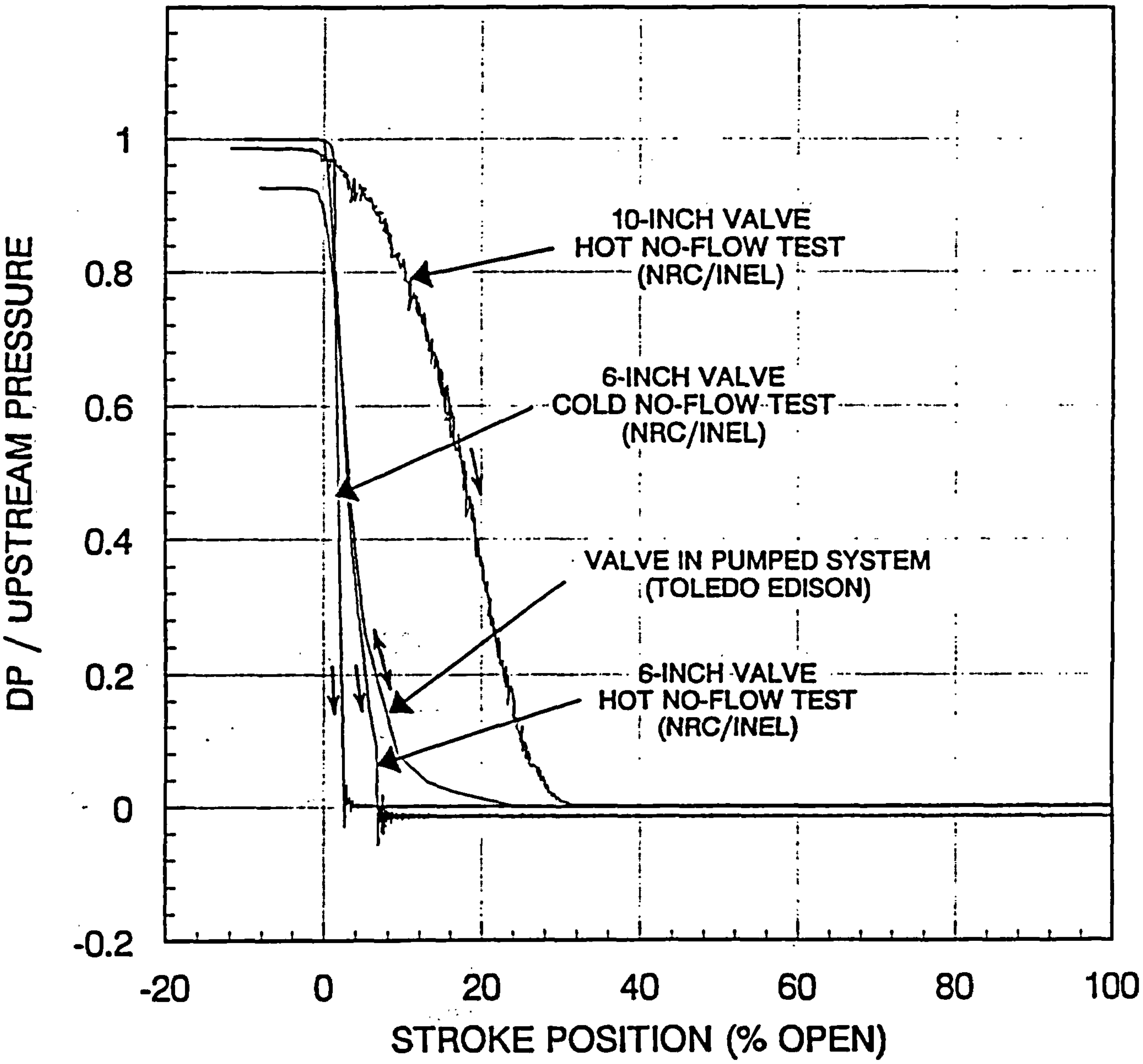


PRESSURE, DP, AND POSITION HISTORIES
FOR NORMAL FLOW TEST--10-INCH VALVE
FIGURE 2-3



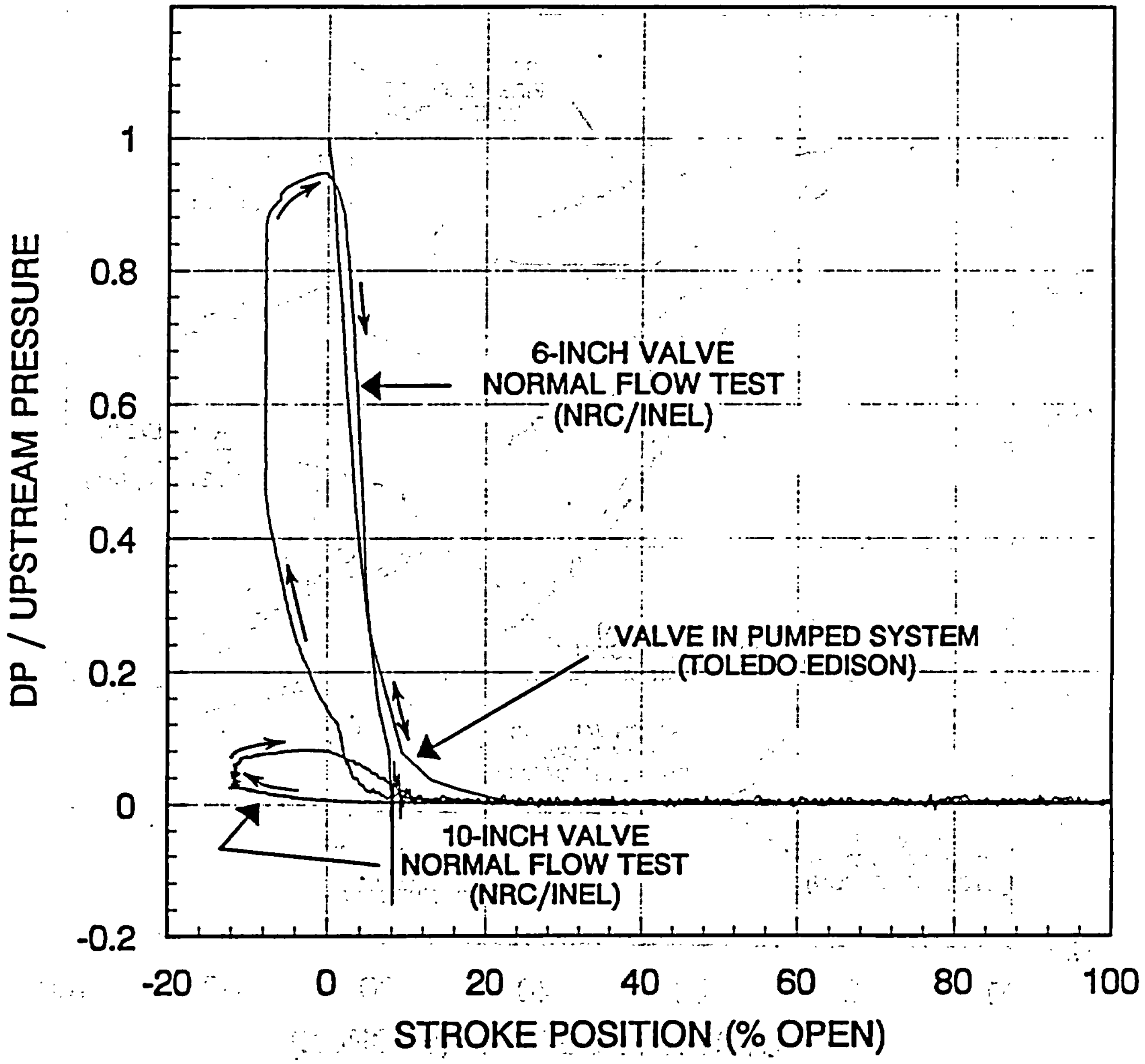
PRESSURE, DP, AND POSITION HISTORIES
FOR NORMAL FLOW TEST--6-INCH VALVE

FIGURE 2-4



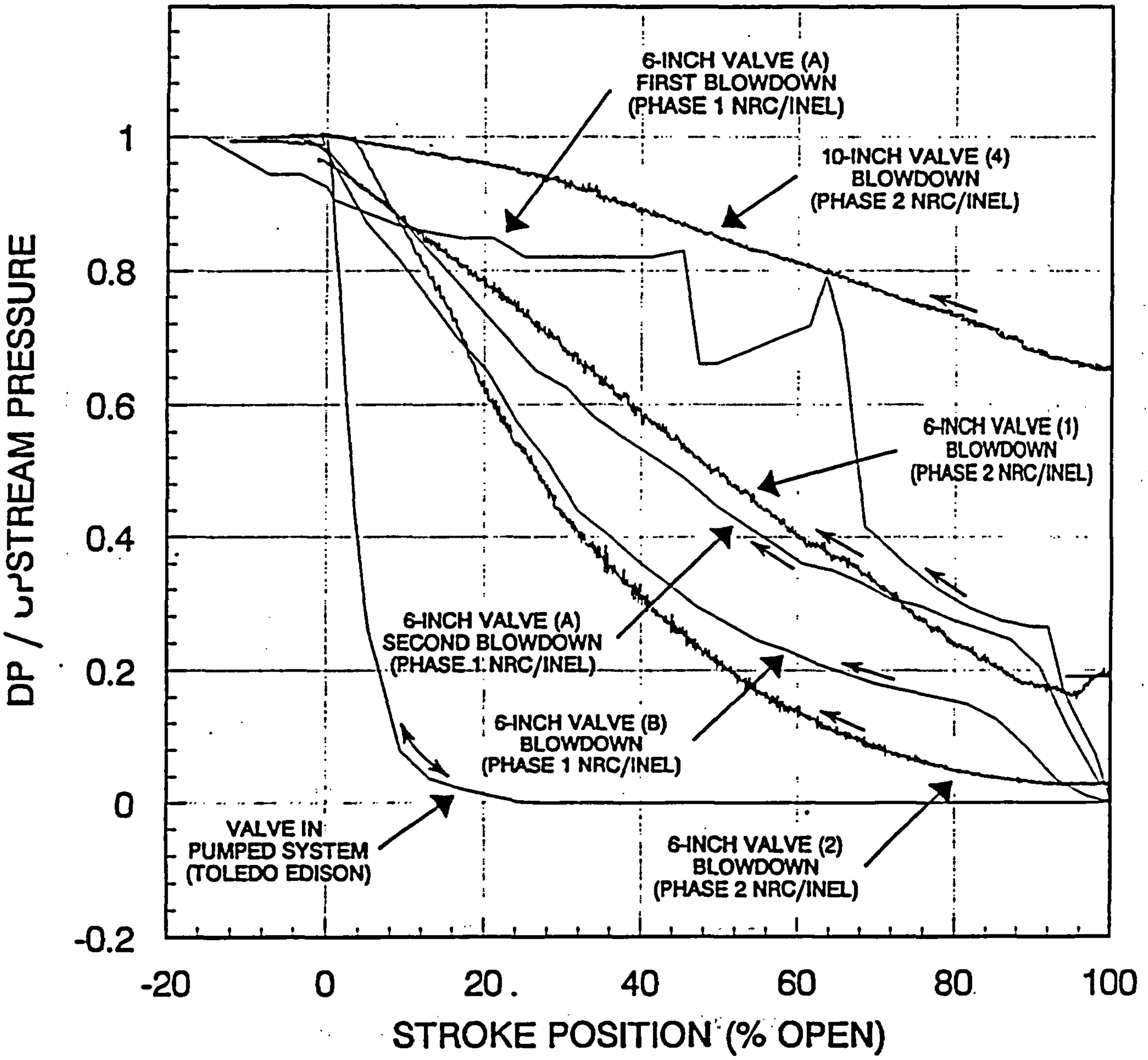
NORMALIZED DP VS. STROKE FOR NO-FLOW TESTS AND VALVE IN PUMPED SYSTEM

FIGURE 2-5



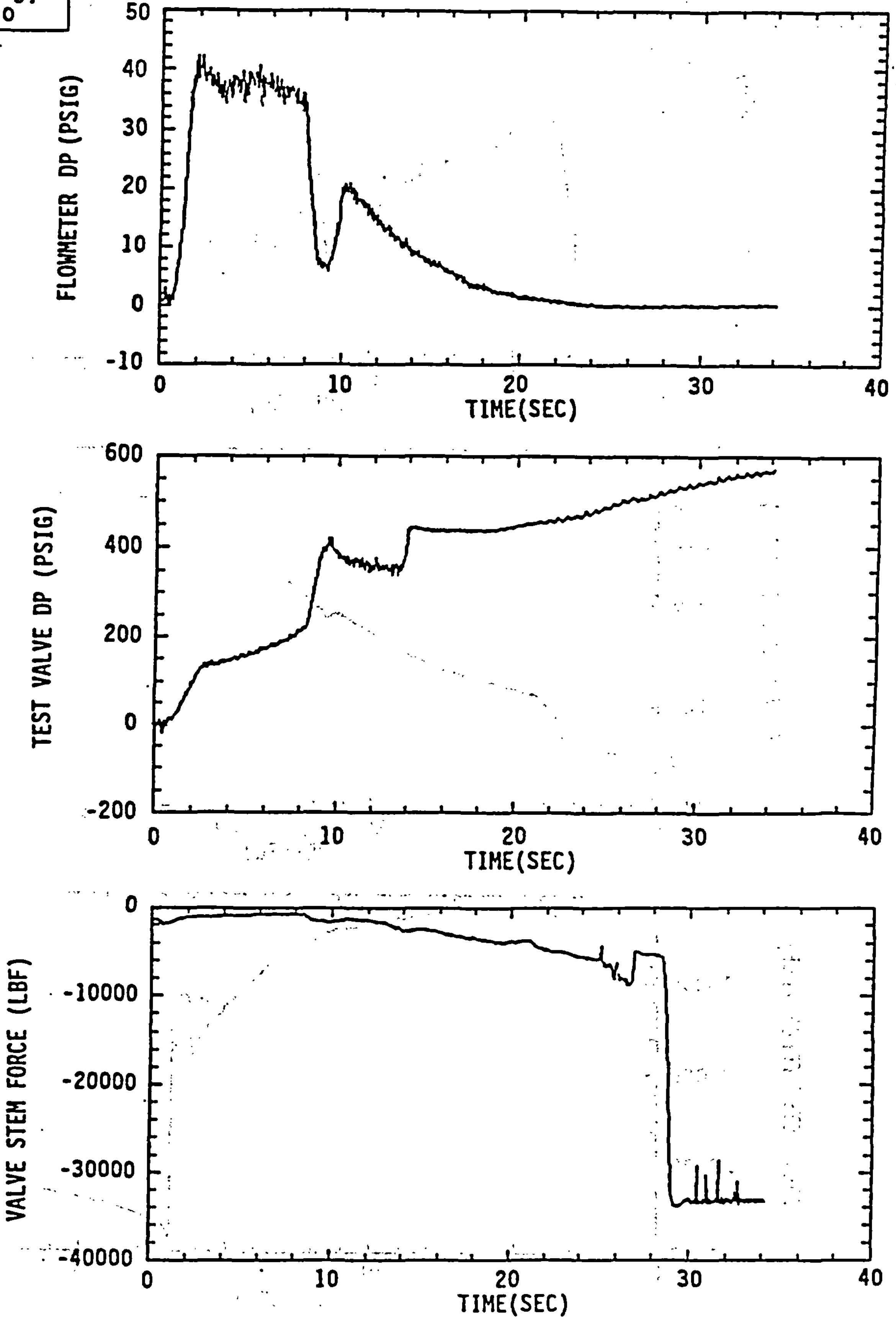
NORMALIZED DP VS. STROKE FOR NORMAL FLOW TESTS AND VALVE IN PUMPED SYSTEM

FIGURE 2-6



NORMALIZED DP VS. STROKE FOR BLOWDOWN TESTS AND VALVE IN PUMPED SYSTEM
FIGURE 2-7

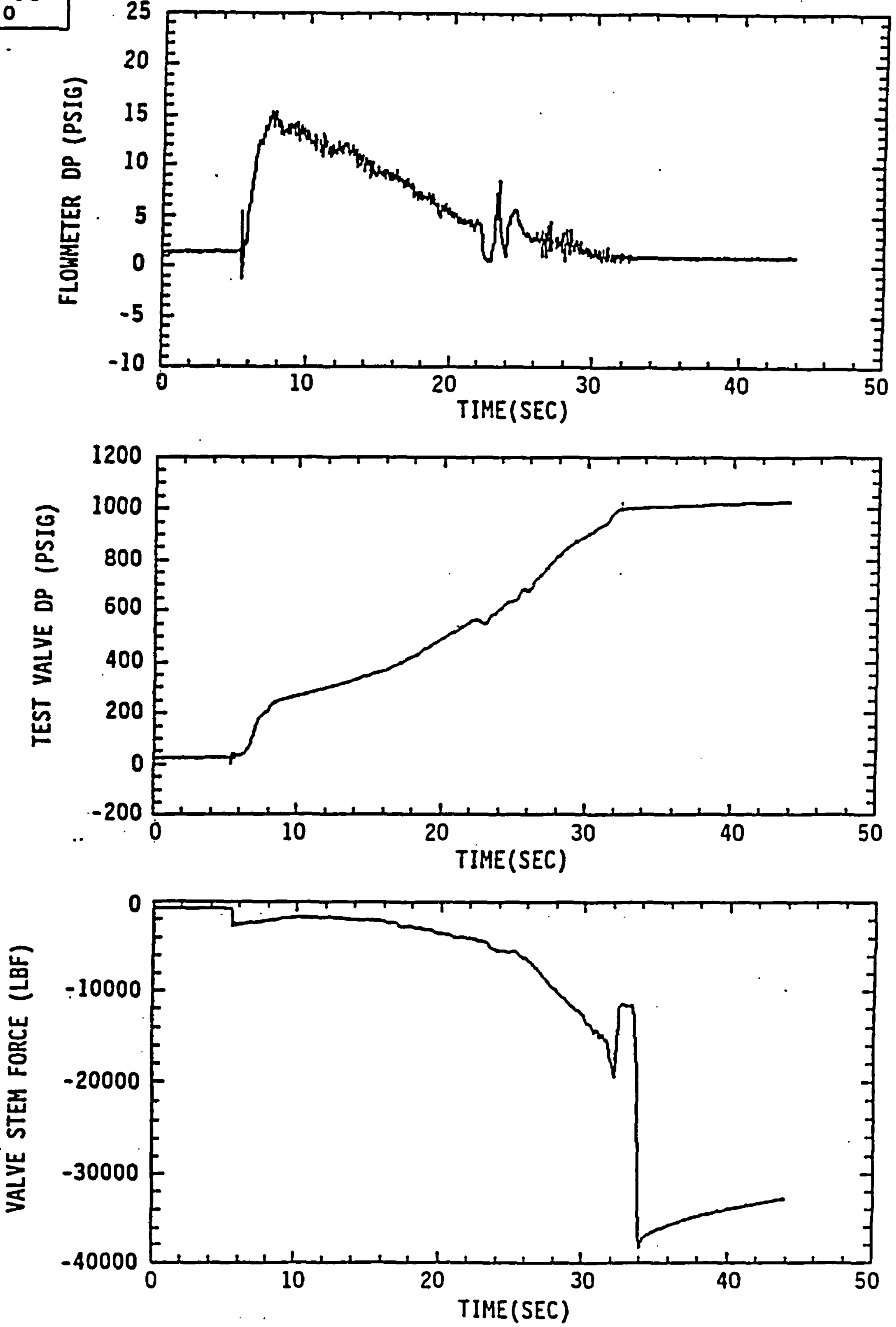
MPR ASSOCIATES
F-140-49-97
11/8/90



FLOWMETER DP, VALVE DP AND STEM FORCE
FOR FIRST VALVE A BLOWDOWN CLOSING STROKE

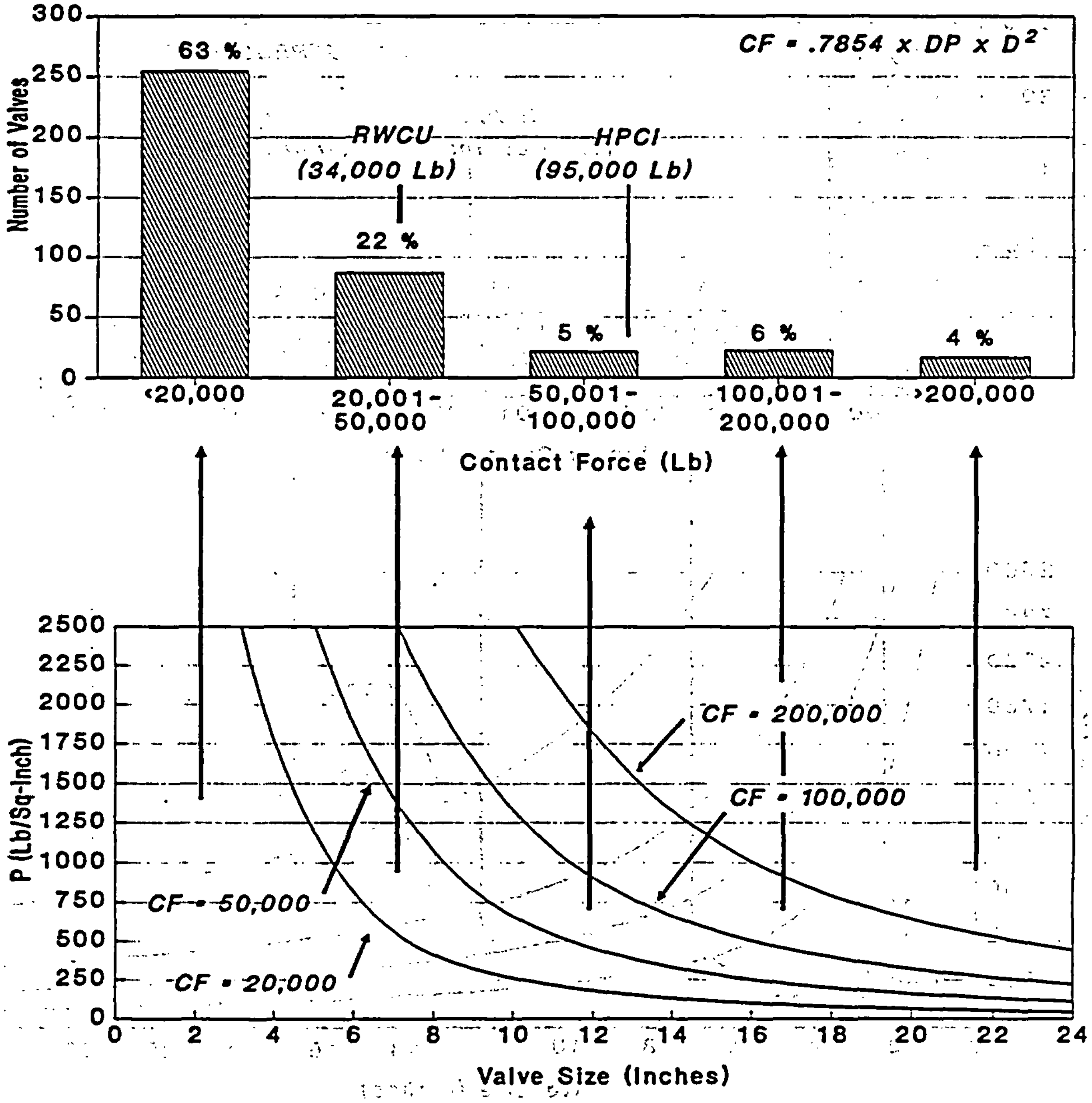
FIGURE 2-8

MPR ASSOCIATES
F-140-49-98
11/8/90



FLOWMETER DP, VALVE DP AND STEM FORCE
FOR SECOND VALVE A BLOWDOWN CLOSING STROKE

FIGURE 2-9

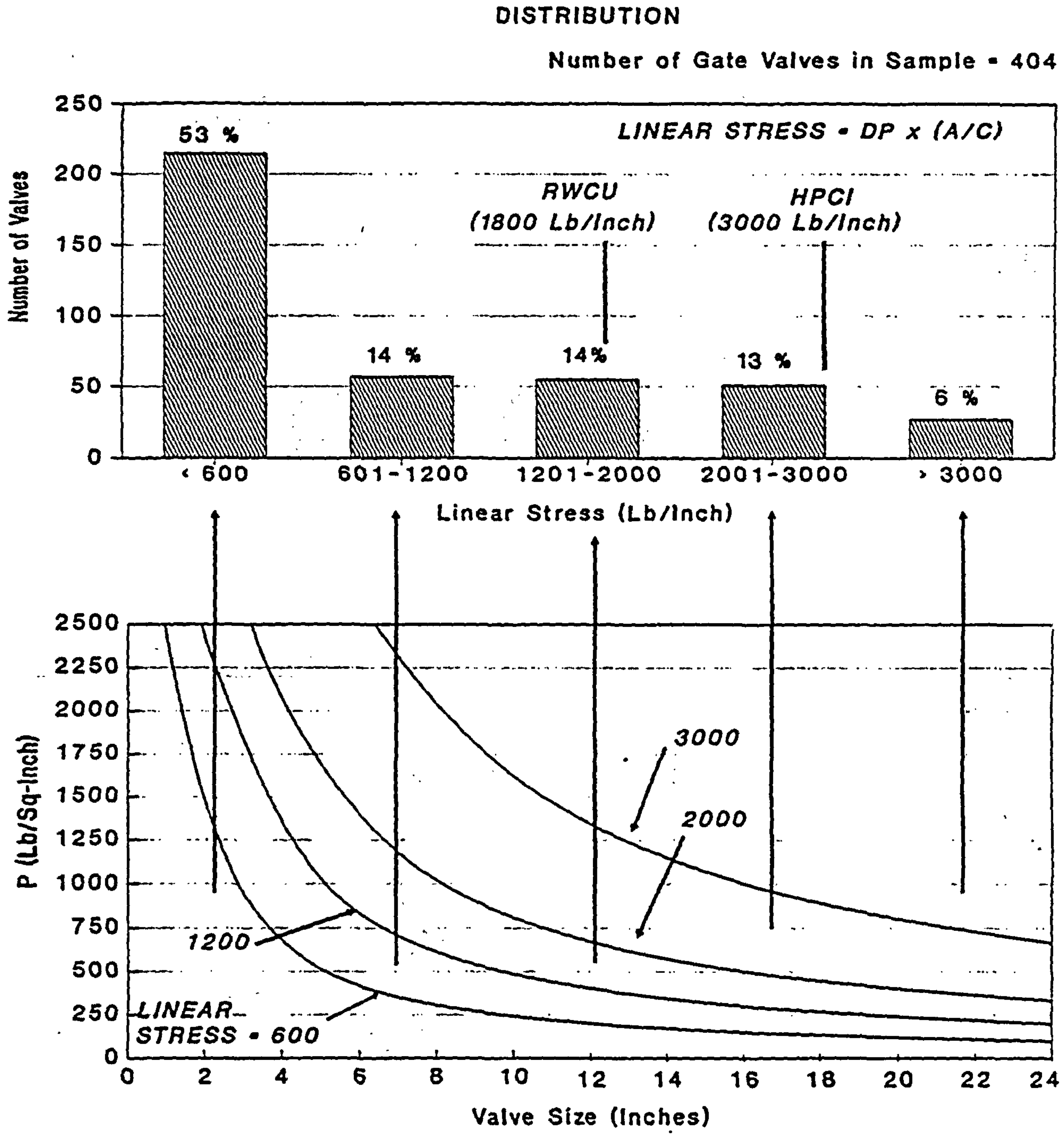


DISTRIBUTION

VALVE SIZE VS. PRESSURE CHART

COMPARISON OF RWCU AND HPCI CONDITIONS TO GATE VALVE POPULATION BASED ON CONTACT FORCE

FIGURE 2-10



VALVE SIZE VS. PRESSURE CHART

COMPARSION OF RWCU AND HPCI CONDITIONS
TO GATE VALVE POPULATION BASED ON LINEAR STRESS

FIGURE 2-11

Section 3

APPLICABILITY OF TEST VALVES USED IN NRC/INEL TESTS

Table 3-1 summarizes construction, configuration, nameplate and history information regarding each of the valves used in the NRC/INEL tests. Table 3-2 provides information on the three Limitorque operators used in the NRC/INEL tests. This report principally addresses the valves.

In general, available documentation from the NRC/INEL tests does not describe in detail the configuration of each valve. The inspection described in Section 4 was effective in obtaining detailed configuration information for Valves 1 through 6 (and the disk from Valve B). This information is applicable to Valves A and B for surfaces which were not reworked between Phase 1 and Phase 2.

Existing documentation from the NRC/INEL tests does not describe in detail the manufacturing/storage/maintenance history of each valve. This was pursued to the extent possible through the valve manufacturers (and refurbishers where applicable); the information presented in Table 3-1 and discussed below reflects the findings of this process. Each test valve is individually described below. Emphasis is placed on the applicability of the test hardware to nuclear power plant valves.

VALVE A (PHASE 1) AND VALVE 1 (PHASE 2)

Valve A was used in the Phase 1 tests. Subsequently, the valve was refurbished and reused as Valve 1 in the Phase 2 tests. Valve A is an Anchor/Darling 6-inch flexible wedge gate valve with an ANSI class pressure rating of 900 lbs. This valve was specifically fabricated by Anchor/Darling in 1988 for use in the INEL Phase 1 test program. This

The data described in Section 4 were obtained by the NRC-funded, joint NRC/EPRI posttest hardware inspection. The data from this effort are part of the "available documentation from the NRC/INEL tests."

This Section of the EPRI report points out that the valve manufacturers whose valves we tested have supplied to the utilities valves with other designs. Section 3.3.1 of this report addresses this issue. A few remarks are also provided here.

valve was fabricated using parts which were in inventory at Anchor/Darling from one of the SNUPPS plants that was canceled in the late 1970's. The figures and information in Section 4 and Appendix D of this report (for Valve 1) show the configuration of this valve. This valve had machined guide slots in the carbon-steel disk, cast guide rails in the carbon-steel body, and Stellite 6 hardfacing on the disk and seat faces. Anchor/Darling indicates that Valve A is similar in design features to a large population of flexible wedge gate valves they have manufactured and supplied to nuclear power plants. However, it is important to point out that Anchor/Darling has also manufactured gate valves with other design features.

- A considerable number of flexible wedge gate valves with integral machined body guide surfaces have been supplied to nuclear power plants.
- A small population of flexible wedge gate valves with machined, hardfaced guide slots and/or rails have been supplied to nuclear power plants.
- A considerable population of double disk (parallel disk) gate valves have been supplied to nuclear power plants.

In each of the above cases, Anchor/Darling indicates that valve performance is affected by the differences in design. Accordingly, Valve A results from the NRC/INEL tests are not considered to be directly

We tested integral machined body guides on Valve 5 (10-inch Powell). The valve was nonpredictable.

With Valves B and 2 (same 6-inch Velan valve), we tested hardfaced versus non-hardfaced guide slots. They performed the same.

In the EPRI/Marshall PORV and block valve tests conducted in 1980, an Anchor/Darling double disc gate valve was tested. The test valves were basically uninstrumented (go/no-go tests). In the block valve test, the Anchor/Darling double disc gate valve did not close with the originally sized operator, requiring a seat design change prior to retest. No data are available to indicate why the Anchor/Darling valve failed, what stem thrust was required to close each valve, or how these results compare to industry calculations.

This statement might lead the reader to infer that the other designs might perform adequately. In light of the above discussion, that might not be a good assumption.

applicable to valves with these other features.	
Anchor/Darling indicates that, at the time Valve A was provided to INEL, it met all of the configuration and tolerance requirements for that particular valve design. Anchor/Darling considers Valve A to be representative of Anchor/Darling valves in service at nuclear power plants which have this same overall design. Unfortunately, detailed dimensional information on Valve A is not available. (Valve 1 dimensions for surfaces not reworked during refurbishment would be applicable to Valve A.) Because of limited information, the extent of the applicability of data from Valve A to a particular valve (whose detailed dimensions may be different from Valve A) may be difficult to evaluate.	Some detailed dimensions are available. To restate EPRI's parenthetical statement, all non-refurbished surfaces of Valve 1 are Valve A surfaces. Comparison of detailed dimensional information to other valves is difficult if not impossible because detailed dimensional information on the valves installed in nuclear plants is typically not available. More documented information exists for Valve A than for the typical nuclear plant valve.
After the Phase 1 test program, Valve A was refurbished to be used as Valve 1 in the Phase 2 test program. The refurbishment was performed by Crane Valve Services. Unfortunately, this refurbishment was not performed in accordance with the Crane nuclear Q/A program, and the available records are minimal. It is not possible to tell from the records what operations were carried out in the refurbishment. The purchase order indicates the following: "Inspect Anchor/Darling valve - 6", 900 pound, Valve serial No. E-A345-1-1 and refurbish. In addition, manufacture a new stem nut for an SMB-0 Limitorque Motor Operator. Refurbishment will require disc and seat repair. The downstream disc face and body seat were previously damaged in testing." The final work invoice indicates that the following additional work was performed:	A complete discussion of this issue is presented in Section 3.3.2 of this report. A few remarks are also provided here.
- Machined and redrilled actuator mounting plate.	This was required to attach the Phase II motor operator.
- Machined and spray welded stem.	The valve stem was gouged in Phase I and had to be repaired.

- Installed Chesterton brand live loaded packing system.	The live loaded packing was installed to test its influence (if any) on valve performance.
INEL indicates that their understanding of the refurbishment was that the damaged disk and seat face surfaces (downstream surfaces in Phase 1) were rebuilt and refinished and that the upstream surfaces from Phase 1 were not refurbished. The valve was turned around for Phase 2 testing, so INEL understood that the load-bearing, downstream surfaces of disk and seat for Phase 2 (i.e. the upstream surfaces from Phase 1) were original, undamaged surfaces[1].	The valve was installed in the system with flow direction reversed from Phase I so that the downstream disc surface and valve body seat ring were original Anchor/Darling surfaces. Valve 1 was disassembled immediately after the Phase II testing to verify that the Crane refurbished surface was not downstream. As verified by INEL and NRC, the original Anchor/Darling surface was in the proper downstream orientation.
Based on information from the valve inspection as discussed in Section 4, Anchor/Darling indicates that the downstream disk face of Valve 1 does not meet the configuration requirements for the Anchor/Darling valve design. Two particular points were noted.	
- The Stellite face was very thin. Such a condition can be detrimental to valve performance because the Stellite may have high iron content, which results in poorer friction, hardness and wear properties. The hardness and iron content measurements from the inspection confirmed that this Stellite face had degraded properties. Specifically, the iron content was about 20% (versus a "normal" value around 5%) and the hardness was 35 Rc (versus an expected value of 40-45).	This surface was manufactured by Anchor/Darling.
- The Stellite disk face had a sharp edge at the OD. Anchor/Darling indicates that in their fabrication process this sharp edge is removed by hand stoning. A sharp edge is potentially detrimental to valve performance because it increases the likelihood of disk/seat damage when the parts come into contact under highly loaded conditions. The seat damage pattern observed in the inspection confirmed that the disk had aggressively attacked the seat during the tests.	The edge configuration of Valve 1 is the same as that delivered by Anchor/Darling on Valve A.
Anchor/Darling has determined that Valve 1 is <u>not</u> representative of Anchor/Darling valves and that data from Valve 1 tests are <u>not</u> applicable	The INEL considers the performance of Valve 1 to be representative of hardware delivered by the manufacturer to the INEL. The valve was

to Anchor/Darling valves in nuclear power plants. The observed configuration of Valve 1 could have been the result of the disk face being machined down during refurbishment at Crane. Such a process could thin the existing Stellite layer and remove an existing bevel at the edge. Unfortunately, available documentation is not sufficient to evaluate this hypothesis, although it is plausible.

VALVE B (PHASE 1) AND VALVE 2 (PHASE 2)

Valve B was used in the Phase 1 tests. Subsequently, the valve was refurbished and reused as Valve 2 in the Phase 2 tests. Valve B is a Velan 6-inch flexible wedge gate valve with an ANSI class pressure rating of 900 lbs. This valve was fabricated by Velan in 1988 specifically for use in the INEL Phase 1 test program. The figures and information in Section 4 and Appendix D of this report show the Valve 2 configuration. Valve B had machined guide slots in the disk which were hard-faced with Stellite 6, and machined, welded-in, carbon-steel guide rails in the valve body. The disk and seat faces were also hard-faced with Stellite 6. Velan indicates that Valve B had design features similar to a considerable population of gate valves which they manufactured and supplied to nuclear power plants. However, it is important to note that Velan has also manufactured gate valves with other design features.

- A considerable number of flexible wedge gate valves with machined, carbon-steel guide slots have been supplied to nuclear power plants. (It appears Valve 2 has this design feature, see below.)

- A considerable population of flexible wedge gate valves with a much different disk design have been supplied to nuclear power plants. The other disk design is much thinner, has longer guide slots and has the T-head connection above the disk seating faces rather than between them. Figure 3-1 shows a general comparison of the two designs. According to Velan, the thin disk design is used only in valves with ANSI class ratings up to and including

delivered with the understanding that it was representative of Anchor/Darling hardware delivered to the nuclear industry.

We agree with the Velan assessment of Valve B applicability: "Velan indicates that Valve B had design features similar to a considerable population of gate valves which they manufactured and supplied to nuclear power plants."

For the Phase II test with Valve 2, the disc was changed to one with carbon-steel guide slots. A comparison of Valve 2 test results with Valve B test results shows no difference due to disc guide hardfacing.

Valve 3 (6-inch Walworth) used a thin disc design. The on-the-seat performance was similar to that of Valves B and 2.

600 lbs.

In each of the above cases, it appears that valve performance can be affected by the differences in design. Accordingly, Valve B results from the NRC/INEL tests are not considered to be directly applicable to valves with these other features. Velan indicates that, at the time Valve B was provided to INEL, it met all of the configuration and tolerance requirements for that particular valve design. Accordingly, Velan considers Valve B to be representative of Velan valves in service at nuclear power plants which have the same overall design. Unfortunately, detailed dimensional information on Valve B is available only for the disk. (Valve 2 body dimensions for surfaces not reworked during refurbishment would be applicable to Valve B.) Because of limited information, the extent of applicability of data from Valve B to a particular valve (whose detailed dimensions may be different from Valve B) may be difficult to evaluate.

After the Phase 1 test program, Valve B was refurbished to be used as Valve 2 in the Phase 2 test program. The refurbishment was performed by the manufacturer, Velan Inc. The Velan refurbishment summary indicates the following was done.

- The disk was replaced with a new disk without hardfacing on the guide slots. Otherwise, the disk was of similar design.
- The valve body seat faces were re-lapped.

Based on information from the valve inspection as discussed in Section 4, Velan indicates that Valve 2 is representative of valves in nuclear power plants which have this same overall design. Data from Valve 2 tests in the NRC/INEL program would not be directly applicable to Velan valves with other design features (i.e. hardfaced disk guide slots and/or body guides, or alternate disk design).

More information exists for Valve B then for a typical valve installed in a plant.

We agree with the Velan assessment of Valve 2 applicability, "Velan indicates that Valve 2 is representative of valves in nuclear power plants which have this same overall design." Based on the above information, we believe the results from Valve B and Valve 2 are applicable to both hardfaced and nonhardfaced disc guide designs.

VALVE 3

Valve 3 is a Walworth 6-inch flexible wedge gate valve with a 600-lb ANSI class pressure rating. This valve was fabricated by Walworth Valve in 1979 for one of the North Anna canceled units (3 or 4). The figures and information in Section 4 and Appendix D show the Valve 3 configuration. This valve had carbon-steel, machined guide rails. The guide rails were fabricated as a single, removable "U" piece which was held in place by a slot at the bottom of the body and dowel pins at the top. The guide was free to deflect between the upper and lower supports. The disk and seat faces were hard-faced with Stellite 6.

Presently, Crane Valves controls and services the Walworth line of gate valves. Crane indicates that the Valve 3 design features are similar to Walworth flexible wedge gate valves supplied to nuclear power plants. They also indicate that this Walworth valve has design features similar to some Crane valves.

After INEL obtained Valve 3, it was shipped to Crane Valve Services for "refurbishment." This work was not performed in accordance with the Crane Nuclear QA program, and the available records are minimal. It is not possible to tell from the records what operations were carried out in the refurbishment. The "Request for Quotation" states the following:

> "Refurbish Walworth 6" 600 pound flex. wedge gate valve either Serial Number D66316, D66350, or D66507 (identified at a later date); Figure 5232 PS. The valve will be furnished to Crane-ALOYCO (C-A) without a motor operator. Refurbishment will include manufacture of new stem nut and mating new motor operator. EG&G/INEL will furnish a Limitorque SMB-0 motor operator to C-A for final valve checkout. C-A will furnish all other parts for refurbishment. CA will disassemble valve and dimensionally inspect and record critical dimensions; reassemble with new gaskets and packing and perform normal checkouts prior to shipping valve."

We agree with the Crane-Aloyco assessment of Valve 3 applicability: "Valve 3 design features are similar to Walworth flexible wedge gate valves supplied to nuclear power plants. They also indicate that this Walworth valve has design features similar to some Crane valves."

The final purchase order was not available. The work invoice indicates that the following additional work was performed:

- machined and redrilled actuator mounting plate.

This was required to adapt the valve yoke for mounting the Phase II motor operator.

No records of dimensional measurements required by the Request for Quotation are available. No records of seat leakage or hydrotests are available.

The records of dimensional measurements taken by Crane-Aloyco are considered proprietary. Full dimensional measurements were taken as part of the NRC/EPRI posttest hardware inspection effort and are contained in this EPRI report. The ANSI/ASME B16.41 Qualification tests contain the hydro and leakage test results.

VALVE 4

Valve 4 is an Anchor/Darling 10-inch flexible wedge gate valve with an ANSI class pressure rating of 900 lbs. This valve was fabricated by Anchor/Darling in 1982 for Hope Creek Unit 2, which was subsequently canceled. The figures and information in Section 4 and Appendix D of this report show the Valve 4 configuration. This valve had machined guide slots in the carbon-steel disk, cast guide rails in the carbon-steel body, and Stellite hardfacing on the disk and seat faces. Anchor/Darling indicates that Valve 4 is similar in design features to a large population of flexible wedge gate valves they have manufactured and supplied to nuclear power plants. However, it is important to point out that Anchor/Darling has also manufactured gate valves with other design features.

We agree with the Anchor/Darling assessment, "that Valve 4 is similar in design features to a large population of flexible wedge gate valves they have manufactured and supplied to nuclear power plants."

- A considerable number of flexible wedge gate valves with integral machined body guide surfaces have been supplied to nuclear power plants.

We tested integral machined body guides on Valve 5 (10-inch Powell). The valve was nonpredictable.

- A small population of flexible wedge gate valves with machined, hardfaced guide slots and/or rails have been supplied to nuclear power plants.

- A considerable population of double disk (parallel disk) gate valves have been supplied to nuclear power plants.

In each of the above cases, Anchor/Darling indicates that valve performance is affected by the differences in design. Accordingly Valve 4 results from the NRC/INEL tests are not considered to be directly applicable to valves with these other features.

After INEL obtained Valve 4, it was shipped to Crane Valve Services for "refurbishment". Unfortunately, this work was not performed in accordance with the Crane nuclear QA program, and the available records are minimal. It is not possible to tell from the records what operations were carried out in the "refurbishment". The purchase order indicates the following:

> "Refurbish Anchor/Darling (A/D) 10", 900 pound flexible wedge gate valve Serial No. E6162-8-2: furnished without motor operator. Refurbishment will include manufacture of new stem nut for an SMB-1 Limitorque motor operator. Refurbishment is not expected to include any new valve parts. In addition, disassemble the valve and dimensionally inspect and record critical dimensions, reassemble with new gaskets and packing and perform normal valve checkouts before shipping the valve. Then package the valve and stem nut for shipment to locations specified at a later date by EG&G."

With Valves B and 2 (same 6-inch Velan), we tested hardfaced versus nonhardfaced guide slots. They performed the same.

In the EPRI/Marshall PORV and block valve tests conducted in 1980, an Anchor/Darling double disc gate valve was tested. The test valves were basically uninstrumented (go/no-go tests). In the block valve test, the Anchor/Darling double disc gate valve did not close with the originally sized operator, requiring a seat design change prior to retest. No data are available to indicate why the Anchor/Darling valve failed, what stem thrust was required to close each valve, or how these results compare to industry calculations.

This statement might lead the reader to infer that the other designs might perform adequately. In light of the above discussion, that may be a poor assumption.

The final work invoice indicates that the following additional work was performed:

- Machined new gasket pull up plugs.
- Machined and redrilled actuator.

No records of dimensional measurements implied in the purchase order are available. No records of seat leakage or hydrotests are available. INEL indicates that, at the start of testing, the valve internal parts were in an as-manufactured condition, i.e. the refurbishment work at Crane did not affect the internal parts.

No dimensional records were requested. ANSI/ASME B16.41 Qualification tests contain the results of hydro and leakage tests.

Anchor/Darling indicates that, based on inspection results, it appears Valve 4 met all of the configuration and tolerance requirements for that particular valve design. Accordingly, Anchor/Darling considers Valve 4 to be representative of Anchor/Darling valves in service which have this same overall design.

We agree with the Anchor/Darling assessment that "Valve 4 met all of the configuration and tolerance requirements for that particular valve design," and that "Anchor/Darling considers Valve 4 to be representative of Anchor/Darling valves in service which have this same overall design."

VALVE 5

Valve 5 is a Powell 10-inch flexible wedge gate valve with a 900-lb ANSI class pressure rating. This valve was fabricated by William Powell Co. in 1979 for the Marble Hill plant, which was subsequently canceled. The figures and information in Section 4 and Appendix D of this report show the configuration of this valve. The valve had carbon-steel, machined guide slots in the disk and carbon-steel, cast, machined guide rails in the body. Stellite 6 hardfacing was on the disk and seat faces. Powell indicates that this valve is generally typical of Powell valves in nuclear service. However, it is important to point out that Powell has supplied gate valves to nuclear power plants with a variety of design features including:

We agree with the assessment that "Powell indicates that this valve is generally typical of Powell valves in nuclear service."

- male and female body guides	
- cast-in and welded guides	Valves A, 1, 4, and 5 used cast-in guide designs, and Valves B, 2, and 6 used welded in designs. Data under blowdown loads are available.
- hardfaced and non-hardfaced guide surfaces	Valves B and 2 tested hardfaced and nonhardfaced disc guide designs. Results show similar performance for the two designs.
- various tee-slots and tee-head configurations	
It appears the features listed above could affect valve performance particularly under blowdown conditions. The data from the NRC/INEL tests would not be applicable to Powell valves with different design features in the above areas.	Again, we caution the reader not to infer better performance for other valve designs.
In addition, Powell indicated that the sharp edge on the seat of the disk of the NRC/INEL test valve, identified during the valve inspection, is typical of Powell 10" 900-lb class pressure seal gate valves; however, it is not typical of most Powell gate valve designs. It appears the sharp edge had an unfavorable effect on valve performance under blowdown conditions.	
After INEL obtained Valve 5, the valve was shipped to Powell for refurbishment. According to Powell, "the valve was disassembled, inspected, reassembled using new gasket, packing, and yoke arm, tested per API 598 (hydrotest and leakage testing), and painted. The valve was equipped with a yoke arm designed to accept a Limitorque SMB-1 actuator."	
VALVE 6	
Valve 6 is a Velan 10-inch flexible wedge gate valve with an ANSI class pressure rating of 600 lbs. This valve was fabricated by Velan Valves	We agree with the Velan assessment of the applicability of Valve 6, "the Valve 6 design features are similar to a considerable population of gate

in 1989 specifically for the INEL Phase 2 test program. The figures and information in Section 4 and Appendix D of this report show the Valve 6 configuration. The valve had machined guide slots in the carbon-steel disk and machined, welded-in, carbon steel guide rails in the body. Stellite 6 hardfacing was on the disk and seat faces. Velan indicates that the Valve 6 design features are similar to a considerable population of gate valves they have supplied to nuclear power plants. However, it is important to note that Velan has also manufactured gate valves with other design features.

- A considerable number of flexible wedge gate valves with hardfaced guide slots have been supplied to nuclear power plants.
- A considerable population of flexible wedge gate valves with a much different disk design have been supplied to nuclear power plants. This disk design is much thinner, has larger guide slots and has the T-head connection above the disk seating faces rather than between them. Figure 3-1 shows a general comparison of the two designs. According to Velan, the thin disk design is used only in valves with ANSI class ratings up to 600 lbs.

In each of the above cases, it appears that valve performance can be affected by the difference in design. Accordingly, Valve 6 results from the NRC/INEL tests are not considered to be directly applicable to valves with these other features. Velan indicates that, at the time Valve 6 was provided to INEL, it met all of the configuration and tolerance requirements for that particular valve design. Accordingly, Velan considers Valve 6 to be representative of Velan valves in service at nuclear power plants which have this same overall design.

valves they have supplied to nuclear power plants."

The remarks made on the 6-in Velan apply here.

Table 3-1

KEY INFORMATION ON INEL TEST VALVES

Item	Valve A & 1	Valve B & 2	Valve 3	Valve 4	Valve 5	Valve 6
Manufacturer	Anchor/Darling	Velan	Walworth	Anchor/Darling	Powell	Velan
Year Manufactured	1988	1988	1979	1982	1979	1989
I.D. Number	E-A-345-1-1	F14-7054B-02TS (MO)	4SDP-MOV422B No. 5232PS Ser. No. D-66350	E-6162-8-2	19023W.F. Ser. No. 93211	B16-2054B-02TS
Drawing Number	W8722603	P2-70916-S01	A-9781-M-171	93-14358	C-060999	P2-72916-S01
Size (in.)	6	6	6	10	10	10
ANSI Class (lb)	900	900	600	900	900	600
Seat Diameter, mean/ID (in)	5.40/5.125	5.59/5.18	5.69/5.44	8.70/8.375	-/8.28	8.37/7.88
Disk Base Material Disk Seat Material Disk Guide Material	A216-WCB Stellite 6 A216-WCB	A105 Stellite 6 Stellite 6 (B) A105 (2)	SA-217-WC6 Stellite 6 SA-217-WC6	SA216-WCB Stellite 6 SA216-WCB	Grade WCB Stellite 6 Grade WCB	A105 Stellite 6 A105
Body Guide Material Seat Ring Base Material Seat Ring Seat Material	A216-WCB A515-70 Stellite 6	A36 A216-WCB Stellite 6	SA-217-WC6 SA105 Stellite 6	SA216-WCB SA-515-70 Stellite 6	Grade WCB (Not Available) Stellite 6	A36 A105 Stellite 6
Stroke Length (in.)	6.125	5.75	5.94	9.69	9.375	8.75
Stem Diameter (in.)	1.50	1.75	1.25	2.00	2.125	2.50
Thread Type	Stub ACME	ACME	ACME	Stub ACME	L. H. ACME	ACME
Thread Pitch (in.) Thread Lead (in.)	1/4 1/4	1/4 1/4	1/4 1/2	1/3 1	1/4 1/2	1/3 2/3
Torque Arm	Yes	Yes	No	Yes*	No	Yes

Table 3-1

KEY INFORMATION ON INEL TEST VALVES

Item	Valve A & 1	Valve B & 2	Valve 3	Valve 4	Valve 5	Valve 6
Packing #Grafoil rings #Braided rings	 3 ** 2	 6 2	(Not Available)	(Not Available)	(Not Available)	 6 2
Year obtained by INEL	1988	1988	1989	1989	1989	1989
Yr. Refurbished	1989	1989	1989	1989	1989	--
Where refurbished	Crane Valve Services	Velan	Crane Valve Services	Crane Valve Services	Powell	--
Other nameplate info.	--	2200 psi 38°C 100°F B16.34 Stem S/S 410 Body Comp. SA105	Bldg. Area MV-2 Mark No. VGW-60B-2 Greensburg Plant Nat'l Bd. No. 1843 Des. Press. 1050 psi @ 630° WOG 440 @ 100° Stem CR13 Code 652325706001N Class 2	Class 1 ASME Section III 2163 psi at 575°F Press Rating 2250 psi at 100°F	Stem CR13 B16.34 Press 2220 at 100°	Made in Canada Forged Steel Body 1480 psi 38°C 100°F B16.34 Stem S/S 410 Body Comp AS105 Dwg. No. 8890-D89

1. This was indicated by INEL in the April 18, 1990 Valve Test Review Meeting. See meeting transcript, p. 48.

* Valve 4 did not have a torque arm.

** Valve 1 was live loaded, packing configuration incorrect.

1. This was indicated by INEL in the April 18, 1990 Valve Test Review Meeting. See meeting transcript, p. 48.

Table 3-2

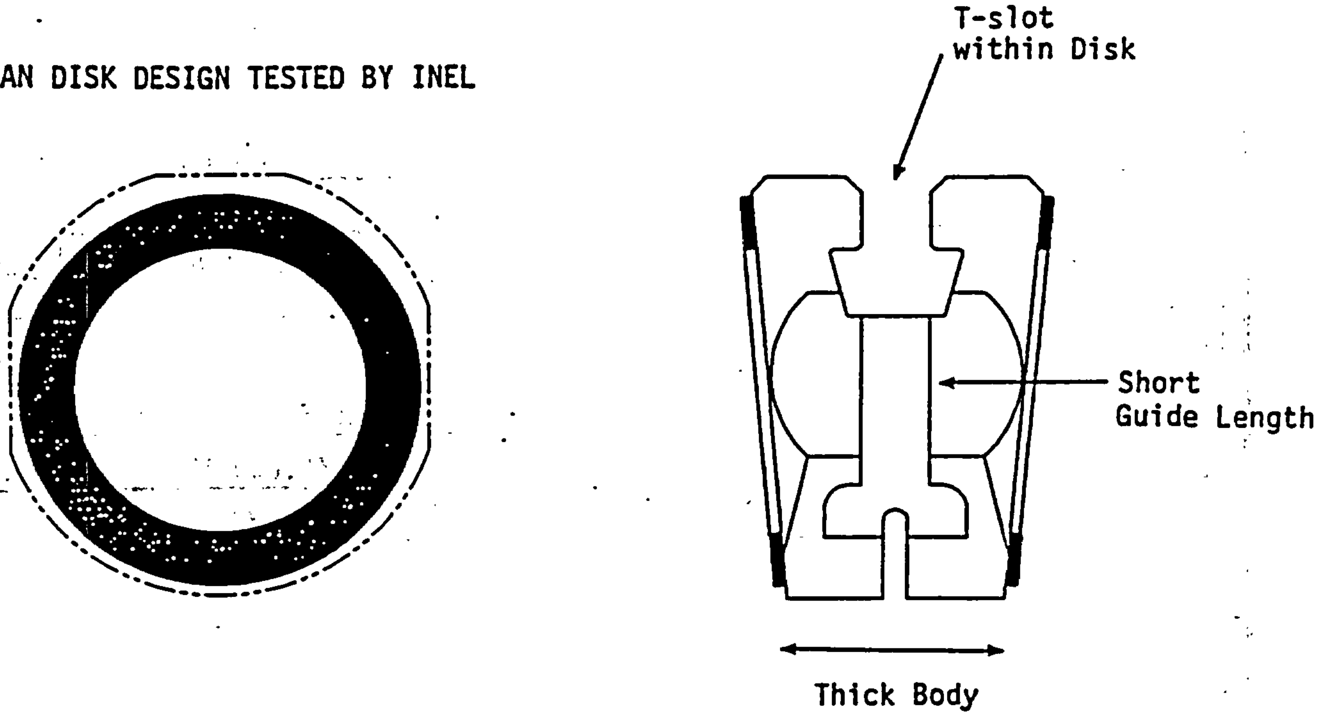
INFORMATION ON LIMITORQUE OPERATORS USED IN NRC/INEL TESTS

Operator Type/Size	SMB-0-25	SMB-1-60	SMB-2-40
Valves Used with	B, 1, 2, 3	4, 5, 6	A
Limitorque Order Number	147441.01	147441.02	360365A*
Unit Ratio	34.9 (Valves B,1,2) 69.5 (Valve 3)	82.5 (Valve 4) 42.5 (Valve 5) 56.6 (Valve 6)	Not Available
Operator Rated Thrust	24,000 lbs	45,000 lbs	70,000 lbs
Operator Rated Torque	500 ft-lb	850 ft-lb	1800 ft-lb
Spring Pack Part No.	0501-184	0701-212	Not Available
Max. Torque Switch Setting/Output Torque	2-1/2, 376 ft-lb	3-1/2, 1012 ft-lb	Not Available
Max. Pullout Torque	314 ft-lb (Valves B,1,2) 625 ft-lb (Valve 3)	1782 ft-lb (Valve 4) 918 ft-lb (Valve 5) 1222 ft-lb (Valve 6)	Not Available
Gear Box Lubricant	Exxon Nebula EP-0	Exxon Nebula EP-0	Not Available
Limit Sw. Gear Box Lubricant	Beacon 325	Beacon 325	Not Available
Limit Switch Type	2-rotor	2-rotor	Not Available
Motor Speed	1800 rpm	1800 rpm	3600 rpm
Motor Voltage	460 V/3 ph/60 Hz	460 V/3 ph/60 Hz	460 V/3 ph/60 Hz
Motor Starting Torque	25 ft-lb	60 ft-lb	40 ft-lb
Year Manufactured	1988	1989	1973*
Year Obtained by INEL	1988	1989	1988*

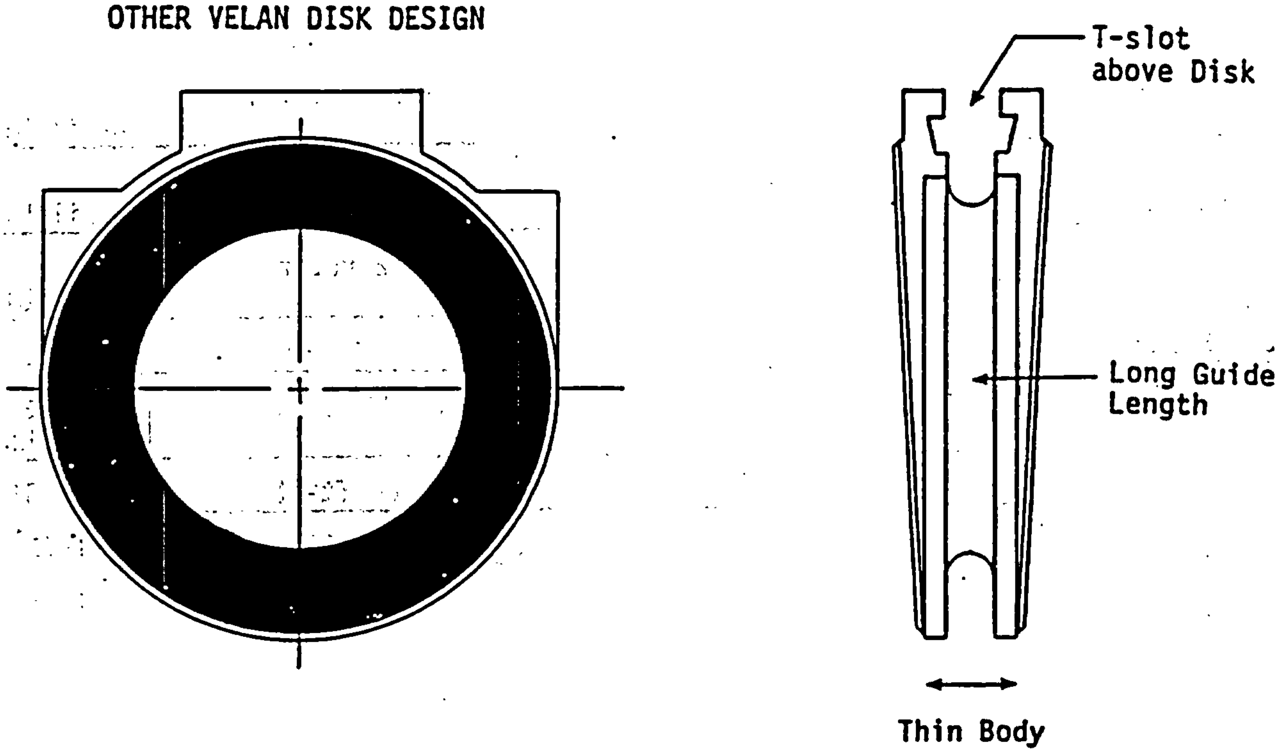
* This operator was originally supplied to Darling Valve by Limitorque. It was modified for INEL. Detailed information on the modified configuration could not be obtained in time to include here.

MPR ASSOCIATES
F-140-49-91
11/12/90

VELAN DISK DESIGN TESTED BY INEL



OTHER VELAN DISK DESIGN



COMPARISON OF TWO VELAN DISK DESIGNS

FIGURE 3-1

Section 4

VALVE INSPECTION

The objectives of the inspection of the NRC/INEL test valves were to develop information regarding the valve configuration and post-test condition. This information is needed to support the evaluation of MOV performance in the tests and to help understand the potential implications of the NRC/INEL test results to valves currently in use in the nuclear industry.

An industry team performed the valve inspection. The industry team was directed by EPRI under the auspices of the EPRI MOV Performance Prediction Program. The Utility Technical Advisory Group (TAG) for this program provided technical direction for the inspection effort. MPR Associates was responsible for the coordination of the inspection and preparation of the inspection plan (Reference 5). The industry team representatives (listed in Table 4-1) reviewed the inspection plan and participated in the actual valve inspection. Specifically, industry team members supervised the dimensional measurements on the test valves and performed individual inspections to assess the post-test condition of the valves. Individual inspection reports provided by team members are included as Appendix C.

Chemical composition measurements were performed by TN Technologies under industry team supervision. INEL provided technical support and equipment for performing valve dimension measurements. INEL efforts in support of the inspection were directed by R. Steele.

All inspection activities were performed in accordance with the

We have no technical comments on this section. However, we feel it necessary to make a few minor corrections as follows.

The NRC funded 100% of INEL costs to perform the posttest inspection. This funding constituted important financial support to the inspection effort. The NRC contribution to the inspection effort also served to professionally accommodate the requests and needs of the inspection team.

The NRC/INEL provided more than technical support and equipment. INEL personnel disassembled and reassembled all valves, provided all handling, performed most measurements, recorded data, took photographs and video footage, and provided quality oversight and data verification.

inspection plan which included procedures and data sheets. In general, inspection activities and procedures for performing measurements were consistent with procedures outlined in the EPRI MOV In Situ Test Guide (Reference 6). Special tests such as surface roughness, chemical analysis, blue check, clearance check and range of position tests are beyond the scope of the In Situ Test Guide and were done in accordance with procedures developed for this task.

VALVE DESCRIPTIONS

Measurements and inspections performed to document the test valve configuration showed that although not all possible design features were included in the six test valves, a wide variety of designs were covered. A summary of the design features is given in Tables 3-1 and 4-2. Table 3-1 provides general information on the valve configuration, while Table 4-2 focuses on the types of guide and seat designs. Each of the valves is briefly described below. (Note that Section 3 discusses the history of each valve and the applicability to nuclear power plant valves.)

Valve 1

Valve 1 is a 6-inch, 900-lb Anchor/Darling flexible wedge gate valve with a pressure seal bonnet. The "top works" of the valve, including bonnet, stem, packing, etc., were not available during the inspection. This valve has a cast steel body including cast guide rails, and has welded-in seat rings which include Stellite seating surfaces. The disk is a steel casting with Stellite overlay to form the seating faces. The stem connects with the disk in a T-slot oriented parallel to the flow axis. Valve 1 was also used as Valve A for Phase 1 testing. The disk was refurbished and the valve turned around for Phase 2 testing.

Valve 2

Valve 2 is a 6-inch, 900-lb Velan flexible wedge gate valve with a bolted bonnet. This valve has a forged steel body. Guide rails are machined from bar stock and welded to the body. Seat rings are also welded into the body and seating surfaces are hardfaced with Stellite. The single-piece disk also has seats that are hardfaced with Stellite. Disk guide slots are located between the disk faces and are not hardfaced. The stem connects to the disk in a T-slot which is oriented perpendicular to the flow direction and is located between the disk faces.

The body of Valve 2 was also used for Phase 1 testing as Valve B with another disk. The disk used for Phase 1 testing was the same design except it had hardfaced guides.

Valve 3

Valve 3 is a 6-inch, 600-lb Walworth flexible wedge gate valve with a pressure seal bonnet. This valve has a cast steel body. Valve 3 has a machined, removable "U"-shaped guide rail. Welded-in seat rings are hardfaced with Stellite as are the seats on the single piece disk. Neither guide rail nor disk guide slot surfaces are hardfaced. Disk guide slots are recessed between the disk seating faces. The disk connects to the stem at a T-slot which is located above the disk seating faces and is oriented parallel to the flow.

Valve 4

Valve 4 is a 10-inch, 900-lb Anchor/Darling flexible wedge gate valve with a pressure seal bonnet. Design features of Valve 4 are essentially the same as Valve 1.

Valve 5

Valve 5 is a 10-inch, 900-lb Wm. Powell flexible wedge gate valve with a pressure seal bonnet. This valve has a cast steel body. Guide rails are cast into the body then machined. Guide rails are not hardfaced. Seat rings are welded into the body and are hardfaced with Stellite. Disk guide slots extend outside of the disk seating faces and are not hardfaced. The disk seats are hardfaced with Stellite. The stem connects to the disk at a T-slot which is located above the seat faces and is oriented parallel to the flow direction.

Valve 6

Valve 6 is a 10-inch, 600-lb Velan flexible wedge gate valve. The Valve 6 design is similar to Valve 2.

MEASUREMENTS OF TEST VALVE CONFIGURATION

Tools and Equipment

Measurements were made with conventional machinists tools such as dial calipers, micrometers, feeler gages, etc. Special tools and equipment required for the inspection included an NDT Instruments NOVA 100-D ultrasonic thickness gage with DF505 probe, Equotip hardness tester, Pacific Transducer Corporation Model 316 hardness tester, Federal Products Corporation Model EAS 2418 surface profilometer with an EGH-1019 general purpose probe, and dental molding compound.

Dimensional Measurements

In general, length measurements on machined surfaces were recorded to the nearest 0.001". Angle measurements were recorded to the nearest 0.1°. Generally, length measurements of as-cast surfaces were recorded to the nearest 0.01". Where the condition of the valve internals did not permit an accurate measurement typical of the pre-test condition, the dimension was taken to the best possible accuracy. In some cases, due to the presence of damage the measurement was made at a different location. Explanations were provided in the Remarks section of valve data sheets for these cases.

The intent of the dimensional measurements was to obtain information on the configuration of the valve in the pre-test condition. In selected cases (based on the judgment of the team members performing the dimensional measurements), separate dimensional measurements were obtained for the damaged configuration.

Sets of body, disk and stem measurements were taken on each of the six valves. Figures 4-1 through 4-9 show simplified generic sketches illustrating the general location of various measurements. Because each valve had a unique configuration, detailed figures depicting each valve are provided as Appendix D. These figures show key design features of the valves and the specific locations at which measurements were taken.

Valve Body Measurements. The valve body dimensions which were measured and recorded are:

- Upstream and downstream flow orifice diameters
- Guide rail thickness
- Body seat to guide rail spacing
- Seat inside and outside diameters
- Seat to seat spacing
- Radius or bevel of seat rings.

Results are summarized in Table 4-3.

Valve Disk Measurements. The valve disk dimensions which were measured and recorded are:

- Disk seat measurements including inside and outside diameters
- Disk guide slot inner and outer dimensions and thickness
- Disk wedge angles
- Dimensions necessary to characterize stiffness of disk
  - Hub diameter
  - Disk thickness at critical locations
- Radius or bevel of seats

Results are summarized in Table 4-4.

Stem/Disk Connection Measurements. Dimensions which were measured and recorded are:

- Depth and width of disk T-slot
- Depth and width of stem T-head
- Stem runout

Results are summarized in Tables 4-5 and 4-6.

Seat, Guide and Stem Surface Characterization

Specific information which was obtained included seat, guide, stem and stem nut surface roughness. Accessible surfaces were measured with a surface profilometer. Inaccessible surfaces were described qualitatively.

Results are summarized in Table 4-7.

Pressure Areas

During the one week inspection period, INEL measured the horizontal projected disk surface areas for evaluating the effects of body and bonnet pressure on stem rejection loads. These data are not included in this report; INEL indicates that the data will be available when they have been collated and organized.

Chemical Composition and Hardness

Chemical composition of disk seat and body seat ring hardfacing was determined using a TN Technologies "Metallurgist-XR" X-ray fluorescence analyzer. Due to access limitations, measurements on the body seat rings were limited to the 10-inch valves and were made only at the 12 o'clock position. Measurements were performed at a number of locations on seven valve disk seats, including Disk "B" from Phase 1 testing.

The purpose of chemical composition tests was to determine the iron content of Stellite disk and body seat hardfacing. Accuracy of test equipment was verified through pre-test, post-test and periodic mid-test measurements on NIST traceable standards. Repeatability of measurements was verified through periodic repetition of selected measurements.

An Equotip hardness tester was used to measure the hardness of disk seat, body seat ring and body guide rail surfaces. A Pacific Transducer Corporation (PTC) hardness tester was used to confirm Equotip measurements on the disk seats. Due to access limitations the PTC hardness tester could not be used on body seats.

The measured iron content and hardness of seat materials are provided in Table 4-8. The iron content of seat hardfacing varied from 3% to 30% and hardness also varied significantly. The high iron content and low hardness in some valves indicates that hardfacing application processes may not have been well controlled resulting in high iron dilution, or that excessive seat machining had taken place leaving only a thin hardfacing layer with high iron dilution.

Replication

Plastic molds were made using a dental molding compound to show detailed body and disk seat configuration including edge bevels and face seat width. Replicas were made at the three, six, nine and twelve o'clock positions. These replicas are being stored at MPR Associates.

POST-TEST CONDITION ASSESSMENT

Post-test condition assessment was by visual inspection, per the inspection plan. Results were recorded on the data sheets. All visual inspections were performed and documented by industry team members. Manufacturer representatives in attendance reviewed and concurred with the information recorded on the data sheets. The objectives of the visual inspection of the INEL test valves were to characterize the location, extent and appearance of surface damage and plastic deformation. Where damage was found the condition of potential mating surfaces was also noted. The condition of many components was documented by photography. Appendix H contains selected photographs of each valve. Depth of surface damage was quantitatively estimated and also characterized by replication with a dental molding compound. A borescope, 30X illuminated microscope, mirrors and surface profilometer were also used for the inspection.

Post-test condition assessment visual inspections showed that the majority of test valves experienced significant wear and damage. Table 4-9 summarizes the results of visual inspections of the valves. Dental molding compound was used to make plastic replicas of the damage observed at various locations. Table 4-10 describes the locations at which replicas were made to document valve damage. These replicas are being stored at MPR Associates. Detailed inspection results are provided as Appendix E.

On all valves some degree of wear was observed on downstream contact faces of the disk seat and body seat ring. The wear ranged from slight burnishing, which is typical of valves which have been in service (Figure 4-10), to severe gouging and gross metal removal. The most severe wear was concentrated along the lower sides of seat faces near four o'clock and eight o'clock positions (Figure 4-11).

All valves exhibited some guide wear. However, severe wear occurred on some valves which involved significant metal galling/removal. Typically, this wear was concentrated near the lower edge of disk guides and body guide rails. Figure 4-12 shows an example of moderate wear on the guides and Figure 4-13 shows an example of severe wear in the guides. Three valves (Nos. 2, 5 and 6) showed evidence of wear on guide faces parallel to the flow direction which are not normally expected to be load bearing surfaces. This damage was most severe on Valve No. 6 (Figure 4-14). The guide rails of two valves (Nos. 3 and 6) were permanently deformed in the downstream direction. Deformation of the valve No. 3 guide rail occurred between top and bottom supports of the removable U-shaped rails, while deformation of Valve No. 6 occurred below the lowest of three welds supporting a welded-in guide (Figure 4-15).

The majority of valves showed no significant wear on the stem or bonnet bore. An exception is Valve No. 4 which had wear indications on the stem where it passed through the bonnet bore and on the bonnet bore (Figure 4-16). Each of the valves had a separate stem nut. No unusual stem nut damage or wear was identified on any of the stem nuts.

SUPPLEMENTAL TESTS

The following supplemental tests were performed to provide special insight on valve behavior by providing a more clear understanding of the total effect of clearances on the relative positions of valve components prior to and during disk seating.

- Blue Check

  A blue check was performed on each of the six test valves. On upstream and downstream disk faces, the overall appearance of the contact pattern was recorded by sketches and photography. Mean contact diameter and width of contact were also measured and recorded. In addition, the position of the contact pattern relative to inside and outside diameters of the seat was described.

- Clearance Check

  Guide-to-guide rail clearances were verified by direct measurement using 12 inch long feeler gages with the valve disk manually placed in the fully closed position.

- Range of Position Test

  The highest possible stem position at which disk to body seat engagement can occur was determined by incrementally lowering the disk and stem (without packing and bonnet) into the body. At predetermined levels the disk and stem were manually tilted or pushed in both upstream and downstream directions to establish extreme disk positions. Points and areas of seat-to-seat contact (if any) at the limits of disk motion were identified at each stem position for each type of loading.

Results of the blue check, clearance check and range of position test are summarized in Tables 4-11, 4-12 and 4-13, respectively. Figure 4-17 shows the locations at which clearances were measured. Detailed results of the range of position test, which include seat contact locations as a function of stem position for disk tilting and disk pushing loads, are provided as Appendix F.

In general, supplemental evaluations confirmed the results of dimensional examinations and the post-test condition assessment. The blue checks showed that the actual seat-to-seat contact areas were generally consistent with the direct measurements performed on the body seats. It was noted that these measurements were simpler to perform than the direct measurements in the valve body. Therefore, this method is likely to be more practical for field applications (e.g. In Situ Test Guide). Photographs of the disk seat blue patterns are provided in Appendix G.

The clearance checks revealed that the total lateral guide to guide rail clearance varied from 0.240 inches to 0.002 inches and that the total clearance measured parallel to the flow direction ranged from 0.299 inches to 0.018 inches. Generally the most severe seat damage occurred for valves with the largest guide clearances in the direction of flow. The range of position test showed that disk seat to body seat ring contact could occur at higher stem positions for valves with larger guide clearances. Feeler gage clearance measurements showed smaller clearances than those determined by comparing the disk and body measurements due to the presence of rolled up material on galled surfaces. Accordingly, clearances obtained by comparison of measurements rather than by the feeler gage method should be used for detailed analyses and for validation of predictive models.

Section 5

TEST DATA REVIEW

PHASE 1 TEST DATA

Two 6-inch 900 lb. flexible wedge gate valves were tested in Phase 1. One qualification test sequence (ANSI/ASME B16.41) and 11 blowdown test sequences were performed on Valve A (an Anchor-Darling valve). Valve B (a Velan valve) was subjected to one qualification test sequence and 5 blowdown test sequences. The blowdown tests were performed at various temperatures and pressures and included cycling the valves at normal flow as well as at blowdown flow conditions. The valves were not inspected following each blowdown test. Results of Phase 1 testing are presented in NUREG/CR-5406 (Reference 1).

PHASE 2 TEST DATA

Six flexible wedge gate valves were tested during Phase 2 -- three 6-inch valves and three 10-inch valves. The two valves used in Phase 1 of testing were refurbished and used in Phase 2. The vendor, size, and pressure class for each valve are listed below.

Valve No.	Valve/Vendor Size	Pressure Class
1	Anchor-Darling 6-inch	900 lb
2	Velan 6-inch	900 lb
3	Walworth 6-inch	600 lb
4	Anchor-Darling 10-inch	900 lb
5	Powell 10-inch	900 lb
6	Velan 10-inch	600 lb

Each of the six valves was subjected to a qualification test sequence (ANSI/ASME B16.41) and a flow interruption test sequence at normal operating pressure and temperature. In addition, two of the valves (numbers 2 and 3) underwent additional flow interruption test sequences in which the test parameters (temperature, pressure, and fluid density) were varied. In all flow interruption test sequences, the valves were cycled at both normal flow and blowdown flow conditions. The valves were not inspected following each blowdown stroke. The valves were only inspected after all testing was completed (see Section 4). Results of Phase 2 testing were presented by INEL at a public meeting in April, 1990 (Reference 2). For this effort, data plots from the INEL data report (Reference 7) were used.

SUMMARY OF DATA USED IN EVALUATION

Appendix A summarizes the test parameters and flow conditions for each valve stroke performed with differential pressure in the tests of both Phase 1 and Phase 2.

There were 85 strokes with differential pressure (DP) in the Phase 1 tests and 149 in Phase 2. Apparent disk factors could not be calculated for some strokes because the DP was too small or the data were insufficient. Table 5-1 summarizes the strokes analyzed in this evaluation and explains why some strokes were not analyzed. In general, there were three types of strokes with DP, as shown in the following table.

After the Phase I tests we were criticized for not performing valve inspections between tests and for further testing damaged hardware. Valve inspections between tests were considered for the Phase II test program, but we later decided against them because of cost factors. Experience had shown us that valve damage could be detected through a sensitive stem thrust measurement. During the Phase II testing, we were able to detect every occurrence of valve damage.

Type	General Procedure	DP Behavior
No Flow (Open strokes only)	Upstream side pressurized and downstream depressurized; valve opened.	DP rapidly dissipated as downstream volume pressurized.
Normal Flow (Close and open strokes)	Flow established using pump (Phase 1) or orifice (Phase 2); valve stroked closed then opened.	DP increased as valve closed and then dissipated as valve opened. In most cases this DP was very small at all times.
Blowdown (Close and open strokes)	Flow established using quick-opening device; valve stroked closed and then partially opened and re-closed.	DP increased as valve closed and then decreased as valve opened. In all cases this DP was substantial throughout the stroke.

ANALYSIS APPROACH

Apparent valve disk factors were calculated using the equation below, which is derived from the classic form of the valve thrust equation for gate valves. The word "apparent" is used because it is assumed that stem force which is not due to packing load or stem rejection load is due to friction between the disk and guides/seats.

The INEL response to the EPRI reports discussion of apparent disc factor is presented in Section 3.4.2.

$$ADF = \frac{F_S \pm (P \times A_S) - F_P}{DP \times A_D}$$

(+) for opening

(-) for closing

Where,

ADF: Apparent valve disk factor

F_S: Measured stem force (lbf)

DP: Differential pressure (psi)

A_S: Cross-sectional area of valve stem (in^2)

F_P: Stem force required to overcome packing load (lbf)

P : Upstream system pressure (psi)

A_D: Disk area (in^2)

F_S, DP and P are taken from the data plots provided by INEL. F_P was determined using data from a valve stroke with no pressure, or using data from a combined opening/closing stroke at constant pressure. A_S and A_D are based on valve geometry. The disk area is based on the mean contact diameter between disk and seat, which was obtained from inspection and measurement of Valves 1 through 6. For valves A and B, manufacturer dimension information was used. The disk and stem areas used for this analysis are tabulated below. Also shown are the disk areas used by INEL. In References 1, 2 and 7, INEL plotted "predicted" stem force assuming disk factors of 0.3 and 0.5, and compared these predictions to measured stem force data. These comparisons imply values of disk factor for the test valves (e.g., greater than 0.5). As shown below, the actual disk areas used here are slightly different from those values used previously by INEL. The areas used by INEL are, in general, slightly lower (average 8%). This causes the INEL computed stem thrusts to be lower than actual and the implied disk factors to be higher than actual. Figure 5-1 shows how the disk areas used in this evaluation and by INEL were determined. The INEL disk area is based on upstream seat ring bore diameter. This evaluation uses a more precise approach based on downstream mean contact diameter.

Valve	A_S (in^2)	A_D (in^2)	A_D (in^2) used by INEL
A	1.767	23.6[*]	20.6
B	2.405	24.4	21.1
1	1.767	21.9[*]	20.6
2	2.405	24.4	21.1
3	1.227	23.9	21.8
4	3.142	58.6	61.0
5	3.547	61.2	61.9
6	4.907	54.7	48.7

Valve apparent disk factors were calculated at four different events during each stroke as described below. Figure 5-2 shows the four events on a stem force versus time plot. Note that this plot is <u>not</u> an actual stem force trace but is intended only to illustrate where and how the events were identified. In particular, the maximum stem force occurred well after isolation in many cases.

Events at which data were evaluated are:

1. At zero stem position, as indicated by the "Valve Stem Position" data plot. INEL reported that, for Phase 2 testing, this position indicator was calibrated before testing so that it would read zero when the disk completely covered the flow area. Valve stem position information is not interpretable in this way for Phase 1 testing. Note that the interpretation of stem position is subject to hysteresis effects due to the stem/disk

The INEL response to the EPRI report's discussion of valve positions for analysis is presented in Section 3.4.1 of this report.

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[*] The disk areas for Valves 1 and A are different because the valve was turned around for Phase 2 testing. The area for Valve A is based on the manufacturer drawing and that for Valve 1 is based on measured dimensions.

clearance (i.e., for a given stem position, the disk can be at either of two locations, depending on whether the stem is pushing or pulling the disk). Therefore, zero stem position may not always represent the instant that a "true" seal between disk and seat is made.

2. At flow isolation (or unisolation). For closing strokes, isolation was generally identified as the point when downstream static pressure fell to zero. For opening strokes, isolation (or unisolation) was identified as the point when downstream pressure increased above zero. This method did not work for normal flow tests, where a downstream orifice was used to control flow and resulted in the downstream pressure remaining at a high level beyond valve closure, (i.e. the DP was small). Further, it appears dynamic pressure (which is measured with a tap facing the flow as opposed to a flush tap which is used to measure static pressure) may be a more sensitive indicator of true isolation. The exact determination of flow isolation should be studied more carefully in a long-term evaluation of the test data.

3. At wedging, as identified from the stem force plots. For closing strokes, wedging was identified as the instant just prior to the essentially vertical section of the stem force plot which corresponds to a rapid increase in stem force. For opening strokes, wedging was identified by the plateau immediately after the initial "cracking" peak on the stem force plot.

4. At maximum stem force (excluding cracking peak) regardless of disk position. This value is the highest stem force during the stroke. On some stem force plots, this coincided with one of the three points mentioned above. On others, there was a maximum stem force which occurred at a time other than isolation, wedging, or zero stem position indication.

ANALYSIS RESULTS

Apparent valve disk factors calculated for each stroke with differential pressure are listed in Appendix B. Results are discussed in Section 6.

Table 5-1

SUMMARY OF VALVE STROKES ANALYZED FROM PHASE 1 AND PHASE 2 MOV TESTING

Valve #	Total # Strokes with DP	Number Analyzed	Strokes Not Analyzed
A	58	38	20 - normal flow tests*
B	27	19	8 - normal flow tests*
Phase 1 Totals:	85	57	28
1	13	12	1 - normal flow tests*
2	52	50	2 - normal flow tests*
3	32	29	3 - stem force plots bad
4	12	10	2 - normal flow tests*
5	17	13	4 - normal flow tests*
6	23	17	6 - normal flow tests*
Phase 2 Totals:	149	131	18

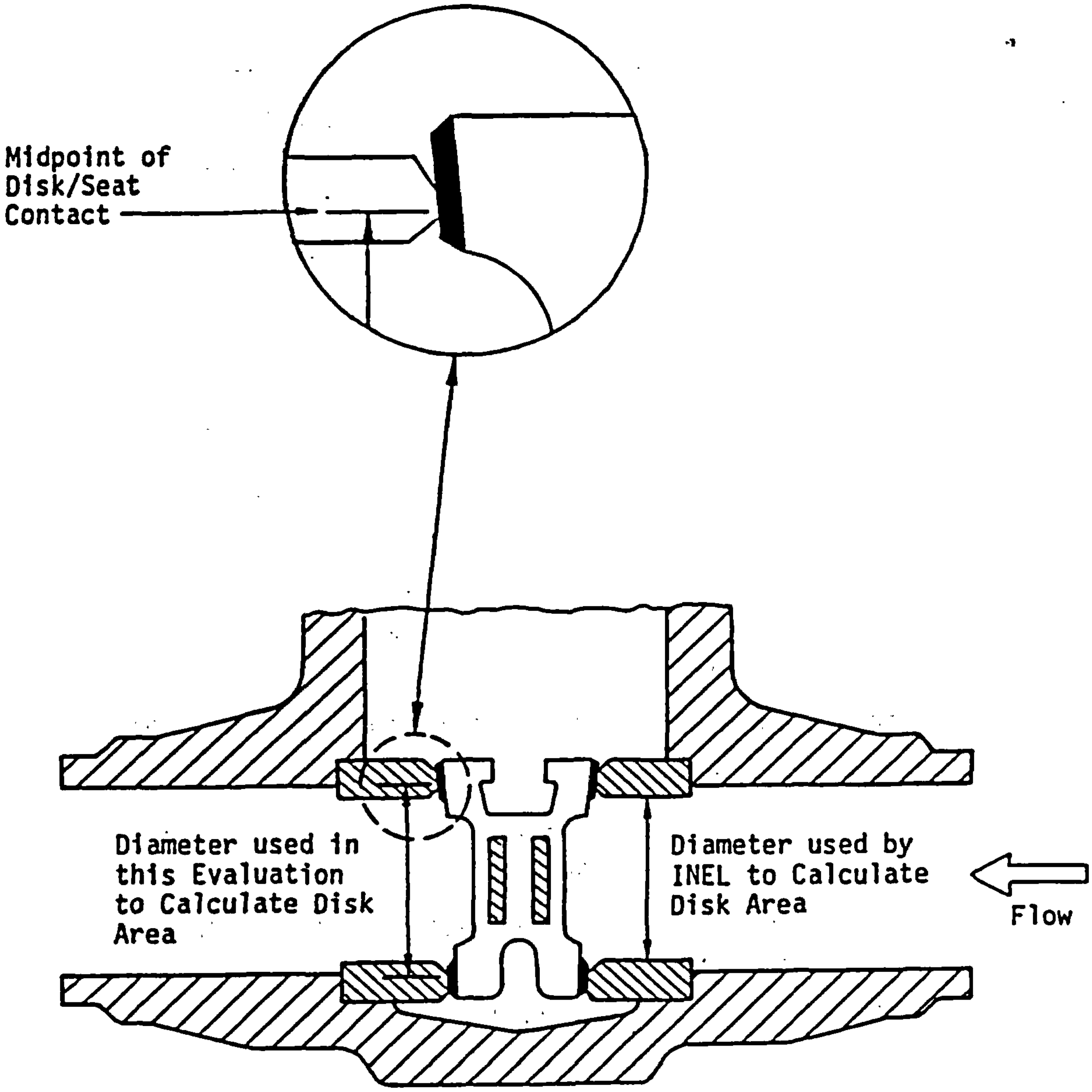
* Differential pressure was too low on these normal flow tests for disk factors to be calculated.

NOTE: For those tests analyzed, disk factor could not always be calculated at all of the desired events during the stroke. Specifically, disk factor could not be calculated at:

1. Zero valve stem position for 7 strokes because valve stem position plots were inaccurate/unavailable. Plots were considered inaccurate if zero stem position occurred prior to cracking or after stem force leveled off to its "running load" (on opening strokes).
2. Zero valve stem position for 19 normal flow strokes because of low DP.
3. Zero valve stem position for the 57 Phase I strokes because valve stem position plots were not interpretable in this manner.
4. Isolation for 19 normal flow tests because of low DP.
5. Isolation for one (1) stroke because isolation could not be identified.
6. Wedging for three (3) strokes because the disk did not wedge.

See Appendix B for a complete stroke-by-stroke list of calculated disk factors.

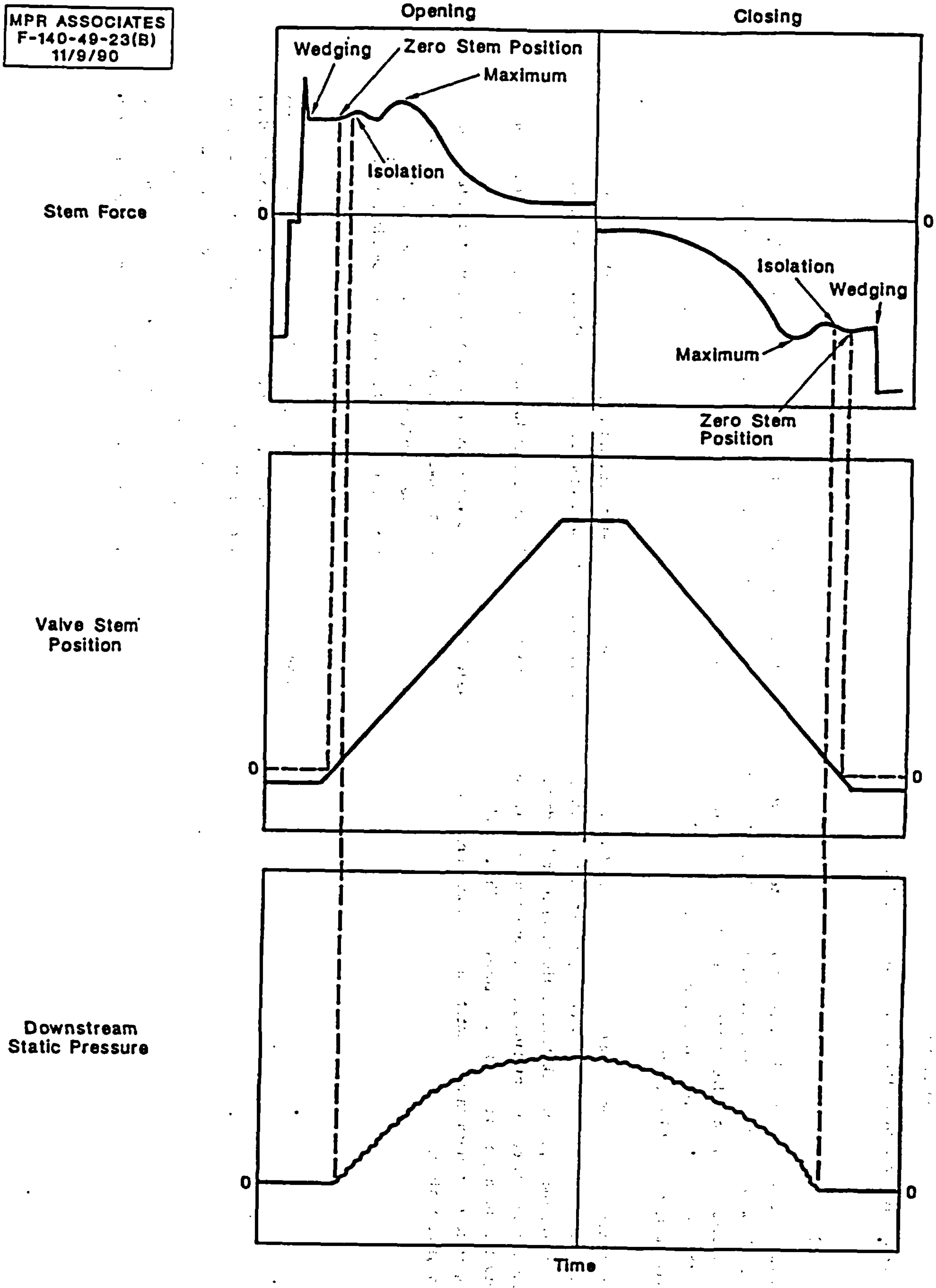
MPR ASSOCIATES
F-140-49-96(A)
11/9/90



DISK AREAS USED IN THIS EVALUATION
AND BY INEL

FIGURE 5-1

MPR ASSOCIATES
F-140-49-23(B)
11/9/90



TIME INSTANTS FOR CALCULATION OF APPARENT VALVE DISK FACTORS FOR NRC/INEL PHASE I AND PHASE II DATA

FIGURE 5-2

Section 6

EVALUATION OF DATA REVIEW AND INSPECTION RESULTS

BLOWDOWN ISOLATION

Table 6-1 summarizes the apparent valve disk factors and test parameters for selected blowdown closing strokes from Phase 1 and Phase 2. The first blowdown stroke for each valve is highlighted in bold. Figure 6-1 summarizes the results from the first blowdown strokes. Several important conclusions should be noted:

1. For Valves A, 4, 5, and 6, all the strokes listed exhibited anomalous behavior (See "Behavior Beyond Friction" below). Therefore, the apparent disk factors listed in the table do not necessarily reflect true friction since damage mechanisms likely resulted in higher required stem thrusts. There could be significant variation in disk factor for valves which have these damage mechanisms.

Table 6-1 is addressed in Section 3.4.2 of this report. The table consistently shows too small a value for the stem force required to isolate flow.

The anomalous behavior identified by EPRI for each valve is discussed below in view of how we used the test results from each valve.

Valve A -	See our discussion of the EPRI reports item 3 below.
Valve 4 -	This valve was badly damaged during the initial design basis blowdown test sequence. No additional blowdown tests were performed with this valve. We did not use the results of the valve in developing the INEL correlation.
Valve 5 -	The high loadings during the initial design basis blowdown test sequence resulted in disc tippage and an interference between the disc and the seat. Subsequent testing did not exhibit this behavior, as the material interface had been removed during the initial design basis blowdown test. Therefore, subsequent testing using this valve was used in developing the INEL correlation.

		Valve 6 - See our discussion of the EPRI report's item 4 below.
2.	As discussed in Section 3, Anchor/Darling indicates Valve 1 is not representative of 6" Anchor/Darling valves; therefore, the disk factors calculated for Valve 1 are not considered applicable to typical Anchor/Darling Valves.	Valve A was delivered to the INEL with the understanding that it is representative of Anchor/Darling valves delivered to the nuclear industry. The downstream disc surface on Valve 1 was the original valve A unrefurbished surface. See Section 3.3.2 for additional details.
3.	Valve A had nitrogen flow rather than the desired saturated water flow for the first blowdown closure stroke. The effects of nitrogen versus water are not known, but this fluid difference would not nominally have been expected to affect the disk cocking/machining behavior observed with this valve. Accordingly, the disk factor for Valve A is considered potentially applicable.	The EPRI report is concerned with the presence of nitrogen during several of the Phase I tests and its effect on the friction factor between the disc and the seats. We have assessed the Phase I tests and concur that the seven tests listed in Table 2-1 of the EPRI report included nitrogen (nitrogen entrainment, not dry nitrogen). However, the eight tests listed in Table 2-2 of the EPRI report did not. It is also important to remember that using the INEL methodology, we saw no difference in the response of the valve during testing that had a nitrogen/steam mixture, compared with the response during testing with a water/steam mixture. See section 3.4.6 for additional details.
4.	As discussed later, it appears Valve 6 was damaged in a hot cycle, no-flow test prior to the first blowdown stroke. Specifically, the guide rails were bent downstream. If the guide rails had not been damaged, it appears similar damage would likely have occurred in blowdown strokes. Accordingly, the disk factor for Valve 6 is considered potentially applicable.	Damage to this valve consisted of disc and seat damage, guide damage, and a bent guide. We initially attempted to use measurements from design basis testing taken when the disc first started to ride on the seats, hoping to avoid the results of abnormal interferences between the bent guide and the disc and the seats. However, upon further assessment of the response of this valve during design basis blowdown testing, we have decided not to use any of the results from this valve in developing the INEL correlation.

5. For Valves B, 2, and 3, the apparent isolation disk factors for the first blowdown stroke are 0.35, 0.33, and 0.19, respectively. These valves did not show anomalous behavior associated with valve damage. Therefore, it appears that disk factors for blowdown isolation strokes from this testing are bounded by a value of 0.35, when anomalous behavior is avoided.

BLOWDOWN UNUSUAL BEHAVIOR

Anomalous Behavior on Blowdown Closure Strokes

This behavior occurred on Valves A, 1, 4, 6 and to some extent on Valve 5. This behavior was characterized by jagged thrust traces and, in some cases (Valves A, 4, and 5), maximum stem thrust prior to wedging (yielding a transient high apparent disk factor). Figure 6-2 is a plot of stem force versus time for the first Valve 4 blowdown closing stroke. The apparent valve disk factor calculated at the force "peak" is 0.58; the disk factor calculated at wedging is 0.32. This plot also illustrates the jagged force traces that were observed.

This behavior is attributed to mechanical interaction of valve internals beyond simple sliding friction, that is, machining or shaping of surfaces. The inspection results support this conclusion. Inspection of Valves 1 through 6 showed evidence of wear/damage on the guide and seating surfaces of all valves; however, major damage was observed on Valves 1, 4, and 6 and, to a lesser extent, on Valve 5. Stem/bonnet bore damage was also observed on Valve 4. Table 6-2 shows a summary of guide and seat damage to Valves 1 through 6; the correlation of major damage to valves showing anomalous behavior is evident.

Disc factors for blowdown isolation tests of valves B, 2, and 3 are not bounded by a value of 0.35. Sections 3.4.1 and 3.4.2 of this report address the EPRI report's evaluation of apparent disc factors at isolation.

The stem force responses do indeed exhibit jagged traces, and such traces are indicative of valve damage. Apparent disc factors calculated at the peak stem force must be used with caution, because the extent of valve damage and the stem force necessary to move the disc against such damage must be estimated, while the actual damage and actual stem force vary considerably from test to test and from valve to valve. Calculating a disc factor just prior to wedging may have some qualified use, but the nonpredictable nature of the valve needs to be emphasized.

The EPRI report has assessed the results of the wear and damage to each valve tested by the INEL. Identifiable wear and damage to the disc seat, body seats, disc guide, and body guides of each valve for the Phase II and the Valve B disc from Phase I testing are described by EPRI in Table 6-2, along with an assessment of whether the conditions noted could have caused anomalous behavior. Generally, the EPRI report concludes that damage to the disc guide and body guides and the disc seat and body seats directly affects whether a valve is considered to be predicable or nonpredictable. Such nonpredictable behavior can result in high stem forces and, as a result, high apparent disc factors. The results from tests showing anomalous blowdown behavior are nonetheless valid. GI-87 valves showing such behavior during testing can be expected to show such behavior under similar conditions should a line break occur in the plant.

It should be noted that the inspection was carried out at the conclusion of the test program after numerous strokes had been performed on each valve. Because there were no inspections during the test sequence, it is not possible to precisely reconstruct the damage scenarios. In all cases except one (Valve 6), it appears the significant damage occurred during the blowdown strokes. This conclusion is based on the strong correlation of major damage with the anomalous blowdown closure behavior (Table 6-2). Specifically, a highly loaded closure stroke provides the best opportunity for the disk guide slot edge and disk seat edge to machine the mating body guide rail and seat ring surfaces. The exception for Valve 6 is discussed more extensively below under the discussion of "No-flow Tests" and under the discussion of "Valve 6".

Pictures of the type of damage referred to in Table 6-2 are given in Section 4.

- Figure 4-13 shows major guide damage (Valve 4)
- Figure 4-11 shows major disk seat damage (Valve 4)
- Figure 4-12 shows moderate guide damage (Valve 5)
- Figure 4-10 shows minor disk seat damage (Valve 6)

These figures show the significant local material deformation which occurred in some valves in the tests. The damage is characteristic of very high local bearing stresses, indicating that guide and seat surfaces

However, the nonpredictability of the results renders them not very useful in the assessment of valve response in general.

The EPRI report expresses concern over the lack of inspections between tests and the possibility that we tested damaged valves. Sections 3.2.2 and 3.3.3 address these issues.

For a nonpredictable valve, the highest loads typically occur while the disc is still riding on the guides. These loads are the result of an increasing differential pressure near closure and the increasing disc were carrying load in a highly nonuniform manner. The surfaces are most susceptible to this when the disk is partially through its stroke and the load is being transferred from the guides to the seat. This is where transient force maximums were seen in the data, e.g. Figure 6-2.

Force Increase During Opening Stroke

This behavior occurred on Valves 4, 5, and 6 (Phase 2 10-inch valves) and, to a very limited extent, on Valves A and B (Phase 1 6-inch valves). This behavior was characterized by a maximum stem force after the flow path was opened (yielding a transient high apparent disk factor). Figure 6-3 is a plot of stem force versus time for a Valve 5 blowdown opening/closure stroke. The apparent disk factor at unwedging is about 0.31, which is consistent with sliding friction. The disk factor at the stem force peak is about 0.45, which indicates phenomena beyond friction appear to be occurring. Also, the DP has dropped off at the time of the force peak, further indicating that phenomena beyond simple sliding friction are occurring.

The behavior also occurred to a very limited extent on hot, no-flow opening tests, which can be attributed to the brief existence of blowdown-like conditions in the very initial parts of these strokes (see discussion of "No-flow Tests" below). Two possible causes are postulated for this behavior: valve damage (analogous to closing strokes as area being exposed to the flow. There is evidence to suggest that clearances between the disc and the guides were larger, allowing the disc to tip excessively. This tippage of the disc concentrated the disc to guide loads and resulted in localized damage to both the disc and the guides.

This damage occurs while the disc is riding on the guides. Once the disc comes in contact with and starts riding on the seats, it straightens somewhat. This helps to distribute the load over a larger area and also allows the harder and stronger Stellite-coated surfaces to carry the load.

We suspect that internal valve damage did not cause the response noted. If it had, we would expect the highest stem force to occur at the same time the highest load between the disc and the seat occurs, i.e., immediately after unseating. This was not the response noted.

discussed above), and flow effects.

Valve damage was observed in the inspections and likely contributed to this behavior. However, damage is not considered to be exclusively responsible for this behavior because:

- The correlation between observation of the behavior and presence of significant damage was not as strong as for the closure behavior. For example, Valve 5 showed the most significant behavior but had much more moderate damage, and Valve 1 showed among the most severe damage but none of the behavior. Damage may have been a significant contributor for Valve 6, where the behavior changed distinctly to this unusual form between the first and second nominally identical hot, no-flow opening strokes (see discussion of "No-flow Tests" below).

- Intuitively, damage consisting of digging and gouging would be much less likely on opening strokes, because the surfaces tend not to interact at aggressive angles. On Valve 6, where a deformed guide was a major damage contributor, this could have (and likely) occurred on the first hot no-flow opening test; hence, damage appears to be a significant contributor for Valve 6.

Flow effects have been identified by INEL as being responsible for the force increase during blowdown opening mid-stroke. This explanation is plausible because local internal pressure data show a reduced pressure below the disk, giving rise to a downward load on the disk from flow effects. Quantitative evaluation of this explanation has not yet been presented by INEL, nor has it been evaluated yet in the EPRI MOV Performance Prediction Program. Quantitative evaluation will require detailed examination of pressure data in the valve body and valve disk/body geometry. Hydraulic modeling to predict pressure distribution will likely also be required.

The detailed explanation of this behavior is a question for future study. Although this behavior can have an impact on valve performance predictions, the applicability of this observed behavior to nuclear power plant valves is not known. In general, nuclear power plant valves do not have to open against design basis blowdown opening conditions such as tested in these NRC/INEL tests. However, some valves need to open in systems where the flow rate may be significant as the valve opens, and there could be the potential for this type of behavior. Accordingly, to the extent this phenomenon is due to flow effects, it would need to be adequately accounted for in valve opening applications. For most nuclear power plant valves, which face opening conditions far less severe than the NRC/INEL blowdown conditions, this effect is not expected to be as strong as observed in the NRC/INEL tests.

High Apparent Friction Near Seated Position

This behavior occurred on Valve 2. The behavior was characterized by significantly higher apparent disk factor (over 0.5) while the disk was travelling at or near the final wedged (hard-seated) position. The average apparent disk factor calculated at blowdown isolation for Valve 2 was much lower, about 0.3. The stem force sharply increased after flow was isolated but before wedging occurred. Figure 6-4 shows a blowdown isolation stem thrust trace, with the points of isolation and wedging marked.

We potentially agree with the EPRI report that most nuclear power plant valves do not have to open on blowdown flow conditions. PORV block valves maybe an exception. We have never quoted a safety function for a valve to initiate blowdown flow. We performed normal flow openings, no flow openings, and maximum flow openings. Some systems in a nuclear plant are connected to large vessels where momentary to slightly more sustained high flows could be anticipated, depending on the downstream volume. The EPRI report acknowledges this fact.

Based on our assessment of this test and the results presented on this figure, the 0.3 apparent disc factor presented in the EPRI report was not at isolation, but instead at a point earlier in the stroke, while the disc was still traveling on the guides. We estimate that another 1.5 seconds of motion occurred before the disc was fully riding on the seats and flow was actually isolated; an additional second passed before wedging occurred. We consider the apparent disc factors as presented by the EPRI report to be typically too low because a value for the stem force measured while the disc was still riding on the guides was used. Note also that this was a 100°F subcooled test. Appendix C of this report describes the fluid dependencies of valve response.

The high disk factor on Valve 2 was also seen on opening strokes. In particular, apparent disk factors of over 0.5 were observed when the disk was sliding from unwedging to unisolation.

The reason for this behavior is not thoroughly understood. The valve inspection provided some insight. First, the disk seat face of Valve 2 had a high iron concentration (20% - see Table 4-8) which can contribute to increased friction. Typical iron concentrations should be in the range 5-10%. However, other valves had observed high iron concentrations and did not show the abnormally high disk factors. Further, iron content would not reasonably explain the sudden changes in apparent friction as the disk approached the wedged position. Accordingly, the high iron content, although it could be a concern, does not appear to explain the particular high disk factor for Valve 2.

Next, it was noted that Valve 2 showed a distinct wear pattern on the body guide rail edges and disk guide slot edges parallel to the flow, which normally are not load-bearing surfaces. Figure 6-5 shows the observed wear pattern on one of the guide rail edges. The wear indicates these surfaces were contacting near the bottom of the stroke. The contact was enhanced by small lateral disk/guide clearances in this direction (total clearance of 0.050 inches - see Table 4-12) and by a tendency of the Valve 2 disk to rotate very slightly (about an axis along the pipe) as it first came into contact with the seat. These effects apparently resulted in the disk engaging the guide rail on the surfaces parallel to flow. Figure 6-6 shows the hypothesized phenomenon.

It appears that as the additional surfaces came into contact, additional friction forces may have been generated resisting valve disk motion.

We have not assessed opening disc factors extensively and have not assessed opening friction factors per the INEL equation at all. However, it is interesting to note that the opening disc factor is very similar to the closing disc factor just prior to wedging.

While the EPRI report considers the response of Valve 2 to be anomalous, the method employed by the INEL (see Appendix C) to assess disc to seat friction factors indicates that the response of Valve 2 was typical of the response of the other predictable valves.

EPRI has identified disc to valve body wear due to rotation of the disc as one possible abnormality with this valve. This valve sustained by far the largest number of strokes. In light of the large number of valve cycles, we believe that the identified markings reflect normal wear for the test conditions the valve was subjected to. The appearance of such wear on a valve is not surprising. None of the valves have any mechanism to prohibit the disc from rotating relative to the pipe center line, other than resistance from the stem and by disc contact with the guides. We have no reason to suspect that any rotation of the disc in Valve 2 is more pronounced than in any other valve. In fact, the limited lateral clearance between the disc and the guide would minimize any rotational tendencies of the disc and prevent aggressive contact angles from occurring. In addition, the methodology employed by the INEL to assess valve response indicates that the behavior of Valve 2 during the testing

These additional forces would be interpreted as a higher apparent disk factor. If this explanation is true, it appears insufficient lateral disk/guide clearance may have been the root cause of the abnormally high disk factor. Because this abnormal behavior may be related to design aspects and to valve-unique clearances, there may be some potential applicability to nuclear power plant valves. However, the root cause needs to be verified before the detailed applicability can be evaluated. In this regard, additional testing to reproduce and isolate these phenomena is warranted.

Unusual Seating Behavior

Unusual seating behavior occurred on closing strokes for Valve 6. The behavior was characterized by a stem force trace which did not have a sharp "corner" when the disk was hard in the seat; instead, the thrust gradually increased more sharply toward the end of the stroke before the disk was hard in the seat. A high apparent disk factor at the point of wedging was calculated. Figure 6-7 is a plot of stem force versus time for Valve 6 and illustrates this behavior.

The valve inspection provided some insight on this behavior. Specifically, the lower end of the guide rails, which were cantilevered, were deformed in the direction of flow. Figure 4-15 shows a picture of the deformed guide rails. The deformation was to such an extent that the disk was wedging between the downstream seat and guide rails, and was gradually forcing the guide rails back toward their original position. Also, the disk guide slot was "digging into" the guide rail on one of the faces parallel to flow, as evidenced by severe damage. The root cause of this behavior is considered to be a guide rail design with inadequate support at the bottom end. Also, insufficient disk/guide lateral clearance may have contributed. It is believed the guide rail deformation occurred during initial hot no-flow testing (see discussion was typical of the other predictable valves tested.

As previously discussed damage to this valve consisted of disc and seat damage, guide damage, and bent guides. The data was not used in the INEL correlation.

of "No-flow Tests" below).

BLOWDOWN FRICTION BEHAVIOR

In the discussion below, "disk factor" refers to apparent valve disk factors calculated as part of this evaluation (see Section 5). Data from blowdown closure and opening strokes were reviewed to identify portions of each stroke, if any, where the sliding of the disk on the seat appeared to be the dominant load phenomenon (rather than machining or shaping of surfaces). This evaluation focused on the brief time period between flow isolation and wedging, and attempted to ensure that the unusual effects as discussed above were excluded. The appearance of the force plot was used to determine periods of apparent sliding friction. For example, Figure 6-2 shows the first blowdown closure stroke for Valve 4. The force plateau right after the peak at isolation is considered to be the disk sliding on the seat; the disk factor in this period is 0.32.

Based on evaluating all of the blowdown closure and opening strokes in this manner, average apparent disk factors due to sliding friction for each valve were determined. Table 6-3 summarizes the average disk factors for blowdown conditions when sliding of the disk on the seat is occurring. As shown in this table, the values are between 0.28 and 0.41 for closing strokes, and are between 0.25 and 0.40 for opening strokes, with the exception of Valve 2 at 0.47. If data for wedging of Valve 2 are considered, the average apparent disk factor is as high as 0.52; however, as mentioned previously, it appears additional surfaces were coming into play during wedging and the apparent disk factor does not necessarily represent true friction. The unusually high value of 0.47 for opening strokes of Valve 2 (based on the point of isolation) may also be affected by this phenomenon. In summary, the blowdown sliding friction disk factor results suggest the traditional 0.3 disk factor used in the valve thrust equation may need to be somewhat increased (to about

The apparent disc factor analysis is discussed in Section 3.4.2 of this report. Averaging these data in this analysis will not improve their usefulness.

0.4) to cover sliding friction under blowdown conditions. The high Valve 2 results suggest that the unusual behavior in this valve can be interpreted as apparent sliding friction.

NORMAL FLOW TESTS

No results could be obtained from normal flow tests on Valves A, B, 4, 5, and 6 because the test configuration and approach resulted in negligible DP during these strokes (see Section 2). In Phase 1 testing (Valves A and B) a low-head pump was used for flow. In Phase 2 testing (Valves 4, 5, and 6), a downstream orifice was used to set the flow, and downstream pressure remained at a high level while the valve was closed and re-opened, resulting in very low differential pressures being developed during the stroke (see Figure 2-3).

For Valves 1, 2, and 3, significant differential pressures were developed (see Figure 2-4), and apparent disk factors could be calculated at the point of wedging/unwedging for both closing and opening strokes. Isolation could not be identified from the downstream pressure plots because of the effect of the downstream orifice as discussed above, and the differential pressure at zero stem position was so low that disk factors could not be accurately calculated.

Results for apparent disk factor during wedging/unwedging of these three valves during normal flow strokes are given below.

The normal flow tests are discussed in Section 3.2.5 of this report. We found the data from these tests useful.

Valve	Average Apparent Disk Factor	Explanation
1	0.34	Based on wedging of 1 closure stroke.
2	0.58	Based on wedging of 6 closure and 6 opening strokes.
3	0.27	Based on wedging of 4 closure and 4 opening strokes.

Note the result for Valve 1 is based on only a single stroke. Also, for Valve 2 it was previously shown that phenomena beyond friction may be occurring during wedging so the 0.58 value above is not likely due to true friction. Nonetheless, it is higher than average wedging disk factor for blowdown conditions (0.48 to 0.52). The value for Valve 3 (0.27) is less than the comparable value for blowdown conditions (0.33 to 0.38). The limitations in the present analyses and the apparent lack of agreement between these tests and others underscores the need to evaluate the normal flow data in more detail. The unusual behavior of the DP during the stroke (Figure 2-6) made these data difficult to evaluate using plots. Until further evaluation is performed using the digital data, it appears no disk factor conclusions can be made from these tests.

NO-FLOW TESTS

In "no-flow" tests, the volume downstream of the test valve was depressurized while the upstream side was kept pressurized, and then the valve was opened. As discussed in Section 3, a brief period of flow actually occurred as the flow path was initially opened up. Particularly with the hot steam "no-flow" tests (10-inch valves), the period of flow was significant (several seconds). Accordingly, the description "no-flow" (adopted here from the INEL reports) may be a slight misnomer.

The brief period of flow in steam tests of 10-inch valves involved considerable DP across the valve. It appears these tests simulated blowdown opening conditions for the first few seconds of the opening stroke. Because of this feature, the unusual force increase after flow

The lack of agreement among the disc factors for the different valves is, more than anything else, an indication that the standard industry equation is deficient.

A no-flow test with a pressurized fluid upstream of the valve will produce a momentary motion of the fluid when the valve is opened. This phenomenon will be more pronounced if the fluid is highly compressible. The term "no flow" is not an attempt to ignore this momentary phenomenon, but rather to distinguish between sustained forced flow and pressure relief. Note also that during the no-flow tests there was no flow at the discharge end of the test facility. The no flow tests are discussed in Section 3.2.6 of this report.

initiated (discussed previously under "Blowdown Unusual Behavior") was seen to some extent on hot, "no-flow" strokes of 10-inch valves. The behavior was only observed to a small extent on Valve 4 but to a more significant extent on Valve 5. Figure 6-8 shows the stem force time history for the first hot no-flow opening of Valve 5. The force peak after start of flow can be clearly seen. Other hot no-flow test results for Valve 5 looked similar.

For Valve 6, the first hot no-flow stroke showed little or no evidence of the unusual behavior, but the second hot no-flow stroke showed significant evidence of this behavior. Figure 6-9 shows the stem force time histories of the first two hot no-flow strokes. These two strokes had essentially identical conditions in terms of pressure, temperature and DP history across the valve. Because the unusual stem force was observed only on the second stroke, it appears flow effects are not responsible for the stem force increase on this valve. Rather, it appears valve damage likely initiated on the first hot no-flow test, which contributed to the subsequent unusual behavior. As discussed in Section 4 and earlier under "Unusual Seating Behavior", Valve 6 had body guide rails bent in the direction of flow (see Figure 4-15). It appears this deformation initiated on the first hot, no-flow test, based on the appearance of the data. It is noted the bent guide damage mechanism could readily occur on an opening stroke, and it appears the DP persisted long enough to allow load to be transferred to the guides on this stroke. Accordingly, valve damage likely contributed to observed valve behavior for all valve strokes following the first hot no-flow test (including all blowdown strokes). The root cause of this damage was a guide rail design which was inadequately supported at the lower end. It should be noted that this guide rail may not have permanently deformed if the valve was installed in a typical nuclear power plant system (non-blowdown) where pressure is relieved more quickly as the valve opens (see Figure 2-5) or in a system with a lower temperature where the material yield stress would have been higher.

The cold no-flow tests performed on all valves preceding the hot no-flow tests generally showed a much lower disk factor, which is discussed later under "Effect of Valve Exposure History".

The hot no-flow tests from all eight test valves were reviewed to define test periods where it appeared sliding friction was the dominant behavior. The force increase after start of flow was excluded from consideration. Average apparent disk factors are summarized in Table 6-4. In general, a favorable comparison between Table 6-4 (No-flow) and Table 6-3 (Blowdown) is observed. Figure 6-10 highlights the comparison. Disk factors for sliding friction are in the range 0.25 to 0.41, except for Valve 2, and Valve 8 to a slight extent. As discussed earlier, it appears unusual phenomena may be involved while Valve 2 is near the seat. The unusual behavior may add to true disk/seat friction, which would likely explain the unusually high disk factor. Nonetheless, it appears generally that valve sliding performance obtained from no-flow tests can be used to predict sliding performance in blowdown tests. For valve designs/applications where behavior beyond friction is avoided at design basis conditions, performance can be adequately predicted or extrapolated from tests at lesser conditions.

EFFECT OF VALVE EXPOSURE HISTORY

Figures 6-11 through 6-26 show apparent disk factor for every valve stroke with DP evaluated in this study. Each plot shows apparent disk factor plotted against <u>total</u> stroke number for that valve (where only strokes with DP are counted). Separate, consecutive plots are provided for opening and closing strokes on each valve. For each stroke, up to 4 apparent disk factor values are plotted, corresponding to the 4 events

Average and apparent disc factors are discussed elsewhere in this report.

Section 3.4.1 addresses our concern with the EPRI reports definition of apparent disc factors at isolation, wedging, or maximum. We have also expressed concern over the choice of a disc area for calculating the disc factor and its applicability to the standard industry disc equation (see Section 3.4.2).

during the stroke which were analyzed (see Section 5). Blowdown and Normal flow strokes are identified by the indications "B" and "N" at the top of each graph; also, observations of anomalous blowdown closure behavior and unusual force increases during opening strokes are indicated by "A" and "U" respectively. Finally, lines have been drawn showing average apparent disk factors for indicated events. All of the values shown on Figures 6-11 through 6-26 are tabulated in Appendix B.

The first major observation is that on <u>all</u> 8 valves the initial cold no-flow strokes yielded low apparent disk factors (0.1 to 0.2). Upon initiation of hot no-flow testing, disk factor increased (to above 0.3). There was also some evidence of disk factor increasing with repeated strokes at cold temperature (see Valves 6 and A, Figures 6-21 and 6-23). In cases where cold temperature tests were conducted after hot tests (Valves A, B and 2), disk factor did not return to the initial low level but instead remained at the higher level. Figure 6-27 is a plot of disk factor (based on wedging) versus temperature covering all strokes of Valve 2, which illustrates the irreversible nature of the disk factor change.

The cause for this behavior is not know, but several mechanisms have been postulated. These include:

- Removal of residual machining oil from disk and seat surfaces
- Removal of an oxide layer on disk and seat surfaces
- Microscopic surface changes on disk and seat surfaces (normal "wear")
- Macroscopic surface charges on disk and seat surfaces (indicating damage).

The INEL data are insufficient to determine the cause. Nonetheless, the data from these test indicate that valve performance information

The tendency of the disc factor to remain high when cold testing is performed after the hot testing has not been assessed by the INEL. An independent assessment of the these phenomena might confirm these trends. We agree that the mechanisms identified here in the EPRI report could contribute. If these trends are confirmed, their impact on our original conclusions will be minimal.

meaningful to hot conditions can be obtained by tests at cold conditions, once the valve has been exposed to hot conditions. Conversely, initial tests at cold conditions may not give bounding information on future valve performance at hot or cold conditions.

LINEAR STRESS

Section 2 discussed the use of a linear stress parameter to evaluate valve application severity. Figures 6-28 through 6-35 are plots of apparent disk factor versus linear stress (differential pressure times disk area divided by circumference of disk) for all valves tested. Opening and closing strokes are indicated on each plot separately, as are blowdown and non-blowdown strokes. There appears to be no clear correlation of strokes overall or for a particular subset of strokes. It appears that linear stress, by itself, is not necessarily an adequate valve severity evaluation parameter for separating valves into "lightly loaded" and "heavily loaded" classes. As discussed in Section 2, it appears the behavior of DP during mid-stroke plays an important role.

DISCUSSION OF INDIVIDUAL VALVES

Although the eight NRC/INEL test valves were discussed in the preceding data evaluations, below is a summary of key performance observations for each valve along with insights from inspections regarding explanations for the observed behavior.

Valve A and Valve 1

Valve A/1 showed a sliding friction apparent disk factor in the range 0.3 to 0.4 but was susceptible to anomalous behavior on blowdown closure strokes. Blowdown isolation disk factors as high as 0.75 were observed on Valve A and as high as 0.86 were observed on Valve 1. The anomalous

The INEL assessment of the closing tests, as presented in Appendix C, concluded that a load dependent response does exist. This response was observed for both the Phase I and the Phase II closure testing. Sections 3.4.2 and 3.4.4 at this report present discussions that might explain why the EPRI work did not demonstrate a load dependent response.

The linear contact stress model should have a distant relationship to the normal loading concept employed by the INEL, but more study is needed.

behavior is attributed to the sizable disk-to-guide clearance in the direction of flow (about 1/4" total clearance). This clearance apparently allowed the disk to displace and/or tip downstream during blowdown closures such that the disk attacked the seat aggressively and led to interaction beyond sliding friction (shaping and machining). Significant disk and seat damage resulted. The damage appeared to be exacerbated by a sharp edge on the disk edge of Valve 1. Anchor/Darling indicates this sharp edge is atypical. Also, the inspection of Valve 1 noted significant guide damage. The as-cast, fairly rough surfaces of the guide rails in conjunction with the sizable disk-to-guide clearance (which allowed tipping to concentrate the guide load over a small area) apparently contributed to the extent of damage.

The disk of Valve 1 had a Stellite iron dilution (20%) much higher than typical, according to the manufacturer, Anchor/Darling. The high iron content may also have exacerbated the behavior for Valve 1.

The first blowdown stroke of Valve A passed nitrogen (rather than the desired saturated water) for the final 60% of the stroke. Although nitrogen is atypical, the potential for the disk to displace and/or tip and aggressively engage the downstream seat would apparently still have been present with water flow. Finally, although damage apparently occurred on the first blowdown stroke of Valve A, several subsequent blowdown strokes were run. Generally, the measured behavior <u>improved with succeeding strokes</u>. The improvement is attributed to the valve disk machining a slightly altered (i.e., "easier") path. This indicates valves should be able to be designed (or perhaps modified) to be able to accommodate blowdown conditions adequately.

It is inconsistent for the EPRI report to suggest that iron dilution may have affected the performance of Valve 1, when in the following discussion of Valve B and Valve 2 results the report states, "**the high iron content did not appear to contribute detrimentally to valve behavior.**"

Valve B and Valve 2

Valve B/2 is somewhat opposite of Valve A/1. Specifically, Valve B and Valve 2 performed quite well at isolating blowdown flows (apparent disk factor 0.3 to 0.4), but showed an undesirable performance feature in that the apparent disk factor for wedging and unwedging (for both blowdown and no-flow conditions) was higher than desired -- about 0.4 to 0.6. The disk and body seat faces were in very good condition on this valve after testing, with only very minor wear. The guides, particularly on Valve 2 (not hardfaced) showed significant wear, but guide wear likely would not have influenced wedging and unwedging performance because the disk is normally sliding on the seat during wedging/unwedging. The short disk guide length probably contributed to the extent of guide wear. The disk had very tight clearances (total about 0.050") in the flow direction, which likely minimized disk displacement and tilting, and helped ensure good blowdown isolation performance. However, this valve also had tight disk/guide clearances in the lateral direction (perpendicular to flow), which it appears may have contributed to the high wedging/unwedging disk factor. The observed wear suggests the disk built up significant loads laterally against the guide during wedging/unwedging, contributing to increased resisting forces. The disk Stellite surface had a high iron dilution (20%), but the high iron content did not appear to contribute detrimentally to valve behavior.

Valve 3

Valve 3 showed good performance in blowdown isolation and no-flow tests, with apparent disk factors near 0.3. Moderate damage was observed on disk and guide surfaces, thus showing that damage does not preclude reasonable performance. This valve had a flexible, U-shaped, removable guide rail which was permanently deformed, apparently during the blowdown tests. Hence, it appears significant damage does not preclude reasonable performance. The guide deformation, similar to that occurring on an overloaded, simply-supported beam, may have helped the valve achieve good performance by easing the transition from guide to seat. However, it is not clear that similar guide deformation will generally result in good performance. Although not observed on Valve 3, it appears flexible and potentially plastically deforming guides could have performance hazards as well, particularly if deflections become excessive.

Valve 4

Valve 4 behaved in a manner similar to Valve 1, i.e. reasonable sliding fiction performance but susceptibility to anomalous behavior on blowdown closures. The maximum isolation disk factor (0.49) for Valve 4 was not as large as Valve 1. The presence of more reasonable disk Stellite iron dilution and the proper manufacturers beveled edge on Valve 4 may have contributed to the lower disk factor.

As with Valve A/1, it appears sizable disk/guide clearances (1/4") in the direction of flow allowed disk displacement and/or tipping during blowdown closure which allowed the disk to aggressively interact with the seat. Significant disk/seat damage was observed.

In addition, Valve 4 showed the following other features:

- Major guide damage -- it appears the rough as-cast guide rail surface contributed to damage.
- Stem/bonnet bore damage -- it appears excessive lateral disk/guide clearance may have allowed the disk to migrate laterally (particularly during the part of the stroke where the guides were damaged), which caused a stem/bonnet bore interference.
- Body seat iron dilution (~11%) somewhat higher than desired -- high iron content may have contributed to the extent of seat damage.

Valve 5

Valve 5 showed good sliding friction performance (0.3 to 0.4 apparent disk factor) but appeared to show limited susceptibility to anomalous behavior during blowdown closure strokes. The sharp edge at the bottom of the disk and the high iron dilution in the disk seat (~30%) contributed to the tendency of the disk to catch on the seat and try to machine it away, but the relatively tight disk/guide clearances in the direction of flow and the smooth machined guide surfaces apparently kept the adverse behavior from getting excessive. Valve 5 also had relatively tight disk/guide clearances in the lateral direction and some indications of wear on the lateral surfaces. However (unlike Valves 2 and 6) there were no indications in the data that this interaction contributed to increased stem thrust requirements.

Valve 6

Valve 6 showed perhaps the most unique behavior during the tests. It showed a limited tendency to anomalous behavior in blowdown isolation tests, and also showed unusually high wedging/unwedging disk factors. It appears the behavior of this valve was dominated by the deformation of the unsupported lower ends of the body guide rails. The seating surfaces were not extensively damaged on this valve and the disk/guide clearances in the direction of flow were relatively tight, suggesting that if the guides had not bent, good performance may have been achieved. However, the disk/guide lateral clearances (perpendicular to flow) were also tight on this valve and there were indications of severe damage on the guide rail surfaces parallel to flow, indicating there may have been some interference with wedging/unwedging performance even if the guide rails had not bent. Finally, the disk showed a higher than desired iron dilution in the Stellite (~20%). However, the effect of iron content cannot be separated from the test results.

The last sentence in this discussion states that wear indications on lateral surfaces did not contribute to increased stem thrusts. However, the EPRI report suggests that similar indications caused the higher stem forces for Valves 2 and 6. The EPRI report's conclusions are based on the use of an incomplete equation for determining stem force. Thus, the EPRI analysis tends to attribute any underprediction by that equation to additional wear or other loads not normally seen. The INEL correlation shows the on-the-seat behavior of Valve 2 and Valve 5 to be essentially identical. The lateral guide wear did not contribute significantly to either valve's performance.

TABLE 6-1
Test Conditions and Apparent Disk Factors Calculated for Phase 1 and Phase 2 Blowdown Strokes

Test*	Valve	Disk Area (in2)	Stem Area (in2)	Pressure (psi)	Temp (F)	Medium	Packing Load (lbs)	Differential Pressure (psi)		Stem Force (lbs)		Apparent Disk Factor	
								Isolation	Wedging	Isolation	Wedging	Isolation	Wedging
A-3-5	Anchor-Darling 6-inch	23.6	1.767	450	480	Hot Water	633	510	525	9,000	5,500	(A) 0.63	0.33
1-1-25	Anchor-Darling 6-inch	21.9	1.767	900	525	Hot Water	1600	870	870	19,500	None	(A) 0.86	**
B-2-5	Velan 6-inch	24.4	2.405	950	524	Hot Water	1621	1000	1000	12,500	14,400	0.35	0.43
2-1-25	Velan 6-inch	24.4	2.405	950	525	Hot Water	500	940	940	10,400	13,400	0.33	0.46
2-2-25	Velan 6-inch	24.4	2.405	1050	545	Steam	500	1060	1060	9,000	14,200	0.23	0.43
2-3-25	Velan 6-inch	24.4	2.405	750	145	Cold Water	500	770	700	5,200	12,900	0.15	0.56
2-6A-25	Velan 6-inch	24.4	2.405	530	455	Hot Water	500	500	500	5,300	8,200	0.29	0.53
2-6A1-25	Velan 6-inch	24.4	2.405	590	440	Hot Water	500	580	600	6,000	9,200	0.29	0.50
2-6B-25	Velan 6-inch	24.4	2.405	860	475	Hot Water	500	830	830	8,800	13,000	0.31	0.52
2-6B1-25	Velan 6-inch	24.4	2.405	950	475	Hot Water	500	920	960	9,200	14,200	0.29	0.49
2-6C-25	Velan 6-inch	24.4	2.405	1280	530	Hot Water	500	1260	1280	12,200	16,100	0.28	0.40
3-1-25	Walworth 6-inch	23.9	1.227	840	525	Hot Water	1000	870	870	5,900	8,200	0.19	0.30
3-1A-25	Walworth 6-inch	23.9	1.227	910	530	Hot Water	1000	900	900	7,000	9,000	0.23	0.32
3-5-25	Walworth 6-inch	23.9	1.227	1100	550	Hot Water	1000	1100	1120	9,100	11,500	0.26	0.34
4-1-25	Anchor-Darling 10-inch	58.6	3.142	710	485	Steam	1600	700	720	23,800	17,500	(A) 0.49	0.32***
5-1-25	Powell 10-inch	61.2	3.547	890	520	Steam	1375	880	880	28,000	23,900	(A) 0.44	0.36
5-1A-25	Powell 10-inch	61.2	3.547	1020	485	Steam	1375	1020	1020	26,500	28,000	(A) 0.34	0.37
6-1-25	Velan 10-inch	54.7	4.907	1000	455	Steam	0	1000	1000	28,000	35,000	(A) 0.42	0.55
6-1A-25	Velan 10-inch	54.7	4.907	1200	480	Steam	0	1190	1190	32,000	43,500	(A) 0.40	0.58
6-1B-25	Velan 10-inch	54.7	4.907	1010	475	Steam	0	1000	1010	19,000	38,200	(A) 0.26	0.60

* Valve Number - Flow Interruption Test Number - Step Number
** Valve did not wedge. Maximum Value of 1.04.
*** Maximum Value of 0.58

NOTES: 1. (A) indicates that anomalous behavior occurred.
2. First blowdown stroke for each valve is in bold.

Table 6-2
SUMMARY OF WEAR/DAMAGE OBSERVATIONS IN SEATS AND GUIDES

Valve	Anomalous Performance in Blowdown Tests?	Summary of Wear/Damage[1]			
		Disk Seat	Body Seat	Disk Guide	Body Guide
1	Yes	Major	Major	Major	Moderate
2	No	Minor	Minor	Moderate	Moderate
B (Disk Only)[4]	No	Minor	---	Minor	---
3	No	Moderate	Moderate	Moderate	Minor[2]
4	Yes	Major	Major	Major	Major
5	Yes[3]	Moderate	Moderate	Moderate	Moderate
6	Yes	Minor	Minor	Major	Major[2]

[1] Definition of wear/damage descriptions is as follows:

Minor -- light surface scratching, less than 0.003 inch deep in carbon steel and less than 0.001 inch deep in Stellite.

Moderate -- distinct surface scratches and small gouges, up to about 0.20 inch deep in carbon steel and up to 0.005 inch deep in Stellite.

Major -- Deep surface scratches and distinct gouges or areas of gross metal removal.

[2] Body guide rails had permanent deflection in direction of flow.

[3] Valve No. 5 showed low disk factor in spite of anomalous features in stem force traces.

[4] Disk B used in Phase I testing only.

Table 6-3

SUMMARY OF AVERAGE SLIDING FRICTION APPARENT DISK FACTORS* UNDER BLOWDOWN CONDITIONS

Valve	Description	Average Apparent Disk Factor		Explanation
		Open	Close	
A	Anchor/Darling, 6", 900#, Hot Water and Nitrogen (A only) Tests	0.33	0.41	Based on wedging during 6 openings and 16 closures.
1		0.40	--	Based on wedging during 1 opening.
B	Velan, 6", 900#, Hot Water, Cold Water (2 only) and Nitrogen (B only) Tests	0.38 (0.35)	0.29 (0.41)	Based on isolation during 3 openings and 7 closures. Value in parentheses is that obtained using wedging for same strokes, which may not be simple friction.
2		0.47** (0.52)	0.28 (0.48)	Based on isolation during 8 openings and 16 closures. Value in parentheses is that obtained using wedging for same strokes, which may not be simple friction.
3	Walworth, 6", 600#, Hot Water Tests	0.38	0.33	Based on wedging during 3 openings and 6 closures.
4	Anchor/Darling, 10", 900#, Steam Tests	0.34	0.34	Based on wedging during 1 opening and 2 closures.
5	Powell, 10", 900#, Steam Tests	0.30	0.36	Based on wedging during 2 openings and 4 closures.
6	Velan, 10", 600#, Steam Tests	0.25	--	Based on isolation during 3 openings.

* Apparent disk factor is determined from measured stem force using the sta industry equation. See Section 5. This table covers only apparent disk fa from data where it appears sliding friction was the dominant phenomena.

** This value is unusually high compared to other values and may be attributab to phenomena beyond simple friction.

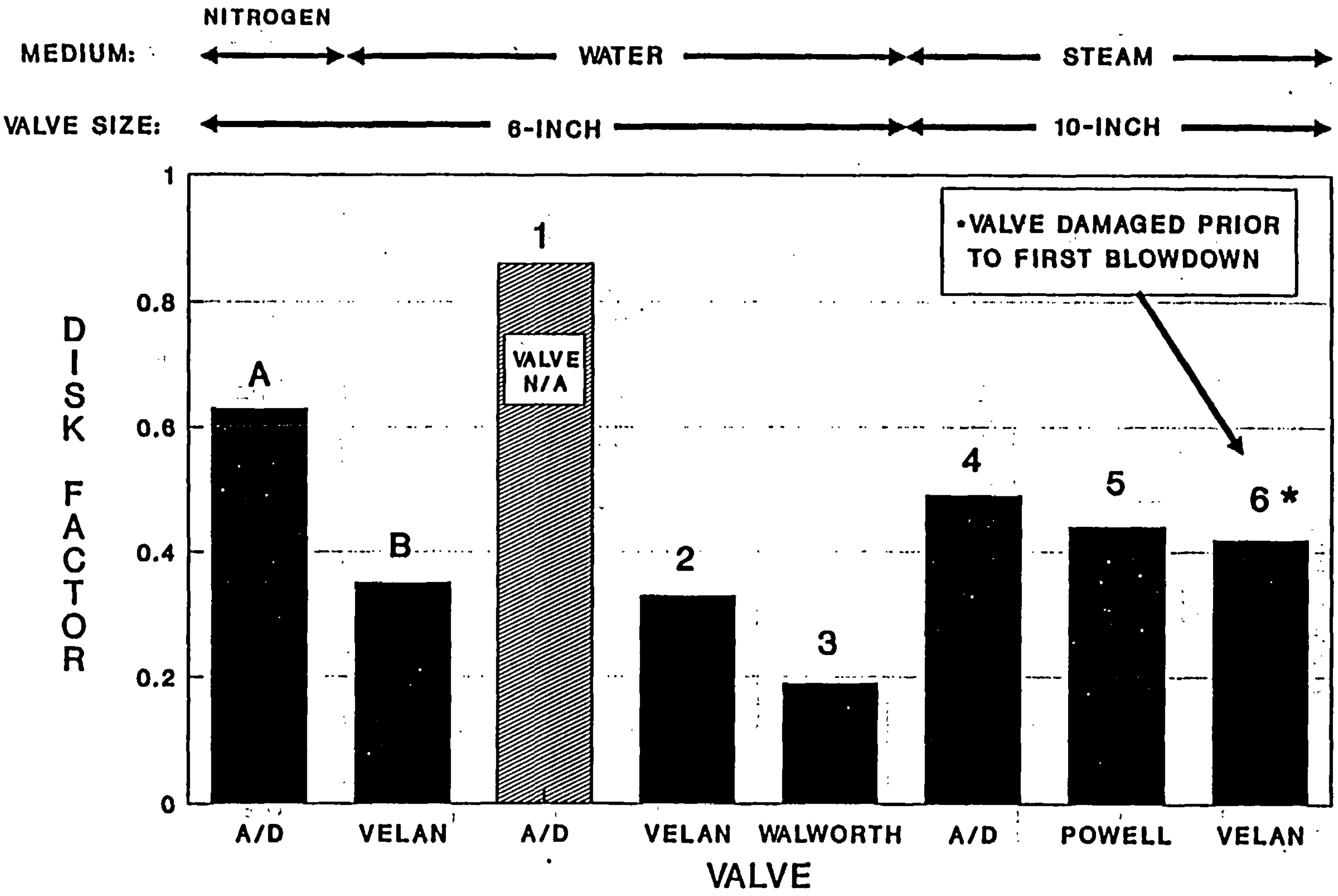
Table 6-4

SUMMARY OF AVERAGE APPARENT DISK FACTORS*
FOR SLIDING FRICTION CONDITIONS IN NO-FLOW TESTS

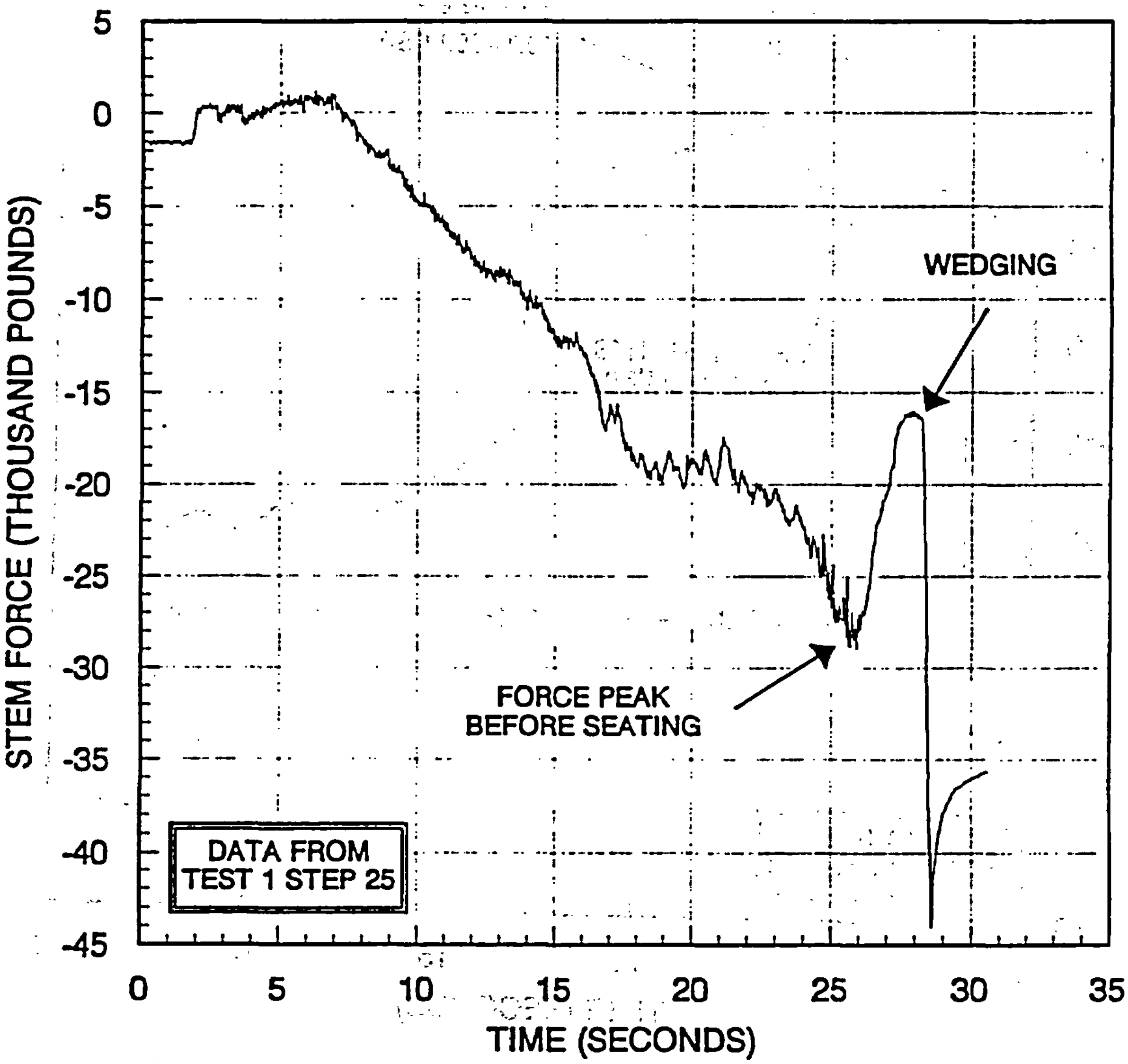
Valve	Average Disk Factor for No-Flow Opening	Explanation
A	0.34	Based on unwedging of 11 strokes.
1	0.33	Based on unwedging of 4 strokes.
B	0.44** (0.46)	Based on unisolation of 5 strokes (value in parentheses is based on unwedging).
2	0.54** (0.54)	Based on unisolation of 9 strokes (value in parentheses is based on unwedging).
3	0.28	Based on unwedging of 8 strokes.
4	0.30	Based on unwedging of 4 strokes.
5	0.28	Based on unwedging of 4 strokes.
6	0.32	Based on unisolation of 5 strokes.

* Apparent disk factor is determined from measured stem force using the standard ind equation. See Section 5. This table covers <u>only</u> apparent disk factors from data where it <u>appears</u> sliding friction was the dominant phenomena.

** These values are unusually high compared to other valves and may be attribu to phenomena beyond simple friction.

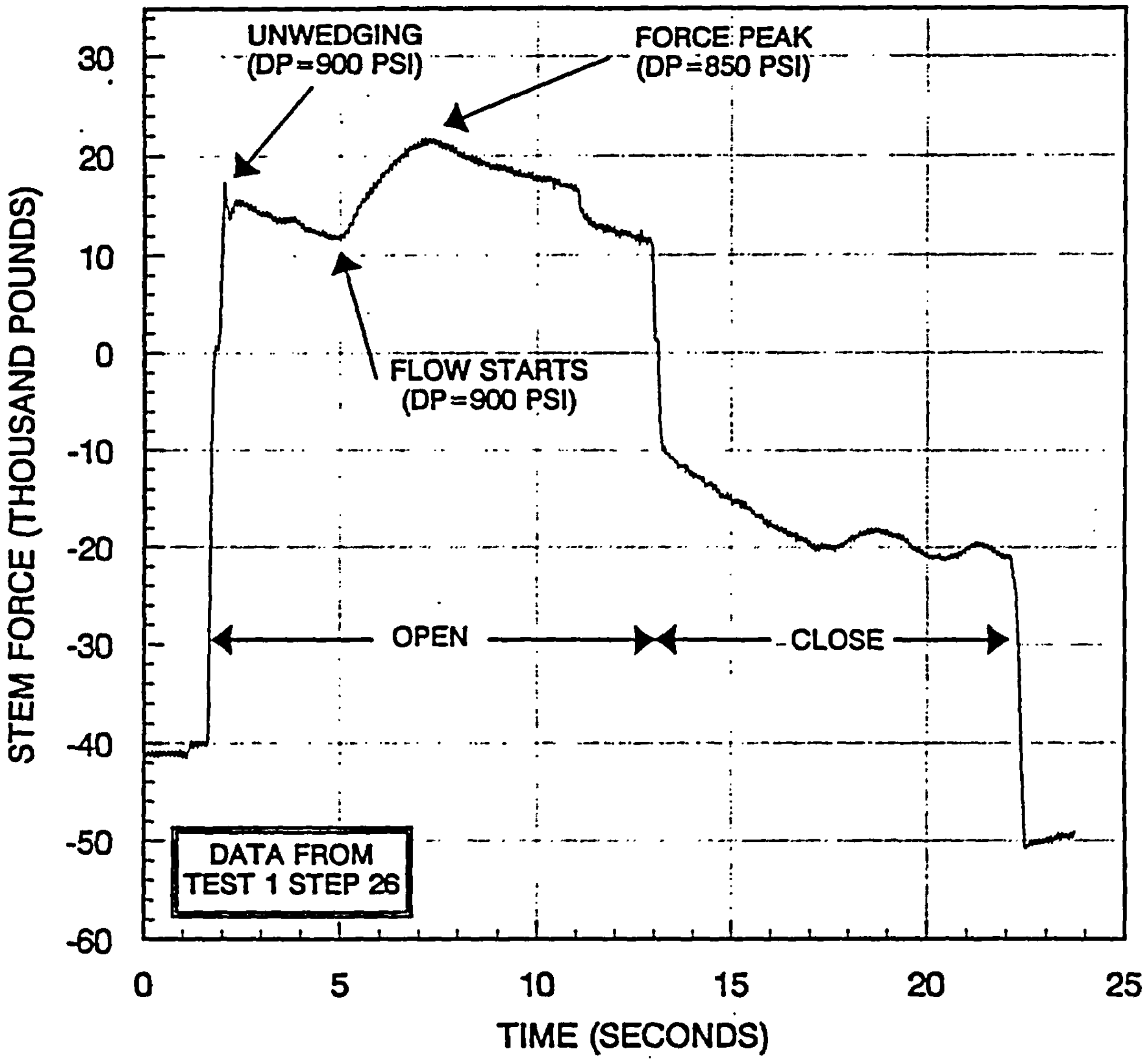


APPARENT DISK FACTORS FOR ISOLATION ON FIRST BLOWDOWN STROKE OF NRC/INEL VALVES
FIGURE 6-1



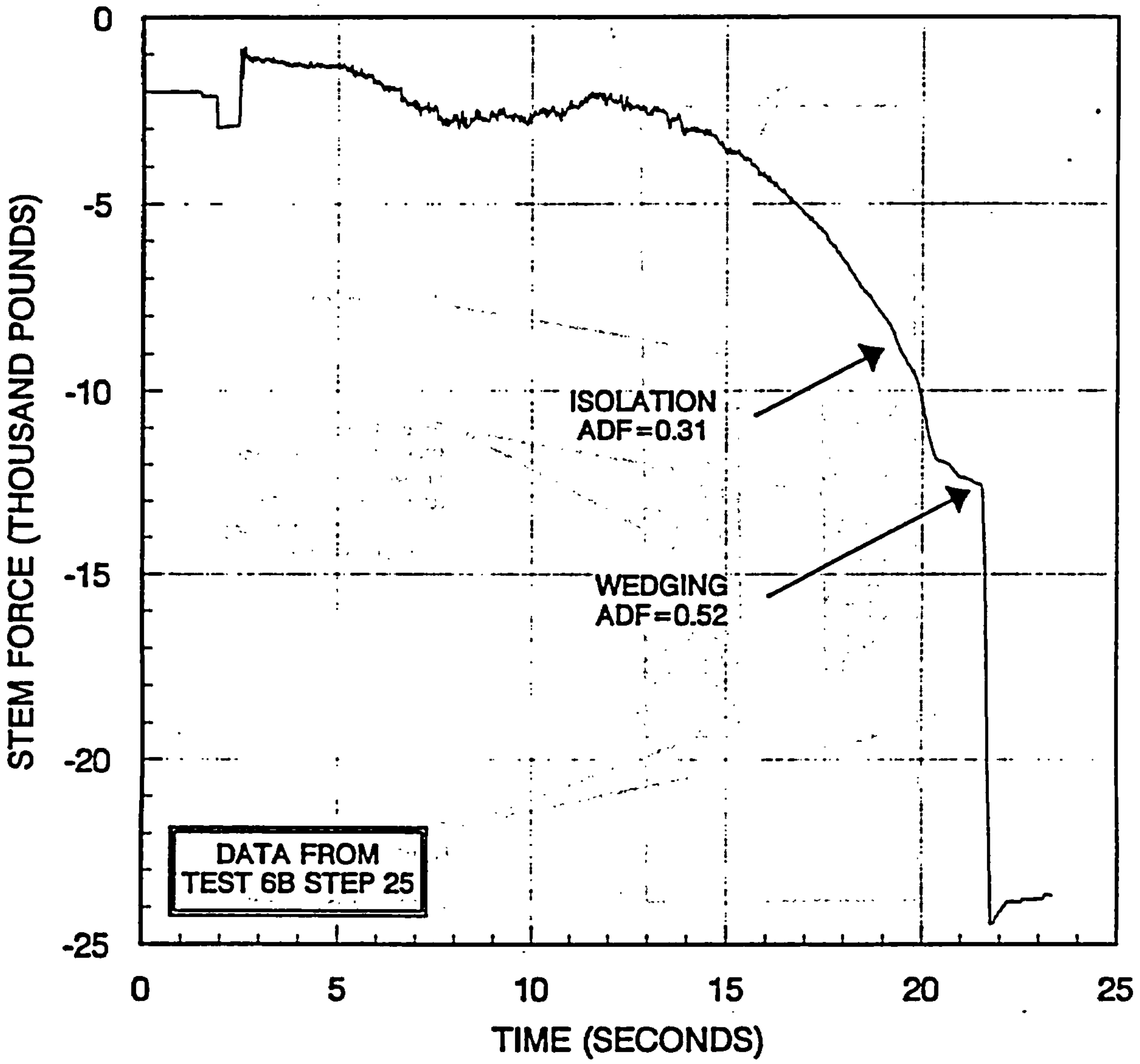
STEM FORCE HISTORY FOR FIRST BLOWDOWN CLOSURE OF VALVE 4

FIGURE 6-2



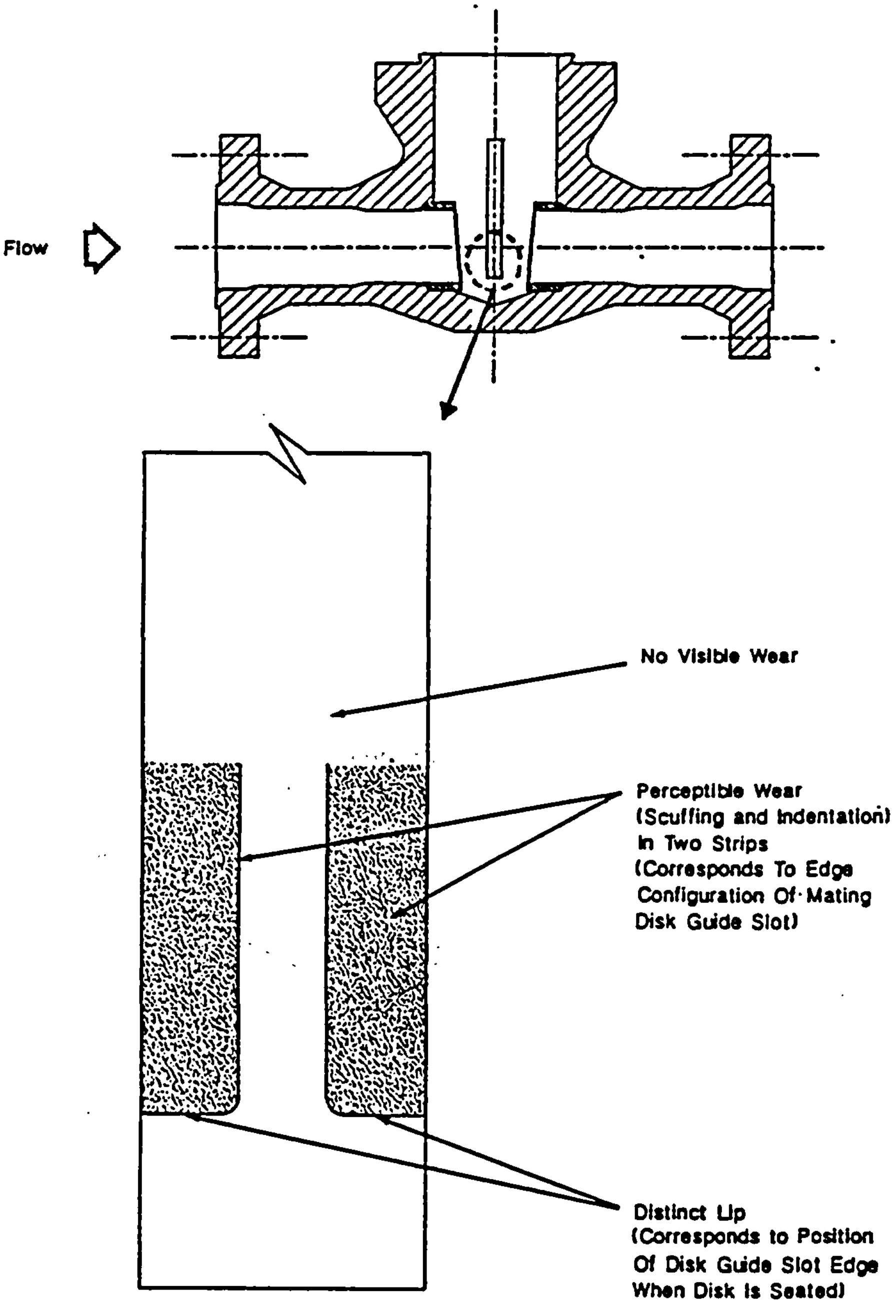
STEM FORCE HISTORY FOR BLOWDOWN OPEN/CLOSURE CYCLE FOR VALVE 5

FIGURE 6-3



STEM FORCE HISTORY FOR
VALVE 2 BLOWDOWN CLOSURE
FIGURE 6-4

MPR ASSOCIATES
F-140-49-93
11/13/90

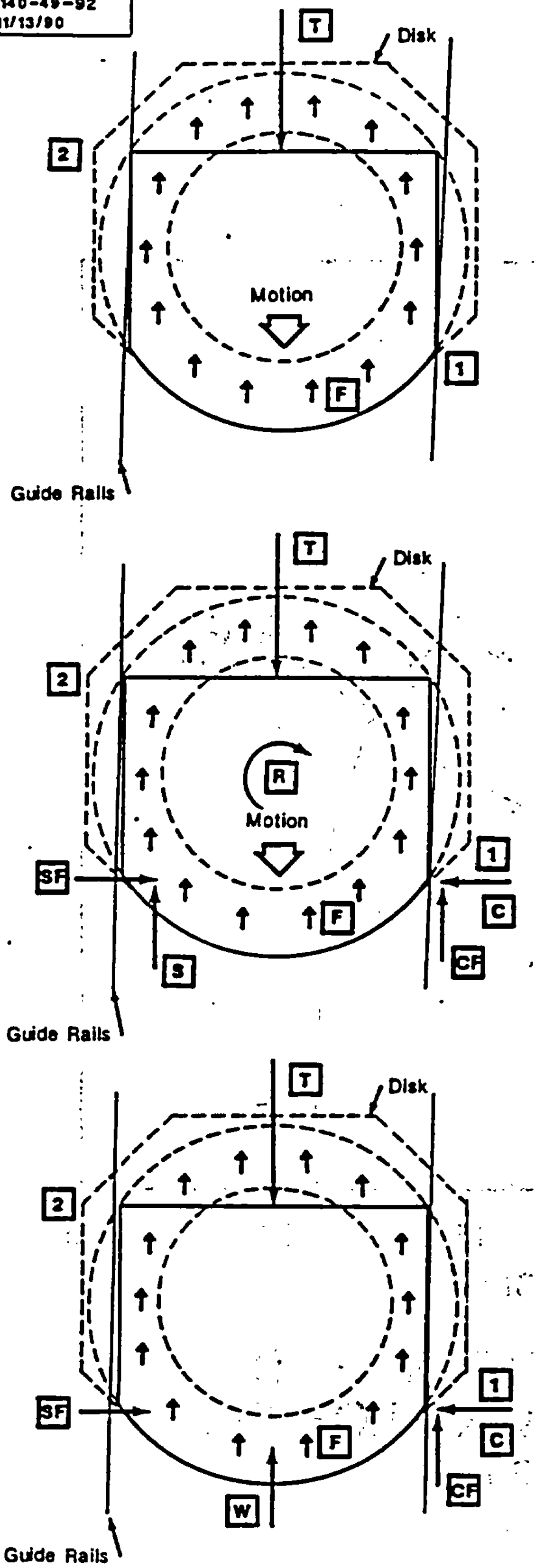


Note:

Because of access limitations, it was not possible to make a photograph of this guide rail wear during the valve inspection. The INEL videotape of valve internals (Reference. 10) shows this guide rail wear.

DIAGRAM OF GUIDE RAIL WEAR IN VALVE 2
FIGURE 6-5

MPR ASSOCIATES
F-140-49-92
11/13/90



1. AT FLOW ISOLATION

Stem thrust **T** is opposed by disk/seat friction forces **F**. Disk is slightly rotated relative to guide rails, and contact occurs at points **1** and **2**, but there are not significant reaction forces. Rotation is exagerated; actual value is less than 1°. Mechanism for disk rotation is not known, but could be slight stem misalignment, flow effects, non-uniform friction, etc.

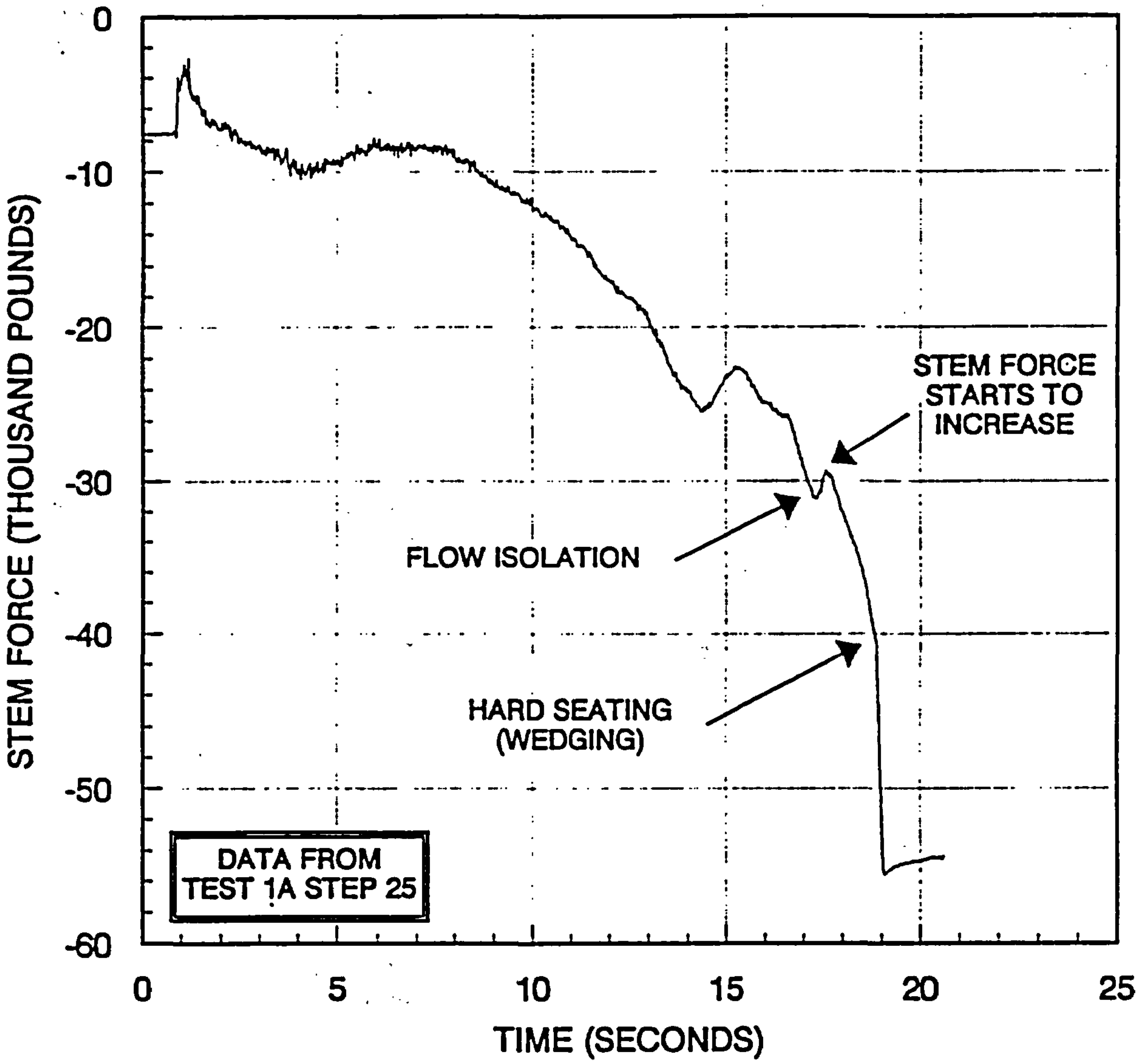
2. APPROACHING HARD SEATING

Because of disk angular position, seat reacts disk eccentrically at first **S**. Disk rotates clockwise to align with seat **R**. Contact force **C** builds up on guide due to squeezing point **1**, reacted by lateral seat friction **SF**. Additional friction at guide **CF** needs to be overcome by stem thrust

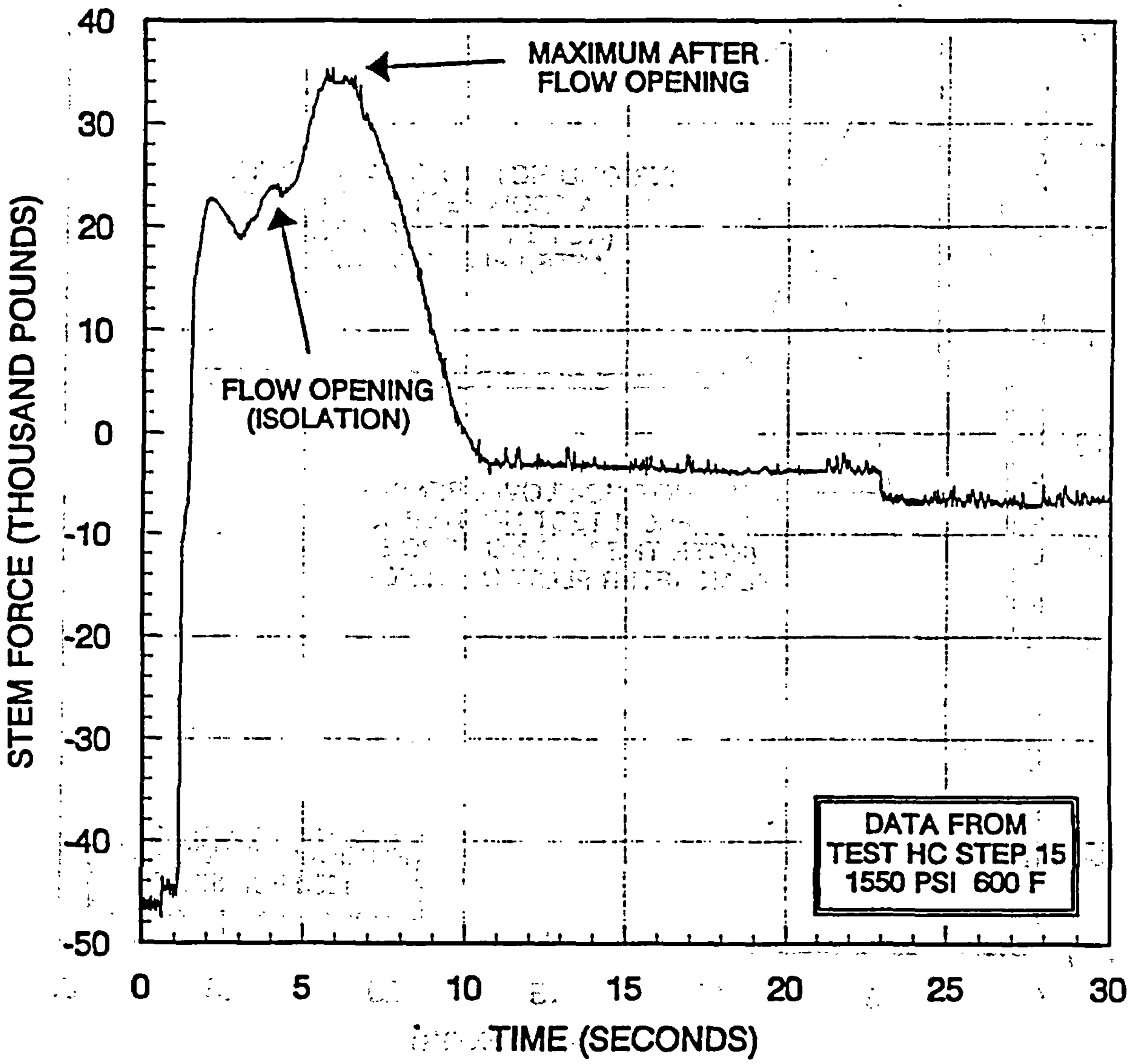
3. HARDSEATED

Disk motion is stopped, and wedging force **W** is established. Disk is sprung into guide at point **1**

HYPOTHESIZED MECHANISM FOR VALVE 2 BEHAVIOR
FIGURE 6-6

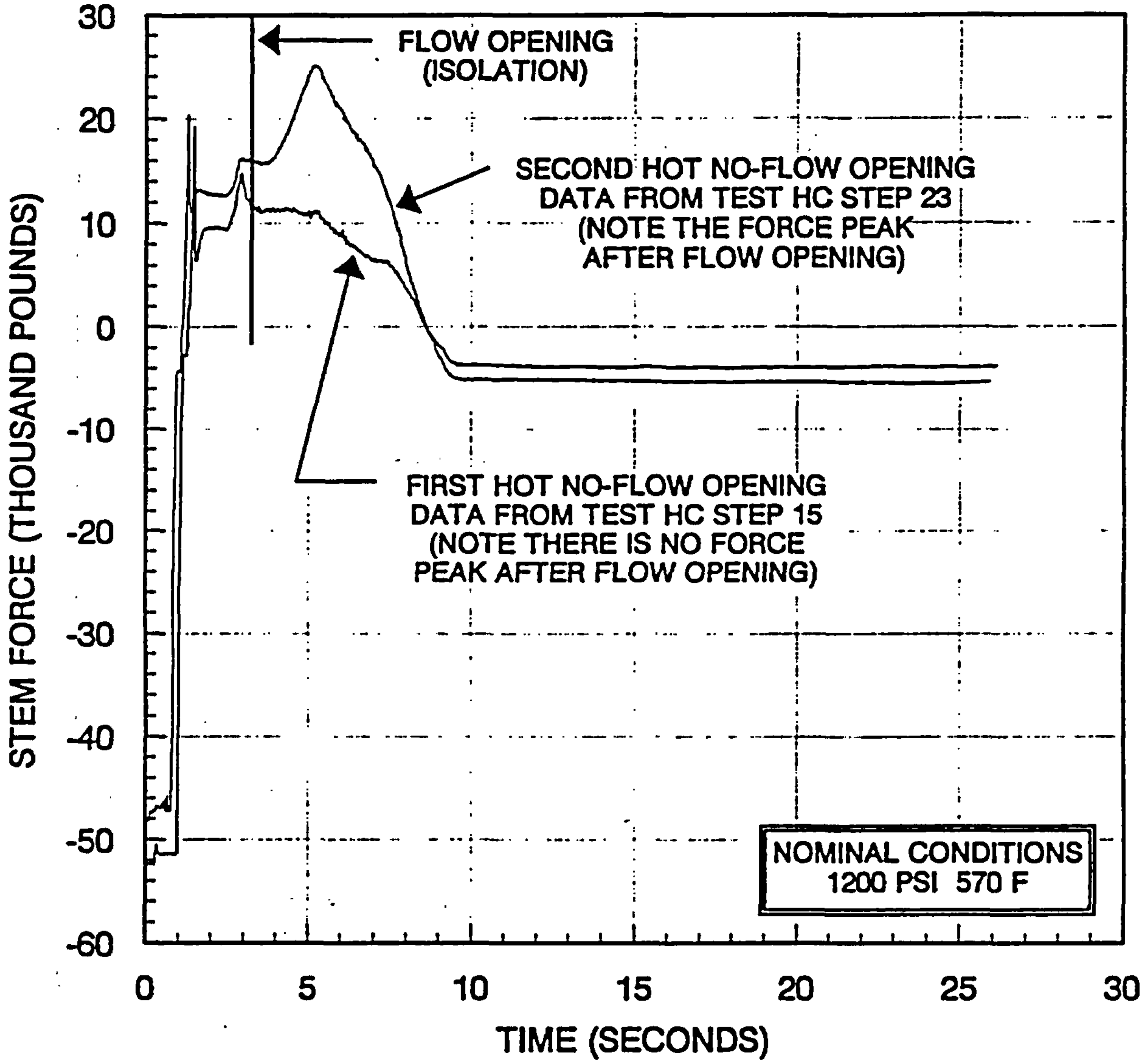


STEM FORCE HISTORY FOR
VALVE 6 BLOWDOWN CLOSURE
FIGURE 6-7



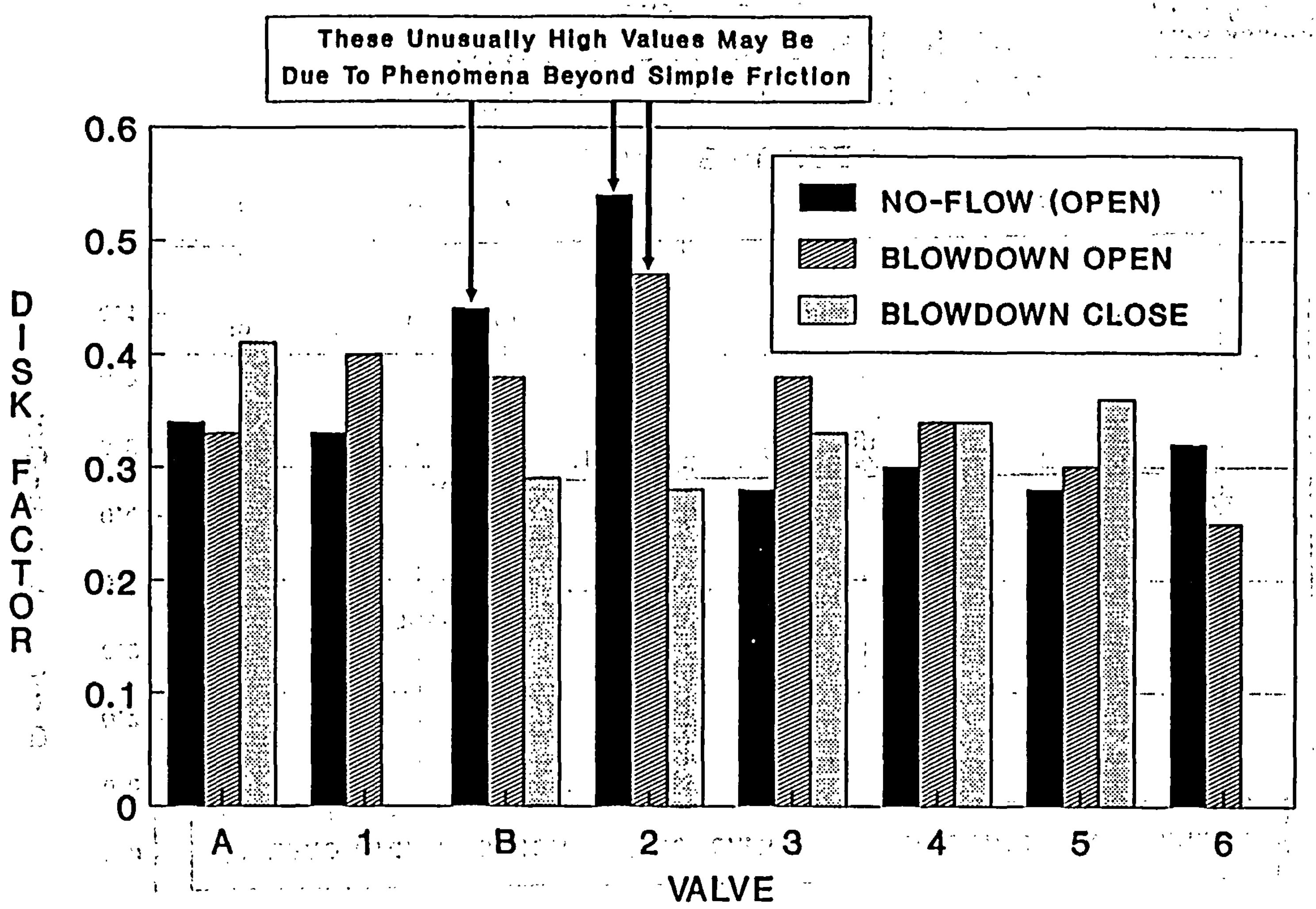
STEM FORCE HISTORY FOR FIRST VALVE 5 HOT NO-FLOW OPENING

FIGURE 6-8



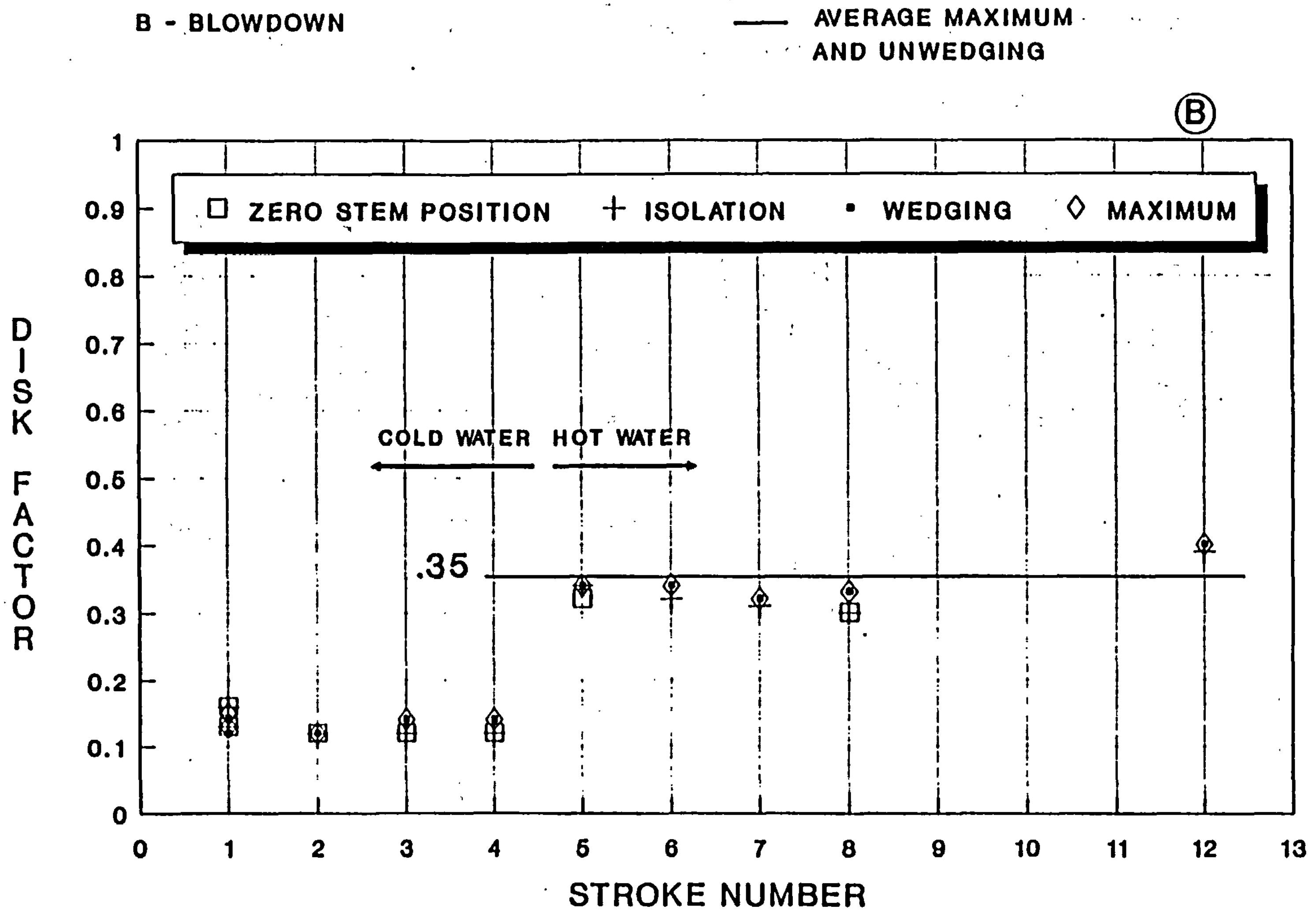
STEM FORCE HISTORY FOR FIRST TWO VALVE 6 HOT NO-FLOW OPENINGS

FIGURE 6-9



APPARENT DISK FACTORS FOR SLIDING FRICTION IN NO-FLOW AND BLOWDOWN STROKES

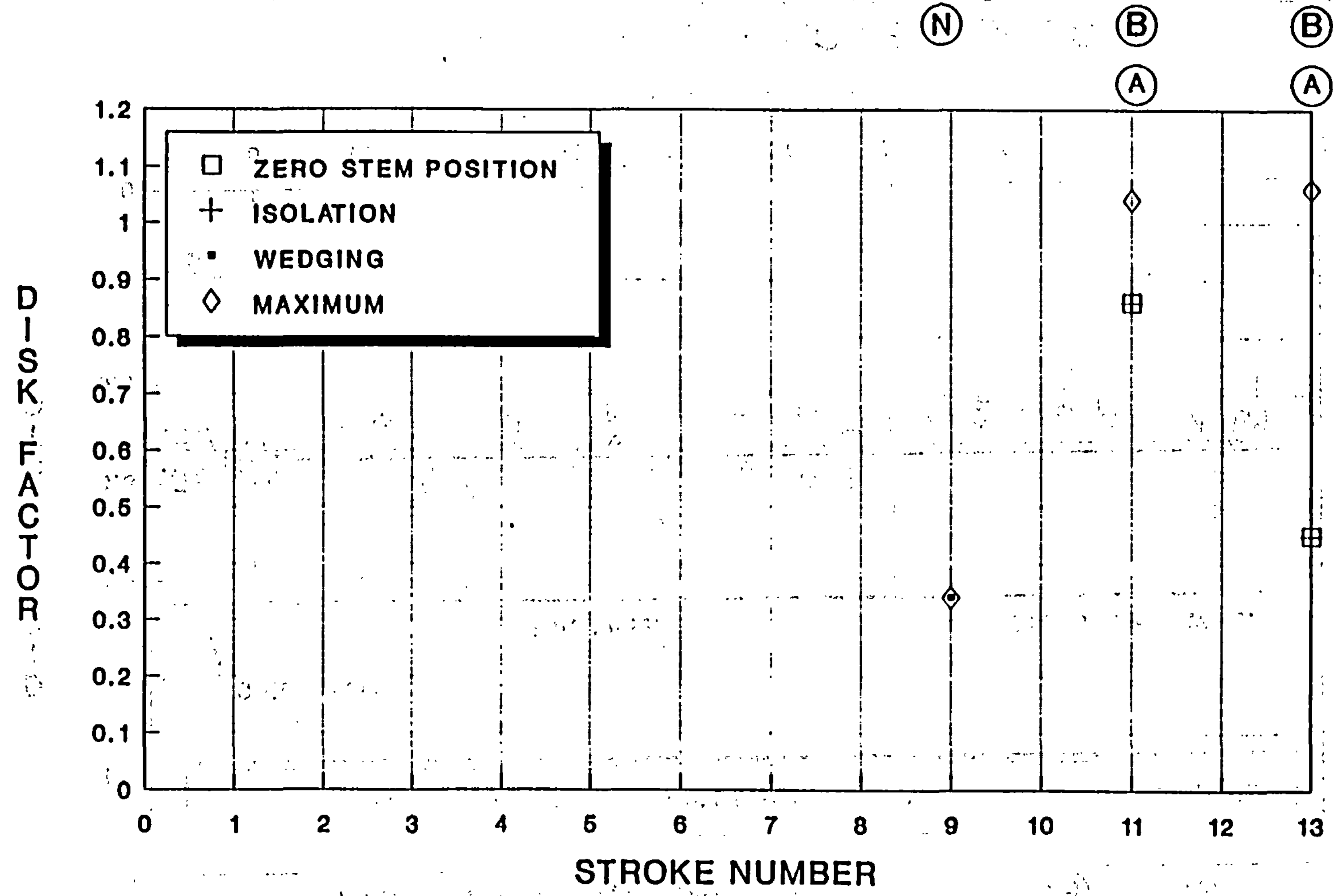
FIGURE 6-10



DISK FACTOR VS STROKE NUMBER
VALVE #1 OPENING STROKES
FIGURE 6-11

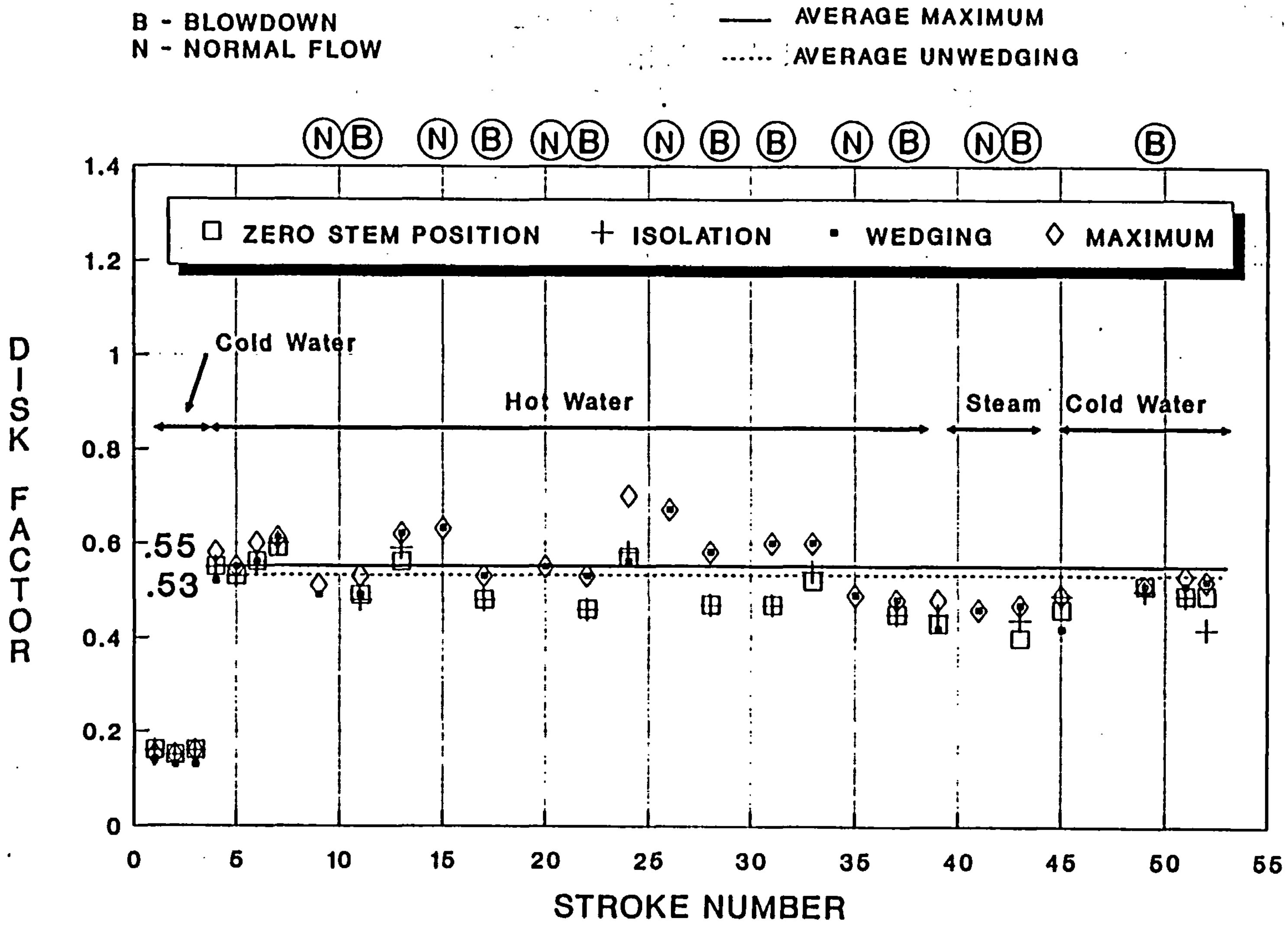
MPR ASSOCIATES
F-140-49-61(B)
11/13/90

B - BLOWDOWN
N - NORMAL FLOW
A - ANOMALOUS BEHAVIOR



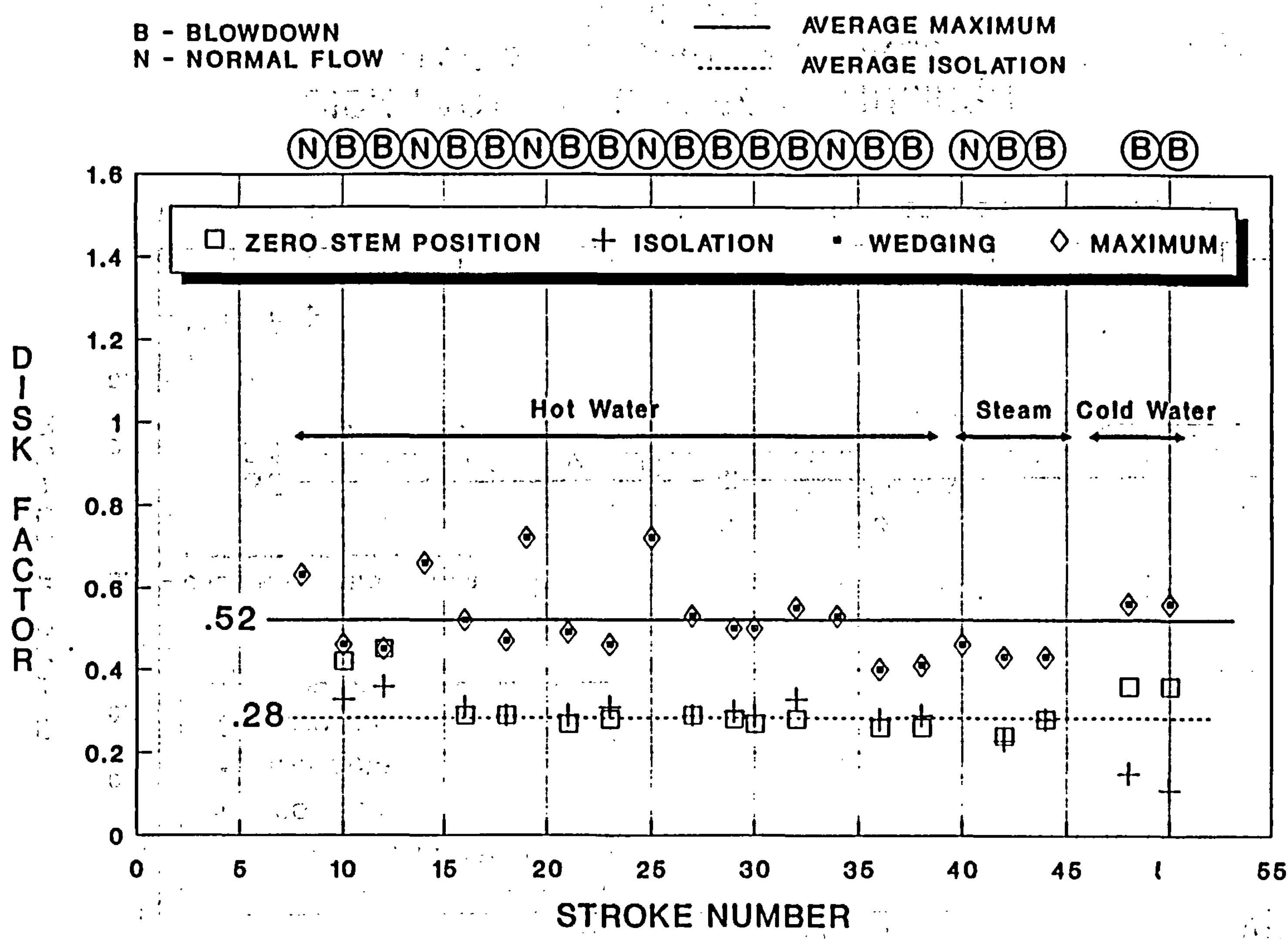
DISK FACTOR VS STROKE NUMBER
VALVE #1 CLOSING STROKES
FIGURE 6-12

MPR ASSOCIATES
F-140-49-62(B)
11/13/90



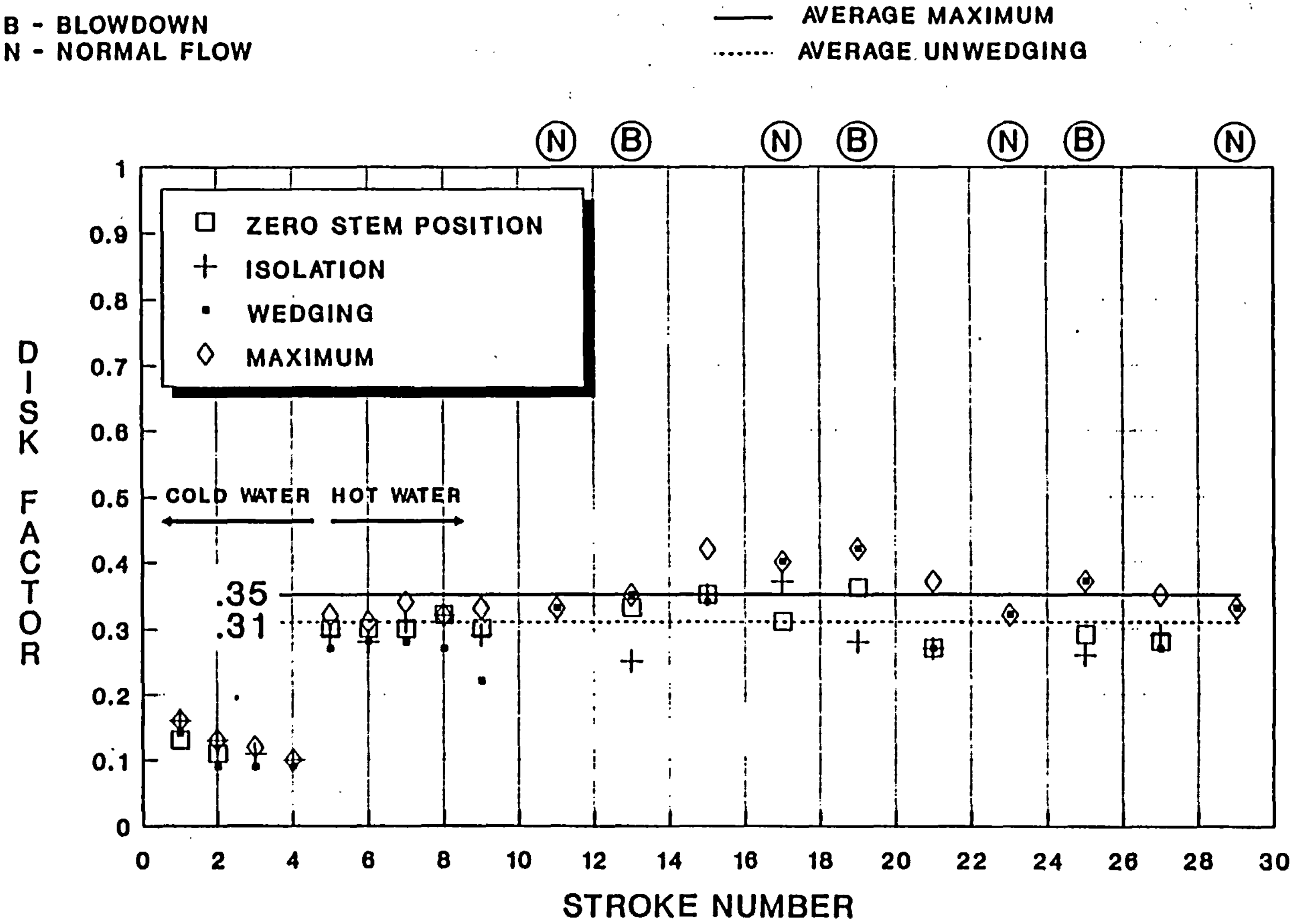
DISK FACTOR VS STROKE NUMBER
VALVE #2 OPENING STROKES
FIGURE 6-13

MPR ASSOCIATES
F-140-49-63(B)
11/13/90



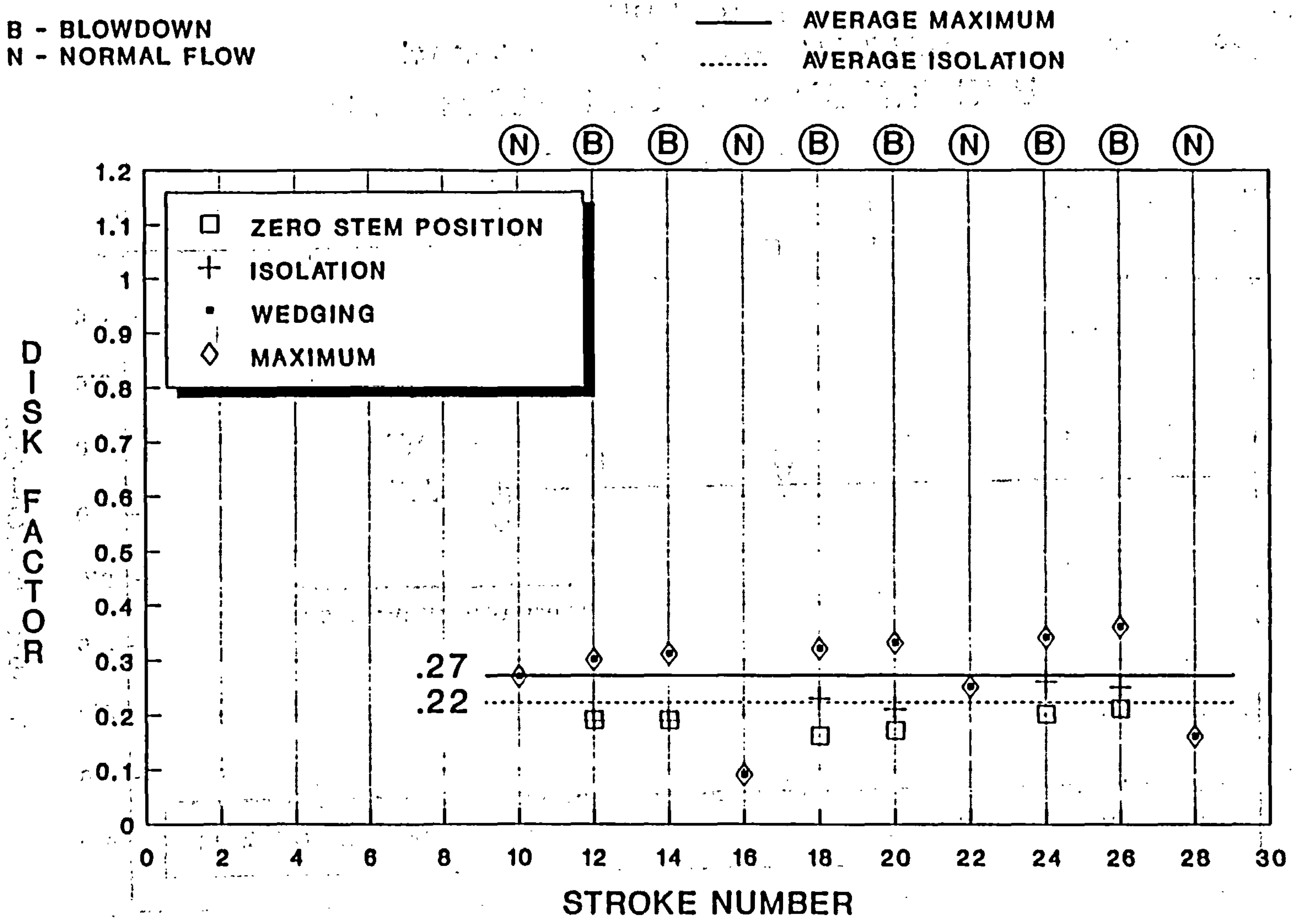
DISK FACTOR VS STROKE NUMBER
VALVE #2 CLOSING STROKES
FIGURE 6-14

MPR ASSOCIATES
F-140-49-64(B)
11/13/90



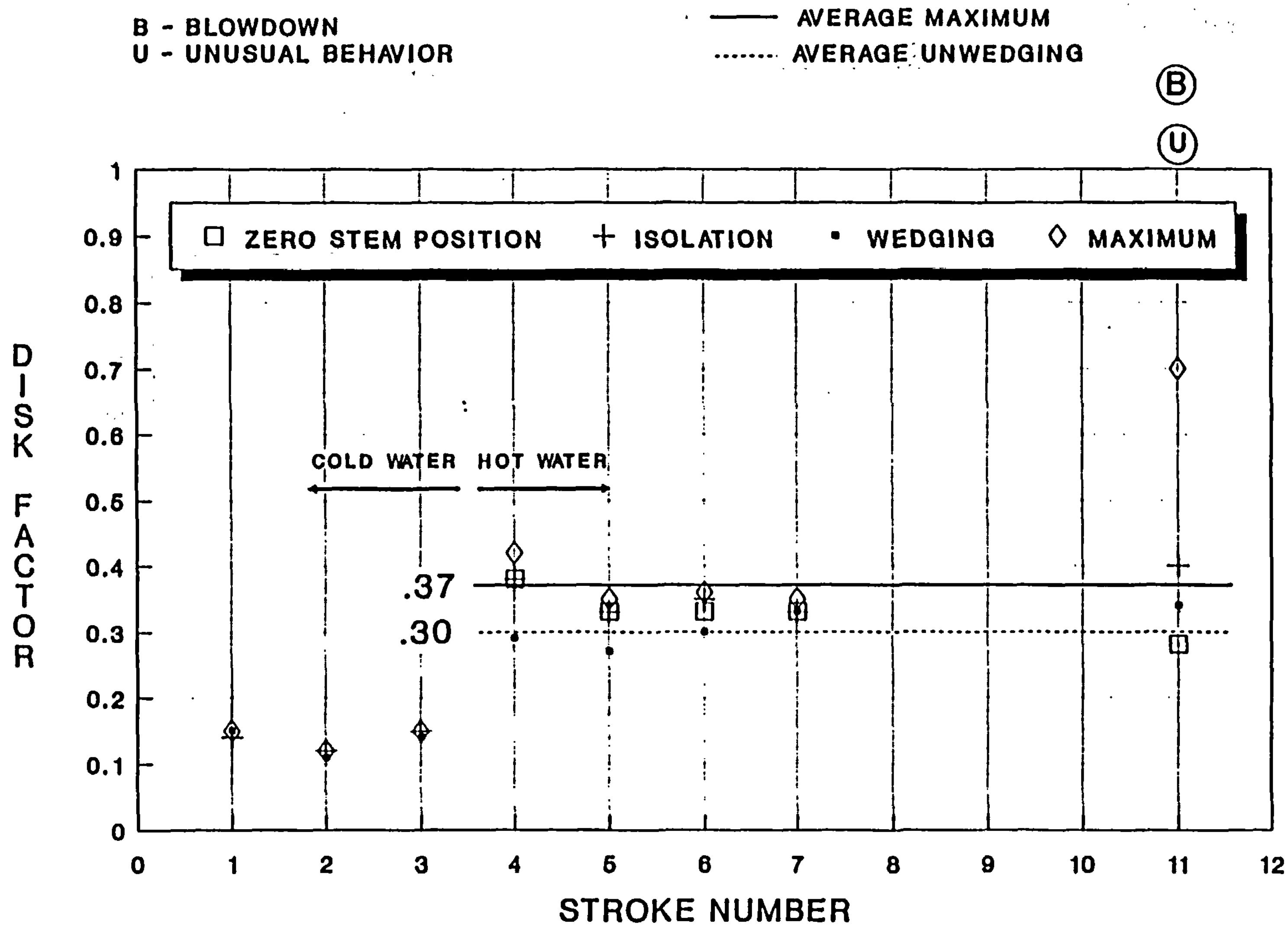
DISK FACTOR VS STROKE NUMBER
VALVE #3 OPENING STROKES
FIGURE 6-15

MPR ASSOCIATES
F-140-49-65(B)
11/13/90



DISK FACTOR VS STROKE NUMBER
VALVE #3 CLOSING STROKES
FIGURE 6-16

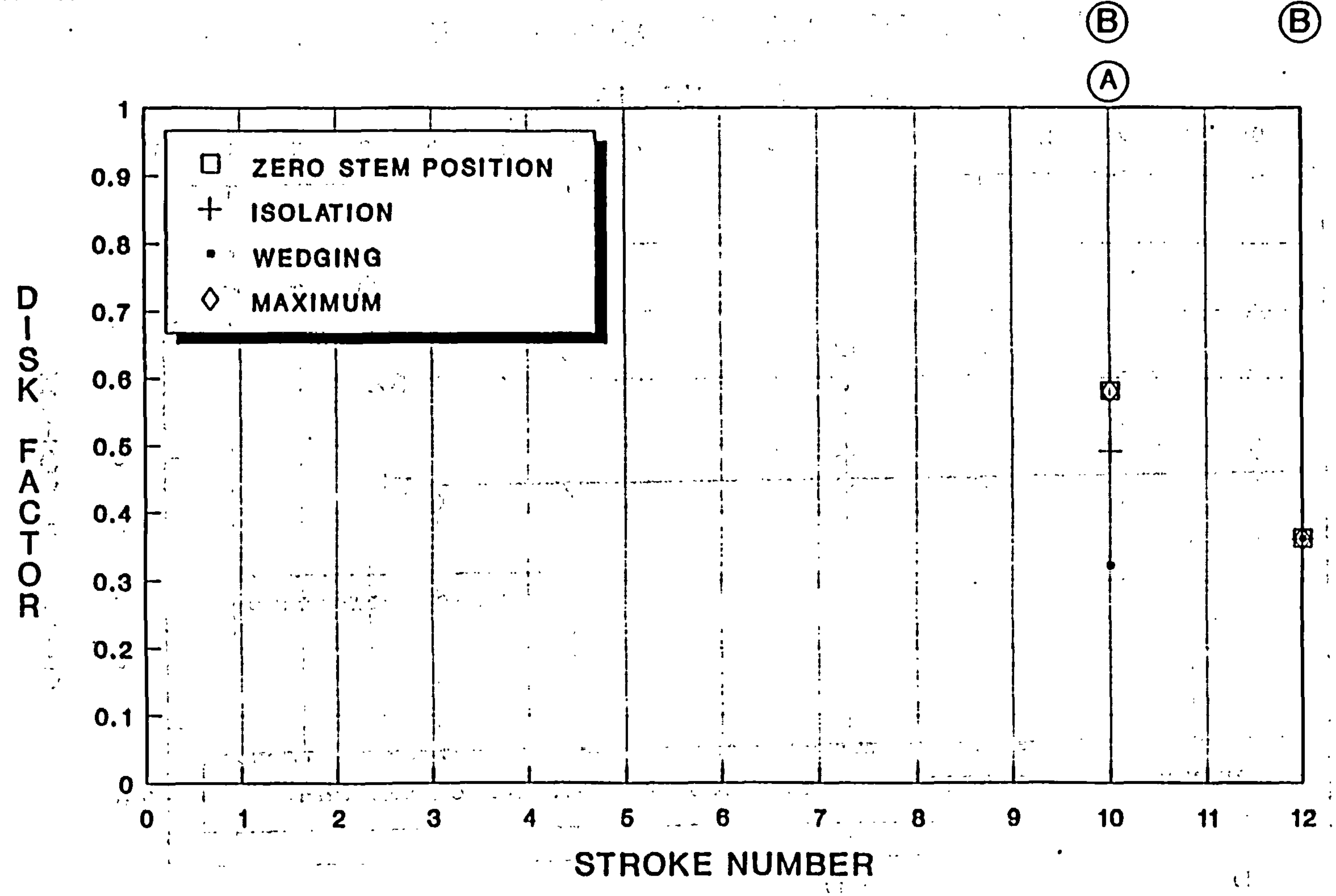
MPR ASSOCIATES
F-140-49-66(B)
11/13/90



DISK FACTOR VS STROKE NUMBER
VALVE #4 OPENING STROKES
FIGURE 6-17

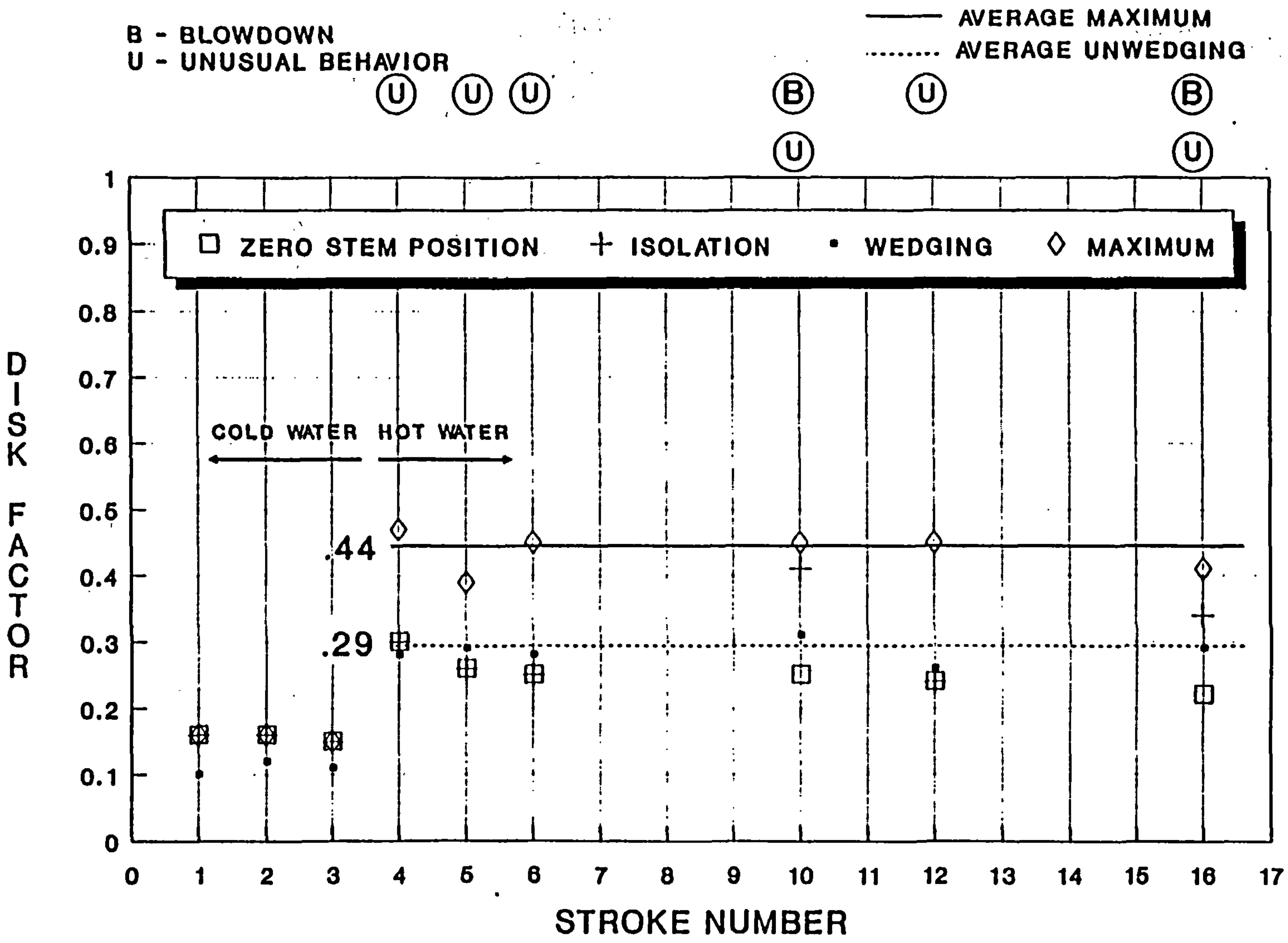
MPR ASSOCIATES
F-140-49-67(A)
10/26/90

B - BLOWDOWN
A - ANOMALOUS BEHAVIOR



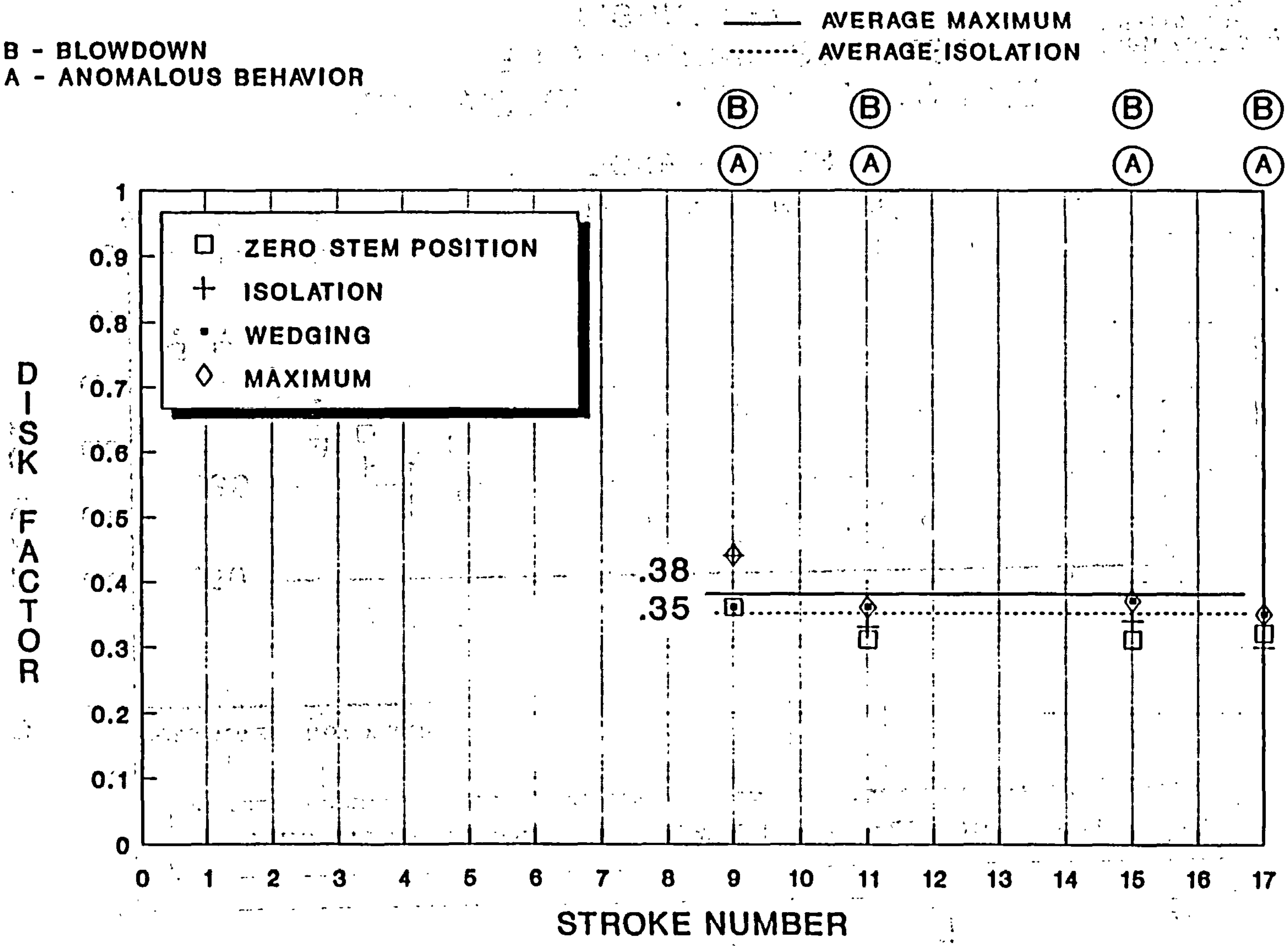
DISK FACTOR VS STROKE NUMBER
VALVE #4 CLOSING STROKES
FIGURE 6-18

MPR ASSOCIATES
F-140-49-68(B)
11/13/90



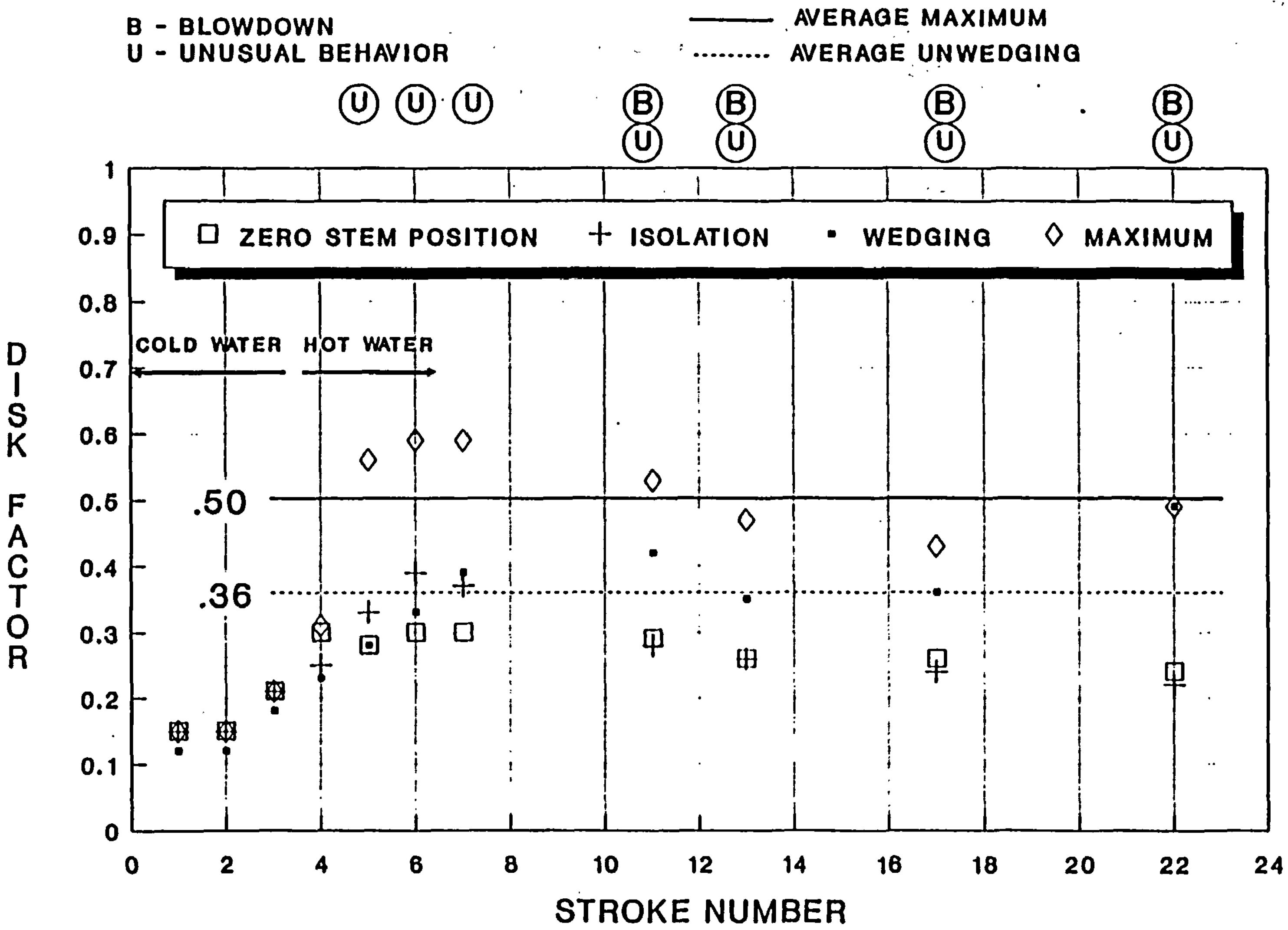
DISK FACTOR VS STROKE NUMBER
VALVE #5 OPENING STROKES
FIGURE 6-19

MPR ASSOCIATES
F-140-49-69(B)
11/13/90



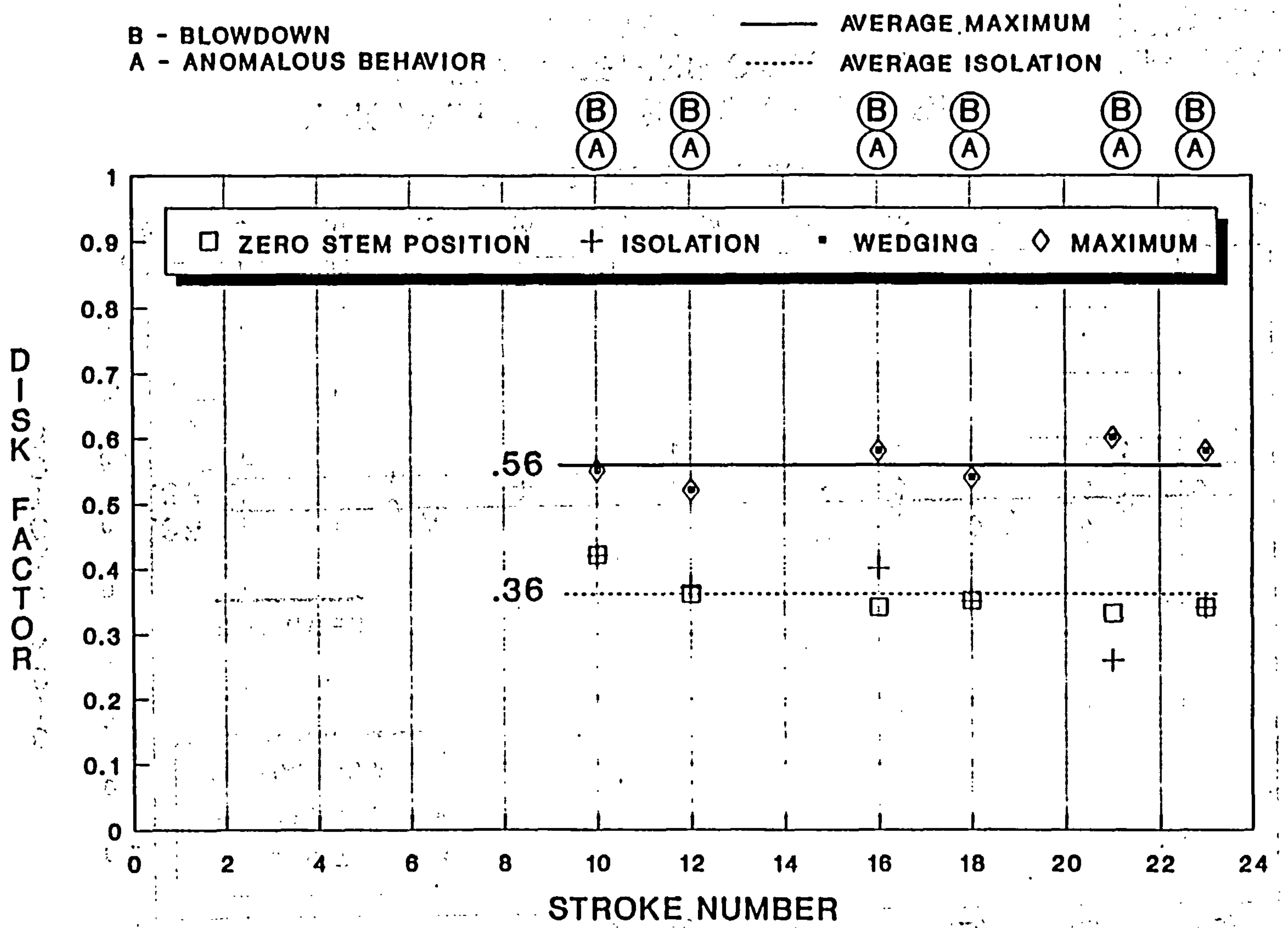
DISK FACTOR VS STROKE NUMBER
VALVE #5 CLOSING STROKES
FIGURE 6-20

MPR ASSOCIATES
F-140-49-70(B)
11/13/90



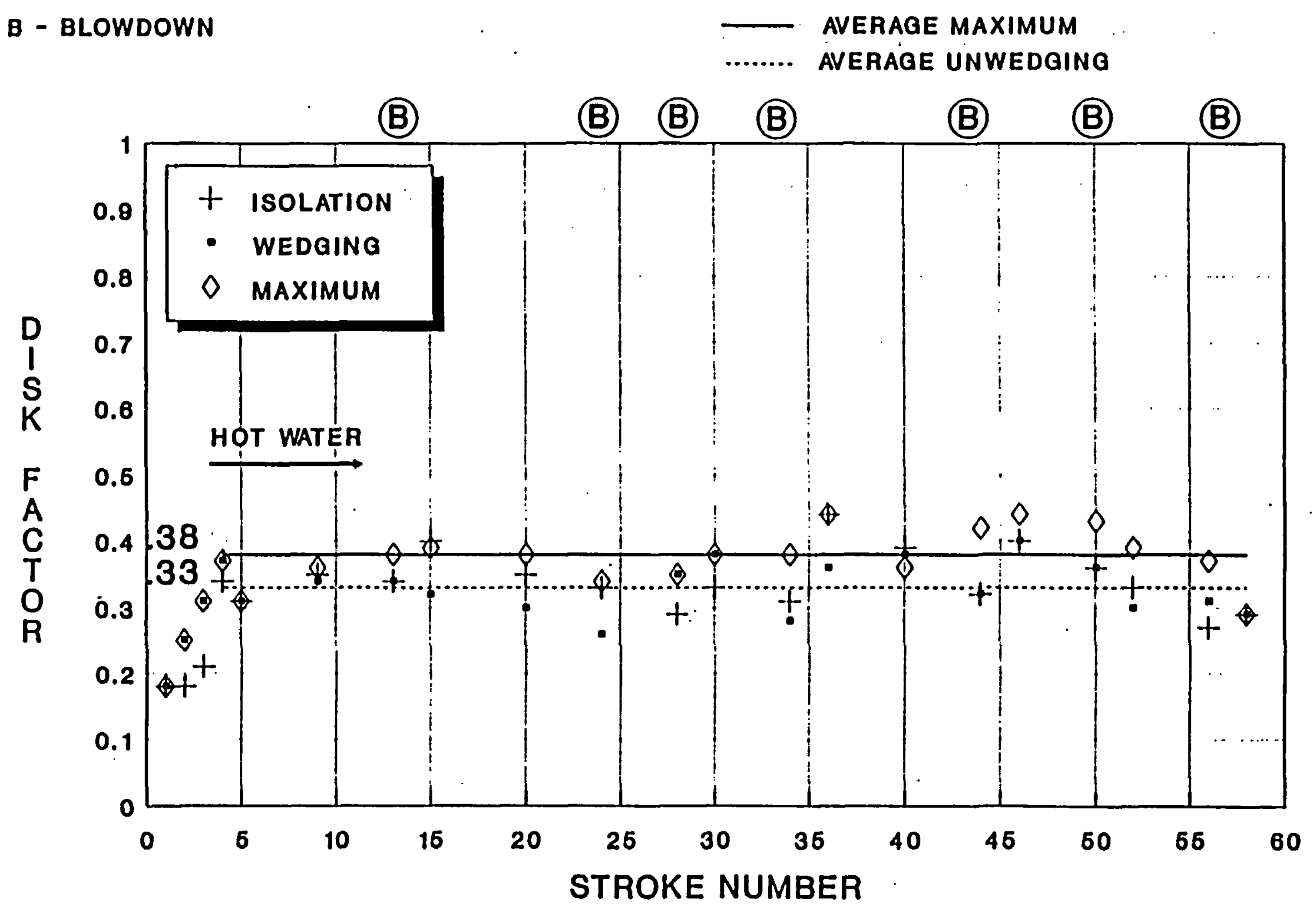
DISK FACTOR VS STROKE NUMBER
VALVE #6 OPENING STROKES
FIGURE 6-21

MPR ASSOCIATES
F-140-49-71(B)
11/13/90



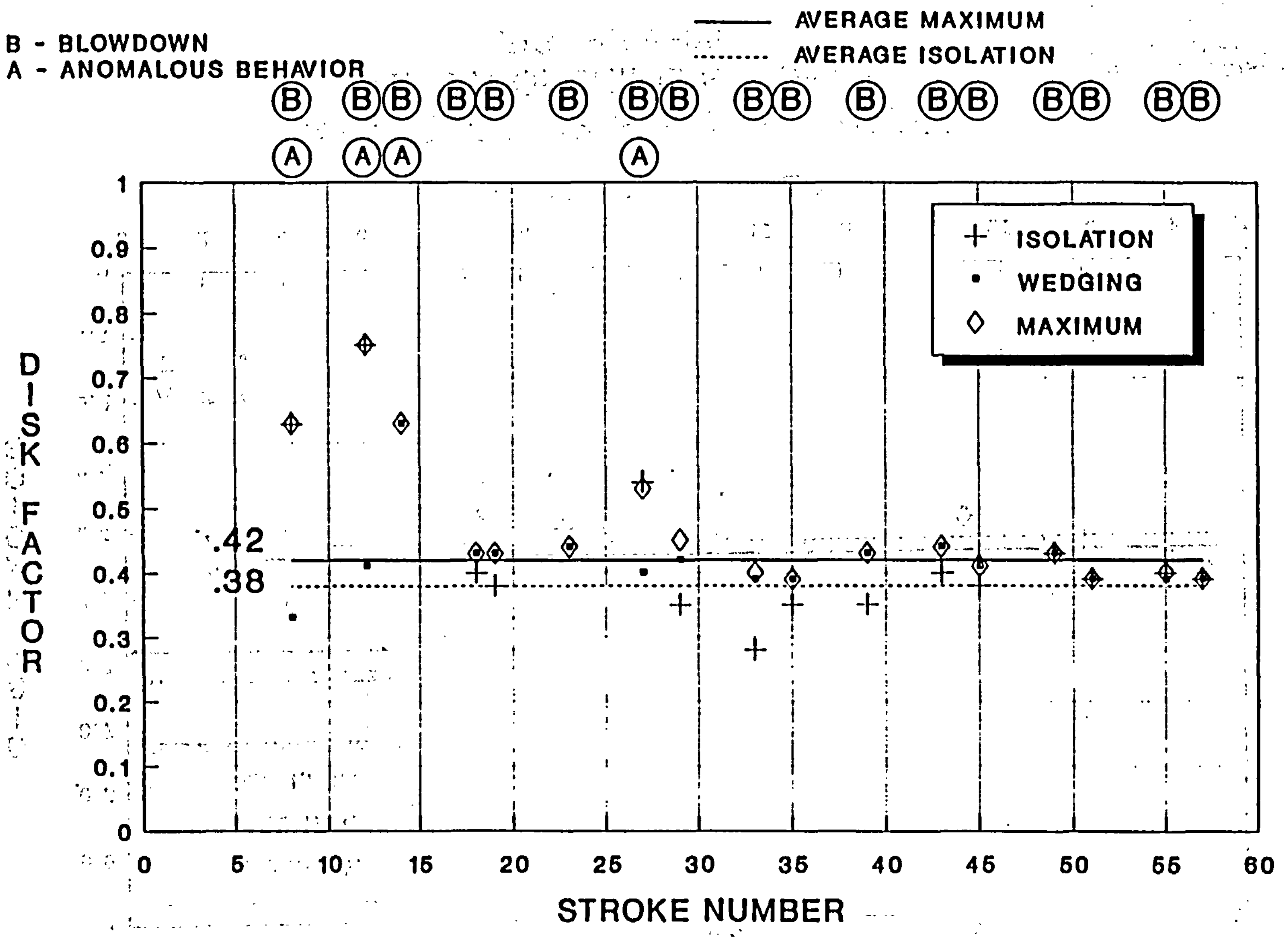
DISK FACTOR VS STROKE NUMBER
VALVE #6 CLOSING STROKES
FIGURE 6-22

MPR ASSOCIATES
F-140-49-72(B)
11/13/90



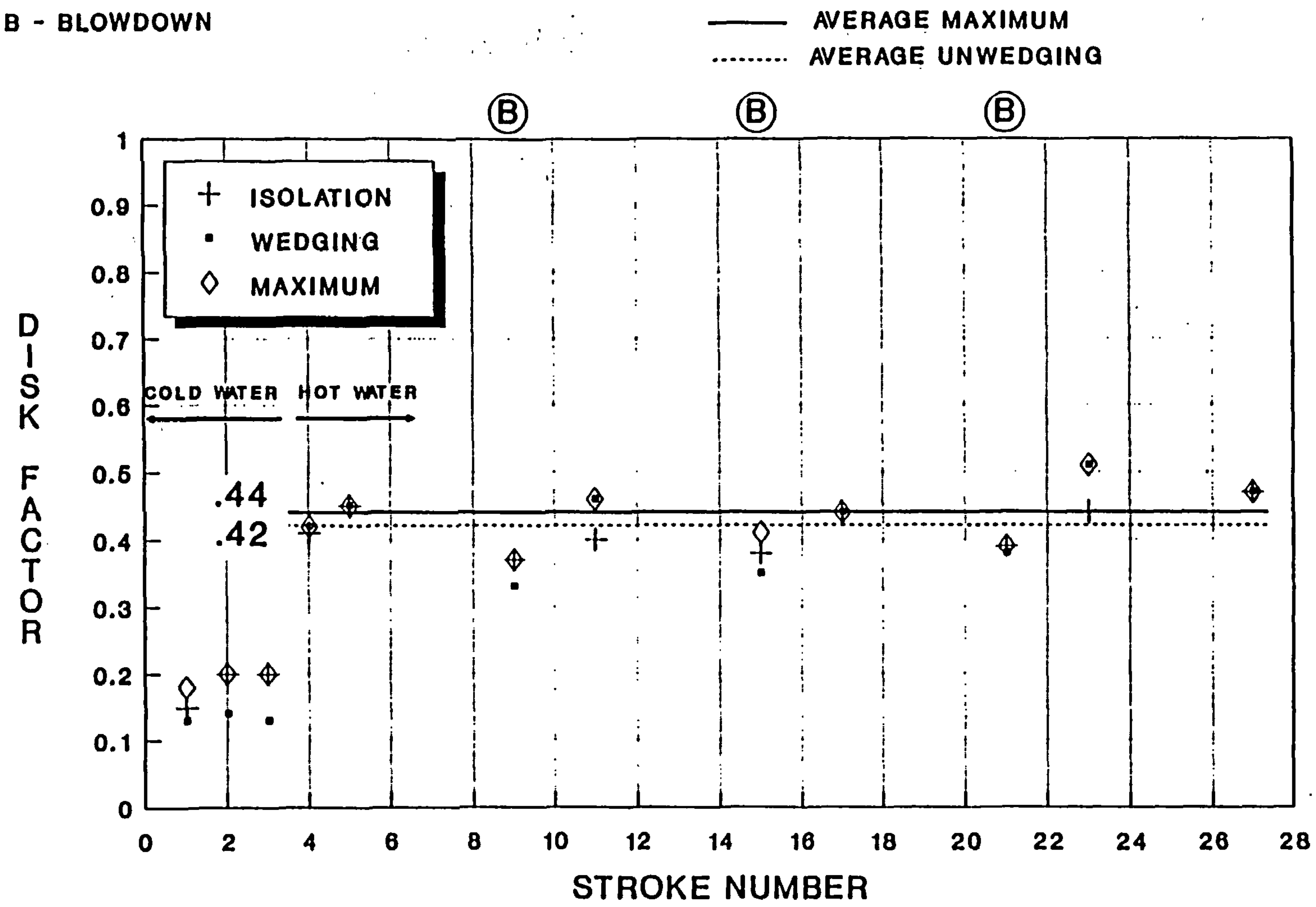
DISK FACTOR VS STROKE NUMBER
VALVE A OPENING STROKES
FIGURE 6-23

MPR ASSOCIATES
F-140-49-73(B)
11/13/90



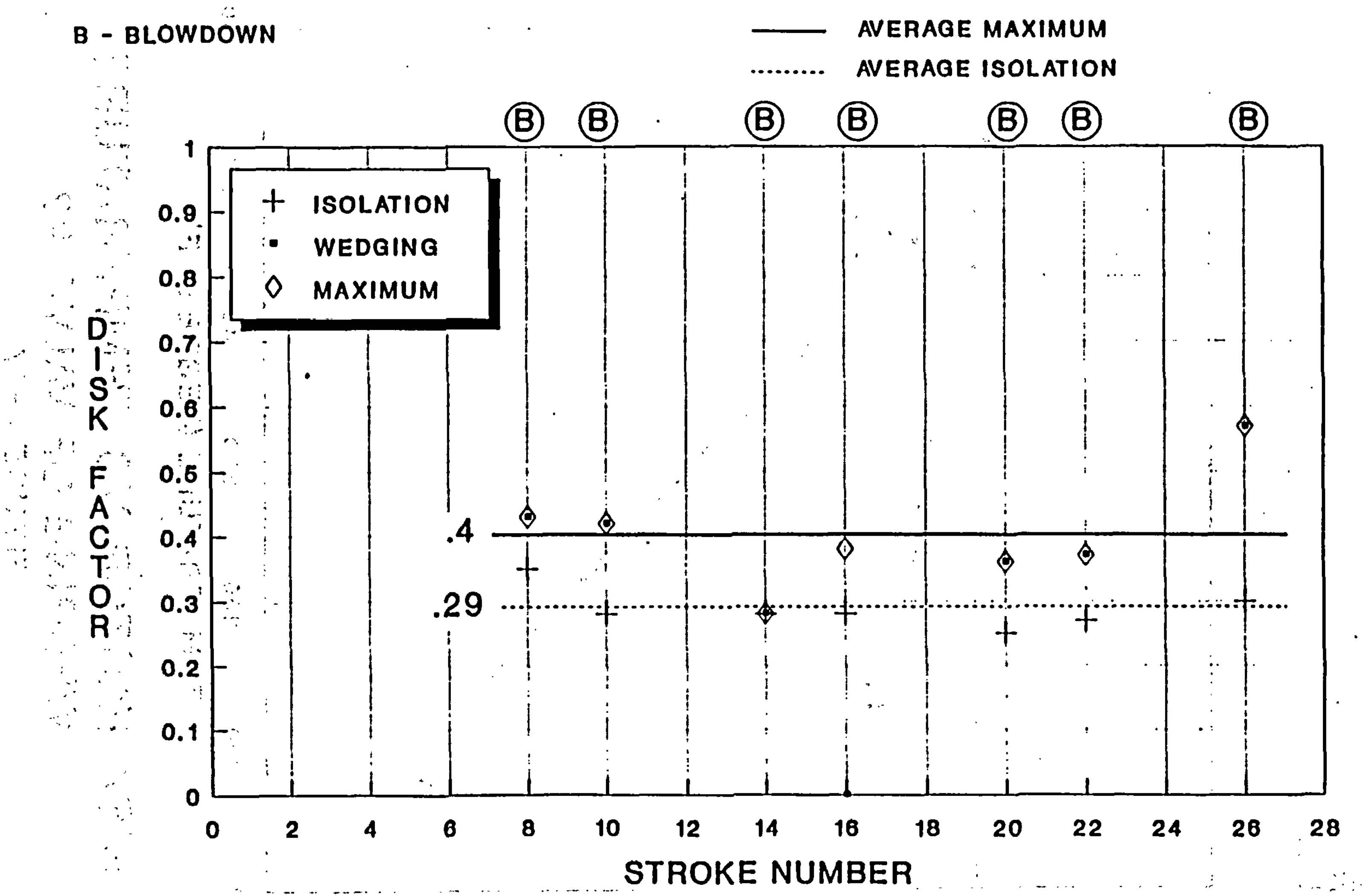
DISK FACTOR VS STROKE NUMBER
VALVE A CLOSING STROKES
FIGURE 6-24

MPR ASSOCIATES
F-140-49-74(B)
11/13/90



DISK FACTOR VS STROKE NUMBER
VALVE B OPENING STROKES
FIGURE 6-25

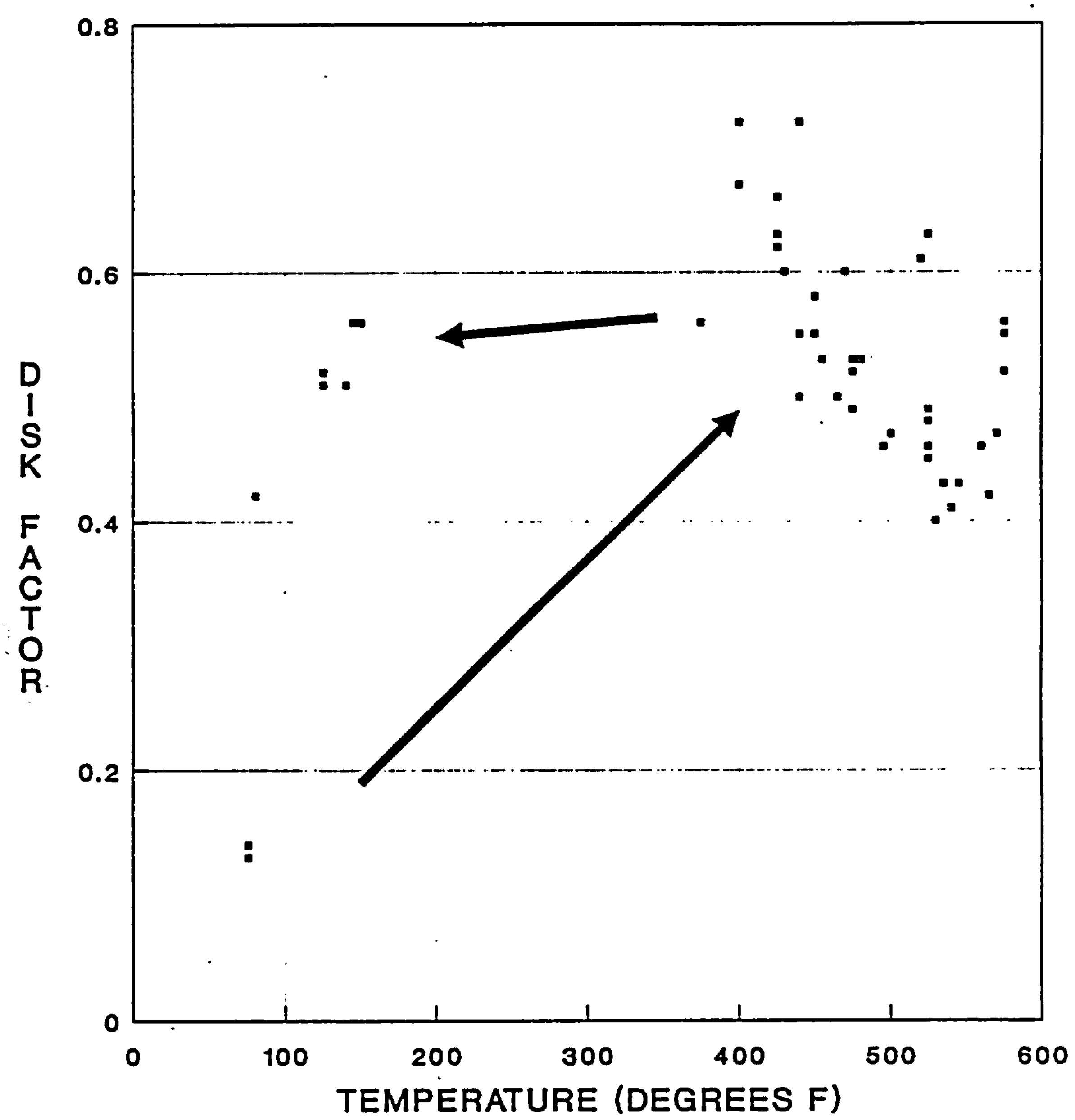
MPR ASSOCIATES
F-140-49-75(B)
11/13/90



DISK FACTOR VS STROKE NUMBER
VALVE B CLOSING STROKES
FIGURE 6-26

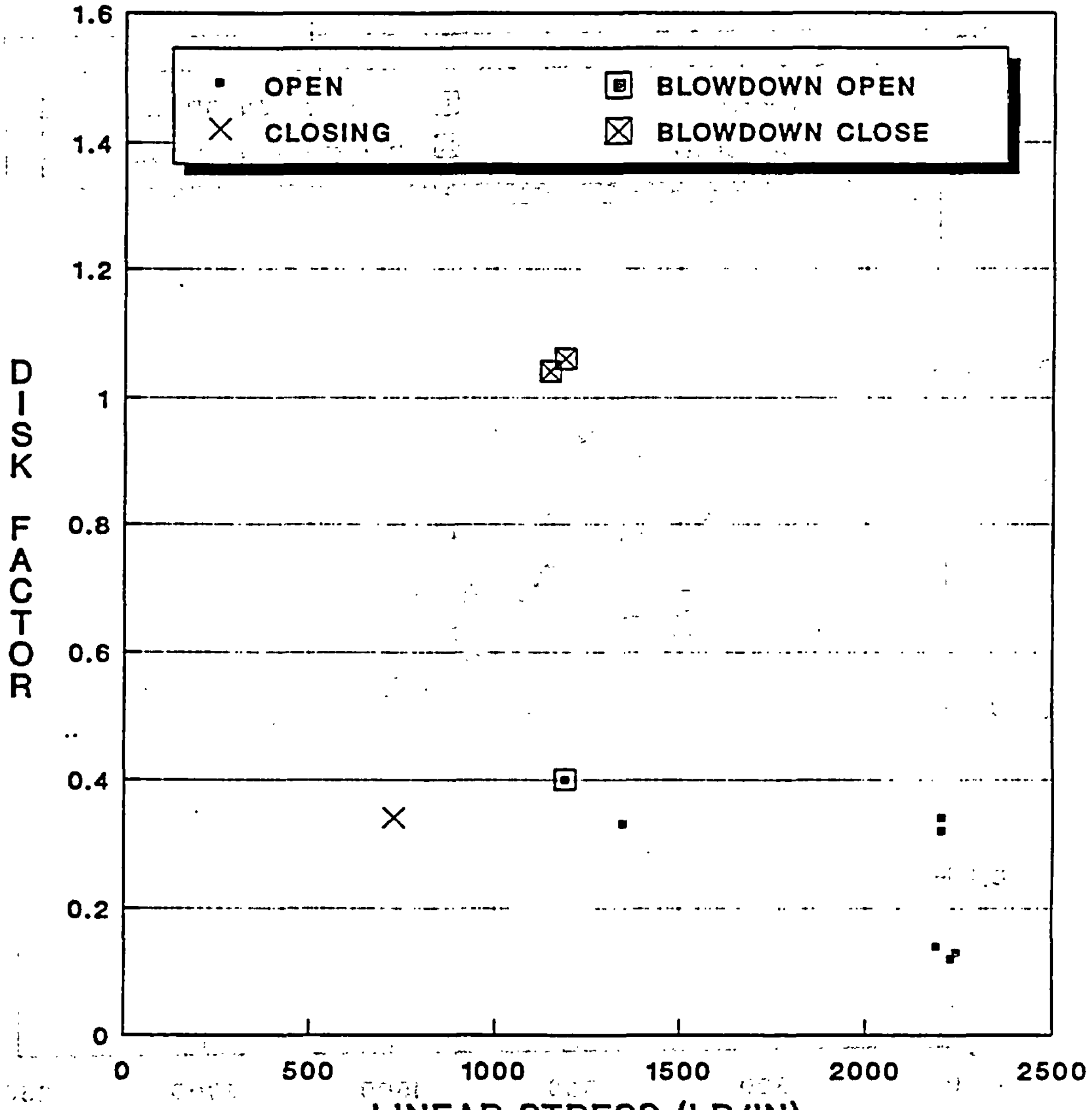
MPR ASSOCIATES
F-140-49-76(B)
11/13/90

MPR ASSOCIATES
F-140-49-77(A)
11/13/90



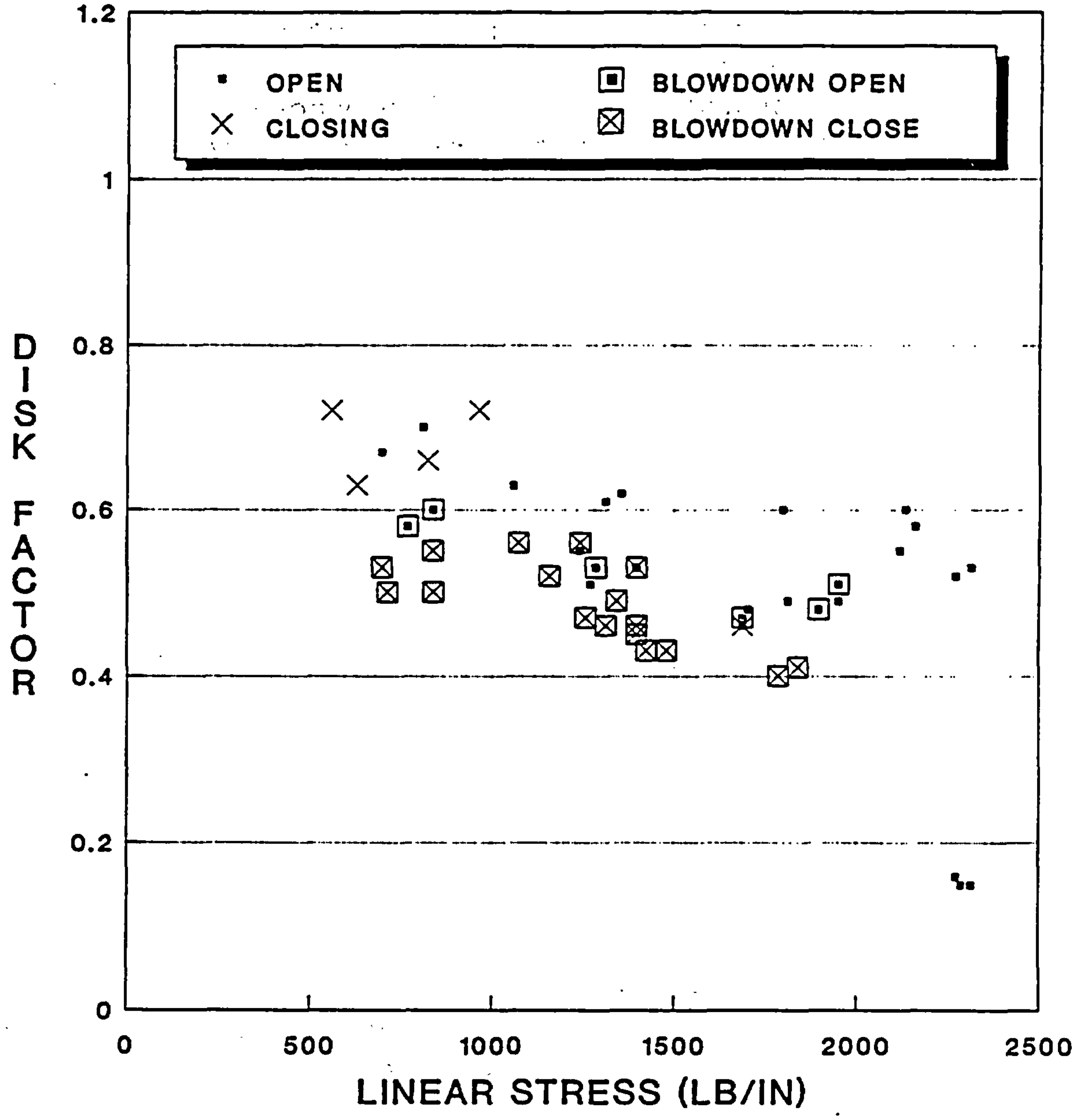
DISK FACTOR VS TEMPERATURE
WEDGING OF VALVE #2
FIGURE 6-27

MPR ASSOCIATES
F-140-49-82(A)
11/13/90



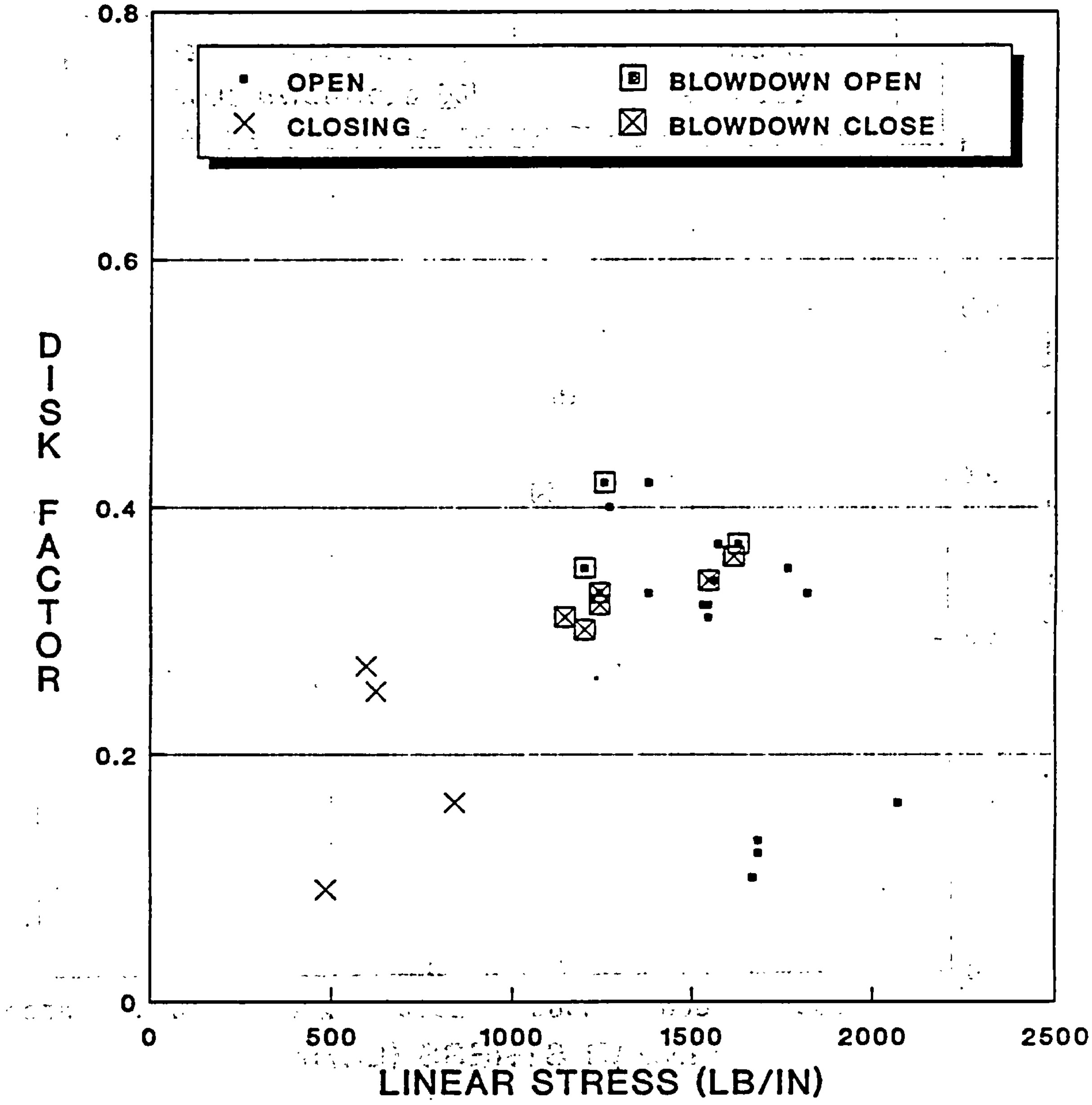
DISK FACTOR VS LINEAR STRESS
VALVE #1 MAXIMUM VALUES
FIGURE 6-28

MPR ASSOCIATES
F-140-49-83(A)
11/13/90



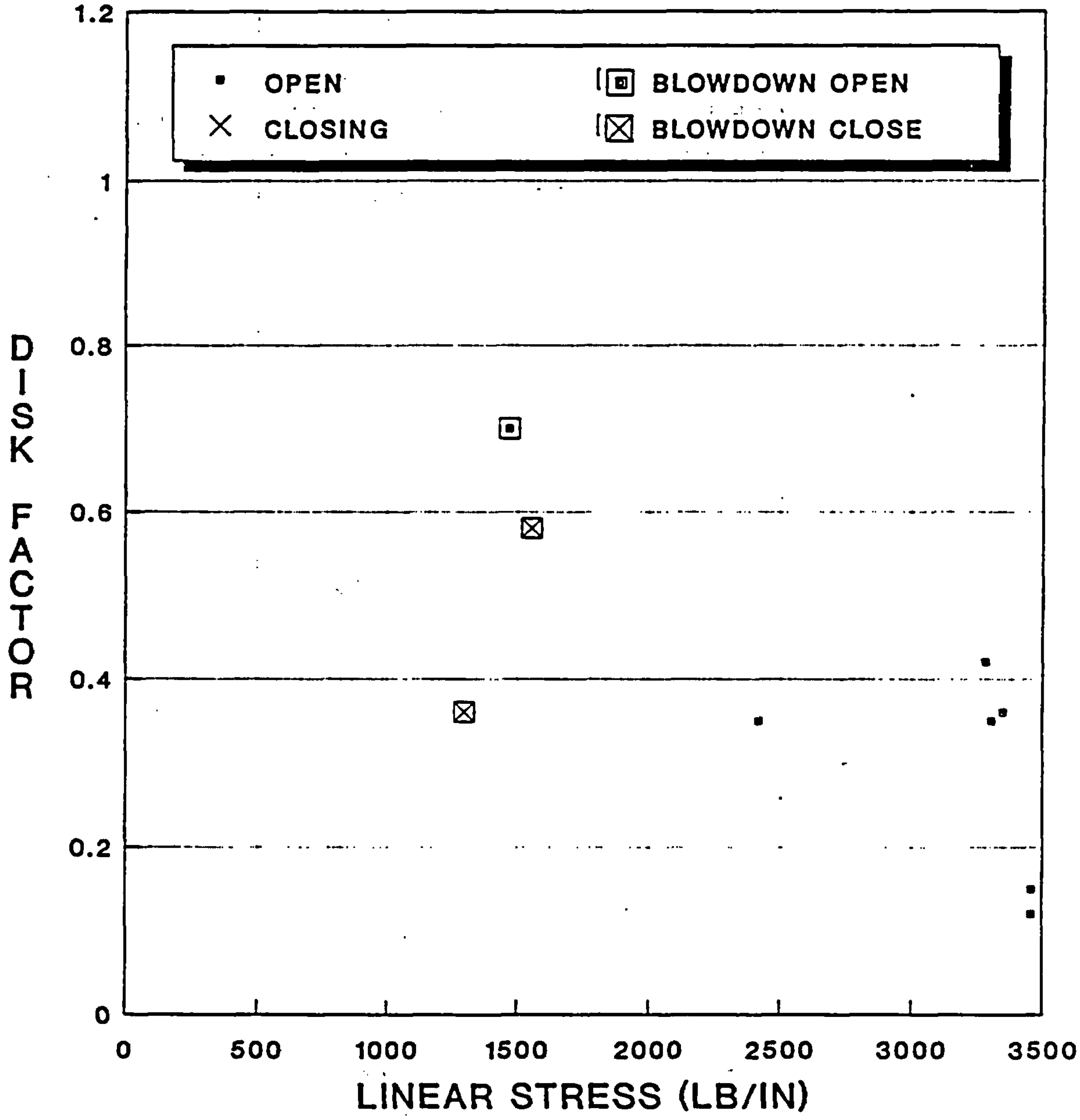
DISK FACTOR VS LINEAR STRESS
VALVE #2 MAXIMUM VALUES
FIGURE 6-29

MPR ASSOCIATES
F-140-49-84(A)
11/13/90



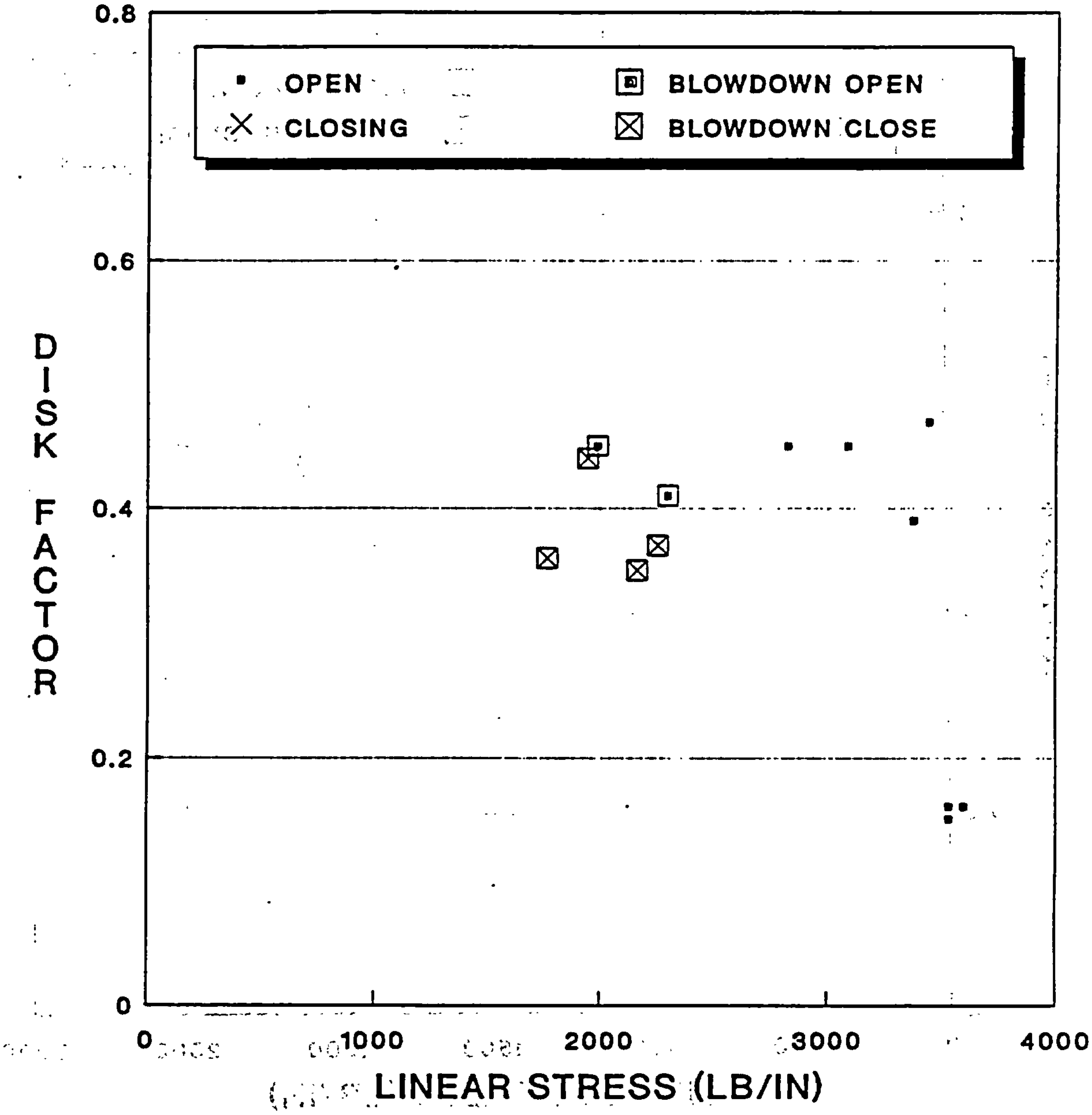
DISK FACTOR VS LINEAR STRESS
VALVE #3 MAXIMUM VALUES
FIGURE 6-30

MPR ASSOCIATES
F-140-49-85(A)
11/13/90



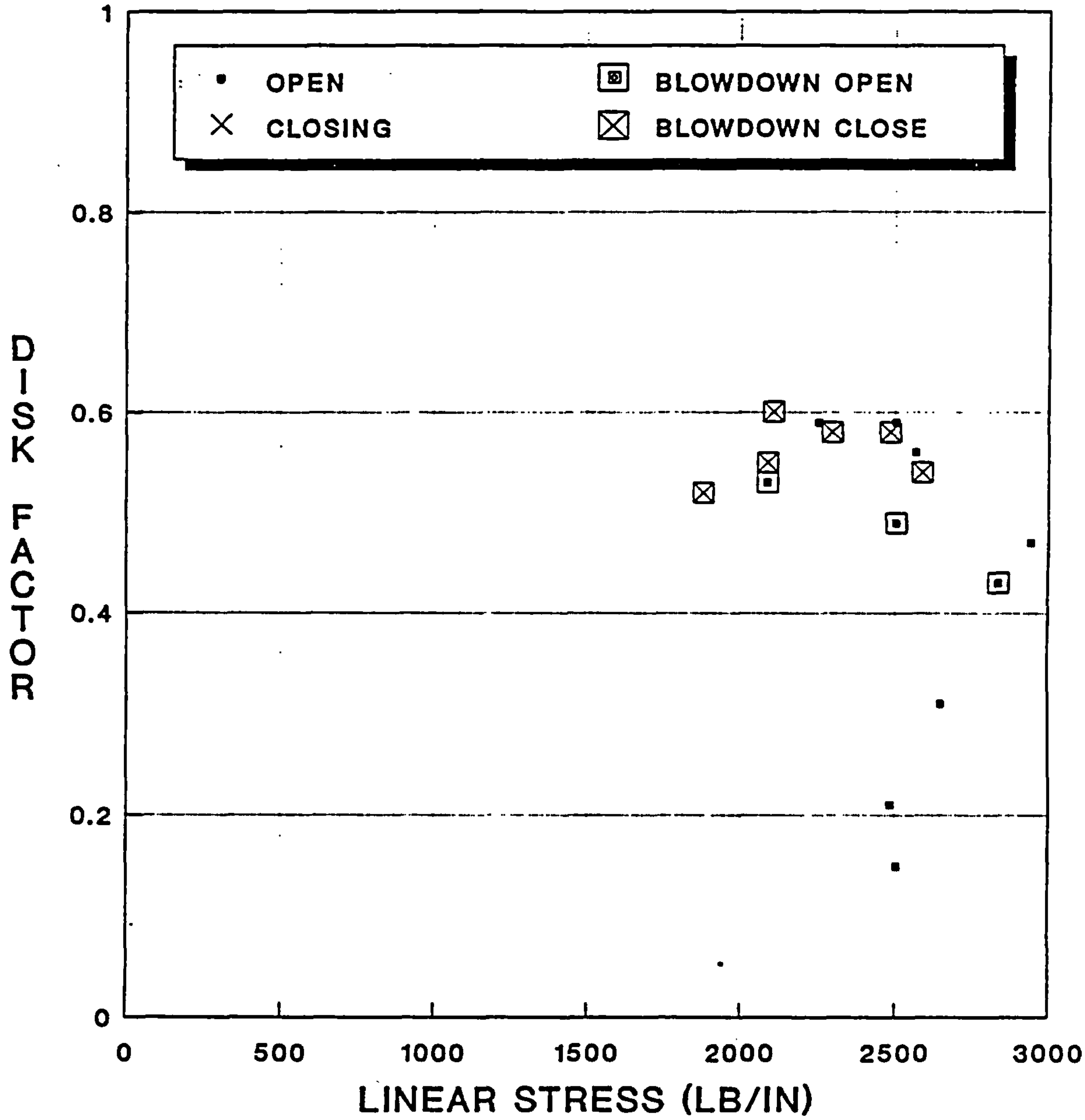
DISK FACTOR VS LINEAR STRESS
VALVE #4 MAXIMUM VALUES
FIGURE 6-31

MPR ASSOCIATES
F-140-49-86(A)
11/13/90



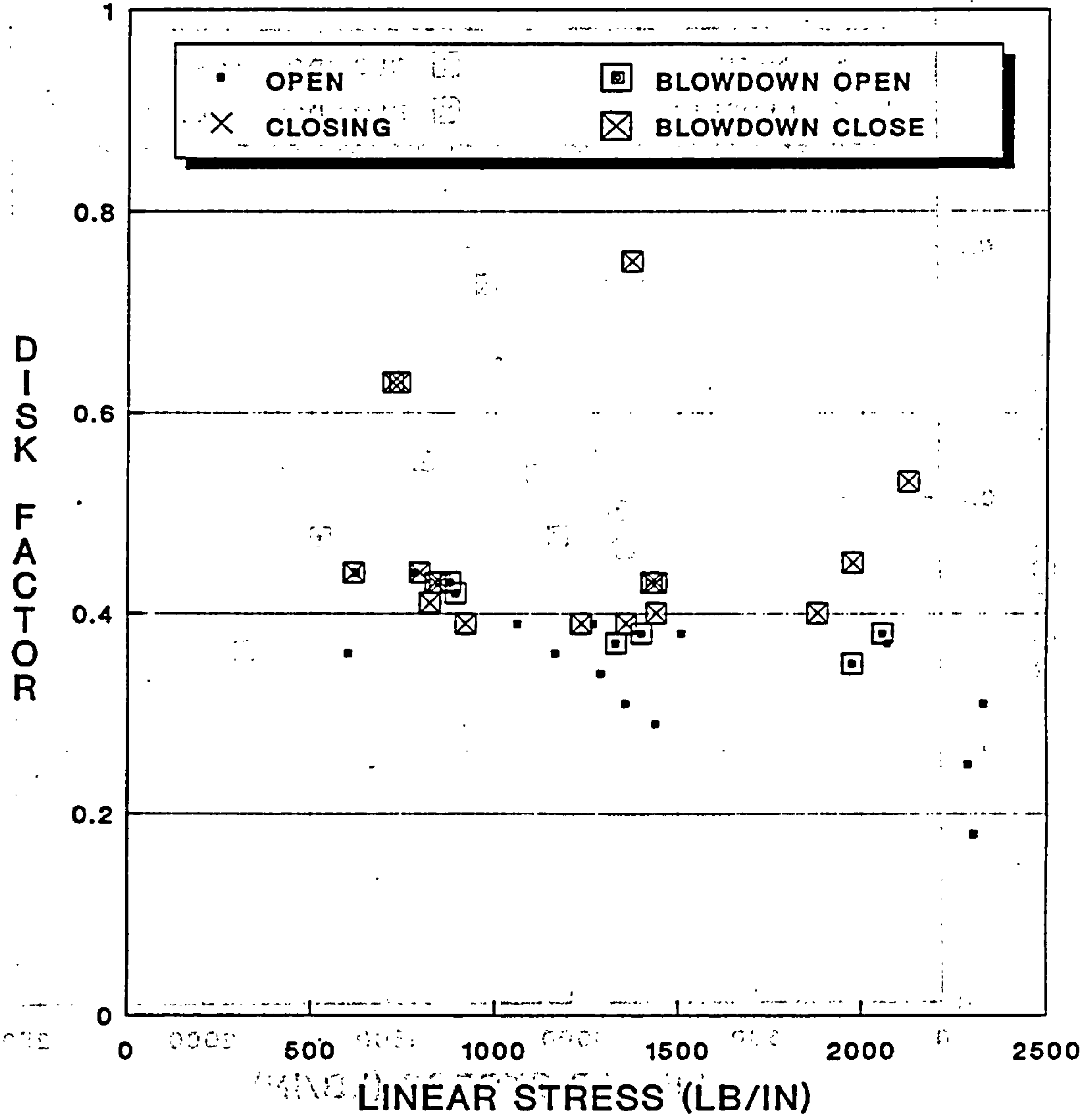
DISK FACTOR VS LINEAR STRESS
VALVE #5 MAXIMUM VALUES
FIGURE 6-32

MPR ASSOCIATES
F-140-49-87(A)
11/13/90



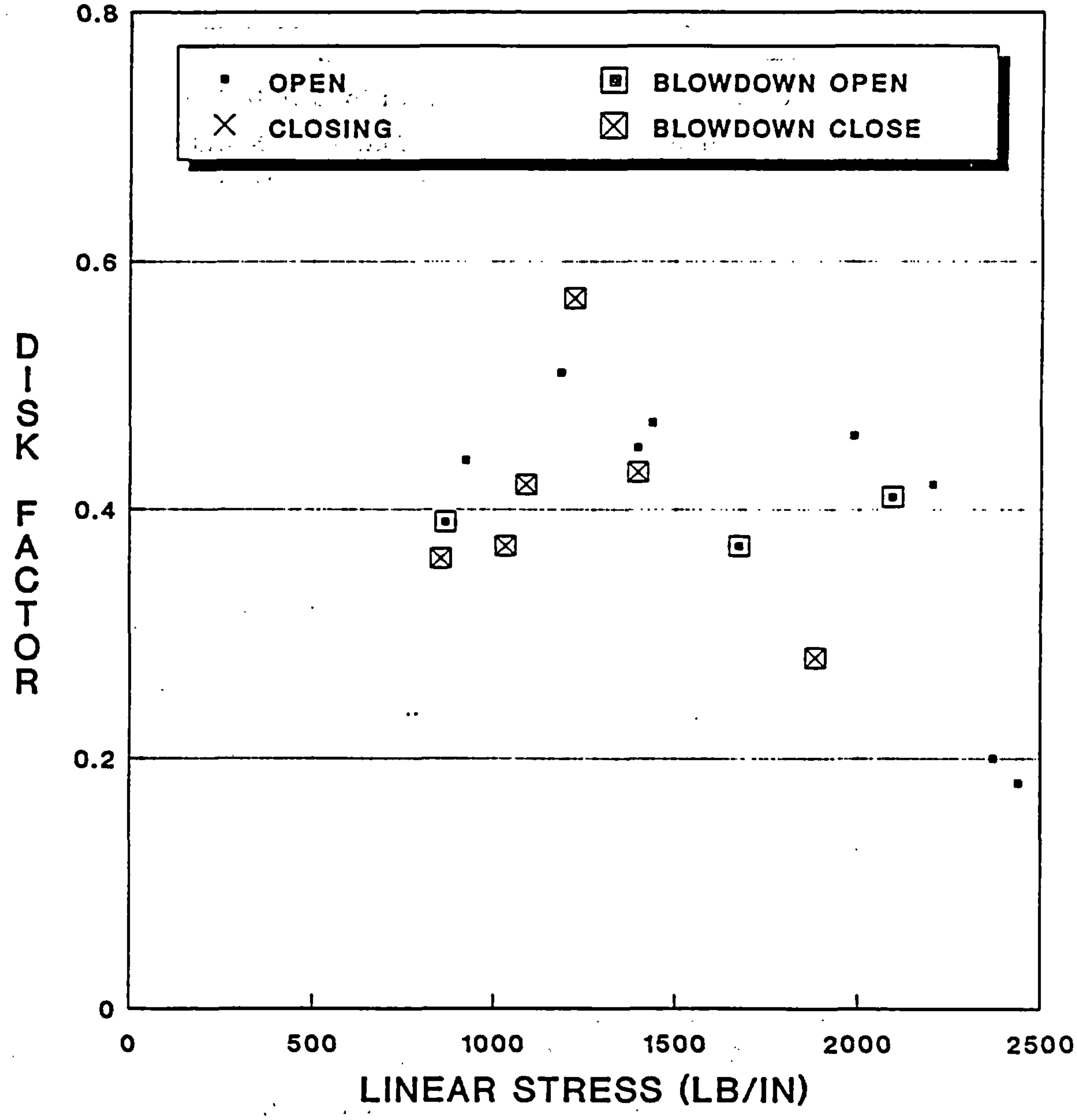
DISK FACTOR VS LINEAR STRESS
VALVE #6 MAXIMUM VALUES
FIGURE 6-33

MPR ASSOCIATES
F-140-49-88(A)
11/13/90



DISK FACTOR VS LINEAR STRESS
VALVE A MAXIMUM VALUES
FIGURE 6-34

MPR ASSOCIATES
F-140-49-89(A)
11/13/90



DISK FACTOR VS LINEAR STRESS
VALVE B MAXIMUM VALUES
FIGURE 6-35

Section 7

RECOMMENDATIONS

DETAILED EVALUATION OF TEST AND INSPECTION DATA

This evaluation effort had limited scope and schedule. It is recommended that the NRC/INEL data be further evaluated in areas discussed below. The objective of these additional evaluations is to develop an improved understanding of some of the areas of question identified in this study, and to support use of these data in the overall EPRI MOV Performance Prediction Program. These additional evaluations will contribute to developing the detailed MOV performance prediction methodology for use by utilities, which provides a suitable approach for MOV evaluation when directly applicable data are not readily available. It may be practical to include some of these evaluations in selected test/development elements of the EPRI MOV Performance Prediction Program. Items to be considered for potential further evaluation are listed below.

1. Confirmation of values obtained from plots in this evaluation using digital data. Use of data plots did not support high resolution and accuracy in interpreting the data. Although no gross errors are suspected, use of the digital data formalizes this process and eliminates inaccuracy from the "plot-reading" step.

2. Detailed evaluation of "normal flow" strokes using digital data. As shown in this report, normal flow data were difficult to interpret and the limited results obtained appeared somewhat suspicious. A detailed evaluation of the digital data permits

INEL comments on this section of the EPRI report are not within the scope of this review.

higher accuracy in interpreting the data and a more detailed study of transient changes in the brief time period where the disk is arriving at the seat. This effort supports obtaining improved information out of these tests and eliminating present unanswered questions.

3. A more detailed evaluation of system flow behavior and flow effects on valve performance, using digital data. As discussed in this report, it appears test system configuration and operation affected the way the valve was loaded by DP. Further, apparent flow effects on valve performance were seen. At present, these effects have not been analyzed and quantified. A more detailed evaluation is needed to support evaluation of these effects in the MOV performance prediction methodology. Specifically, it appears these effects should have a less detrimental effect on valve performance for most power plant valves than for the NRC/INEL test valves. Additional work is needed to quantify this expectation.

4. A detailed review of data quality, using the digital data. Although not discussed in this report, some instances of apparent zero shifts were observed in the data. In general, these were not substantial, but could affect the accuracy of calculated disk factors. Additional work is needed to identify and quantify these areas of the data, so that final quantitative values being used in the EPRI MOV Performance Prediction Program are well-qualified.

5. Evaluation of surface roughness data from the valve inspection and correlation with valve performance data. This report summarizes an extensive amount of surface roughness information;

in some cases, it appears valve behavior <u>may</u> have been affected by surface roughness. An evaluation of detailed features of the test data and comparison to observed roughness is useful to support the MOV performance prediction program and to develop guidelines (which could be incorporated in valve specifications) regarding acceptable surface conditions.

6. Evaluation of dimensional data from the valve inspection, including development of a disk/guide/seat interaction model and comparison to test data. This report shows valve behavior was apparently strongly affected by the nature of disk/guide/seat interaction. The substantial dimensional data gathered from the inspection should be evaluated in light of an analytical model of disk/guide/seat behavior. This effort would support development of a methodology to be able to predict, independent of tests, whether a valve will behave normally or anomalously in a specific application. Also, configuration requirements for valve specifications (e.g., clearances) would ultimately flow out of this effort.

7. Evaluation of iron content measurements and comparison to test data and other data sources. As discussed in this report, a wide variation of disk and seat Stellite iron content was observed in the test valves, and the effect on valve performance is not understood. A more systematic look at the INEL data and other potential data sources could help to improve the understanding. This is important for guiding friction tests in the EPRI MOV Performance Prediction Program, and ultimately, for developing appropriate requirements for valve specifications.

ELEMENTS OF EPRI MOV PERFORMANCE PREDICTION PROGRAM

Based on this review of the NRC/INEL data and the valve inspection activities, several insights were gained which should be considered in the EPRI MOV Performance Prediction Program. It is noted that the existing EPRI Program Plan already includes several elements which will address valve performance issues coming out of these tests. Additional items not identified explicitly in the existing plan but which should be included are listed below.

1. Test hardware (valves and operators) should be extensively characterized <u>prior</u> to testing. Information should be obtained and documented according to procedures, and should include dimensional measurements, photographs, and performance information such as motor characteristics, spring pack stiffness, etc. This approach provides the needed information to properly evaluate the test data and observations.
2. The hardware vendors should be involved with the test program to provide immediate information on valve set up, performance, dimensional characteristics, inspection interpretations, etc. This approach helps avoid wrong interpretations and tangents which could be detrimental to completing the program in a focused way.

3. Valves should be internally inspected between strokes to check for damage. This approach avoids having to guess when damage occurred after several tests are performed. It appears use of a borescope/fiberscope through an access nozzle may provide an acceptable approach.

4. Valves should be tested at conditions generally progressing from less severe to more severe. This approach allows damage thresholds to be determined and maximizes the amount of useful

data prior to damage.

5. Flow loops for testing should cover conditions typical of nuclear power plant systems containing applicable MOV's. Further, the systems should have configurational and operational flexibility so that ranges of parameters (e.g., flow, pressure) can be covered in the tests. This approach provides maximum usefulness of the test program.

6. The MOV performance prediction methodology should incorporate insight which has been gained from the NRC/INEL tests. For example,

   - Guide clearances, guide support and edge configurations all appear to affect the potential for disk cocking/binding/gouging behavior. These features should be included in the methodology to screen out susceptibility to this behavior.
   - DP loading during mid-stroke appears to strongly influence potential disk cocking/binding/gouging behavior. The DP versus stroke characteristics should be considered in the methodology to screen out susceptibility to this behavior.
   - Disk/seat friction coefficients may be slightly higher than typically assumed values of 0.3. A value of 0.4 appears sufficient to cover friction phenomena based on the NRC/INEL tests.

7. Separate effects elements for friction testing should plan to cover effects of stroke/temperature history and iron content. This is particularly important so that justified information is available on how friction may change in an installed application. Potential effects of machining oil, oxide layers, topography changes and damage should be addressed in these tests.

8. Separate effects analyses and flow loop tests to cover the flow effects on valve stem force need to be included. This topic is only lightly addressed in the existing program plan; information on the extent to which these effects influence typical power plant valves is needed.

9. Additional testing of NRC/INEL Valve 2 or special testing to reproduce and explain the phenomena causing the Valve 2 unusual behavior is warranted. This testing should include investigation of unexpected disk/guide contact and should seek to identify the root cause of the Valve 2 behavior and explore potential modifications to alleviate the behavior.

VALVE DESIGN FEATURES

Several aspects of valve design which are important to achieving good performance under severe conditions were qualitatively identified by this effort. In general, these important aspects are consistent with existing experience and intuition; however, quantitative methods for rigorous valve design may not in all cases be fully developed. These important valve design aspects are discussed below in a qualitative way.

Important Hardware Features

1. Disk-to-guide clearance needs to be kept to a small enough value so that disk tipping and potential aggressive interaction with the seat are minimized. Also, tight clearances in the direction of flow permit a valve design which engages the seat at an overall lower stem position, thus minimizing potential disk/seat machining. However, clearances need to be kept large enough so that the disk does not bind on the guides. In the NRC/INEL tests it appears such binding may have occurred in the lateral direction.

2. Guide slot and guide rail surface finish should be a smooth, machined finish to promote favorable valve performance. As-cast, unmachined surfaces do not necessarily preclude acceptable valve operation, but do tend to aggravate damage.

3. Edge configuration of guide slots, disk seats and body seats should be a rounded or beveled configuration to ensure favorable sliding performance. Sharp edges appear to increase the potential for gouging/machining damage of surfaces.

4. Body guide rail length needs to be sufficient to ensure the disk does not tip off the end of the guide rail. Sufficiently long guide rails thus minimize the potential for disk/seat machining damage.

5. Disk guide slot length needs to be long enough to minimize disk tipping on the guides, and also to provide adequate bearing area to carry the disk load without damaging the materials.

6. Support of body guide rails should be adequate to ensure that elastic or plastic deformation does not occur which would inhibit smooth disk/seat interaction. In particular, it appears cantilevered guide rail ends can lead to performance difficulties. Simply supported guide rails can give adequate performance as shown in the INEL tests. However, a simply supported guide rail which is expected to plastically deform under normal conditions would not likely be a favorable approach.

7. Guide slots and guide rails should be hardfaced for improved performance behavior under blowdown isolation conditions. One

NRC/INEL test valve had hardfaced disk guides and the wear/damage was significantly less.

8. Iron content of Stellite hardfacing should be controlled during valve manufacturing to ensure favorable friction and wear properties. Iron dilution from the base material into the Stellite should be minimized by controlling Stellite application processes and subsequent machining.

Important System Application Parameters

1. DP versus stroke can be an important parameter in evaluating MOV performance in a specific application and in designing a valve for the application. Blowdown conditions typically give significant DP during mid-stroke, which more severely challenges gate valves.

2. Temperature and/or temperature/stroke history can be an important parameter in evaluating test data from a gate valve and predicting valve thrust requirements in the future. Valves in cold applications, in particular, may show disk factor increases with stroking for a considerable time. Hot conditions may stabilize disk factor, although complete data are lacking.

3. Flow rate may be an important parameter, particularly for gate valves which need to open as a design basis condition. High flow appears to add to the required stem force to open the valve.

Section 8

PERSPECTIVES ON NRC AND INEL CONCLUSIONS

This effort has yielded insight on existing, documented NRC and INEL conclusions with regard to these test results. For the purpose of this effort, NRC conclusions as documented in Information Notices 89-88 and 90-40 (References 8 and 9) were examined, and INEL conclusions as documented in NUREG/CR-5406 for Phase 1 testing (Reference 1) and the April 18, 1990 public presentation for Phase 2 testing (Reference 2) were examined. Only conclusions related to MOV performance are addressed; conclusions related to in-situ testing, diagnostics, training, etc., are not included in the scope of this report.

NRC conclusions are listed in Table 8-1 along with an explanation of additional insight yielded by this study. INEL conclusions are given in Table 8-2, along with an explanation of additional insight yielded by this study. On both of these two tables, the NRC and INEL conclusions have been recorded in the table exactly (word-for-word) as they appear in the appropriate source documents.

Tables 8-1 and 8-2 should be consulted for the detailed insight on each NRC and INEL conclusion. Three overview perspectives are noted:

1. Some of the NRC and INEL conclusions imply applicability of the test results beyond what is warranted. As an example, some conclusions are based exclusively on observations during blowdown opening tests. Generally nuclear power plant valves are not subjected to these extreme conditions.

In this section we have altered the original format of the EPRI report. The text has not been changed. We list the text of the EPRI reports Tables 8-1 and 8-2 in the left hand column, starting with the NRC/INEL conclusion EPRI report is responding to, followed by the EPRI response. Our review comments are in the parallel right hand column.

The NRC/INEL conclusions quoted in the EPRI report are exact quotations. They were worded carefully in an attempt to avoid confusion over the applicability of each conclusion. As we discuss in the remainder of this section, we believe the applicability of our conclusions is clear and correct.

2. In some cases, the conclusion implies more than is supported by the data. For example, the NRC conclusion that "...during the KWU tests, several blowdowns did not achieve full seating of the valve" is overstated and misleading. In reality, out of 38 blowdown closure strokes, only two (on a single valve) did not achieve full seating.	The quoted conclusion is correct; however it should have also included the Phase I testing, where valve B, a predictable, valve failed to fully seat. It should also be noted that the torque switches on all the valve operators were set higher than the industry would have set them prior to this testing. The idea was to close the valves and determine from the data the required stem force to close. Without this policy, many more of the valves would not have achieved full seating.
3. Some conclusions imply unduly restrictive approaches to deal with certain situations. For example, the INEL conclusion that "only testing at design basis conditions will provide insights on predictable or nonpredictable behavior" excludes legitimate engineering alternatives.	Our conclusions reflect the state of the art with regard to MOV testing and operability. The quoted statement is correct; we know of no method available today for determining whether a valve is nonpredictable other than full scale testing. Research is being performed to understand and predict this behavior; however, at the present time no "legitimate engineering alternative" to design basis testing exists.
I.N. 89-88: The test results are generally applicable to any MOV that must open or close in a high flow, a high differential pressure, or a low subcooling situation. The NRC/INEL tests examined specific flexible wedge gate valves under specific flow conditions. As discussed in this report, there are many other types of valve designs (including other gate valve designs, globe valves, etc.), and many MOV's are exposed to design basis conditions considerably different than the NRC/INEL test conditions. If a valve in a nuclear power plant is similar to only one aspect of the NRC/INEL test conditions (e.g. high differential pressure), this does not mean that the valve will behave in a manner similar to the INEL test valves. Accordingly, it appears the test results are potentially applicable only to similar gate valves under blowdown conditions.	This statement from I.N. 89-88 is true. In fact, some of the NRC/INEL test results are applicable beyond the applications stated in this quote. One of the findings of the NRC/INEL valve test program was that the industry equation for sizing and setting valve operators is incomplete. If an equation for predicting valve stem force is incorrect or incomplete, legitimate questions arise concerning any application sized with that equation. The INEL valves were tested over a wide range of pressures, temperatures, and flow rates. Data curves characterizing valve performance were developed from the resulting data. The analysis effort produced a correlation for stem force shows that on-the-seat valve performance is predictable from low flow to blowdown flow. While it is true that blowdown conditions apply only to valves that might experience those conditions, the overall results of the test program are applicable to many rising stem valves.

I.N. 89-88: Even with the high settings used during the KWU tests, several blowdowns resulted in closure of the flow area but did not achieve full seating of the valve.

Based on review of the test data, only two tests on a single valve were identified where full seating was not achieved. These two tests were the two blowdown closure strokes for Valve 1 (Test 1 steps 25 and 26). Since it appears that Valve 1 was likely damaged prior to the second blowdown stroke, the failure to seat on step 26 is not totally surprising. Most importantly, as discussed in this report, Valve 1 is not typical of valves produced by this manufacturer due to some unusual features in the test valve. For all other test valves, full seating was obtained.

I.N. 89-88: The valves required stem thrusts well in excess of those predicted by the industry design formula in use at the time of their design and manufacture.

This report examines, to the extent possible, data from <u>all</u> of the NRC/INEL test strokes with DP. It is found that, for a substantial portion of the strokes, the apparent disk factor is less than or marginally in excess of that assumed by industry design formula. However, there are selected strokes for some valves under specific conditions which showed required stem thrusts considerably in excess of industry formula. These were typically associated with blowdown conditions, which are <u>not</u> similar to the majority of safety-related MOVs in nuclear power plants. Accordingly, great care is necessary in applying the NRC/INEL results to industry valves.

The NRC statement quoted is a statement of fact. As stated above, the NRC statement should have included the Phase I testing, where valve B also failed to fully seat. The typicality of the hardware is discussed in Section 3.3 of this report.

The NRC statement quoted is a statement of fact. Standard industry calculations for full DP closure were performed for each of the valves prior to testing. The torque switches were set well above the setting calculated to ensure closure, and the maximum stem forces during closure were measured. In all cases, the stem force measured during blowdown closure was well in excess of that calculated using standard industry methods.

As stated in Sections 3.4.1 and 3.4.2 of this report, the analysis procedures upon which the EPRI report bases this conclusion are incorrect. The standard industry stem force equation is incomplete, and with the typical orifice area and typical 0.3 disc factor used to size the majority of Flex Wedge gate valves in the industry, it often produces non-conservative results compared to the stem force measurements taken during the INEL testing. A careful review of the Licensee Event Reports and NRC bulletins (I. E. Bulletin 85-03, for example) shows that plant experience with valves in pumped flow systems is consistent with this NRC

	conclusion. A number of valves in pumped systems have failed when subjected to design basis conditions.
I.N. 89-88: The required stem thrust of the valves was not linearly dependent on the differential pressure across the valve at the time of closure. This circumstance precludes determination of the required stem thrust from data that could be obtained under normal plant operating conditions. Under blowdown conditions, some of the NRC/INEL test valves exhibited "anomalous" behavior which was characterized by gouging/machining of valve internals rather than sliding friction. It is agreed that when this behavior occurs, valve performance may not be linearly dependent on applied differential pressure. However, when this behavior is avoided (as is expected to be the case for the vast majority of industry MOVs, e.g., in pumped systems), performance extrapolation to design basis conditions is reasonable. The EPRI MOV Performance Prediction Program includes elements to identify the potential for anomalous behavior in MOV applications, and will develop data to support extrapolation methods.	With regard to the standard industry equation, this NRC statement is true. In our early analyses we made an unsuccessful attempt using the standard industry equation, to determine disc factor from low pressure tests and relate that to the blowdown tests. That attempt failed because, as explained in Section 3.4.2 and in Appendix C of this report, the standard industry equation is incomplete. The INEL correlation includes additional forces acting on the disc, making this kind of extrapolation possible.
I.N. 89-88: The thrust at which torque switch trip occurs was not constant with respect to the loading history of the valve. Many within the industry refer to this as the "rate of loading" phenomenon. However, the testing indicates that there may be more involved than variations of the torque switch spring pack's response time. Although rate-of-loading effects apparently were present, this area of data was not examined in detail. The EPRI MOV Performance Prediction Program has elements to assess "rate-of-loading" phenomena.	This NRC quote is a statement of fact. The MOV load sensitive behavior is real. It has been observed in full-scale design basis tests and during utility in-plant tests. We have duplicated this phenomenon in the laboratory using our MOV load simulator. This behavior is still under investigation, but early data relate the problem to degradation of stem nut lubrication during cycling at high stem loads and not to the spring pack response.
I.N. 89-88: The stem factor (i.e., the ratio of the motor operator's output torque to the valve's stem thrust) appears to be	This NRC quote is a statement of fact. As stated above, the MOV load sensitive behavior is real. Research into this phenomenon is ongoing.

dependent on direction and magnitude of the load being applied to the stem.

Examination of stem factor results was beyond the scope of this initial evaluation. Existing information available from INEL or NRC (References 8 and 1) does not show information regarding dependence of stem factor on stem travel direction. Limited information on stem factor apparently varying with load magnitude is given in Reference 1 for the Phase 1 tests, but available data are not sufficient to permit an independent evaluation. It appears further study of this conclusion has not been addressed by INEL for the Phase 2 results. The EPRI MOV Performance Prediction Program includes elements to study and ultimately predict stem factor, including tests of several valves and lubricants over prolonged periods.

I.N. 89-88: Several of the valves significantly damaged themselves during closure.

As discussed in this report, indications of significant internal damage were observed during inspection of the valves. The data and the damage patterns are indicative that damage occurred during the blowdown closures. Unfortunately, in no cases were the valves inspected after non-blowdown strokes or after the <u>first</u> blowdown stroke, so the time of damage cannot be determined.

I.N. 90-40: Regardless of fluid conditions (i.e., steam, slightly subcooled water; or cold water), the tested valves required more thrust for opening and closing under various differential pressure and flow conditions than would have been predicted from standard industry calculations and typical friction factors. Thus, a potential exists for the underestimation of thrust requirements for valves in applications, and under fluid conditions, other than those of the valves involved in the NRC research.

Damage to the test hardware occurred. INEL has stated numerous times that the damage was due to the tremendous loads experienced under blowdown conditions. We have also shown that careful examination of stem force traces can be used to identify when damage occurred. The lack of inspections between tests does not detract from the significance of the fact that more than half of the valves suffered damage when exposed to their design basis conditions.

This quote from the NRC Notice is correct. Sections 3.4.1 and 3.4.2 address the EPRI report's analyses of apparent disc factors. The industry equation is incomplete and did not produce conservative results for any of the valve strokes referenced even those at loads lower than blowdown loads. A prudent review of utility LERs establishes a historical and technical basis for the NRC remark.

This report examines, to the extent possible, data from all of the NRC/INEL test strokes with DP. It is found that, for a substantial portion of the strokes, the apparent disk factor is less than or marginally in excess of that assumed by industry design formula. However, there are selected strokes for some valves under specific conditions which showed high required stem thrust. These were typically associated with blowdown conditions, which are not similar to the majority of safety-related MOVs in nuclear power plants. The technical basis to apply these data to other valves/flow conditions does not exist. Most MOVs (e.g., in pumped systems) have design basis conditions where DP builds up only in the nearly closed position, which is much less severe than the NRC/INEL blowdown tests. A key element of the EPRI MOV Performance Prediction Program is to develop appropriate methods and data to evaluate valves based on design features and flow conditions.

I.N. 90-40: Some of the tested valves sustained considerable internal damage during the blowdown tests. The occurrence of internal damage can cause the thrust required to operate a valve to exceed the thrust requirements predicted by the valve thrust equation. Such valves were referred to as "unpredictable" in the test program and included the 6-inch Anchor/Darling valve and the 10-inch Anchor/Darling, Powell, and Velan valves. In some instances, this increase in required thrust can be considerable and might exceed the capability of the motor or operator. Thrust requirements to close unpredictable valves under design-basis loads cannot be accurately determined without testing the valves (either individually or as prototypes) under these conditions.

As discussed in this report, indications of significant internal damage were observed during inspection of the valves. The data and damage patterns are indicative that damage occurred during the blowdown closures, and valves with major damage correlated to observation of unpredictable or anomalous behavior in the blowdown tests. The 6-inch

The NRC statement quoted here is correct, and the EPRI report essentially agrees. The valves were damaged under their design basis loadings. At this time no one knows the loading at which nonpredictable behavior begins. Until it is known how high a load a given valve can experience without damage, there is no justification for the assumption that damage will occur only at blowdown loads.

Anchor/Darling, 10-inch Anchor/Darling and 10-inch Velan valves were in this category; this report shows that the 10-inch Powell valve was only slightly in this regime. With regard to thrust requirements for such valves, the EPRI MOV Performance Prediction Program includes elements to identify potential anomalous behavior based on design features and flow conditions. Because most MOVs have much less severe design-basis conditions (e.g. pumped flow) than the NRC/INEL blowdown tests, it is expected most MOV applications will not be potentially anomalous.

I.N. 90-40: The research program revealed that the testing of a valve under static or low flow conditions cannot always be used to accurately predict the behavior of the valve under design-basis conditions by extrapolation. For example, the valves that were damaged during blowdown tests operated normally under less severe flow tests. Thus low-flow tests might not identify a valve that requires significantly more thrust than predicted by the valve thrust equation (i.e., a valve that is unpredictable).

This NRC conclusion, which is confirmed by this study, underscores the fact that the label "unpredictable" or "anomalous" refers to a valve application and not to simply a valve. The normal operation of the NRC/INEL valves under less severe conditions indicates that most valves in nuclear power plants (which see less severe conditions) would be expected to operate normally. As discussed in the item above, the EPRI MOV Performance Prediction Program includes elements to identify valve applications with potentially anomalous behavior.

The EPRI report agrees with this NRC conclusion. All of the Phase I and II valves were designed and installed to isolated pipe break flow in the RWCU or HPCI systems. The valves that performed nonpredictably did so under their design basis conditions. Other valves performed predictably under the same conditions. The loading at which any nonpredictable valve becomes nonpredictable has not been determined.

I.N. 90-40: During opening of the valves, the maximum required thrust did not always occur at unseating. Rather, in certain instances, it occurred much later during the valve stroke. At nuclear plants, the staff has found that torque switches for MOV's are sometimes bypassed only during the initial portion of the opening stroke on the assumption that the thrust required to unseat the valve would be the maximum thrust for the full stroke.

The EPRI report agrees that higher loads sometimes occurred during opening after unseating instead of before. This phenomenon is not fully understood, so the flow or DP at which higher opening forces become significant is unknown. Restricting it to blowdown flow opening cases may not be justifiable. The INEL has attributed the force increase to other effects in addition to Bernoulli effects. The additional force is

> Thus, the research results raise a concern that the torque switches in some MOVs at nuclear plants might not be bypassed for a sufficient period of time during the opening stroke.

On some blowdown opening tests an increase in stem force was observed after flow initiated. INEL has attributed the force increase to flow (Bernoulli) effects. As discussed in this report, MOVs in nuclear power plants except for PORV block valves do not have blowdown opening conditions. Under typical opening conditions this effect is expected to be much less severe. The EPRI MOV Performance Prediction Program will include elements to identify and quantify additional loads which may occur in mid-stroke due to flow effects. It is also noted that the possibility of higher loads occurring after unseating would not necessitate increasing torque switch bypass period, as long as torque switch settings are adequate to cover the increased load.

I.N. 90-40: For certain tests, the valve was closed from a partially open position. This partial stroking of the valve failed to predict the thrust requirements and to identify nonpredictable performance that were found during closure of the valve from a full open position. For example, during certain blowdown tests, valve damage began to occur before the valve was half closed. The accumulated damage over the full stroke influences the thrust required to close the valve.

This NRC conclusion is speculative in nature; specifically, it neglects how valve damage <u>prior</u> to a stroke can also be influencing behavior. In the partial stroke blowdown closure tests which showed differing behavior from full-stroke tests, the partial stroke was <u>always</u> conducted after a full-stroke in which damage was suspected to have occurred. It appears the damage may have created a "modified" valve condition which behaved differently from the initial stroke. To confirm this, we compared partial-stroke results with the <u>subsequent</u> (not prior) full-stroke blowdown closure. There were <u>no</u> cases where a subsequent full-stroke

produced by the total instantaneous pressure distribution on the valve internals at any point in the stroke.

It is true that no subsequent full closure test was more severe than a prior partial closure test. No such test sequence was performed. In all cases, the first blowdown test was, for all intents and purposes, a full closure test. The NRC conclusion would have been more accurate if it had stated that partial stroking "would have failed to predict" thrust requirements needed for full closure. Nevertheless, the intent of the NRC conclusion is correct. Valve damage on some nonpredictable valves began early in the valve stroke, and the accumulated damage over the entire stroke influenced the thrust required to close the valve. Partial valve strokes that do not include this early portion of the stroke can not indicate the influence of early damage on maximum stem thrust. The EPRI report is correct in the observation that subsequent testing was less severe than earlier tests. Each time the valve was cycled it machined itself again to eliminate interferences (the cause of nonpredictable behavior). For some valves, subsequent cycles showed predictable-like behavior after this machining.

showed more severe or more nonpredictable behavior than a partial stroke. In summary, there are no NRC/INEL data which show more severe behavior in a full-stroke closure than in a partial stroke closure for initially undamaged valve conditions in both cases.	
I.N. 90-40: Table 1 (of I.N. 90-40) provides a summary of the blowdown tests and the minimum required thrust to close the tested valves. The table also indicates whether the valve thrust equation would have bounded the thrust requirement if valve friction factors of 0.3 or 0.5 had been used . * The notes to Table 1 of I.N.90-40 indicate that 5 of 8 test valves are not bounded by a friction factor of 0.5 and no tests are bounded by a friction factor of 0.3.	The information contained in Table 6-1 in the EPRI report is not accurate. See Sections 3.4.1 and 3.4.2.
The results presented in Table 6-1 of this report show a more complete evaluation of the information given in Table 1 of NRC I.N. 90-40. There are three important insights:	
- Table 1 of I.N. 90-40 gives only the maximum thrust measured during the stroke; in most cases the thrust to isolate flow was considerably less. In use of these results to evaluate blowdown isolation functions, it appears flow isolation is pertinent.	Section 3.4.1 shows that the EPRI evaluation erred in its identification of flow isolation. The data contained in Table 1 of I.N. 90-40 are correct.
- As discussed in this report, results from Valve 1 are not considered applicable to Anchor/Darling 6-inch valves.	As discussed in Section 3.3.2 of this report, the working surface of the Valve 1 disc was the Valve A surface that Anchor/Darling delivered to the INEL with the understanding that the valve was representative of their hardware delivered to the nuclear industry.
- The disk areas used by INEL in the industry equation are generally less than the values which should be used with the equation. This gives an incorrect "appearance" that higher disk factors are needed.	We have discussed the use of apparent disc factor and mean seat diameter throughout in this report. The data in Table 1 of I.N. 90-40 are an accurate representation of the stem force required to close the valves. As explained in Section 3.4.2 of this report, the standard industry is

	inadequate for assessing valve performance. This is true whether either the orifice area or the mean seat area is used as the disc area term in the equation. We used the orifice area in our analyses because that is the term that was originally used to size many of the operators for the valves, and because it is the least conservative term used by industry.
In summary, this report supports a conclusion that all valves except one (Valve A) would isolate flow with a disk factor less than 0.5 and that several cases isolated with disk factors less than 0.3; this is quite in contrast to the NRC conclusion that 5 valves are not bounded by 0.5 and that no cases are bounded by 0.3.	The EPRI reports' conclusion is incorrect for the reasons stated above.
NUREG/CR-5406 (Phase 1): The typical industry sizing equation using the standard variables did not conservatively estimate the total thrust needed to close the tested valves; disc factors higher than the normal 0.3 disc factor (μ_d) were encountered.	In Section 3.4.2 we discuss the use of apparent disc factor based on mean seat diameter. Mean seat diameter was not used to size the majority of valve operators in the industry. In Section 3.4.1 explain the error in the EPRI report's selection of the valve position associated with flow isolation. Data indicate that flow occurred through the valves beyond the designated isolation position. Comments concerning disc factors obtained using that analysis are incorrect.
This report examines, to the extent possible, data from all of the NRC/INEL test strokes with DP. The conclusion that disk factors higher than 0.3 were encountered is correct. An important finding is that a large number of strokes, particularly those for which anomalous behavior did not occur, are bounded by a disk factor only slightly greater than 0.3, i.e. in the 0.3 to 0.4 range.	This comment may lead the reader to believe that the difference between a 0.3 and 0.4 disc factor is small. This is far from true. Valves sized with a 0.3 disc factor will require one third more thrust if operating at 0.4. Even with the gross conservatisms often employed, 33% additional force is difficult to bound (conservatisms must also cover operator repeatability, stem factor changes, etc.).
NUREG/CR-5406 (Phase 1): Temperature also affects the thrust requirements of these gate valves...... The disc factor needs to be increased for both the opening and closing direction to account for	This comment on this Phase I conclusion is correct. The stem thrust does appear to irreversibly increase in the first hot cycle. Our analysis of the Phase II data supports this observation. However, for different

the higher loads associated with high temperature operation.

As discussed in this report, the disk factor irreversibly went to a higher value starting with the first stroke at hot conditions, on every valve. Subsequent tests, whether at hot or cold conditions, did not significantly affect disk factor. The explanation of this behavior is not presently known. Nonetheless, once the valve passed through this transition, temperature does <u>not</u> appear to influence thrust requirements.

NUREG/CR-5406 (Phase 1): Industry has also assumed that for valve opening thrust requirements, the highest load would be when the disc lifted off the seat. This was also determined for the valves tested not to be true. The highest opening loads with flow occurred at different degrees of opening for both valves, but in both cases they were well off their respective seats when the maximum thrust was measured.

On some blowdown opening tests an increase in stem force was observed after flow initiated. INEL has attributed the force increase to flow (Bernoulli) effects. As discussed in this report, MOVs in nuclear power plants except for PORV block valves, do not have blowdown opening conditions. Under typical opening conditions this effect is expected to be much less severe. The EPRI MOV Performance Prediction Program will include elements to identify and quantify additional loads which may occur in mid-stroke due to flow effects.

NUREG/CR-5406 (Phase 1): The thrust sizing equation is not applicable to valves that sustain damage (such as galling and plastic deformation of the sliding surfaces) at design basis loadings.

This conclusion appears to be correct. Since the thrust sizing equation is based on sliding friction, the equation will not predict the force to

reasons, temperature effects (degree of subcooling) cannot be completely ignored. Appendix C discusses thin film lubrication and how it influences on-the-seat disc friction. Data support a change in friction from lower energy fluids (greater than 70°F subcooled) to high energy fluids (less than 70°F subcooled).

The EPRI report agrees with this INEL observation. The blowdown opening tests are discussed in Section 3.2.4 of this report. The results are valid for the conditions of the test. If an application exists for high flow opening, the results should be considered. We have not yet conducted a complete analysis of the opening tests. However, preliminary analyses indicate other effects in addition to Bernoulli effects.

The EPRI report appears to agree with this INEL conclusion.

machine metal. The EPRI MOV Performance Prediction Program includes elements to identify valve design features and improvements which ensure minimal damage and predictable performance at design basis loadings.

NUREG/CR-5406 (Phase 1): The design basis hot water blowdown testing has shown that, given enough thrust, typical gate valves will close against the high flow resulting from a line break. Proper operator sizing depends on correct identification of the values for the sizing equation. Evidence exists that values used in the past may not be conservative for all valve applications, especially at design basis loadings. The following items need to be considered during sizing of gate valve operators:

1. Gate valve guide design and clearances can have a significant effect on the operator stem thrust requirements at design basis fluid loadings.
2. The degree of subcooling at the valve inlet can greatly influence valve closure forces. Valve operator force requirements increase as inlet fluid conditions approach saturation temperatures.
3. Industry trends toward using 100% system pressure for all pressure terms in the sizing calculation are justified for high-flow applications.

This effort examined the data and valve inspection results and identified valve design items (in Section 7) which are important for valve performance. Clearances and fluid conditions (Items 1 and 2 of INEL conclusion) are important parameters. We note the INEL conclusion on subcooling here disagrees with their conclusion from Phase 2 results (see below); this discrepancy has not been resolved. Overall, it is not clear if <u>subcooling</u> is the proper fluid condition parameter on which to base comparisons.

The EPRI report is correct--our subcooling conclusions from Phase I do disagree with the conclusions from Phase II. The Phase I data were evaluated using the industry equation, and the observations regarding subcooling were unexpected. To further investigate this observation, the Phase II instrumentation was designed to better evaluate the subcooling influence. In our efforts to correlate the Phase I and II data, we found that the industry equation could not be used. Appendix C shows the more complete INEL correlation. Using our method, the Phase I and II data analyses support one another and produce identical conclusions. The scatter of the data analyzed according to the INEL correlation shows two distinct patterns separating at approximately 70°F subcooling.

NUREG/CR-5406 (Phase 1): Tests have shown that some form of valve type testing outside the plant might be necessary to establish specific valve design thrust requirements and verify that a given valve design exhibits linear characteristics when subjected to design loads.

Type testing may be one acceptable approach. However, the data and inspection results suggest it should be possible to determine if predictable behavior will be achieved in a given valve application based on valve design features and fluid conditions. The EPRI MOV Performance Prediction Program includes elements to develop methods and data to determine if a valve application will have predictable behavior. Most MOVs have conditions much less severe than the NRC/INEL tests and are not expected to be as susceptible to anomalous behavior.

Our conclusion that some form of type testing might be required to determine predictable behavior is correct. At the present time we know of no way other than testing to determine predictable/nonpredictable behavior.

NUREG/CR-5406 (Phase 1): For the valves that have a linear thrust response, valve opening tests (with a full pressure drop and no flow) at normal operating temperatures performed with valve diagnostic test equipment can provide insights for the valve disc factor and therefore degradation in valve performance for both opening and closing.

Based on the results in this report, this conclusion is correct. However, it appears that tests do not necessarily have to be at normal operating temperature, as long as the valve has been previously stroked at normal operating temperature.

We consider our original statement to have been speculative. When we complete the in-depth analysis of the Phase II opening data, we will be able to respond to this comment more thoroughly.

NUREG/CR-5406 (Phase 1): Contrary to common belief, the ratio of operator torque to stem thrust [stem factor (μ_s)] is not a constant but changes with valve loading.

This INEL conclusion is based on Phase 1 data. Unfortunately, insufficient data from the Phase 1 tests is available to allow the conclusion to be independently evaluated. INEL has not addressed this

This INEL statement was based on Phase I data. Since that time this conclusion has been substantiated by the Phase II data, utility testing, and our special effects testing on the INEL MOV load simulator. The Phase I data were sufficient for our analysis of the stem factor.

conclusion in their Phase 2 results. The EPRI MOV Performance Prediction Program includes elements to study and ultimately predict stem factor.

NUREG/CR-5406 (Phase 1): Improper operator lock ring installation following test or maintenance can invalidate in-situ test results and render the valve unable to perform its design function.

We mentioned this in the first place only because we found that care needed to be taken when installing the lock ring.

Although addressing this conclusion was beyond the scope of this effort, it seems reasonable that proper maintenance/re-assembly are required to achieve proper function.

April 18, 1990 Presentation (Phases 1 and 2): NRC Gate Valve Tests have shown that there are two classes of valves:

- Those that respond predictably during operation under load, albeit with a higher than expected disc friction.
- Those that respond unpredictably, sustaining internal mechanical damage during operation under load.

The EPRI report argues that predictability/nonpredictability is more a matter of valve application. The valves used in Phase I and II were purchased with the GI-87 application as the design basis. It was under these design basis conditions that we observed the two kinds of response. The April 1990 presentation addressed GI-87 concerns. (See Figure 1 of this report.) However, it is not known at what loading a valve first experiences damage. We believe our statement is accurate.

The remainder of the comment deals with apparent disc factor; we respond to that issue elsewhere in this report.

Based on the work described in this report, it appears behavior should be classified by valve application (i.e. valve design <u>and</u> fluid conditions) and not simply by valve. The evaluation of the NRC/INEL tests described in this report shows that some valves under specific flow conditions will show anomalous (unpredictable) behavior; these same valves under other flow conditions do not. Accordingly, fluid conditions (not <u>just</u> valve design configuration) are important to determining the class of behavior. Further, based on the work described in this report, it appears most of the valve strokes with predictable behavior did <u>not</u> have friction significantly higher than expected. Generally, a disk factor in the range 0.3 to 0.4 was observed when the behavior was predictable.

April 18, 1990 Presentation (Phases 1 and 2):

> All of the valves required more force to open and close at line break flow than would have been predicted by the standard industry thrust equation using the normal 0.3 constant coefficient of friction, regardless of fluid conditions.

As discussed earlier, opening tests at line break conditions generally do not match design basis conditions of nuclear power plant valves. For valve closing tests, if flow isolation is used as a functional criteria, and the correct disk areas are used in the equations, the INEL conclusion is not true. Several blowdown isolations were bounded by 0.3 and only one valve (A) exceeded 0.5. (Valve 1 has been excluded as inapplicable.)

April 18, 1990 Presentation (Phases 1 and 2):

> There were some subtle differences in response during the parametric studies; these differences indicate that there may be a better equation to predict actual thrust. Such an equation would be more important to PWRs than BWRs.

This effort did not explore subtle differences in the parameter studies. However, it is noted this conclusion refers to parametric studies at line break conditions. This report shows line break conditions are not highly prevalent in PWRs; hence, the importance to PWRs is not understood.

April 18, 1990 Presentation (Phases 1 and 2):

> We believe the nonpredictable behavior is a function of the following valve design deficiencies:
>
> 1) Internal disc-body guide clearances that allow the disc to tip downstream under differential pressure loading,

We discuss the applicability of the opening tests and apparent friction factor calculations elsewhere in this report. (See Sections 3.2.4 and 3.4.2 for example.) The INEL conclusion is accurate.

The INEL statement is correct. Refer to Appendix C of this report for an explanation of how the parametric studies support a better stem force correlation. The correlation distinguishes between valve performance at low versus high subcooling. Thus, the correlation applies to both BWRs and PWRs, but the differences in subcooling might be more important to PWRs, where some valves are required to operate under steam conditions while others are required to operate at high subcooling (100°F). The difference is significant; a valve assessed with the INEL correlation, seating with a friction factor at 0.4 at low subcooling (less than about 70°F subcooling), would seat with a friction factor of about 0.5 at high subcooling.

The EPRI report agrees with our statement regarding design deficiencies leading to nonpredictable behavior.

resulting in one or a combination of the following:

A. The disc tips far enough to engage the seat at an aggressive angle, machining the conical seat off as it closes.

B. The disc tips far enough to reduce the load bearing guide surface, resulting in localized deformations.

2) Disc-to-body guide surface finishes are excessively rough, resulting in high friction and rapid surface degradation.

This report identified key valve design parameters in Section 8. Among them are clearances and guide surface finish, so these INEL points appear correct. It is important to note there may be other influences such as disk and seat edge configuration, Stellite iron content, fluid conditions, etc. The EPRI MOV Performance Prediction Program includes elements to develop methods and data to predict the potential for anomalous behavior in valve applications.

April 18, 1990 Presentation (Phases 1 and 2):

The valves that exhibited predictable thrust at a higher than expected friction value also showed signs of damage from the loadings, although less than the valves with nonpredictable thrusts.

The data review and inspection results described in this report show that valve damage was much less severe in the cases where anomalous behavior was not observed. This INEL conclusion appears correct; it also applies to the numerous predictable cases where the friction was not significantly higher than expected.

The EPRI report agrees with this INEL statement. The reference to friction not higher than expected is based on the EPRI report's apparent disc factor calculations. We take issue with those calculations (see Sections 3.4.1 and 3.4.2 of this report).

April 18, 1990 Presentation (Phases 1 and 2):

> Post-test inspection of valve internals indicated that these valves, operating at design basis loadings, are very near to their guide surface physical fragility limits.

The results described in this report indicate the guide and seat materials were challenged locally beyond their normal load bearing capability. However, there was no evidence that any one of the valves was near a gross failure. Accordingly, use of the word "fragility" (implying near a breakage limit) is strongly questioned.

April 18, 1990 Presentation (Phases 1 and 2):

> Nothing in the low flow or differential pressure opening tests would provide any evidence of how the valve would behave under design basis loadings.

The INEL tests showed behavior of some valves was different in normal flow or no-flow tests than under blowdown conditions. The work described in this report shows that for valves not showing anomalous behavior, apparent disk factors between no-flow and blowdown tests show reasonably good agreement. (See INEL conclusion 7 above.) Accordingly, this INEL conclusion (i.e. "nothing") is not correct for all valves. The EPRI MOV Performance Prediction Program includes elements to identify valve applications with potentially anomalous behavior.

April 18, 1990 Presentation (Phases 1 and 2):

> Until valve design guide tolerances and surface finishes have been improved for valves that must operate under full flow loadings, only testing at design basis conditions will provide insights on predictable or nonpredictable behavior.

The data review and inspection results described in this report show that there were unique features associated with each valve which could be

The INEL statement clearly addresses surface fragility, not structured fragility. The nonhardfaced surfaces showed heavy bearing pressure and metal smearing. The next step is galling, which would put the valve in the nonpredictable category.

One cannot tell from the tests mentioned if the valve would behave in a nonpredictable manner. The conclusion is correct for the valves tested and for the specific tests.

The April 1990 presentation addressed GI-87 valves. The INEL remark is restricted to full flow applications as stated. At this time no methods exist, other than full scale testing, to determine predictable/nonpredictable behavior.

qualitatively related to the observed valve behavior. Although detailed methods are not yet developed, quantitative prediction of the potential for anomalous behavior in a given valve application appears feasible. The prediction methods need to account for fluid conditions and valve design features. Most MOVs have much less severe conditions (e.g., pumped flow) than the NRC/INEL tests and are not expected to be as susceptible to anomalous behavior. The EPRI MOV Performance Prediction Program includes elements to develop methods and appropriate data to predict the potential for anomalous behavior in valve applications. Accordingly, this INEL conclusion does not recognize other approaches to dealing with this issue.

April 18, 1990 Presentation (Phases 1 and 2):

> Industry in general has assumed that for valves that must open under potentially high flow loads, unseating is the highest load. The highest loading was unseating with all of the 6-inch valves, but not with the 10-inch valves.

We agree that this conclusion, the result Phase II analysis and re-analysis of Phase I data, disagrees with the original Phase I conclusion. The INEL conclusion stated here is correct. The blowdown opening issue is discussed in Section 3.2.4 of this report.

It is noted that this conclusion disagrees with the third INEL conclusion given above which indicated that the highest load was after unseating on two 6-inch valves.

On some blowdown opening tests an increase in stem force was observed after flow initiated. INEL has attributed the force increase to flow (Bernoulli) effects. As discussed in this report, MOVs in nuclear power plants except for PORV block valves do not have blowdown opening conditions. Under typical opening conditions this effect is expected to be much less severe. The EPRI MOV Performance Prediction Program will include elements to identify and quantify additional loads which may occur in mid-stroke due to flow effects.

April 18, 1990 Presentation (Phases 1 and 2):

> Valves that must open, and valves that could be mispositioned and have to open, should be tested at the temperature at which they will be required to operate.

The comment on this Phase I conclusion is correct. However for different reasons, temperature effects (degree of subcooling) are important. See Appendix C for temperature effects on thin film lubrication and how it influences friction.

The evaluation results presented in this report indicate that increased temperature strokes in the NRC/INEL gave rise to an irreversible increase in disk factor. Disk factor was not sensitive to temperature changes after this occurred. Although the mechanism and explanation for this behavior is not understood, the NRC/INEL data do not support the INEL conclusion. It appears that, for elevated temperature applications, useful information can be obtained from cold tests after the valve has been exposed to hot conditions.	
April 18, 1990 Presentation (Phases 1 and 2): The difference in required thrust between hot and cold testing must be accounted for when determining the required thrust for valves that must open. As discussed above, the NRC/INEL data show that differences are small after the valves have been exposed to design basis temperature.	The INEL potentially agrees. See above.
April 18, 1990 Presentation (Phases 1 and 2): The results also show that 0.3 disc friction factor is not conservative for valve opening under low flow conditions. As discussed in this report, a disk factor of 0.1 to 0.4 was observed during low-flow opening tests for most INEL test valves. This result is generally consistent with industry practice.	The EPRI report's apparent disc factor calculations and flow isolation positions are incorrect. These issues are addressed in full in Sections 3.4.1 and 3.4.2 of this report. Our comment is correct.
April 18, 1990 Presentation (Phases 1 and 2): Many torque switches are bypassed for unseating, so in those cases motor capacity not opening torque switch setting, is the concern. Motor capacities should be verified. Examining this conclusion in detail is beyond the scope of this effort. It appears reasonable that when the motor capacity is limiting, this capacity should be verified to exceed thrust requirements.	This INEL remark was made to alert the utilities that when raising torque switch settings or bypassing them, motor capacities should be verified. We made this observation in the April 1990 meeting because of the number of motors that burn out in the plants every year.

April 18, 1990 Presentation (Phases 1 and 2):

> Our low flow and differential pressure test results provide some evidence that even in the less demanding service, a 0.3 disc friction factor is not conservative.

See discussion of disk factor above.

See discussion of apparent disc factor calculations and flow isolation positions discussed in Section 3.4.1 and 3.4.2 of this report.

APPENDIX B

Sections 1, 2, and 3 of NUREG/CR-5558, "Generic Issue 87: Flexible Wedge Gate Valve Test Program, Phase II Results and Analysis," January 1991.

GENERIC ISSUE 87, FLEXIBLE WEDGE GATE VALVE TEST PROGRAM, PHASE II RESULTS AND ANALYSIS

1. INTRODUCTION

The Idaho National Engineering Laboratory (INEL), under the sponsorship of the U.S. Nuclear Regulatory Commission (NRC), is performing research[a] to resolve specific generic issues and develop and improve industry mechanical equipment qualification and operating and maintenance consensus standards. This overall research effort includes a program that tested the operability (opening and closing) of six full-scale motor-operated gate valves typical of the containment isolation valves installed in boiling water reactor (BWR) reactor water cleanup (RWCU) process lines and high-pressure coolant injection (HPCI) turbine steam supply lines. The valves were qualified and parametrically tested above, at, and below the pressures, temperatures, and flow conditions of a worst-case downstream pipe break in the RWCU and HPCI turbine supply lines outside of containment. One of the RWCU valves also was tested with steam to provide insights for the reactor core isolation cooling (RCIC) turbine steam supply line isolation valves.

The purpose of the test program was to provide technical input for the NRC effort regarding Generic Issue (GI)-87, "Failure of the HPCI Steam Line Without Isolation." GI-87 also applies to the RCIC and RWCU isolation valves. All three of the GI-87 BWR process lines communicate with the primary system, pass through containment, and normally have open containment isolation valves. The concern with these containment isolation valves is whether they will close in the event of a pipe break outside of containment. A high energy steam or water release in the auxiliary building could result in common cause failure of other components necessary to mitigate the accident. The test program also provides information applicable to the implementation of Generic Letter (GL) 89-10, "Safety-Related Motor Operated Valve Testing and Surveillance," for all light water reactor (LWR) safety-related motor-operated valves (MOVs) and selected position-changeable MOVs in safety-related systems.

The analyses performed to date on the measured data obtained during the GI-87 Valve Test Program and the conclusions derived from the analyses are discussed in this report. A complete analysis of the data required by the program objectives will follow in a later report. We are issuing this report now because the findings to date contain information that may be beneficial to the industry when responding to current regulatory recommendations. Additionally, the Phase II testing did not answer all of the test objectives because we could not locate a dc motor in time for the test program. That work and the open questions regarding stem factor and rate of loading will be performed on the INEL valve load simulator.

For those individuals or organizations who wish to do their own analysis of the data, the measured data are available from the NRC Public Document Room. The Phase I program is reported in *BWR Reactor Water Cleanup System Flexible Wedge Gate Isolation Valve Qualification and High Energy Flow Interruption Test* [EG&G Idaho, Inc. (EG&G Idaho), 1989] (NUREG/CR-5406). The Phase II Test Program actual measured data are reported in *Generic Issue-87 Flexible Wedge Gate Valve Test Program Phase II Data Report*, (EG&G Idaho, 1990). The Phase II data are also available in International Business Machines Corporation (IBM) personal computer (PC)-compatible format. There is also a video tape documenting the post

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test disassembly and inspection of the test valves. Both the video and the magnetic data can be obtained through the INEL Technology Transfer Office at (208) 526-6042.

1.1 Background

Two sets of experiments have been conducted for the GI-87 research program. In Phase I, two full-scale RWCU valves typical of those in operating plants were tested with high energy water. The results of the Phase I program, as previously stated, were reported in NUREG/CR-5406. These results challenged the validity of many gate valve design rules. The two-valve sample was small and one valve sustained damage as a result of the high flow loading. Because of this, some experts in the industry did not accept the results as having general applicability. In the Phase II program, the NRC increased the valve sample size to six valves representative of those installed in both the HPCI and RWCU Systems.

Phase II test program objectives were reevaluated and modified to include the lessons learned in Phase I and to include tests on the RWCU valves that would be applicable to RCIC valves. The resulting objectives were as follows:

- Determine the valve stem force required to close typical RWCU, RCIC, and HPCI system isolation valves at typical operating conditions and under blowdown conditions
- Compare valve closing loads to opening loads at various system conditions
- Evaluate valve closure force components, such as disc friction, packing drag, stem rejection load, and fluid dynamic effects
- Measure the effects of temperature, pressure, and valve design on valve closing and opening loads
- Evaluate the terms and variables in the present standard valve and motor-operator sizing equations
- Provide detailed information to assist in the NRC effort regarding GI-87
- Correlate the data to develop a methodology for in-situ motor-operated valve testing, supporting the implementation of GL 89-10.

The results of the testing may also contribute to specific guidelines being developed to improve valve qualification and in-plant test standards such as American National Standards Institute (ANSI)/American Society of Mechanical Engineers (ASME) standards B16.41 (1983), OM-8, and OM-10.

Surveys of utility installations performed before the Phase I program determined that in the BWR systems of interest, the flexwedge gate valve with a Limitorque[a] motor operator was the predominant configuration. To avoid duplication, we reviewed previous applicable industry test programs. The review included the Electrical Power Research Institute (EPRI) power-operated relief valve/block valve testing at Duke Power in 1980; the Central Electric Generating Board (CEGB), United Kingdom; gate valve testing performed at Kraftwerk Union (KWU), Federal Republic of Germany; and the KWU testing performed for their own plant designs. The EPRI and CEGB work were go-no-go tests; however, the results showed that both flexwedge gate valves and parallel disc designs did have problems. The KWU work on their own gate valve designs resulted in many gate valves being replaced with globe valves. Where they could not replace the gates, they developed a structurally stiff design with rather close internal clearances. The U.S. has valves with close and large clearances, but none of our designs are as structurally stiff as the KWU designs. The KWU testing indicated that we might expect trouble based on their findings.

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[a] Mention of specific products and/or manufacturers in this document implies neither endorsement or preference nor disapproval by the U.S. Government, any of its agencies, or EG&G Idaho, Inc., of the use of a specific product for any purpose.

The previous test programs did not answer our GI-87 questions, however. It must be noted here that after reviewing all of our test results, the most flexible U.S. design performed better than our moderately stiff designs. Therefore, a valve may perform correctly without being stiff. The valve design needs to be tested with the worst-case tolerances to ensure operability.

The NRC Office of Inspection and Enforcement (IE) Bulletin 85-03, "Motor Operated Valve Common Mode Failures During Plant Transients Due to Improper Switch Settings," and GL 89-10, require the utilities to develop and implement a program to ensure that the switch settings on selected safety-related MOVs are set and maintained correctly to accommodate the maximum differential pressure expected on these valves during both normal and abnormal events within the design basis. The GI-87 valves are a subset of this larger class of safety-related valves.

Industry has helped to meet these criteria by developing new MOV diagnostic test equipment and methods for in-situ valve testing. Prior to the GI-87 Valve Test Program, the motor-operator control switches settings were based primarily on standard industry practices and analysis. Very little design basis testing had been conducted in or outside of the plants. Utilities typically verified the analytically-determined MOV output torque or stem force through valve seating or backseating loads with little or no valve hydraulic loading. The GI-87 Phase I test results cast some doubts on this industry practice, primarily on whether the true design basis load can be determined analytically.

1.2 Motor-Operator Sizing

The gate valve is a high recovery positive shutoff valve and is typically used in systems where minimal pressure drop is desired when the valve is open. The design is ideally suited for isolation purposes and usually is not used for throttling flow. When the disc is in the seat, the upstream pressure load on the disc assists in sealing. This feature is less important in the flexwedge than in the parallel disc gate.

There are a number of calculations made to determine the correct operator size for a given valve application. The term sizing means that the output power available from a given motor operator is determined by its size. Typically, the larger the operator the higher the allowable output. Table 1 lists the typical maximum output in torque and stem force for the various SMB Model Limitorque operators. This table should only be used to understand what sizing means. Requalification of motor operators and other limitations on valve hardware can affect the use of a specific operator size.

The four most important calculations that are made in sizing a motor operator for a specific valve application are (a) total stem force necessary to operate the valve at its design basis load, (b) the operator torque necessary to produce that force, (c) the operator gear ratio (including the stem nut thread necessary to produce the needed valve stroke time), and (d) the size and speed of the electric motor necessary to produce the needed operator torque for that gear ratio. To be conservative, other calculations are made, such as degraded voltage concerns, which do not need to be explained for a basic understanding of motor-operator sizing. Two of these calculations, the gear ratio and the electric motor sizing, appear to be well understood and the results are repeatable in application. The required stem force and the operator torque to produce that force appear to be the areas that have not been conservatively predicted in the past for some classes of valves.

Figure 1, a cutaway drawing of a typical motor-operated gate valve, shows the components important to this discussion. The necessary forces currently defined by industry to close the valve and isolate flow must overcome the resistance imposed by three loads: (a) the disc frictional drag load caused by the differential pressure across the disc as the valve closes, (b) the stem rejection load caused by static pressure on the stem, and (c) the packing drag load. Industry has developed a set of equations for use in sizing motor operators. The first equation in this set predicts the total stem force, as detailed below. Each manufacturer modifies the variables in the equation slightly; however, in the long run the application of the equation is the same.

Table 1. Limitorque operator nuclear ratings

Model-Size	Ratio[a] Range	Rated Torque (ft-lb)	Rated Stem force (lb)	Maximum Threaded Stem Diameter (in.)
SMB-000	12.5- 30.6	90	8,000	1.375
	33.5-100.0	90		
	102.0-136.0	90		
SMB-00	9.7- 22.0	250	14,000	1.75
	23.0-109.0	250		
	114.0-183.9	190		
SMB-0	11.8- 26.1	500	24,000	2.375
	26.4- 96.2	500		
	102.6-150.8	500		
	158.3-247.0	340		
SMB-1	11.6- 25.7	850	45,000	2.875
	27.2- 88.4	850		
	92.4-171.6	780		
	191.7-234.0	625		
SMB-2	10.6- 25.6	1800	70,000	3.5
	26.2- 82.5	1800		
	84.8-150.0	1250		
	153.0-212.5	950		

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a. Unit overall gear ratio.

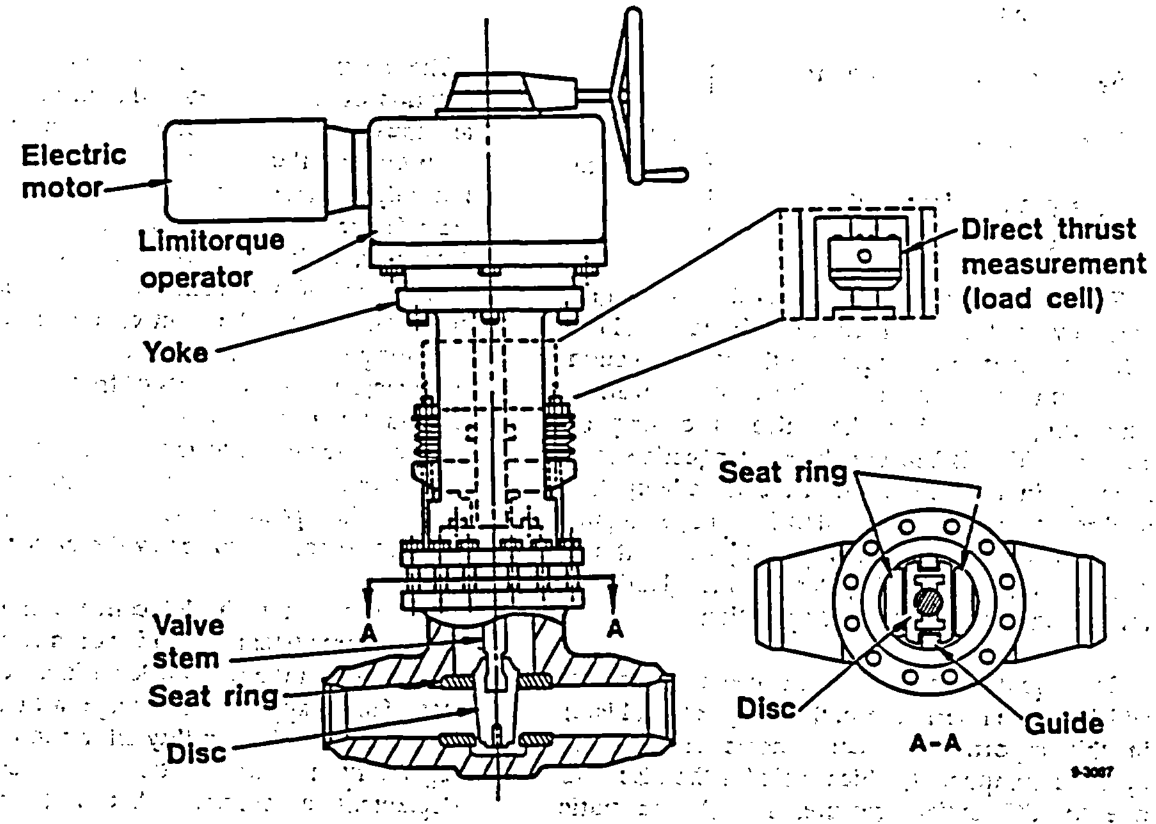

Figure 1. Typical motor-operated valve showing components important to calculating stem force. Two of the test valves were modified by installing a load cell in the valve stem.

$$F_t = \mu_d A_d \Delta P \pm A_s P + F_p \tag{1}$$

where

F_t = total stem force

$$\left.\begin{array}{l} \mu_d = \text{disc factor} \\ A_d = \text{disc area} \\ \Delta P = \text{differential pressure} \end{array}\right\} \text{dynamic component}$$

$$\left.\begin{array}{l} A_s = \text{stem cross-section area} \\ P = \text{stem pressure} \\ F_p = \text{packing drag load (a constant).} \end{array}\right\} \text{static component}$$

For wedge-type gate valves, the disc factor (μ_d) normally used by the industry in Equation (1) is 0.3. Note that in this equation the stem rejection load can be either positive or negative, dependingon whether the valve is closing or opening. This is because the stem rejection load is always in a direction out of the valve body; this load resists valve closure and assists in opening the valve. The packing load is typically constant and depends on the packing design, the gland nut torque, and the direction of operation.

The equation is divided into two components, which will be referred to in the analysis found later in this report. The components are (a) the dynamic component, which includes the disc load due to differential pressure, and (b) the static component, which is the sum of the stem rejection and packing drag loads. The pressure values (P and ΔP) used in the force equation are supplied to the valve manufacturer by each individual utility. Determining the motor-operator torque necessary to produce that force is complicated by the fact that motor operators control output torque, not stem force. Thus, in determining the necessary output torque one must consider the conversion of operator torque to stem force. The torque-to-stem force relationship normally used in sizing motor operators depends on a stem factor calculation given by

$$T = \mu_s F_t \tag{2}$$

where

T = operator torque

μ_s = stem factor

F_t = total stem force [from Equation (1)].

The stem factor used in Equation (2) is a function of stem diameter, thread pitch and lead, and the coefficient of friction between the operator stem nut and the valve stem. As in Equation (1), the only variable that cannot be measured in the stem factor equation is the coefficient of friction. Normally, it is assumed that only damage and lubrication of the stem/stem nut threads can significantly alter the stem coefficient of friction. Limitorque personnel, in their diagnostic work, have measured coefficients of friction from 0.10 to 0.20 in actual operation. Losses internal to the motor operator, up to the capacity of the electric motor, will typically be accounted for by the torque spring/switch position. Losses in the stem factor will not be accounted for by the motor operator.

The problem with the conversion of torque-to-stem force (stem factor) is not in conservatively bounding it in the sizing calculation. It is that the stem factor appears to change with stem load. This will complicate utility efforts to comply with regulatory recommendations to develop and implement a program that will ensure that safety-related motor-operator torque switch settings (the switch that regulates the motor-operator output torque) are chosen, set, and maintained correctly to accommodate the maximum differential pressure load expected on the valves during both normal and abnormal events within the design basis. Additionally, MOV torque-to-force relationships can vary with age and maintenance. Torque springs age, changing the torque switch setting in comparison to output torque. The stem factor can change for two primary reasons: (a) lubrication quality at the valve stem-to-motor-operator stem nut interface, and (b) degradation of the threads of either component. The stem factor can also improve with wear between the stem and stem nut threads.

The INEL believes the biggest motor-operator sizing problem today is verifying the capability of the operators in the plants. This problem is compounded for gate valves and to some degree for all rising stem motor-operated valves according to NRC GI-87 valve test results. This indicates that the variables used by industry in the past for determining valve opening and disc force [Equation (1)] at high flow were not conservative, and that the stem factor may vary with load, making it very difficult for the utility to diagnostically determine operator capability in place without design basis testing. This is not always possible in a plant.

Motor-operator sizing topics that apply to both GI-87 and GL 89-10 will be discussed in more detail in later sections of this report.

2. APPROACH TO TESTING

Six full-scale, representative nuclear valve assemblies were tested under various normal operations and design basis pipe break conditions for the RWCU, HPCI, and RCIC systems. Table 2 lists the test valves and motor operators used in both Phase I and II test programs.

As shown in Table 2, the two valves used in Phase I were reused in Phase II. Phase I Valve A was refurbished and became Valve 1 in Phase II. The valve's internal manufacturing tolerances allowed the disc to tip downstream during the Phase I testing, causing damage to the disc guide surfaces. Gate valves are bidirectional; therefore, the valve was turned around for Phase II, reversing flow through the valve to see how the internal manufacturing tolerance stackup in the other direction affected valve performance. Valve B from Phase I was returned to its manufacturer for a valve disc replacement and became Valve 2 in Phase II. The valve disc or gate in Phase I was equipped with hardfaced disc guides, representative of valve assemblies built after 1970. For Phase II, the hardfaced guide disc was replaced with a normal material disc guide, representative of those valves made before 1970. With the exception of Valve B in Phase I, all other valves in both phases had normal carbon steel disc guide surfaces representative of the largest majority of the installed gate valves. All valves in both phases had hardfaced sealing surfaces on both the body and the discs. Valves 3, 4, and 5 were new valves obtained through canceled nuclear plant surplus. These three valves and the two valves used in Phase I were returned either to their manufacturer or to a nuclear valve service center for refurbishment and/or inspection prior to their use in Phase II testing. Valve 6 was manufactured new for the Phase II Program. Prior to Phase II testing, each valve body was assembled with instrumented spool pieces and instrument taps as shown in Figure 2.

Table 2 also identifies the 460-Vac, 3-phase, 60-Hz Limitorque electric motor operators used on the valve assemblies. For Phase II, the same SMB-O-25 was used on all three 6-in. valve assemblies, and the same SMB-1-60 was used on the three 10-in. valve assemblies. The motor-operator stem nuts and helical reduction gears were changed to accommodate the valve stem thread pitch and lead and to establish, as close to as possible, a 30-s stroke time for all six valves. For valve stem force measurements, two of the valves were instrumented with direct stem-mounted load cells, as shown in Figure 1. The other valves used a set of four load cells mounted between the valve yoke and motor operator. During final checkout of the motor operators, Limitorque ran a special torque spring deflection versus operator output torque calibration on their dynamometer. By using a linear variable displacement transformer (LVDT) and the Limitorque torque spring deflection versus operator output torque relationships, we were able to monitor apparent motor-operator torque on-line during the test program. Figure 3 shows the general location of the valve response instrumentation used during the Phase II test program.

The Phase II test program was performed in the late summer and early fall of 1989 at the KWU facilities near Frankfurt, West Germany. Two test loops were used. Figure 4 shows the loop used for the 6-in. valve tests; Figure 5 shows the loop used for the 10-in. valve tests. Both test loops used a 22-MW oil-fired boiler for heating and test media propellant. The 6-in. valve test stand also had the capability of being charged with gaseous nitrogen for cold water high flow testing. Both test stands were equipped with bypass lines around the loop blowdown device. These lines were used to establish normal flow through the valves for normal-service functional testing. Maximum flow was established on the 6-in. valve test loop through a rupture disc and on the 10-in. valve loop through quick opening valves.

The data collection objectives for Phase II testing were driven by the lessons learned from the Phase I program, where the performance of the valves under higher loadings was unlike previous industry claims for valve performance. Valve thermal hydraulic inlet conditions appeared to influence these performance problems (i.e., the measurements made during the Phase I program

Table 2. Valve and operator information

Test Hardware

Valve Manufacturer and Valve Identification

	Valve Designation				
	Phase I	Phase II	Size	Class	Type
Anchor/Darling[a]	A	1	6-in.	900 lb	Flexwedge Gate
Velan[a]	B	2	6-in.	900 lb	•
Walworth		3	6-in.	600 lb	•
Anchor/Darling		4	10-in.	900 lb	•
Wm. Powell		5	10-in.	900 lb	•
Velan		6	10-in.	600 lb	•

Motor-Operator Manufacturer	Size	Valve Used
Limitorque	SMB-0-25	1, 2, 3 and B
Limitorque	SMB-1-60	4, 5, and 6
Limitorque	SMB-2-40	A

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a. Valves A and B from Phase I were refurbished for Phase II as Valves 1 and 2.

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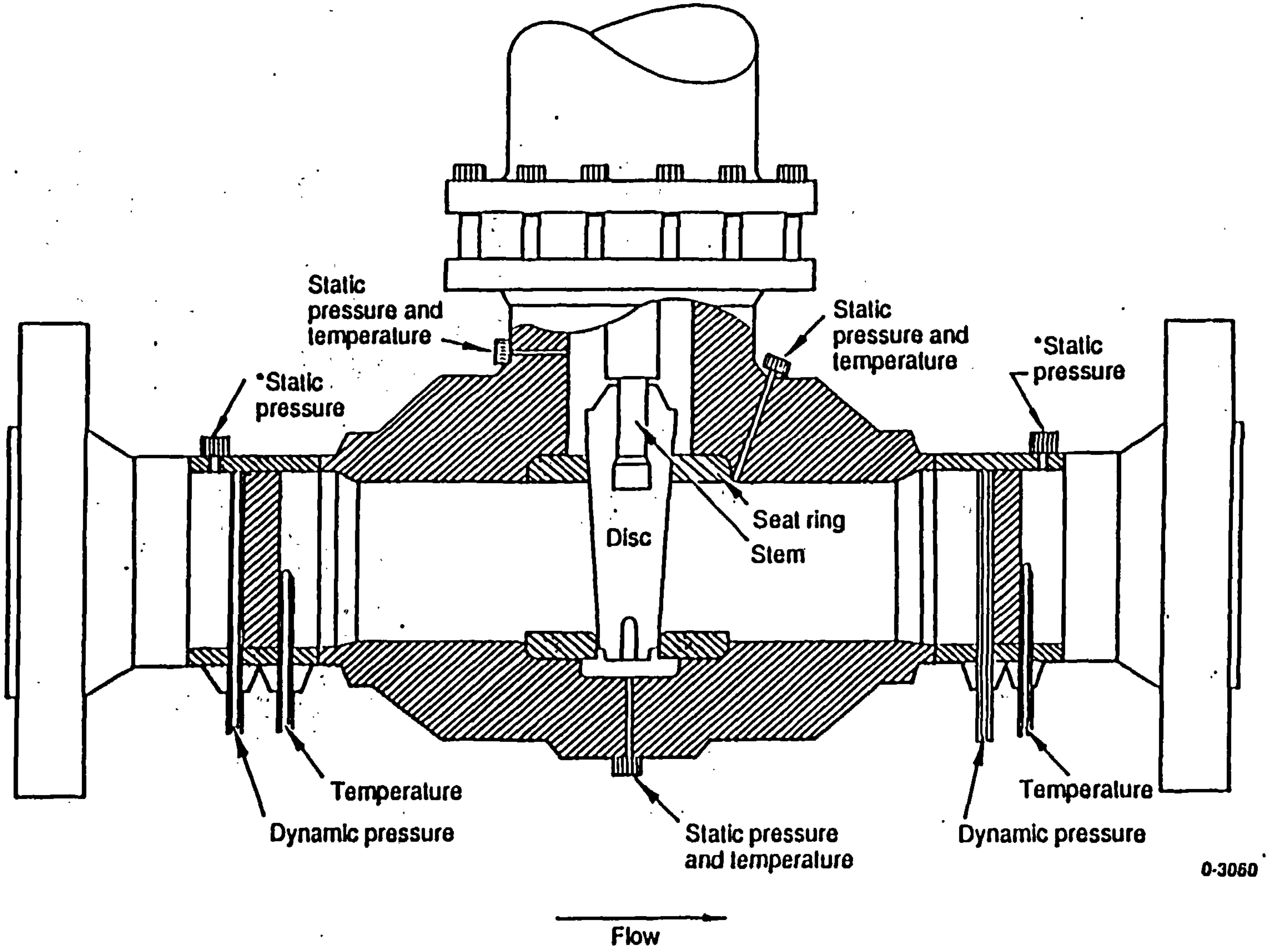
were not sufficient to allow a thorough analysis of specific thermal hydraulic influences). The Phase II measurements, instruments, and data-collection tools were optimized as thoroughly as practical to characterize the test valves' and motor-operators' performance at the various test conditions. Inputs to these measurement and data collection schemes included suggestions from experts at the INEL, from the NRC staff at planning meetings, and from industry experts at several review meetings.

To quantify the test loop thermal hydraulic conditions and valve response, an average of 70 channels of information were measured and recorded on a high-speed tape recorder. The tape recorder was an integral part of the INEL data acquisition system (DAS). The DAS transducer excitation voltage was measured at the transducer and the system adjusted the internal voltage to account for line losses. The outputs from the transducers were then measured by the DAS and committed to the tape.

The DAS was also configured to make incremental calculations of the stem force throughout the closing and opening cycles using the measured values for the parameters in Equation (1) (differential pressure, disc area, etc.) and a constant disc factor, either the common 0.3 or a more conservative 0.5. We performed our calculations in this manner to see how well the equation modeled the actual stem forces during the entire cycle. A comparison of the calculated forces to the measured forces shows where the deviations



*Rotated 90 for clarity

Figure 2. Valve assembly showing instrumented spool pieces.

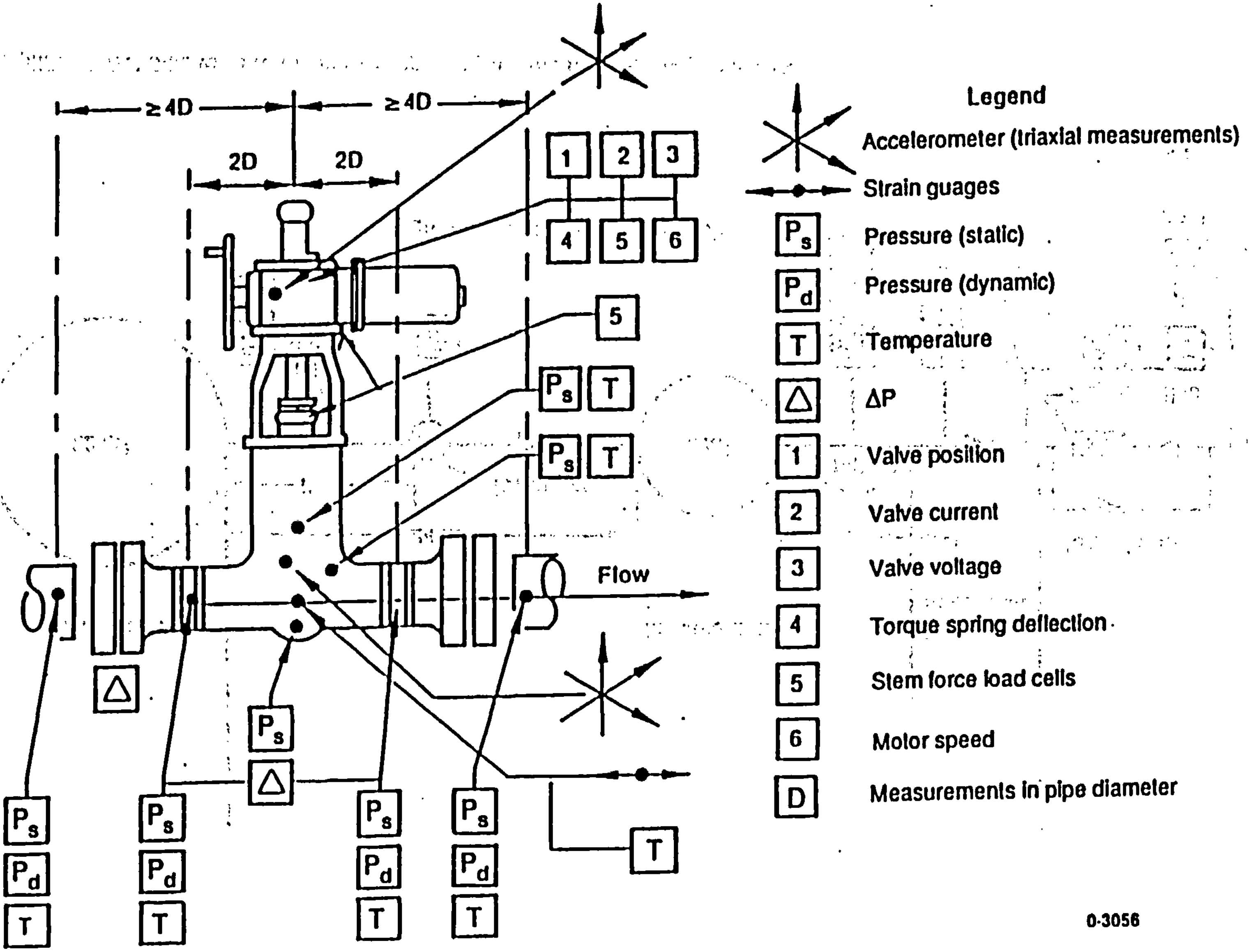


Figure 3. Phase II valve assembly and local piping instrumentation.

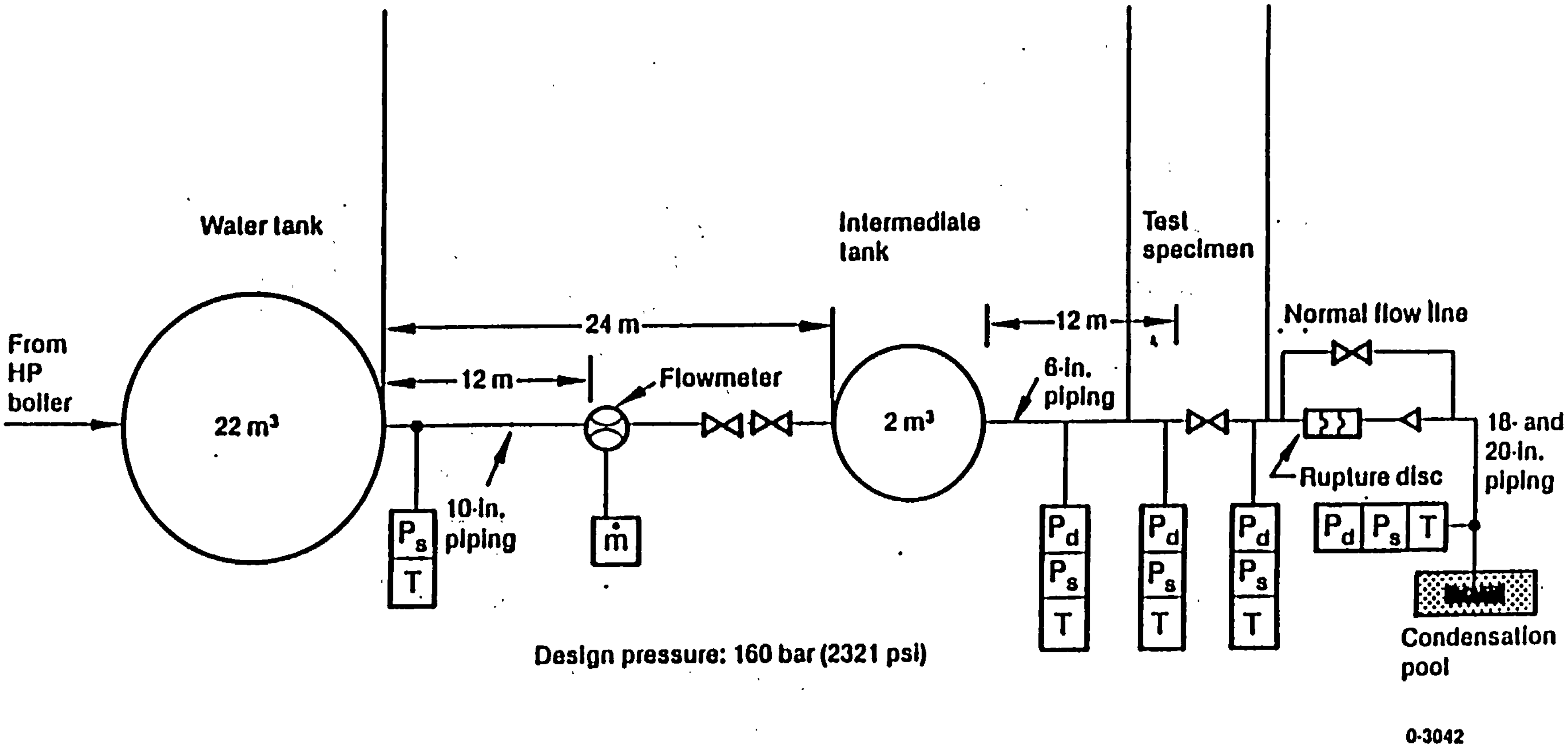


Figure 4. Simplified KWU 6-in. valve test loop showing configuration, lengths, and piping sizes.

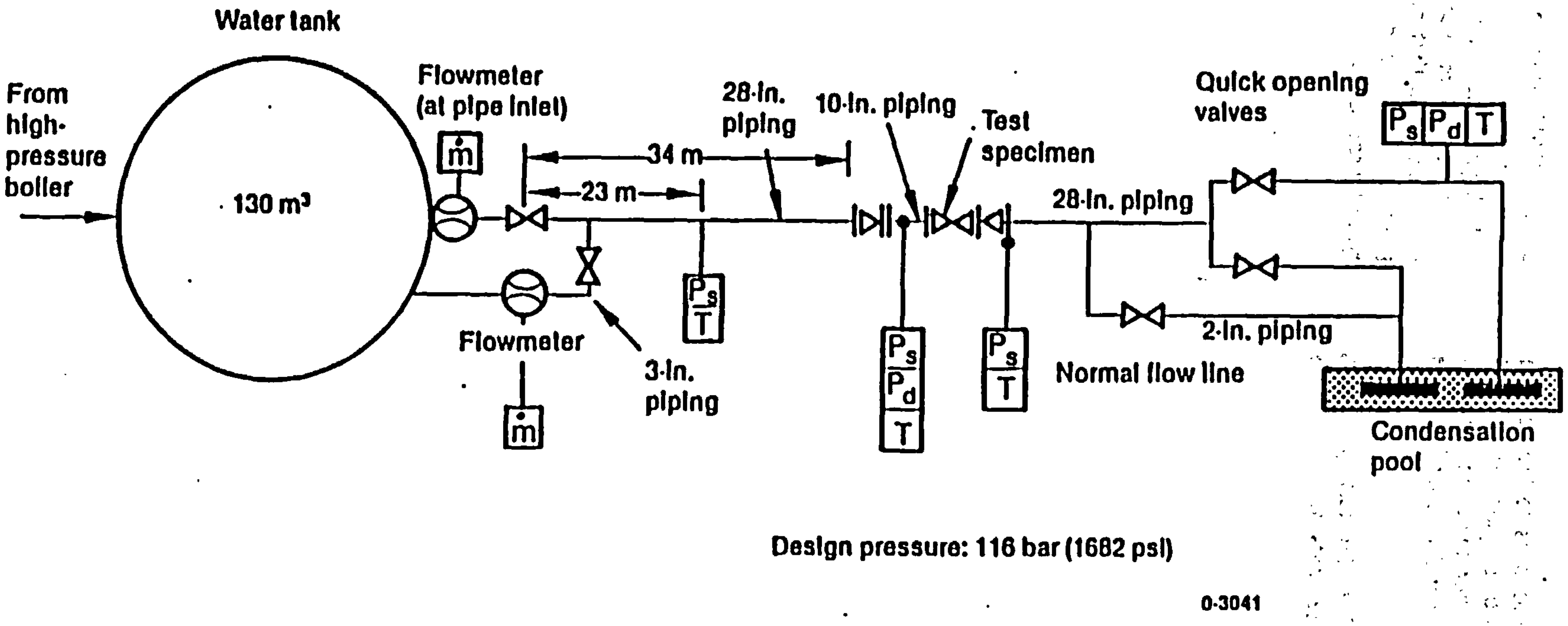


Figure 5. Simplified KWU 10-in. valve test loop showing configuration, lengths, and pipe sizes.

start to take place and allows us to look at the fluid conditions and other parameters and determine if influences other than the terms in Equation (1) affect the stem forces during valve operation.

At various times during the test programs, parallel diagnostic measurements were made by Bechtel-KWU Alliance, General Physics, Liberty Technology, Limitorque, Movats, Westinghouse, and Wyle Laboratories. This allowed the diagnostic vendors to compare measured loadings, similar to those that might be developed during in-plant testing, to design basis loadings, which typically cannot be developed in the plant.

3. TESTING

Six qualification tests and seventeen flow interruption tests were performed. Seven of the flow interruption tests were design basis tests; the other ten were parametric studies. The parametric studies were an attempt to understand the effects of pressure, temperature, and fluid properties on valve performance. The fluid conditions and valve operating responses provided information concerning valve and motor-operator performance at various valve loadings.

The two lists below summarize the qualification and flow interruption test procedures for each valve. The basic test procedure for each valve through the design basis flow interruption test was nearly the same, with a few exceptions (listed later).

The following list is an overview of the test procedure performed in accordance with the test plan for each valve through the design basis flow interruption test, which was always performed first on each valve assembly:

- The valve was installed in the test loop
- The motor operator was installed and limit control switches were set
- Instrumentation was installed
- The torque switch was set
- A baseline opening and closing test without pressure was performed
- Cold leakage test (Annex A of ANSI/ASME B16.41)
- Cold cyclic test (Annex B of ANSI/ASME B16.41)
- Hot cyclic test (Annex C of ANSI/ASME B16.41)
- Flow interruption test at the normal operating pressure and temperature (NOP/NOT) for the valve's representative system (Annex G of ANSI/ASME B16.41). The details of this step are provided below.

Exceptions to this basic procedure are as follows:

- Because of operator limitations at the very high torque switch settings used, some of the under-voltage tests recommended by the standard in hot and cold cycling were not performed.
- The torque switch settings in some cases were increased after hot cycling to ensure valve closure. (Our objective was to close the valve and determine from the measurement how much stem force was actually required to isolate flow and seat the valve. In one case (Valve 1), we underestimated the closing force; we obtained flow isolation but did not fully seat the valve.)

The flow interruption test consisted of the following numbered steps. The numbers reference the headers of the Phase II plots used in this report:

- Bring the test loop and valve up to NOP/NOT (Step 7)
- Close the valve at NOP/NOT without flow (Step 13)
- Depressurize the downstream side of the valve (Step 15)
- Open the valve against NOP/NOT upstream pressure (with the downstream valves closed) (Step 17)
- Establish normal flow through the test valve by opening the valve in the normal flow line (see Figures 4 and 5)
- Close and reopen the test valve at normal system flow (Step 18)
- Close the valve in the normal flow line

- Establish line break flow through the test valve and close the test valve (Step 25)
- Reopen the test valve 30% open and reclose at maximum flow (Step 26)
- Depressurize the test loop and open and close the test valve while still at temperature without system pressure (Step 30).

Following the flow interruption tests, we reviewed the quick look plots, which served two purposes:

- To determine if the valve had been damaged during the test. Valve stem force plots are very good indicators of valves sustaining damage during the high flow tests (see Figure 6).
- To determine if the thermal hydraulic conditions at the valve inlet met the test objectives.

If the valve was damaged by the loading (as determined from a review of the stem force plot), we stopped testing and installed the next valve. If the valve was not severely damaged and the thermal hydraulic conditions were met, we then subjected the valve to parametric studies (varying the pressure and/or temperature). If the thermal hydraulic conditions were not met, we repeated the test.

Table 3 provides the test matrix for the flow interruption test sequences performed on each valve. The temperatures and pressures listed for each sequence include the target pressures and temperatures for a nearly closed valve. Facility capability limitations necessitated that some tests be started with a slightly higher pressure than the target pressure. In some cases, the valve was started from less than 100% open in the maximum flow closures so that the target pressure would be achieved as closely as possible when the valve was nearly closed.

Table 4 provides the maximum working pressures for the valve classes tested in this program and the test pressures for the leakage and cyclic tests. Test pressures were not always maximums for the valve class because of facility limitations; however, they did bound the qualification pressure for the intended service.

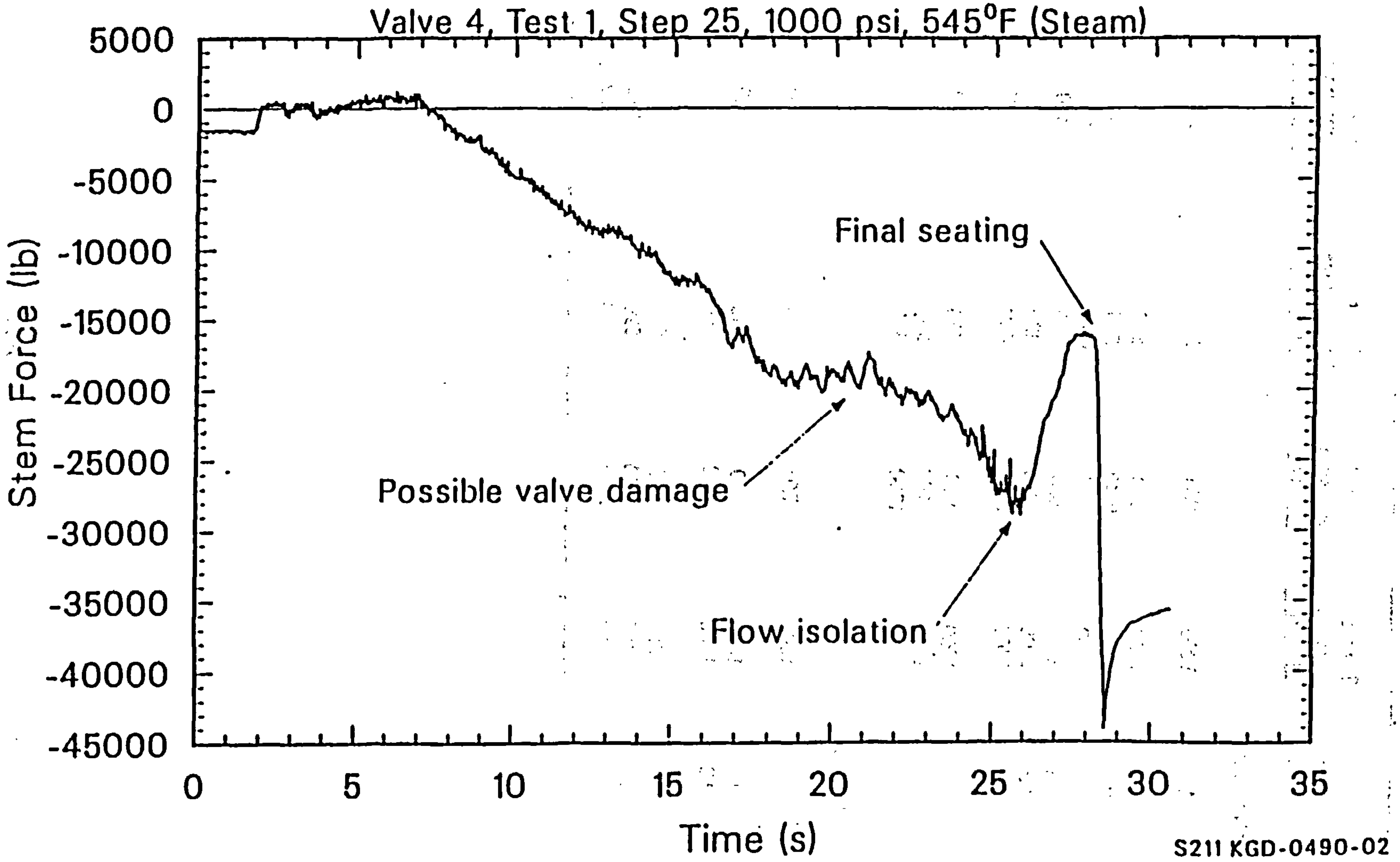


Figure 6. Valve stem force history from Phase II testing shows nonlinear performance of the valve, indicating valve damage.

Table 3. Flow interruption test target temperatures and pressures

Valve No.	Test No.	Target Pressure (psig)	Actual Pressure (psig)	Target Temperature (°F)	Actual Temperature (°F)	Media
6-in. Valve Tests						
1	1	1000	900	530	520	Hot water
2	1	1000	950	530	520	Hot water
2	2	1000	1040	545	550	Steam
2	3	1000	750	<100	<100	Cold water
2	6A	600	600	300	450	Hot water
2	6B	1000	1000	430	470	Hot water
2	6C	1400	1300	480	520	Hot water
3	1	1000	920	530	520	Hot water
3	5	1200	1100	550	550	Hot water
3	7	1400	1300	580	570	Hot water
10-in. Valve Tests						
4	1	1000	750	545	510	Steam
5	1A	1000	800	545	520	Steam
5	1B	1400	1040	590	550	Steam
6	1A	1000	990	545	580	Steam
6	1B	1400	1400	590	590	Steam
6	1C	1200	1100	570	550	Steam

Table 4. Valve qualification test pressures

Maximum ANSI working pressure by pressure class for these allovs

Valve No.	Class	Temperature (°F)	Maximum Working Pressure (psig)
1, 2, 4, 5	900 lb	<100	2250
	900 lb	600	1815
3, 6	600 lb	<100	1500
	600 lb	600	1210

Cold Leakage Test Annex A

Valve No.	Temperature (°F)	Test Pressure (psig)
1	<100	2200
2	<100	2200
3	<100	1500
4	<100	2200
5	<100	2200
6	<100	1500

Cold Cyclic Test Annex B

Valve No.	Temperature (°F)	Test Pressure (psig)
1	<100	1650
2	<100	1650
3	<100	1200
4	<100	1600
5	<100	1600
6	<100	1200

Hot Cyclic Test Annex C

Valve No.	Temperature (°F)	Test Pressure (psig)
1	600	1650
2	600	1650
3	550	1200
4	610	1600
5	610	1600
6	550	1200

APPENDIX C

J. C. Watkins, R. Steele, K. G. DeWall

"NRC Test Results and Operations Experience Provide Insights for a New Gate Valve Stem Force Correlation"

Nineteenth Water Reactor Safety Information Meeting
October 1991

NRC TEST RESULTS AND OPERATIONS EXPERIENCE PROVIDE INSIGHTS FOR A NEW GATE VALVE STEM FORCE CORRELATION[a]

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ABSTRACT

The Idaho National Engineering Laboratory (INEL) is performing motor-operated valve (MOV) research in support of the U.S. Nuclear Regulatory Commission's (NRC's) efforts regarding Generic Issue 87, "Failure of HPCI [High-Pressure Coolant Injection] Steam Line Without Isolation," and Generic Letter 89-10 (GL-89-10), "Safety-Related Motor-Operated Valve Testing and Surveillance." This paper presents the results of testing to assess valve and motor operator performance under varying pressure and fluid conditions. This effort included an examination of the methods used by the industry to predict the required stem force of a valve, and research to provide guidelines for the extrapolation of in situ test results to design basis conditions.

This research has identified several inconsistencies with the existing industry gate valve stem force equation and has challenged the overly simplistic assumptions inherent in its use. This paper discusses the development of the INEL correlation to bound the stem force necessary to close flexwedge gate valves whose operational characteristics have been shown to be predictable. The authors also present a method whereby the results of testing such valves at low differential pressure can be used to bound valve response at conditions up to their design basis.

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[a] Work supported by the U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Division of Engineering and Division of Safety Issues Resolution, under DOE Contract No. DE-AC07-76ID01570; G. H. Weidenhamer and O. O. Rothberg, Technical Monitors.

INTRODUCTION

Flexwedge gate valves were tested in two U.S. Nuclear Regulatory Commission (NRC) test programs and reported in NUREG/CR-5406 (DeWall and Steele, 1989) and NUREG/CR-5558 (Steele et al., 1990). Both reports were published in support of Generic Issue 87. After the latter report was published, we developed a technique to (a) bound the stem force of a five-degree flexwedge gate valve closing against medium to high flow conditions and (b) validate a low differential pressure closure test and then bound the stem force of a flexwedge gate valve closing against design basis conditions.

In the two test programs mentioned above, six valves with a total of seven different internal designs were tested. The valves were subjected to a broad range of fluid conditions and flow rates, from normal system flows to design basis line break flows. Two of the valves, including the valve that was tested with two discs, performed in a manner we have called predictable. A predictable valve is one that does not exhibit evidence of internal damage during testing. In such valves, the highest stem forces occur when the disc is riding on the valve body seats just before wedging. Conversely, an unpredictable valve exhibits evidence of internal valve damage during testing, characterized by an erratic, sawtooth shaped stem force response. In these valves, the highest stem force requirements typically occur while the disc is riding on the guides rather than just before wedging.

The test results were initially evaluated with the standard industry gate valve stem force equation. Although some of the manufacturers modify the variables in this equation slightly, the application of the equation is basically the same.

$$F_t = \mu_d A_d \Delta P \pm A_s P + F_p \qquad (1)$$

where

F_t = stem force
μ_d = disc factor
A_d = disc area
ΔP = differential pressure across the valve
A_s = area of the stem
P = pressure upstream of the valve
F_p = packing drag force.

For wedge-type gate valves, the industry has normally used a disc factor of 0.3, although they sometimes specify a more conservative disc factor of 0.5. The disc factor acts in conjunction with the disc area and the differential pressure, and the three multiplied together represents the largest component in the stem force equation. However, the disc area term is not used uniformly throughout the industry. This term is based on the orifice diameter by some manufacturers, on the mean seat diameter by others, or even on the orifice diameter times one or more factors to artificially enlarge the area on which the differential pressure acts. We used a disc area based on the orifice diameter when we evaluated the standard industry stem force equation because it represents the least conservative use of the term by industry. This results in a lower estimate of required stem force.

Comparisons of the industry equation, Equation (1), with selected test results are shown in Figure 1. This figure presents the results of the same valve isolating a break at a common upstream pressure of approximately 1000 psig, but with the fluid at various degrees of subcooling. The subcooling ranges from none (steam) to approximately 400°F (cold water) with intermediate values of 10°F and 100°F. The recorded stem force is shown as a solid line; the dashed lines show two calculations of the stem force history using the industry equation and real time test data with standard industry disc factors of 0.3 and 0.5. This figure shows that at flow isolation, each test required more force to close the valve than would be estimated using the standard industry disc factor of 0.3. In fact, for the tests shown on this figure, the more conservative industry disc factor of 0.5 ranges from acceptable (the steam test) to marginally acceptable (the 10°F subcooled fluid test) to unacceptable (the 100°F and the 400°F subcooled fluid tests). Note that although the results of the industry equation are presented over the entire closure cycle, the equation represents a bounding estimate of the maximum stem force. As such, only the estimated stem force at the final horizontal line, just before wedging, is applicable. The results are presented for the entire closure to aid in identifying trends in the recorded stem force, not to assess the equation throughout the closure cycle. Note also that although the same valve and operator were used for each test, the closure durations are different. Due to facility limitations, some of the tests were initiated with the valve partially closed.

It is also interesting to note that the shape of the recorded stem force from flow initiation to flow isolation varies depending on the degree of subcooling of the fluid. In tests with greater subcooling, the stem force during the initial portion of the closure is lower. In fact, during the test with cold water, the stem force trace was initially positive (i.e., the valve was self closing during this portion of the closure). However, just prior to wedging, the required stem force is generally higher in tests with greater subcooling of the fluid so that closure against cold water requires more force than closure against steam.

ASSESSMENT OF THE DISC FACTOR

As we studied the test results and analyzed the industry equation, it became increasingly evident that the disc factor used in the equation was not well understood. It appeared that the disc factor depended on parameters not currently being accounted for, such as the subcooling of the fluid. Thus, we examined the equation in more detail, and specifically the disc factor term as currently defined. To perform this evaluation, we used both the baseline and applicable parametric testing to determine what influence pressure and fluid properties, such as subcooling, had on the required stem force of a valve.

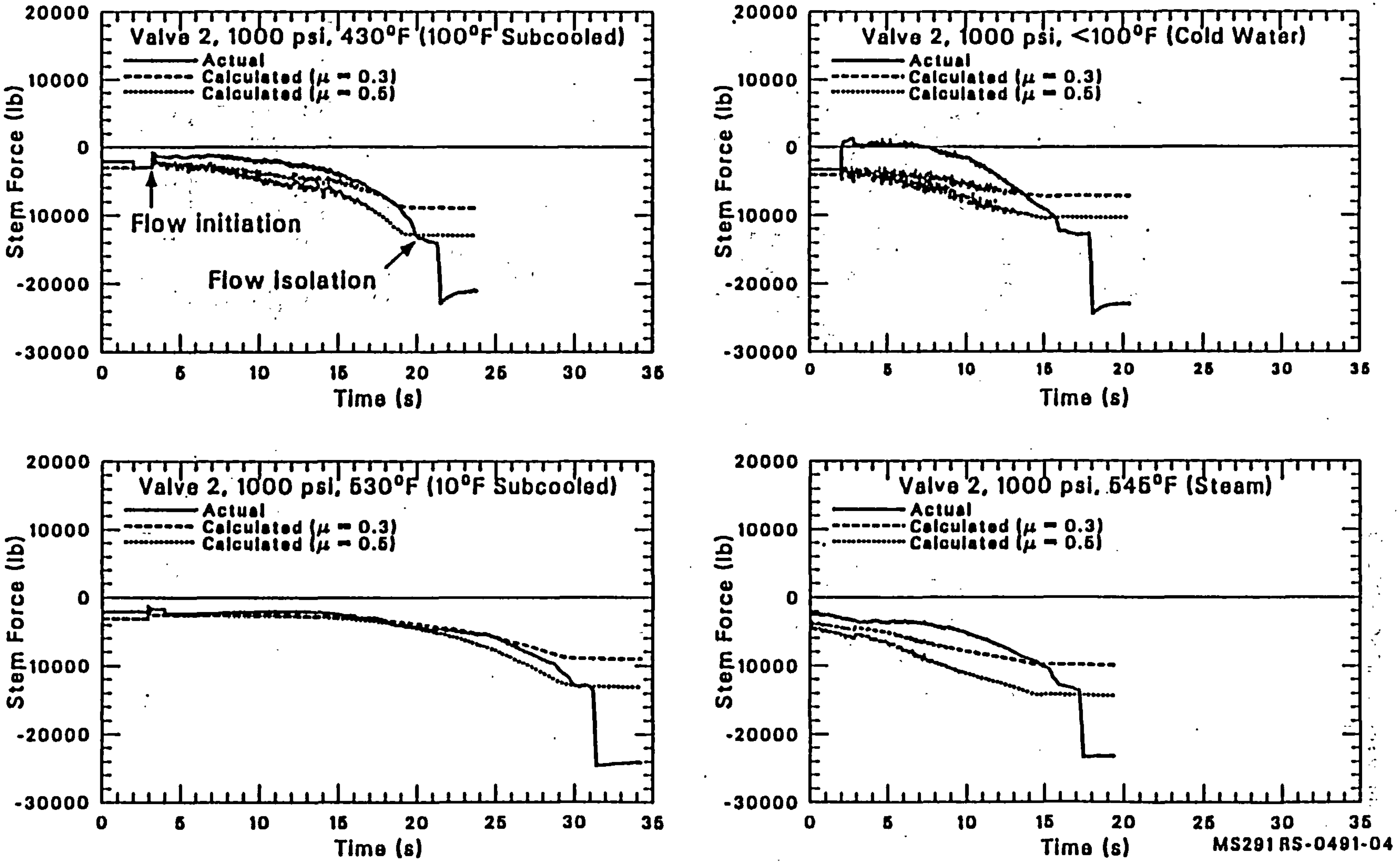

Figure 1. Comparison of the standard industry gate valve stem force equation with selected test results.

If all of the parametric studies could have resulted in just one parameter being varied, then the tests could have been compared to each other to determine the effect of that one parameter (e.g., fluid properties). That was not the case, however. It was impossible to provide such precise temperature and pressure control at the valve. This, along with other facility limitations, such as the total system supply volume, resulted in tests that cannot be compared to one another without some type of normalization.

We normalized the test results using Equation (1) by solving for the disc factor. This was possible because the stem force, the system pressure, and the valve differential pressure throughout the closure cycle were known. The results of a typical comparison are shown in Figure 2. The plot is read from right to left as the valve closes. As time increases, the disc factor increases in the negative convention (indicating valve closure) and is plotted against stem position. The zero stem position represents that point in the valve closure where the horizontal visual area is blocked so that you could not see down the pipe. Remember, however, that although the visual area is blocked, fluid can still flow under the disc and through the valve. At this point, the disc area term in Equation (1) becomes constant. The differential pressure term is also near its maximum during this portion of the valve closure. From the zero stem position to the minus 10% stem position, the stem travel involves seating and finally wedging. There are no terms in the industry equation to represent the increased resistance before wedging. The figure also indicates that the disc factor is influenced by fluid properties, steam being the best performer with the lowest disc factor and cold water the worst with the highest disc factor. This fluid properties effect is evident not only at the zero stem position, but from the minus 5% to the minus 10% stem position, when the disc is riding on the seats just before wedging. This effect is contrary to what was expected; one would expect water to be a better lubricant than steam.

Our next effort was to determine if the disc factor was dependent on pressure. Figure 3 shows a comparison for using three parametric tests where the fluid properties remained constant but the pressure was varied. Although the disc factor did not exhibit a significant pressure dependency at the zero stem position, it did from the minus 5% to the minus 10% stem position when the disc was riding on the seats just before wedging. The figure also indicates that the disc factor was lowest during the 1400 psig test and highest during the 600 psig test. This, too, is contrary to what was expected; one would expect a lightly loaded disc to have a thicker lubrication film and thus a lower coefficient of friction than a heavily loaded disc.

Figure 4 depicts the effect of pressure in the opening direction, further highlighting inconsistencies with Equation (1). This plot is read from left to right as the valve opens. Although the disc factor (a positive value because the valve is opening) did not exhibit a pressure dependency at the zero stem position, it did from the minus 5% to the minus 10% stem position. This trend is similar to what was observed in the closing direction. The figure also reaffirms our previous observations that the disc factor is lower during a high-pressure test and higher during a low-pressure test. The opening disc factor is also observed to be higher than the closing disc factor at its peak, non-wedging value.

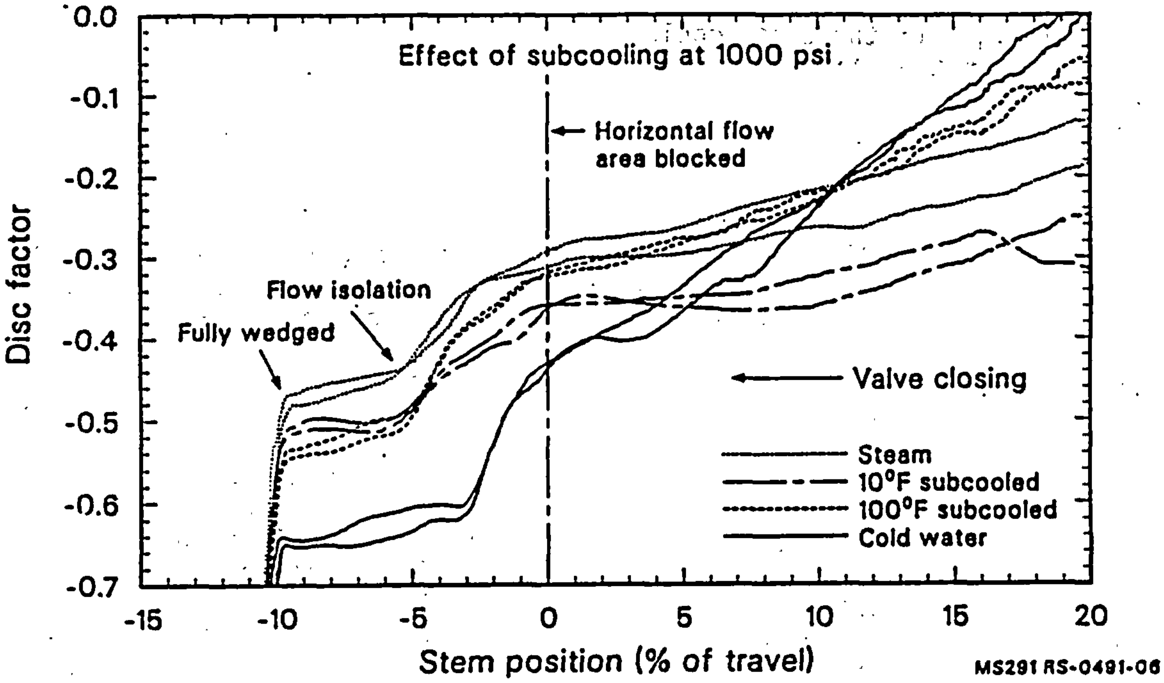

Figure 2. Disc factor for Gate Valve 2 closing on line break flow, effect of subcooling at 1000 psig.

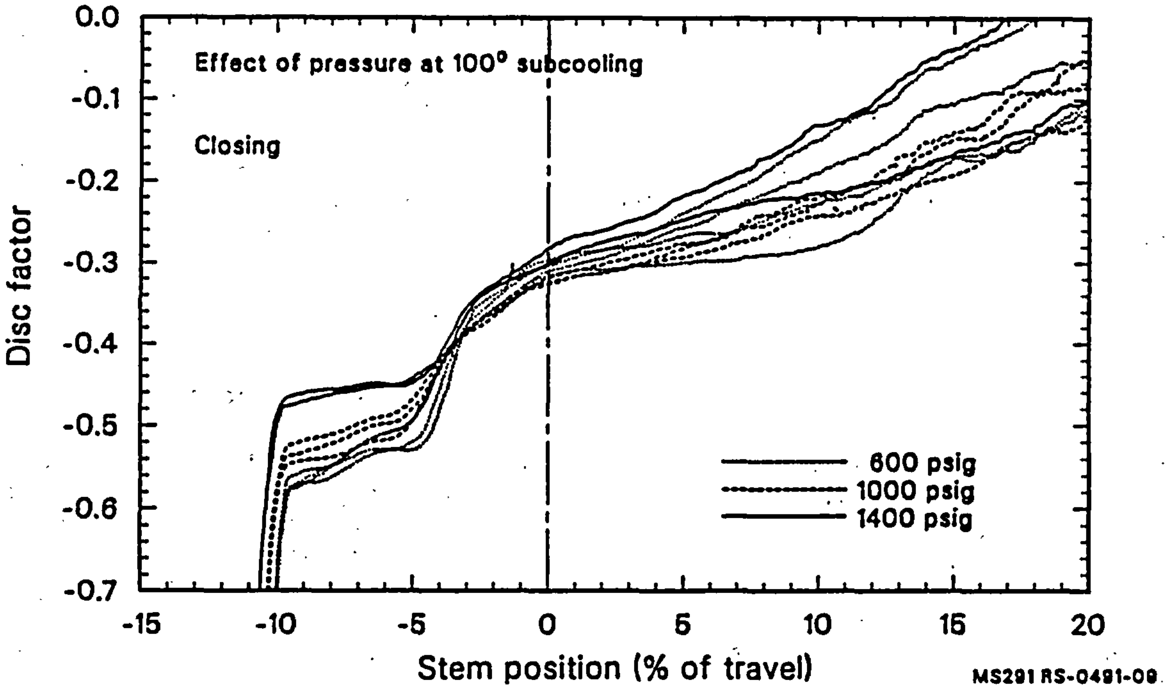

Figure 3. Disc factor for Gate Valve 2 closing on line break flow, effect of pressure at 100°F subcooling.

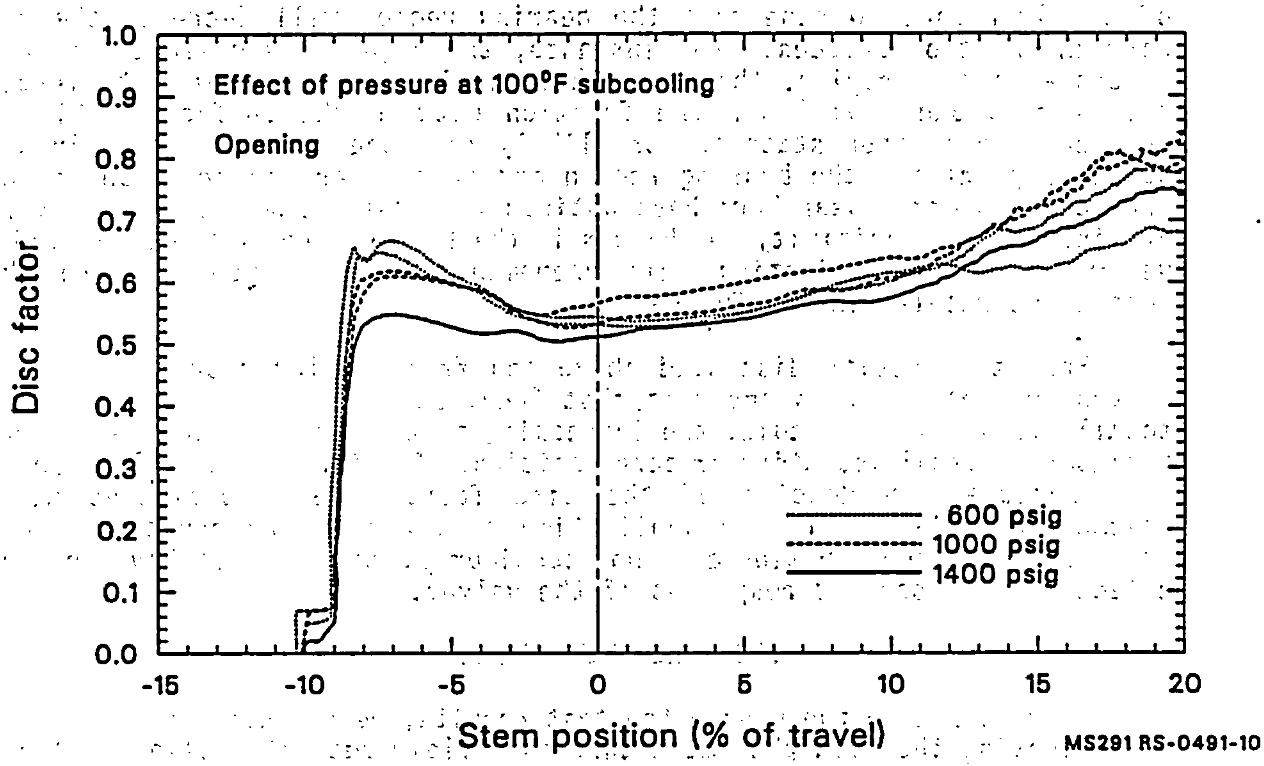

Figure 4. Disc factor for Gate Valve 2 opening on line break flow, effect of pressure at 100°F subcooling.

The previously unaccounted influence of fluid subcooling and pressure on the disc factor is very evident. This influence is also contrary to what one might expect in terms of the effectiveness of a lubricant. However, what was expected is based on a lubrication that separates the load bearing surfaces with a relatively thick film of lubricant to minimize metal-to-metal contact. This type of lubrication is known as thick film lubrication. In the event the load bearing surfaces are not separated by a film of lubrication, metal-to-metal contact can occur. This condition is known as thin film lubrication. The deficiencies of this type of lubrication are aggravated by surface areas that are too small to carry the maximum load, a load that exceeds the maximum expected or design basis load, or a decrease in the velocity between the moving surfaces.

When metal-to-metal contact exists, any condition that increases the ability of the lubricant to penetrate the bearing region will decrease the friction between the two surfaces. For instance, the higher the differential pressure across a bearing region, the more likely a given lubricant will be forced into this region and thus lower the friction between the surfaces. Likewise, a lubricant in a vapor state is more likely than the same lubricant in a liquid state to penetrate the bearing region and thus lower the friction between the surfaces. Other researchers have noticed these same phenomenon; however, they attribute this sensitivity to changes in the temperature of the fluid and metal. We are still investigating this phenomenon, and we hope to provide more conclusive results in the future.

From the results discussed above and from similar results for the other valves evaluated, it is apparent that Equation (1) is incomplete and does not totally identify and predict the increasing stem force once the disc is past the horizontal visual isolation or zero position. In addition, the fluid subcooling and pressure dependencies of the disc factor are inconsistent with past assumptions inherent in the application of the industry equation. Thus, we concluded that the equation does not consider parameters that have an important effect on the observed responses of the valves.

FLOW PHENOMENA THROUGH A VALVE

In response to the unexpected test results, we directed our efforts toward investigating the flow phenomena through a flexwedge gate valve and the effect that pressures throughout the valve had on the resultant stem force. Figure 5 shows a cross section of a typical flexwedge gate valve and identifies those areas on the disc and stem where the various pressure forces can act. This figure also indicates where we drilled three pressure measurement ports into each of the valve bodies prior to the Phase II testing to assist in this internal pressure distribution study. Figure 6 shows a typical pressure distribution observed during our testing. The pressure in both the bonnet region of the valve and under the disc are lower than the upstream pressure during most of the valve closure cycle. This reduction in pressure is due to the Bernoulli effect, the result of fluid accelerating through a valve in response to a reduction in the flow area. This phenomenon is dependent on the pressure and subcooling of the fluid and on the magnitude of the reduction in flow area through the valve. Thus, the Bernoulli effect will be system and fluid dependent. The bonnet area also shows a lower pressure because of the split in the disc and because of the

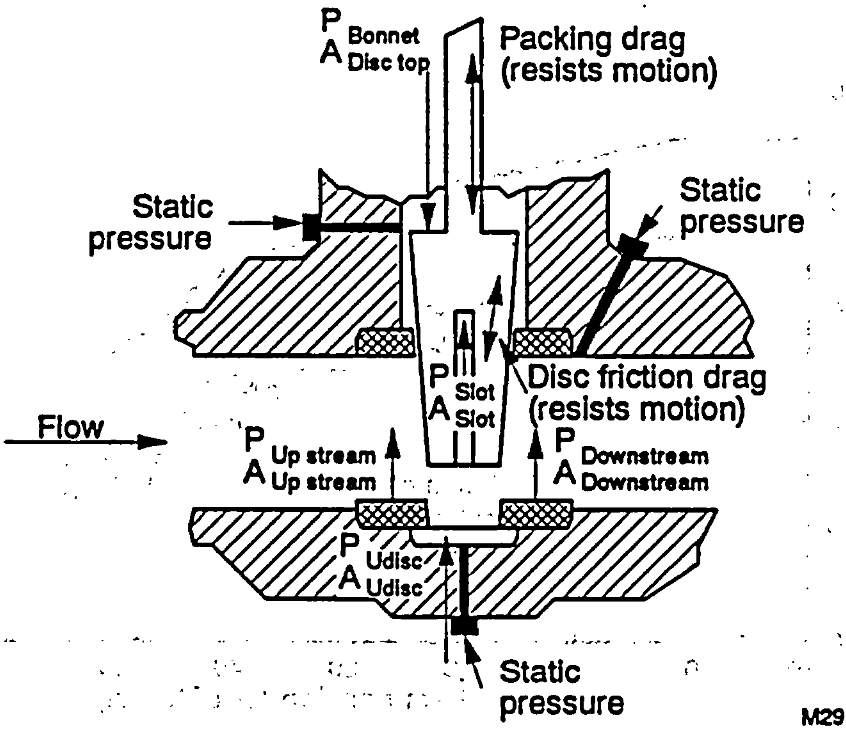

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Figure 5. Gate valve disc cross section showing pressure forces.

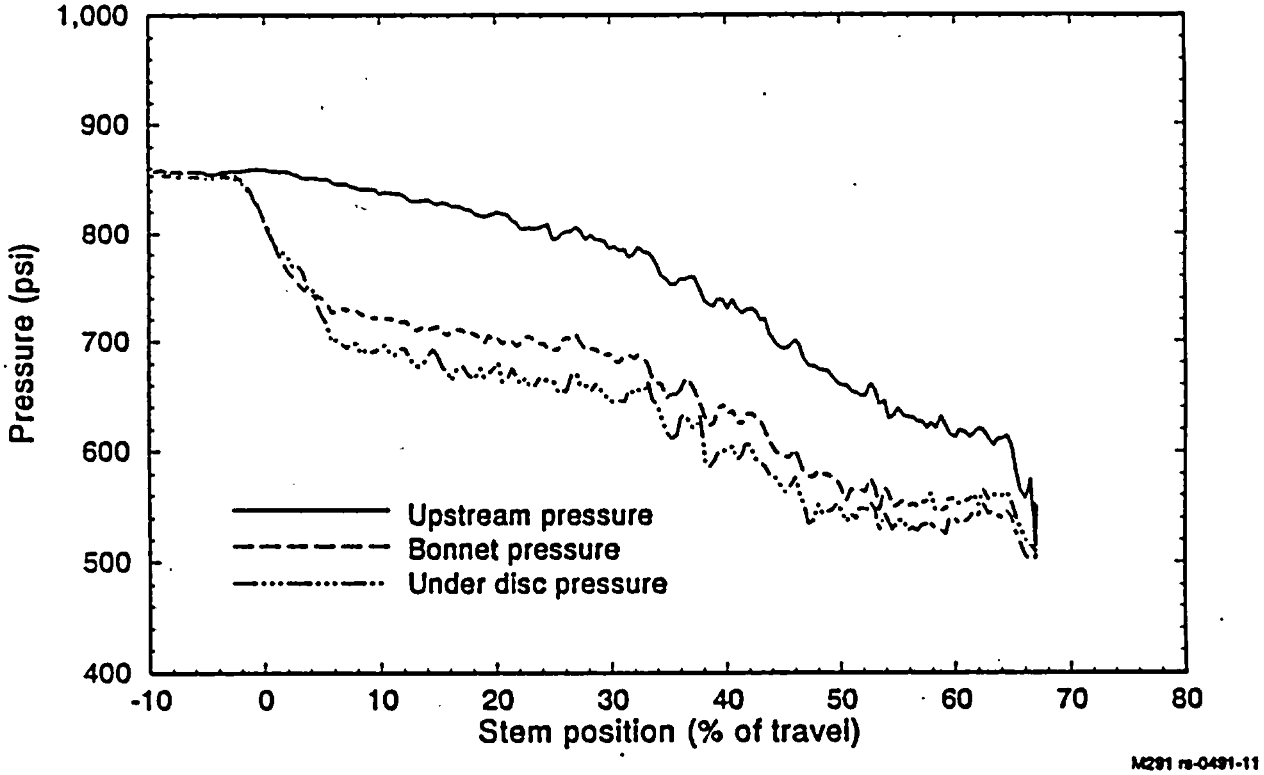

Figure 6. Gate valve internal pressure distribution.

gap between the disc and the valve body seats; these structural features provide a path such that the pressure in the bonnet region can more closely follow the pressure in the region under the disc.

However, from the minus 3% to the minus 10% stem position during this test, the pressures converge. During this portion of the valve stroke, flow has been isolated and the disc is riding on the valve body seats; however, wedging of the disc has not yet begun. It is also during this portion of the valve stroke that predictable valves exhibit the largest stem force. Thus, we concentrated our efforts on this segment of the valve closure cycle. Wedging forces were not considered because these forces are not the result of fluid dynamic and frictional effects, but instead depend on the force capabilities of a given operator and on the structural stiffness characteristics of a specific disc and valve body.

DEVELOPMENT OF THE INEL CORRELATION

Our first effort was to develop a relatively detailed free body diagram of the disc while it is moving in the closing direction, after the flow has been isolated but before wedging. This was done with the hope of better understanding the pressure and area terms that effect the stem force. Figure 7 presents the results of this effort and identifies all the nonsymmetrical forces acting on the disc. Note that according to the free body diagram, the forces acting on the disc ultimately react through the valve body seats, which are at a slight angle (for a flexwedge gate valve) relative to the horizontal and vertical valve coordinate system. To account for this slight seat angle so that the forces are expressed in values consistent with the definition of a traditional friction factor, we found it necessary to transform the horizontal and vertical forces into a coordinate system that is normal and tangent to the valve body seating surfaces.

Following this logic, we theorized the existence of two horizontal forces acting on the disc. The first horizontal force (F_{up}) is due to the upstream pressure (P_{up}) acting on that area of the disc defined by the mean diameter of the downstream seating surface. The downstream seating surface presents a circular profile in the horizontal plane. The mean seat diameter was selected because it best approximates that area of the disc in contact with the crown of the downstream seating surface over which the various pressure forces act. F_{up} is defined as

$$F_{up} = P_{up}\left[\frac{\pi D_{mean}^2}{4}\right] \qquad (2)$$

Resisting this force (F_{up}) is a horizontal force (F_{down}) due to the downstream pressure (P_{down}) also acting on that area of the disc defined by the mean diameter of the downstream seating surface. F_{down} is defined as

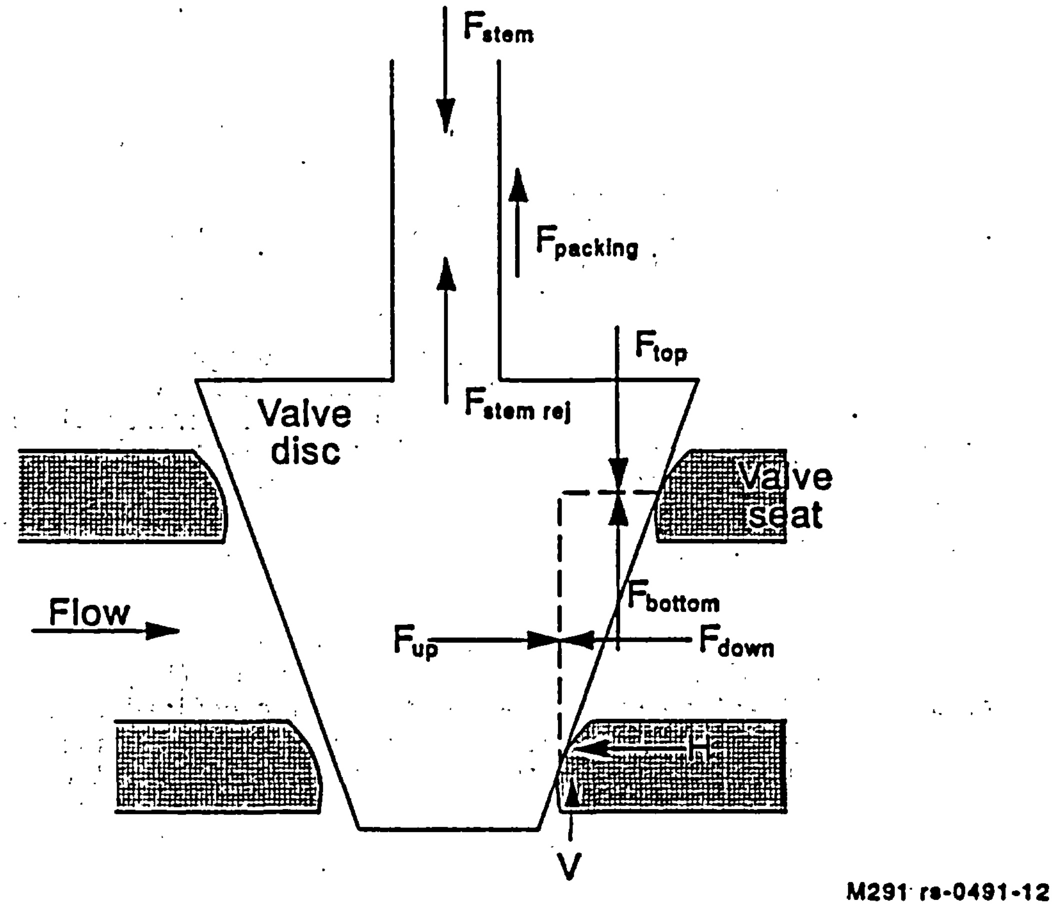

Figure 7. Gate valve disc cross section showing unbalanced forces just before wedging.

$$F_{down} = P_{down}\left[\frac{\pi D^2_{mean}}{4}\right] \tag{3}$$

These two forces represent the only horizontal forces acting on the disc and provide a far more realistic estimate of the horizontal force component than the orifice area term which is often used in the industry equation. The net horizontal force component (H) can be expressed as

$$H = F_{up} - F_{down} \tag{4}$$

Likewise, the free body diagram indicates that there are actually five vertical forces acting on the disc. The first vertical force is due to the operator and represents the net stem force delivered to the valve.

$$F_{stem} = \text{stem load} \tag{5}$$

The second is due to the resistance of the packing while the valve is closing. The effect of the disc and stem weights is also included in this term.

$$F_{packing} = \text{packing drag} - \text{disc and stem weight} \tag{6}$$

The third represents the stem rejection force, the result of the pressure under the disc (P_{up} once the flow has been isolated) trying to expel the stem.

$$F_{stem\ rej} = P_{up}\left[\frac{\pi D^2_{stem}}{4}\right] \tag{7}$$

The fourth force is due to the pressure in the bonnet region of the valve (P_{up} once the flow has been isolated) acting on the area of the disc defined by the mean diameter of the seat cast in the vertical direction. This area term is the result of the slight angle of the seat in a flexwedge type gate valve (nominally a five-degree angle) and results in an elliptical area over which the pressure acts. The major diameter is equal to the mean diameter of the seat; the minor diameter is equal to the mean diameter of the seat times the tangent of the angle the seat makes with the vertical axis of the valve.

$$F_{top} = P_{up}\left[\frac{\pi D^2_{mean}}{4}\right]\tan\alpha \tag{8}$$

Resisting F_{top} is a fifth force due to the downstream pressure (P_{down}) acting on the area of the disc defined by the mean diameter of the seat cast in the vertical direction. This force is also the result of the slight angle of the seat.

$$F_{bottom} = P_{down}\left[\frac{\pi D^2_{mean}}{4}\right]\tan\alpha \tag{9}$$

The net vertical force component (V) during valve closure can thus be expressed as

$$V = F_{stem} - F_{packing} - F_{stem\ rej} + F_{top} - F_{bottom} \tag{10}$$

The net horizontal and vertical forces can now be recast into the plane defined by the valve body seat and normalized to remove the effect of valve size. Figure 8 shows these two forces and their resolution into forces normal and tangent to the seats. Note that the two normal forces resulting from this transformation act in the same direction, whereas the two tangent or sliding forces oppose each other. These can be expressed as follows for the normalized normal force (F_n) and the normalized sliding force (F_s), respectively

$$F_n = \frac{H\cos\alpha + V\sin\alpha}{\left[\frac{\pi D^2_{mean}}{4}\right]} \tag{11}$$

$$F_s = \frac{H\sin\alpha - V\cos\alpha}{\left[\frac{\pi D^2_{mean}}{4}\right]} \tag{12}$$

The analysis described above allows us to better characterize the normal and sliding forces acting on a flexwedge gate valve disc just before wedging. Our next effort was to determine if the Phase I and Phase II flexwedge gate valve test data supported a relationship between these forces. We extracted from our data base the test results of all predictable valves during the closure cycle when the disc was riding on the seats. We did not include the results of any

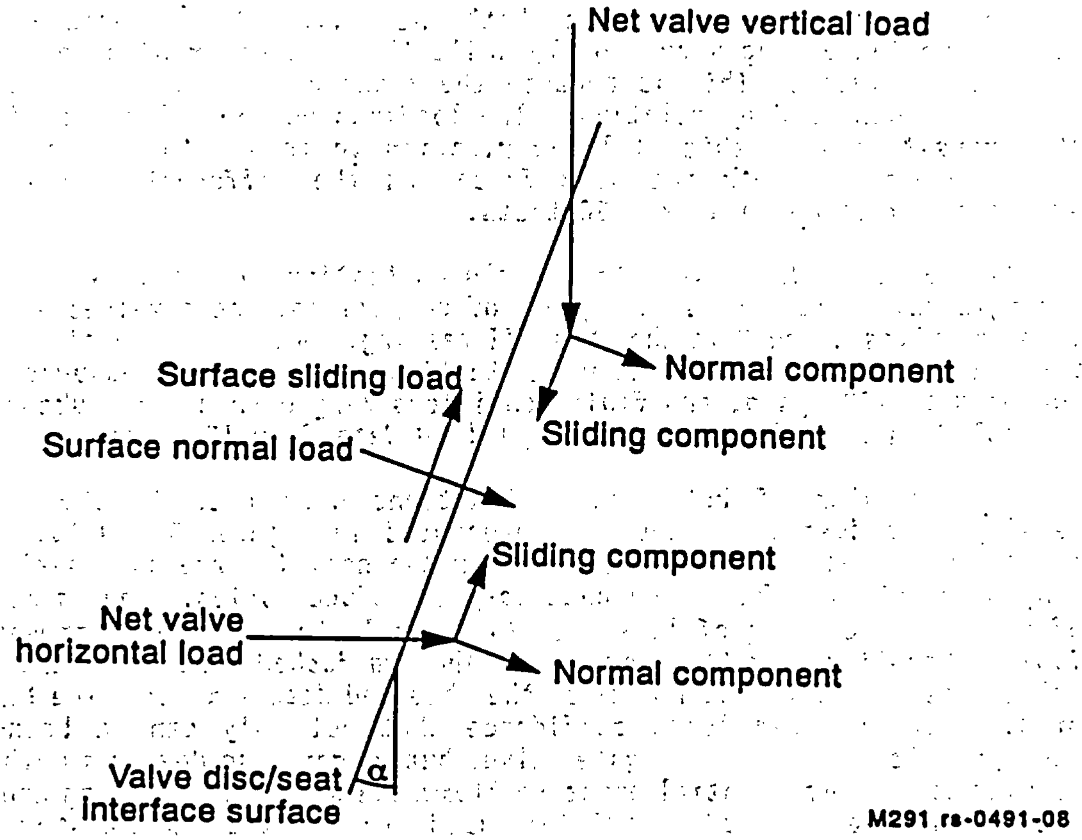

Figure 8. Resolution of horizontal and vertical gate valve disc forces into surface normal and sliding forces.

testing if severe internal damage was evident. However, if the valve exhibited evidence of internal damage while the disc was riding on the guides but showed no evidence of such behavior while the disc was riding on the valve body seats, we included the results.

The Phase II data extraction included testing with three valves representing two valve sizes (6-in. and 10-in.). Design basis flow isolation tests and normal operating flow isolation tests were used; upstream pressures ranged from 600 psig to 1400 psig, and fluid conditions ranged from steam to 400°F subcooled water. However, the results of tests when the differential pressure was less than 20% of the upstream pressure or when both the differential pressure and the stem force were increasing very rapidly while the disc was riding on the valve seat were not included. This is because the magnitude and trends of the resulting forces are obscured by relatively low loadings on the valve disc (which affect the transition from thick film lubrication to thin film lubrication), and by rapid changes in both the stem force and the differential pressure. This extraction yielded data from 30 tests.

The Phase I data extraction included testing with two valves representing a single valve size (6-in.). By way of comparison, these valves were nearly the same as Valves 1 and 2 in the Phase II testing. Only design basis flow isolation tests were used from the Phase I testing. Upstream pressures ranged from 400 psig to 1400 psig, and fluid conditions ranged from 10°F subcooled to 140°F subcooled water. This extraction yielded data from 12 tests.

The results of both data extractions were used in the force balance developed as described above and presented in Figures 9 and 10. The results reveal two linear relationships between the normal force on a seat (F_n) and the tangent or sliding force (F_s) necessary to induce motion. One is representative of a fluid subcooling of less than 70°F, while the other is representative of a fluid subcooling of 70°F or greater. The two dashed lines on either side of the solid line represent the limits of the observed data scatter. The tight grouping of the data scatter lends confidence that not only can we bound the force requirements of a flexwedge gate valve, but we can also devise a method where the results of low differential pressure flexwedge gate valve testing can be verified and then the design basis conditions used to bound the maximum stem force. Note also that the dashed lines do not extend below a normalized normal force of 400 lb_f/in^2. Due to the limited low pressure and low differential pressure data available and the postulated friction mechanism, the applicability of the INEL correlation is currently limited to normalized normal forces of 400 lb_f/in^2 and above. We are continuing to extend the applicability of the INEL correlation.

THE INEL CORRELATION

We can now rearrange the previously developed force balance and solve for the stem force based on a linear relationship between the normalized normal and sliding forces. Using Figures 9 and 10, the slope of the solid line (the friction factor between the disc and the seat) can be used to relate the normalized normal force (F_n) to the normalized sliding force (F_s) as

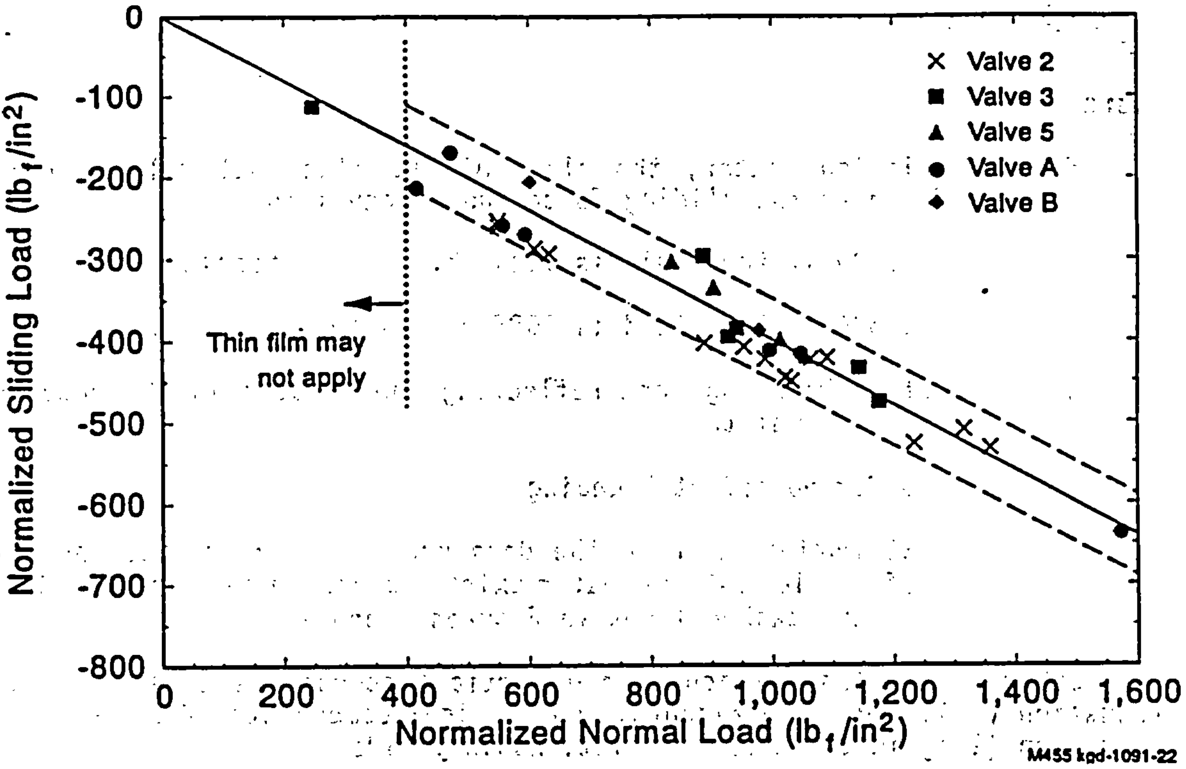

Figure 9. Normalized surface sliding force versus normalized surface normal force for gate valves closing against less than 70°F subcooled fluid.

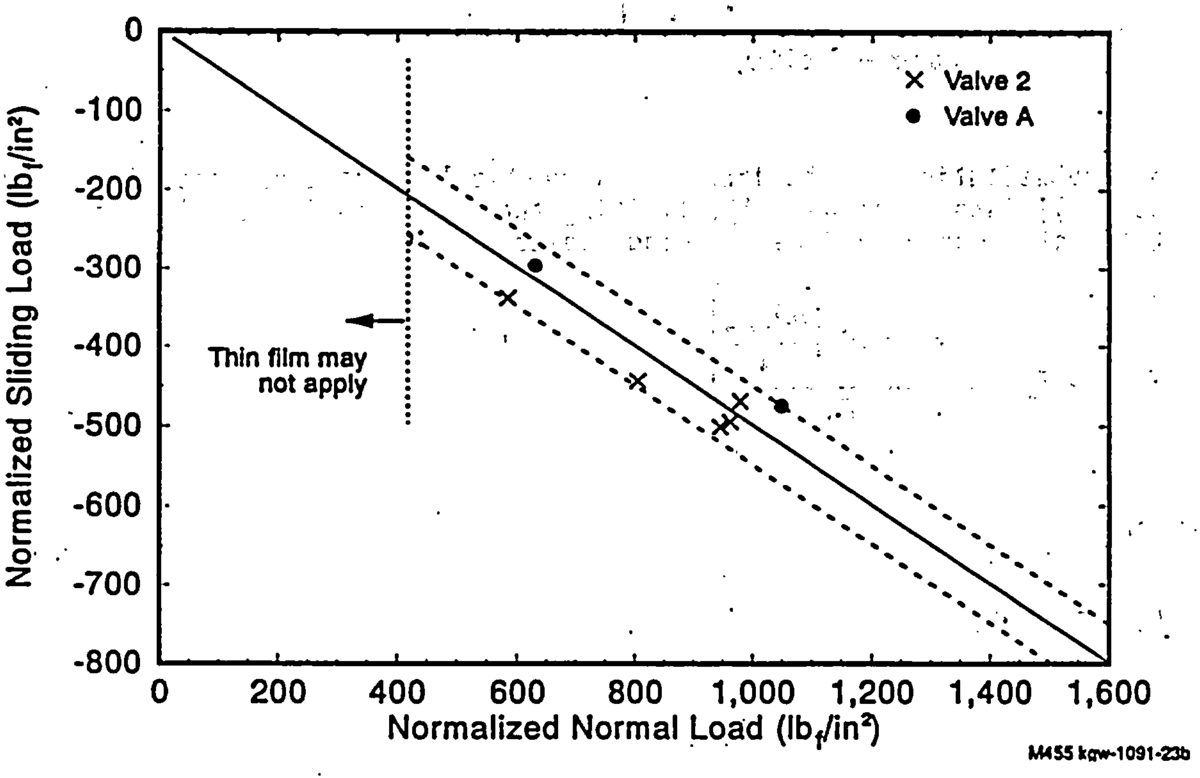

Figure 10. Normalized surface sliding force versus normalized surface normal force for gate valves closing against 70°F or greater subcooled fluid.

$$F_s = -f\,F_n \pm C \tag{13}$$

where

f = friction factor, the slope of the line that relates the normal force to the sliding force and is equal to

0.400 if the fluid is less than 70°F subcooled

0.500 if the fluid is 70°F or greater subcooled

C = offset bounding term reflecting the scatter in the observed data and is equal to

0 for no offset bounding

50 lb_f/in^2 to bound the data provided a normalized normal force of 400 lb_f/in^2 or greater exists according to Equation (11) (shown as the dashed lines in Figures 9 and 10).

Substituting the horizontal and vertical components of the normal force [Equation (11)] and the horizontal and vertical components of the sliding force [Equation (12)] into the above relationship yields

$$V = \frac{H\,(f\cos\alpha + \sin\alpha) \pm C\left[\frac{\pi D_{mean}^2}{4}\right]}{(\cos\alpha - f\sin\alpha)} \tag{14}$$

Now, substituting the horizontal and vertical force components [Equations (4) and (10)] into Equation (14), limiting the final result to a bounding estimate of the stem force, and rearranging yields

$$F_{stem} = F_v + \frac{\theta_1 F_h + 50\left[\frac{\pi D_{mean}^2}{4}\right]}{\theta_2} \tag{15}$$

where

$$F_h = F_{up} - F_{down} \tag{16}$$

$$F_v = F_{packing} + F_{stem\ rej} - F_{top} + F_{bottom} \qquad (17)$$

$$\theta_1 = f \cos\alpha + \sin\alpha \qquad (18)$$

$$\theta_2 = \cos\alpha - f \sin\alpha \qquad (19)$$

f = friction factor and is equal to

0.400 if the fluid is less than 70°F subcooled

0.500 if the fluid is 70°F or greater subcooled.

Thus, Equation (15) can be used to bound the maximum stem force requirements of a flexwedge gate valve closing against medium to high flows whose operational characteristics have been demonstrated to be predictable at design basis pressures and temperatures. This method will also provide the basis by which the results of in situ tests conducted on predictable valves at less than design basis conditions can be verified. Then the design basis conditions can be used to bound the maximum stem force. Note that the correlation applies only to flexwedge gate valve closure against medium to high flows, flows that will result in a normalized normal force of 400 lb_f/in^2 or greater according to Equation (11).

USE OF THE INEL CORRELATION

To use the INEL correlation to bound the closing stem force requirements of a flexwedge gate valve, the analyst must first determine if operational characteristics of the valve are considered to be predictable. If the valve is predictable, the following information can be used to bound the stem force:

- The mean diameter of the valve body seat (the average of the inside diameter and the outside diameter of the valve body seats measured in the plane perpendicular to the stem)
- The angle the valve body seat makes with the vertical or stem axis
- The outside diameter of the stem
- An estimate of the maximum packing drag expected less the effects of the weight of the disc and stem
- The maximum upstream pressure that would exist after flow isolation but prior to wedging, typically the design basis pressure

- The maximum differential pressure that would exist after flow isolation but prior to wedging, typically the design basis differential pressure

- The subcooling of the fluid at design basis conditions, either less than 70°F subcooled or 70°F or greater subcooled.

With this information, the net horizontal force (F_h) can be estimated with Equation (16) and Equations (2) and (3). The net vertical force (F_v) can then be estimated with Equation (17) and Equations (6) through (9). The angle between the seat and the vertical or stem axis can then be used with Equations (18) and (19) to estimate terms associated with transforming the horizontal forces into forces on the disc and seat, and finally into a vertical force. Thus, all the terms in Equation (15) can be determined, and the maximum stem force necessary to isolate flow at the specified pressure and differential pressure can be estimated.

By way of example, the actual upstream pressure and differential pressure recorded after flow isolation but prior to wedging during one of the tests will be used, and the maximum stem force requirements of the valve using the INEL correlation will be estimated. The result will then be compared with the actual stem force recorded during the test.

The results from Valve 2, Test 3, Step 25 will be used for this comparison. Since this was a cold water test (400°F subcooled fluid), the 70°F or greater subcooled friction factor will be used in the INEL correlation. Pertinent valve information and the pressure and differential pressure recorded just before wedging are

Stem diameter	1.750 inches
Orifice diameter	5.187 inches
Seat inside diameter	5.192 inches
Seat outside diameter	5.945 inches
Packing drag	200 lb_f
Upstream pressure just before wedging	746 psig
Differential pressure just before wedging	753 psid

This information can be used with the INEL correlation as follows:

$$D_{mean} = \frac{(seat\ ID + seat\ OD)}{2} = \frac{(5.192 + 5.945)}{2} = 5.569$$

$$A_{mean} = \frac{\pi D^2_{mean}}{4} = \frac{\pi(5.569)^2}{4} = 24.354$$

$$A_{stem} = \frac{\pi D^2_{stem}}{4} = \frac{\pi(1.750)^2}{4} = 2.405$$

$$F_{up} = P_{up}\ A_{mean} = (746)(24.354) = 18{,}168$$

$$F_{down} = P_{down}\ A_{mean} = (746 - 753)(24.354) = -170$$

$$F_{top} = P_{up}\ A_{mean} \tan\alpha = (746)(24.354) \tan 5 = 1590$$

$$F_{bottom} = P_{down}\ A_{mean} \tan\alpha = (746 - 753)(24.354) \tan 5 = -15$$

$$F_{stem\ rej} = P_{up}\ A_{stem} = (746)(2.405) = 1794$$

$$F_h = F_{up} - F_{down} = 18{,}168 - (-170) = 18{,}338$$

$$F_v = P_{packing} + F_{stem\ rej} - F_{top} + F_{bottom} = 200 + 1794 - 1590 + (-15) = 389$$

$$\theta_1 = f \cos\alpha + \sin\alpha = 0.500 \cos 5 + \sin 5 = 0.585$$

$$\theta_2 = \cos\alpha - f \sin\alpha = \cos 5 - 0.500 \sin 5 = 0.953$$

$$F_{stem} = F_v + \left[\frac{\theta_1\ F_h + 50\ A_{mean}}{\theta_2}\right] = 389 + \left[\frac{(0.585)(18{,}338) + (50)(24.354)}{0.953}\right] = 12{,}924$$

During this test, the peak stem force recorded just before wedging was 12,787 lb_f. Thus, the INEL correlation bounds the actual recorded stem force. Similar comparisons using the industry equation do not consistently bound the observed stem force with either a 0.3 or a 0.5 disc factor and using either the orifice area or the mean seat area.

LOW DIFFERENTIAL PRESSURE TEST VERIFICATION

Utilities have numerous flexwedge gate valves in systems throughout a nuclear power plant; many of these valves must function in various design basis events. The capability of these valves to operate at design basis conditions usually cannot be verified with in situ testing, especially for valves where design basis conditions include high pressures and medium to high flows. Usually, only low flow and low differential pressure conditions can be developed near valve closure. Where the utility can demonstrate that their medium to high flow valve designs exhibit predictable behavior at design basis conditions, through type testing or other means, in situ testing at low flows and differential pressures can be used in conjunction with the INEL correlation to verify that the valve being tested is representative of the valves tested by the INEL. If so, the INEL correlation can then be used to bound the stem force requirements of the candidate flexwedge gate valve at design basis conditions. This is accomplished as follows:

Step 1: A differential pressure test is performed. The results of the testing are then used to estimate the normalized normal and sliding forces for the valve according to Equations (11) and (12). If the upstream pressure and differential pressure while the disc is riding on the seats results in a normalized normal force of not less than 400 lb_f/in^2 and if the resulting forces fall within the upper and lower bounds expected for valves of this design (see Figures 9 and 10), the valve is considered to be representative of the valves tested by the INEL. If the resulting forces do not fall within the expected band, the results of our testing are not representative of the valve being tested and the INEL correlation may not be applicable.

Step 2: If the results of Step 1 fall within the expected band, actual design basis conditions can be used in the INEL correlation to bound the stem force requirement of the valve being tested. This maximum stem force estimate is then used, along with the other necessary motor operator sizing calculations, to verify the size of the operator and the setting of the torque switch to ensure that sufficient stem force is available to operate the valve at design basis conditions.

CONCLUSIONS

The industry's traditional gate valve sizing equation is incomplete regardless of the disc area term or the disc factor used. This is because more terms are included in the disc factor than the sliding friction term.

A new correlation was developed based on the results of two full-scale flexwedge gate valve qualification and flow interruption test programs. This correlation has been shown to consistently bound the stem force requirements of a flexwedge gate valve whose operational characteristics have been shown to be predictable. This correlation also allows a flexwedge gate valve to be verified based on the results of a low differential pressure test. If so verified, the results of the INEL correlation are shown to be applicable at design basis conditions.

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NOTICE

APPENDIX D

INDUSTRY GATE VALVE SIZING SHEETS

LIMITORQUE MOTOR OPERATOR CALCULATIONS

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P.O.No.or PROJ.:F2-72916-S                  SMB - 1                        REF.:
CUSTOMER NAME:  E.G. & G. IDAHO                                                 VELAN
VELAN NO.:                         ITEM(S):                           7054P  DWG No.:
VALVE DESCRIPT.:       10 "        900# PS     GATE     FORGED                8890.092
-----------------------------------------------------------------------------------------

LINE PRESS.:         1000 PSIg  DIFF.PRESS.:    1000 PSI   @ TEMP.        550 F
ORIF. DIA.:         7.875 in    THREAD                     THREAD
STEM DIA.:          2.500 in    FACTOR:       0.01962      PITCH:     0.3333 in
MOTOR DES.RPM.:      1800       STEM SPEED:    10.00 in/minTHREAD
PULL OUT EFFEC.:    0.40        APPL.FACT.:     1.00       LEAD:      0.3333 in
REDUCED VOLTAGE:    0.80        MOT.STALL-                 LIFT:        8.44 in
STALL EFFECIEN.:    0.50        TORQUE:        42.00 ftlb
H/W RATIO:         25.30        UNIT EFF.:      0.30       FREQU.:        60 HZ
MOT.TORQUE:            40 ftlb  CURR.SUPPL.:     460 VOLT  TYPE:     AC
-----------------------------------------------------------------------------------------

STEM THRUST:      FHYDR.= ORIF.DIA.^2 x PI/4 x DIFF.PRESS. x SEAT FACT.=        14612 lb
                  PISTON EFFECT= STEMDIA.^2 x PI/4 x LINEPRESS.=                  4909 lb
                  PACK.FRICT.LOAD=                                                8482 lb
                  TOTAL STEM THRUST =                                            28003 lb
STEM TORQUE = STEM THRUST x STEM THREAD FACT.=                                     549 ftlb
THEOR. O/A OR UNIT RATIO = MOTOR DESIGN R.P.M. x THREAD LEAD/STEM SPEEDT =       47.01
ACTUAL O/A OR UNIT RATIO = MOTOR DESIGN R.P.M. x THREAD LEAD/STEM SPEEDA =       56.64
MOTOR CALC. TORQUE =  STEM TORQUE /(PULLOUTEFF x APPL.FACT. x O/A RATIO) =       24.25 ftlb
MOTOR CALC. TORQUE @ REDUCED VOLTAGE =                                           37.90 ftlb
N.B. IF DC SUPPLY, DO NOT SQ. % V.
STALLED TORQUE @ 110% VOLT.= MOT. STALL TORQUE x ST. EFF. % x O/A RATIO =         1645 ftlb
STALL THRUST = STALL TORQUE / STEM THREAD FACTOR =                               83824 lb
MAX. ALL. ACTUATOR STALL THRUST =                                               112500 lb
H/W PULL= 2 x STEM TORQUE /(HWRATIO x UNITEFF. x HWDIA.x ADD.GEAR x EFF.)          145 lb
MAX.TORQUE SWITCH SETTING @ RED.VOLT.=MOT.TORQUE x P/O EFF. x APP.FACT. x       752.15 ftlb
MAX. H/W TORQUE = MAX. VALVE TORQUE / (H/W RATIO x UNITEFF.) =                   72.40 ftlb
OPERATING TIME = (60 x LIFT) / STEM SPEED =                                      50.60 sec
-----------------------------------------------------------------------------------------

SMB - 1            E - ACTUATOR            40 ftlb    MOTOR MOTOR MAX.THRUST=   45000 lb
MAX. STEM TORQUE     850 ftlb  ADDITIONAL GEAR :      no    MAX.STEM DIA.=      2.750 in
H/W RATIO =          25.3 :1   ADD.G/RATIO=     1.00 :1     O/A RATIO RANGE  42.5-88.40
CURRENT SUPPLY:      460 VOLT  STD.H/WHEEL:       12 in     MUST OPERAT RED.V   0.80
TYPE:             AC/3/60 HZ   OVERSIZED H/WHEEL :    no
BEVEL GEAR ACTUATOR DIRECTLY MOUNTED ONTO VALVE:      no    MAX.ALLOW.THRUST:        lb
ACTUATOR MODEL:           RATIO:               MAX.STEM:    MAX.ALLOW.TORQUE:        ftlb
-----------------------------------------------------------------------------------------

                 REV. 0           REV.1              REV.2             REV.3
COMPILED BY:
APPROVED BY:
IND.REV. BY:
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LIMITORQUE MOTOR OPERATOR CALCULATIONS

```
P.O.No.or PROJ.:P2-72916-S                SMB - 1                    REF.:
CUSTOMER NAME:  E.G. & G. IDAHO                                             VELAN
VELAN NO.:                      ITEM(S):                            7054P  DWG No.:
VALVE DESCRIPT.:      10 "      900# PS     GATE      FORGED               8890.092
-------------------------------------------------------------------------------------

LINE PRESS.:          1000 PSIg  DIFF.PRESS.:     1000 PSI    @ TEMP.        550 F
ORIF. DIA.:          7.375 in    THREAD                       THREAD
STEM DIA.:           2.500 in    FACTOR:        0.02425       PITCH:      0.3333 in
MOTOR DES.RPM.:      1800        STEM SPEED:      12.27 in/minTHREAD
PULL OUT EFFEC.:     0.40        APPL.FACT.:       1.00       LEAD:       0.6667 in
REDUCED VOLTAGE:     0.80        MOT.STALL-                   LIFT:         8.44 in
STALL EFFECIEN.:     0.50        TORQUE:          42.00 ftlb
H/W RATIO:          25.30        UNIT EFF.:        0.30       FREQU.:         60 HZ
MOT.TORQUE:            40 ftlb   CURR.SUPPL.:       460 VOLT  TYPE:      AC
-------------------------------------------------------------------------------------

STEM THRUST:     FHYDR.= ORIF.DIA.^2 x PI/4 x DIFF.PRESS. x SEAT FACT.=        14612 lb
                 PISTON EFFECT= STEMDIA.^2 x PI/4 x LINEPRESS.=                 4909 lb
                 PACK.FRICT.LOAD=                                               8482 lb
                 TOTAL STEM THRUST =                                           28003 lb
    TORQUE = STEM THRUST x STEM THREAD FACT.=                                    679 ftlb
T[illegible]. O/A OR UNIT RATIO = MOTOR DESIGN R.P.M. x THREAD LEAD/STEM SPEEDT =  94.02
ACTUAL O/A OR UNIT RATIO = MOTOR DESIGN R.P.M. x THREAD LEAD/STEM SPEEDA =      92.40
MOTOR CALC. TORQUE =  STEM TORQUE /(PULLOUTEFF x APPL.FACT. x O/A RATIO) =      19.37 ftlb
MOTOR CALC. TORQUE @ REDUCED VOLTAGE =                                          28.70 ftlb
N.B. IF DC SUPPLY, DO NOT SQ. % V.
STALLED TORQUE @ 110% VOLT.= MOT. STALL TORQUE x ST. EFF. % x O/A RATIO =        2683 ftlb
STALL THRUST = STALL TORQUE / STEM THREAD FACTOR =                            110666 lb
MAX. ALL. ACTUATOR STALL THRUST =                                             112500 lb
H/W PULL= 2 x STEM TORQUE /(HWRATIO x UNITEFF. x HWDIA.x ADD.GEAR x EFF.)        179 lb
MAX.TORQUE SWITCH SETTING @ RED.VOLT.=MOT.TORQUE x P/O EFF. x APP.FACT. x    1504.31 ftlb
MAX. H/W TORQUE = MAX. VALVE TORQUE / (H/W RATIO x UNITEFF.) =                  89.46 ftlb
OPERATING TIME = (60 x LIFT) / STEM SPEED =                                     41.28 sec
-------------------------------------------------------------------------------------

SMB.- 1           E - ACTUATOR           40 ftlb     MOTOR MOTOR MAX.THRUST=   45000 lb
MAX. STEM TORQUE      250 ftlb  ADDITIONAL GEAR :     no     MAX.STEM DIA.=     2.750 in
H/W RATIO =          25.3 :1    ADD.G/RATIO=      1.00 :1    O/A RATIO RANGE  42.5-88.40
CURRENT SUPPLY:       460 VOLT  STD.H/WHEEL:        12 in    MUST OPERAT RED.V   0.80
TYPE:              AC/3/60 HZ   OVERSIZED H/WHEEL :   no
BEVEL GEAR ACTUATOR DIRECTLY MOUNTED ONTO VALVE:      no     MAX.ALLOW.THRUST:         lb
ACTUATOR MODEL:          RATIO:              MAX.STEM:       MAX.ALLOW.TORQUE:         ftlb
-------------------------------------------------------------------------------------

                 REV. 0            REV.1             REV.2             REV.3
COMPILED BY:
APPROVED BY:
IND.REV. BY:
-------------------------------------------------------------------------------------
```

MOTOR OPERATOR CALCULATIONS

P.O. NO. OR PROJECT: E.G.G. REF.:

CUSTOMER NAME:

VELAN NO.: ITEMS: VELAN DWG. NO.:

VALVE DESC: 6 " 900 LBS. GATE FORGED

LINE PRESS: 1650 PSI

ORIF. DIA.: 5.188 ORIF. AREA: 21.14 ΔP 1650 PSI @ TEMP. °F.

STEM DIA.: 1.75 STEM AREA: 2.404 THD: 1/4 P 1/4 L LIFT: 5 7/8 "

STEM THRUST: O.A. x ΔP x SEAT FACT.: 21.14 x 1650 x 0.3 = 10543

LINE PRESS. x S.A. = 1650 x 2.404 = 3967

Packing Friction Load = 4948

Total Stem Thrust = 19558 #

STEM TORQUE = STEM THRUST x STEM FACT. 19558 x 0.01391 = 272 '#

O/A OR UNIT RATIO = $\frac{\text{MOTOR DESIGN R.P.M.}}{\frac{\text{STEM SPEED IN./MIN.}}{\text{THREAD LEAD}}} = \frac{1700}{\frac{12.157}{1/4}}$ = = 34.96

MOTOR CALC. TORQUE = $\frac{\text{STEM TORQUE}}{\text{PULL OUT EFF. x APPL. FACT. x O/A RATIO}} = \frac{272}{0.4 \times 0.9 \times 34.96}$ = 21.61 '#

MOTOR CALC. TORQUE @ REDUCED VOLTAGE = $\frac{\quad}{(\%\text{Volts})^2}$ = = '#

N.B. IF DC SUPPLY, DO NOT SQ. % V.

STALLED TORQUE = MOT. STALL TORQUE x ST. EFF. % x O/A RATIO =

@ 110% VOLTAGE 29.6 x 0.55 x 34.96 x 1.21 = 689 '#

H/W PULL = $\frac{\text{2 x STEM TORQUE}}{\text{H/W RATIO x UNIT EFF. x H/W DIA.}} = \frac{2 \times 272}{21.1 \times 0.3 \times 1}$ = 86 #

MAX. TORQ. SW. SETTING = MOT. TORQ. x P/O EFF. x APP. FACTOR x O/A RATIO:

(@RED. VOLTAGE) 25 x -- x 0.4 x 0.9 x 34.96 = 315 '#

MAX. H/WHEEL TORQUE = $\frac{\text{MAX. VALVE TORQUE}}{\text{H/W RATIO x EFF.}}$

$= \frac{585}{21.1 \times 0.3}$ = 70 '#

OPERATING TIME = (60 x LIFT) ÷ STEM SPEED = 29 SECONDS. (APPROX.)

SMB - 0 OPERATOR WITH 25 FT.# MOTOR. MAX. THRUST: 24,000 #

MAX. STEM TORQUE = 500 '# O/A RATIO RANGE = 26.4 - 150.8

H/W RATIO = 21.1 :1 ADD GEAR -- :1 MAX. STEM DIA.: 2 3/8

CURRENT SUPPLY 460 AC VOLTS 3PH 60 CY MUST OPERATE AT 90 %VOLTAGE

	0 REV.	1	2	3	4	5	6
COMPILED BY:							
APPROVED BY:							
IND. REV. BY:							

APPENDIX E

PHASE I AND II INSTRUMENTATION DIAGRAMS AND ACCURACIES

PHASE I

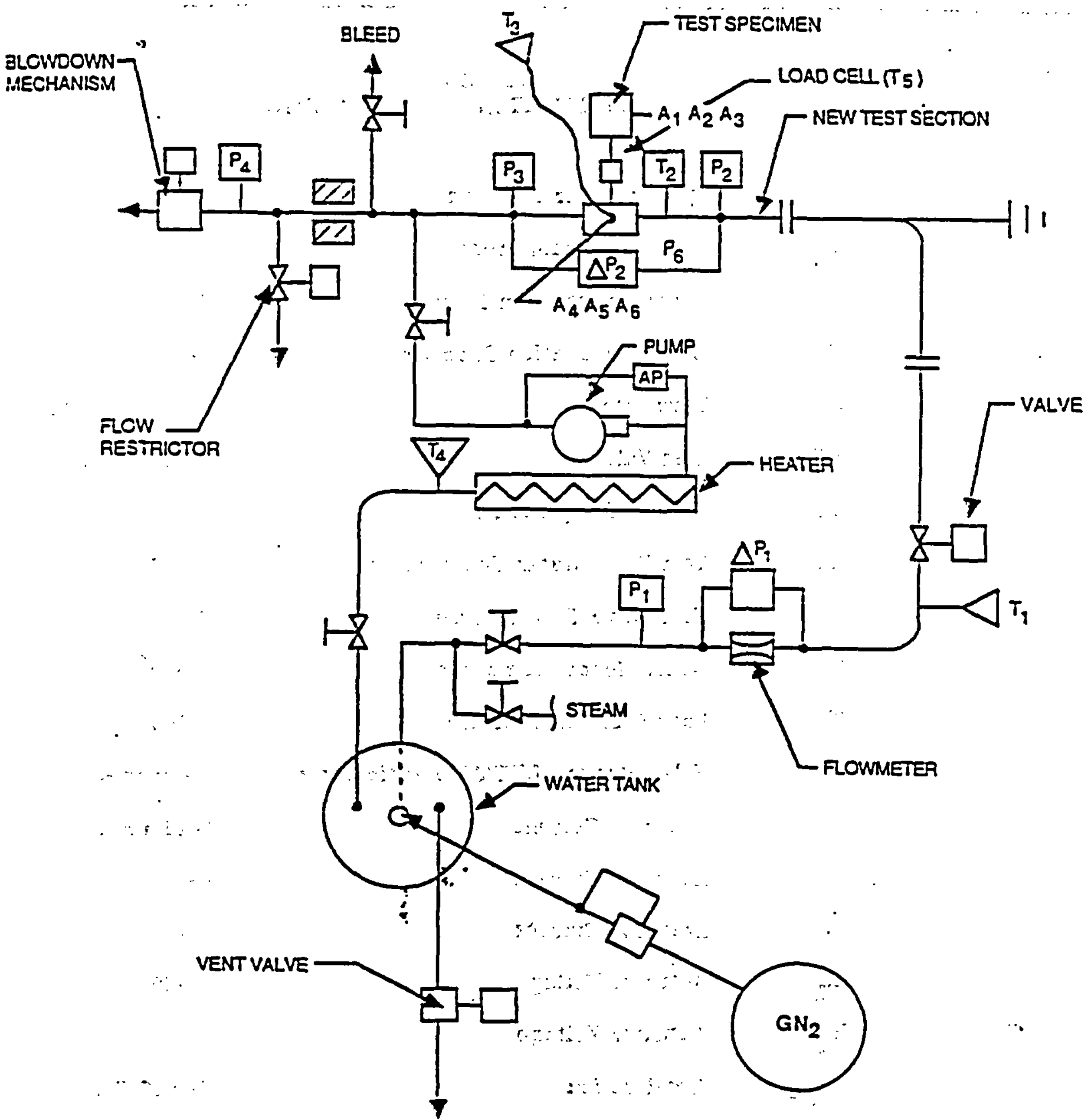

FIGURE 1. SYSTEM SCHEMATIC

PHASE I

TABLE I
INSTRUMENTATION REQUIREMENTS

P_1	System Water Pressure	0-2500 psig
P_2	Valve Upstream Pressure	0-2500 psig
P_3	Valve Downstream Pressure	0-2500 psig
P_4	Discharge Section Pressure	0-2500 psig
ΔP_1	Flow rate	0-500 in. water
ΔP_2	Test Valve	0-2500 psid
T_1	System Temperature	0-600°F
T_2	Test Valve Water Temperature	0-600°F
T_3	Test Valve Temperature	0-600°F
T_4	Water Heater Temperature	0-600°F
T_5	Load Cell Temperature	0-600°F
ST	Valve Stroke - LVDT/Potentiometer	0-6 inches
I_1	Actuator Current	0-15 amps
I_2	Actuator Current	0-15 amps
I_3	Actuator Current	0-15 amps
E_1	Actuator Voltage	0-480 VAC
E_2	Actuator Voltage	0-480 VAC
A_{1-6}	Acceleration	0-1000 G's
F	Actuator Force	0-40,000 lbs.
LS_1	Open Limit Switch	on/off
LS_2	Closed Limit Switch	Light
TS	Closed Torque Switch	on/off
S	Motor Speed	0-3600 RPM

PHASE I

INSTRUMENTATION EQUIPMENT SHEET

[illegible]

DATE: 04/20/88
TECHNICIAN: J. KENNEDY

JOB NUMBER: 49064-01
CUSTOMER: E.G. & G.

TEST AREA: SRV SITE 4
TYPE TEST: CERTIFICATION

NO.	INSTRUMENT	MANUFACTURER	MODEL#	SERIAL #	WYLE #	RANGE ±	ACCURACY ±	CALDATE	CALDUE
1	X-Y PLOTTER	H/P	7046A	13	095463	.5MVTO10V.1CM	.2%FS	03/04/88	06/02/88
2	DATALOGGER	FLUKE	2240B	070008	003190	KJT1.5DEG	.02%RD	04/05/88	09/30/88
3	FREQ COND	DAYTRONICS	3340A	372	106937	0-50,000 HZ	.05%	04/14/88	10/11/88
4	COND STRAIN	DAYTRONIC	3270	N/A	100415	100HZ/5VDC	.05%	01/27/88	07/25/88
5	GEN SIG	TEKTRONIX	FG501	141312	092907	0.01HZ-1MHZ	3%	04/05/88	09/30/88
6	FREQ CNT	TEKTRONIX	DC503	180993	092567	.1-100MHZ	1x10-5	04/05/88	09/30/88
7	DIG MTR	TEKTRONIX	DM501A	022452	095656	DC	.05%	04/05/88	09/30/88
8	PWR SUPPLY	TEKTRONIX	PS503A	B054701	101195	20VDC	.1%REG	04/05/88	09/30/88
9	OSCILLOSCOPE	TEKTRONIX	212	B200341	102153	DC-500KHZ	5%	12/23/87	06/20/88
10	SG CONDITIONER	VISHAY	2120	073259	104114	DC-5KHZ	1%G	04/02/88	07/01/88
11	SG CONDITIONER	VISHAY	2120	073145	104113	DC-5KHZ	1%G	04/02/88	07/01/88
12	SG CONDITIONER	VISHAY	2120	073355	104111	DC-5KHZ	1%G	04/02/88	07/01/88
13	SG CONDITIONER	VISHAY	2120	073250	104110	DC-5KHZ	1%G	04/02/88	07/01/88
14	POWER SUPPLY	VISHAY	2110	072934	104109	±15VDC	1%RANGE	04/02/88	07/01/88
15	AMPL CHARGE	ENDEVCO	2721B	BR01	000375	1-10KHZ	5%F	04/02/88	09/29/88
16	AMPL CHARGE	ENDEVCO	2721BM	BP52	000385	1-10KHZ	±5%F	04/02/88	09/29/88
17	AMPL CHARGE	ENDEVCO	2721B	BR41	000374	1-10KHZ	5%F	04/02/88	09/29/88
18	AMPL CHARGE	ENDEVCO	2721B	BR30	000376	1-10KHZ	5%F	04/02/88	09/29/88
19	AMPL CHARGE	ENDEVCO	2721B	BR09	000372	1-10KHZ	5%F	04/02/88	09/29/88
20	AMPL CHARGE	ENDEVCO	2721B	BP63	000371	1-10KHZ	5%F	04/02/88	09/29/88
21	AMPL CHARGE	ENDEVCO	2721BM	BP96	000377	1-10KHZ	±5%F	04/02/88	09/23/88
22	AMPL CHARGE	ENDEVCO	2721BM	BP97	000369	1-10KHZ	±5%F	04/02/88	09/29/88
23	AMPL CHARGE	ENDEVCO	2721BM	BR41	000471	1-10KHZ	±5%F	04/02/88	09/29/88
24	PWR SUPPLY	ENDEVCO	4221A	AB41	092934	15VDC	.1% REG	04/02/88	09/29/88
25	AMPL GALVO	HONEYWELL	T66A5	1618	094505	DC TO 5 KHZ	1%F	04/02/88	09/23/88
26	AMPL GALVO	HONEYWELL	T66A50	HIC378	095257	DC TO 5 KHZ	1%	04/02/88	09/23/88
27	AMPL GALVO	HONEYWELL	T66A50	1001	096561	DC TO 5 KHZ	1%	04/09/88	10/06/88
28	FILTER BP	ROCKLAND	852-01	1293407	100414	DC-100 KHZ	2%	04/04/88	09/30/88
29	OSCILLOGRAPH	CEC	HR3000	4012	101947	DC-10KHZ	2%	04/04/88	09/30/88
30	RECORD TAPE	BELL&HOWELL	4010	4100	011189	DC-5KHZ	.5%LIN	04/04/88	07/01/88
31	RECORD TAPE	BELL&HOWELL	4010	5110	011436	.5DBBW	.5LIN	04/04/88	07/01/88
32	DECADE RES	IET	RS-201	100748	100748	1-10M OHM	1%	09/23/87	09/23/88
33	ACCEL	BRUEL & KJAER	4366	1104940	101821	2KGSV/5KGSK	5%	04/06/88	07/05/88
34	ACCEL	BRUEL & KJAER	4366	1104945	101808	2KGSV/5KGSK	5%	04/06/88	07/05/88
35	ACCEL	BRUEL & KJAER	4366	1104948	101767	2KGSV/5KGSK	5%	04/06/88	07/05/88
36	ACCEL	BRUEL & KJAER	4366	1104942	101819	2KGSV/5KGSK	5%	04/06/88	07/05/88
37	ACCEL	BRUEL & KJAER	4366	1104837	101816	2KGSV/5KGSK	5%	04/06/88	07/05/88
38	ACCEL	BRUEL & KJAER	4366	1104931	101763	2KGSV/5KGSK	5%	04/06/88	07/05/88

THIS IS TO CERTIFY THAT THE ABOVE INSTRUMENTS WERE CALIBRATED USING STATE-OF-THE-ART TECHNIQUES WITH STANDARDS WHOSE CALIBRATION IS TRACEABLE TO THE NATIONAL BUREAU OF STANDARDS.

INSTRUMENTATION D.E. [illegible] 4/20/88

CHECKED & RECEIVED BY K.C. Millsaps 4/20/88

Q.A. TR Hamilton 4/23/88

PHASE II

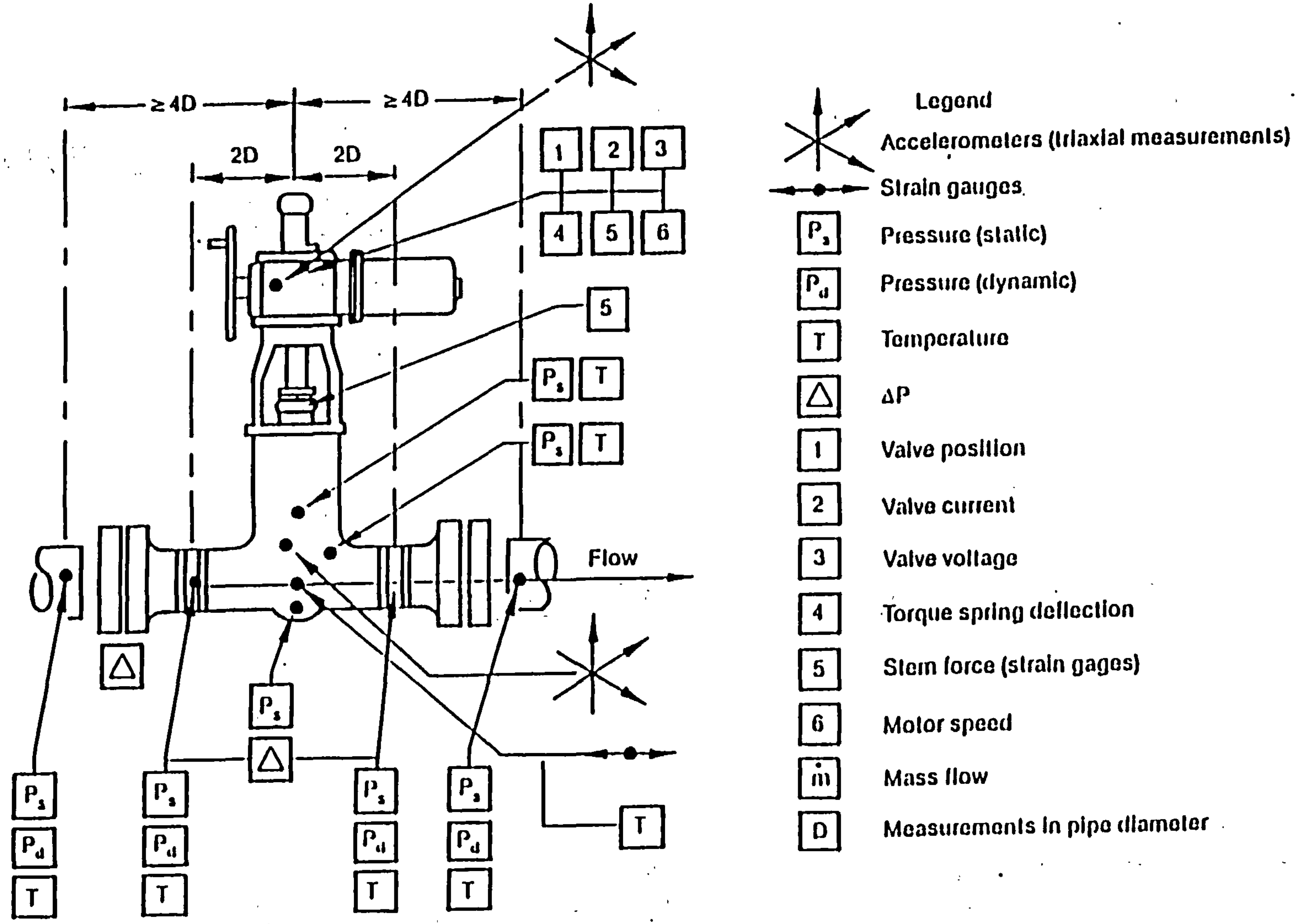

Figure 5. Valve and piping instrumentation.

PHASE II

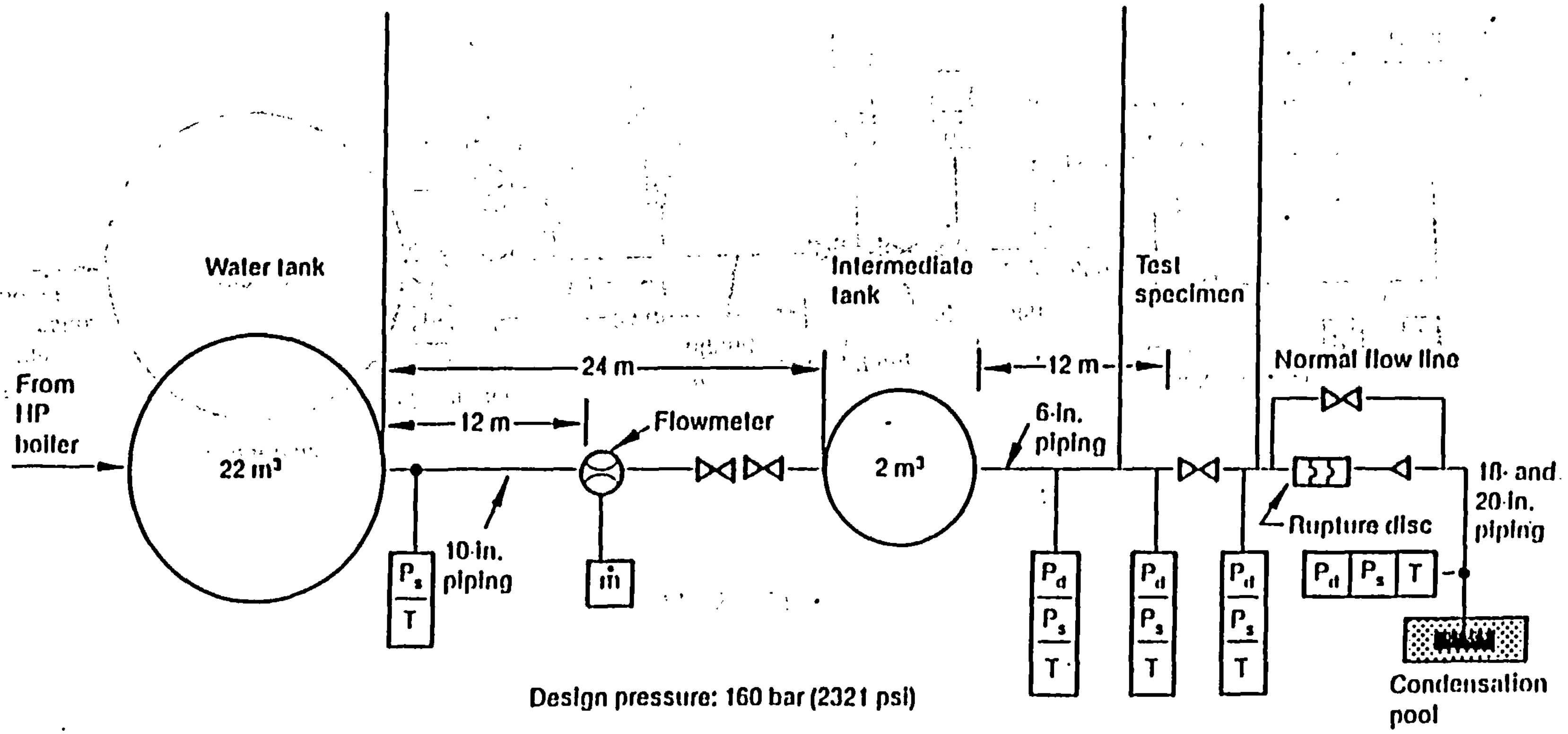

Figure 3. Simplified diagram of KWU 6-in. valve test loop, showing configuration, lengths, and piping sizes. Legend is shown in Figure 5.

PHASE II

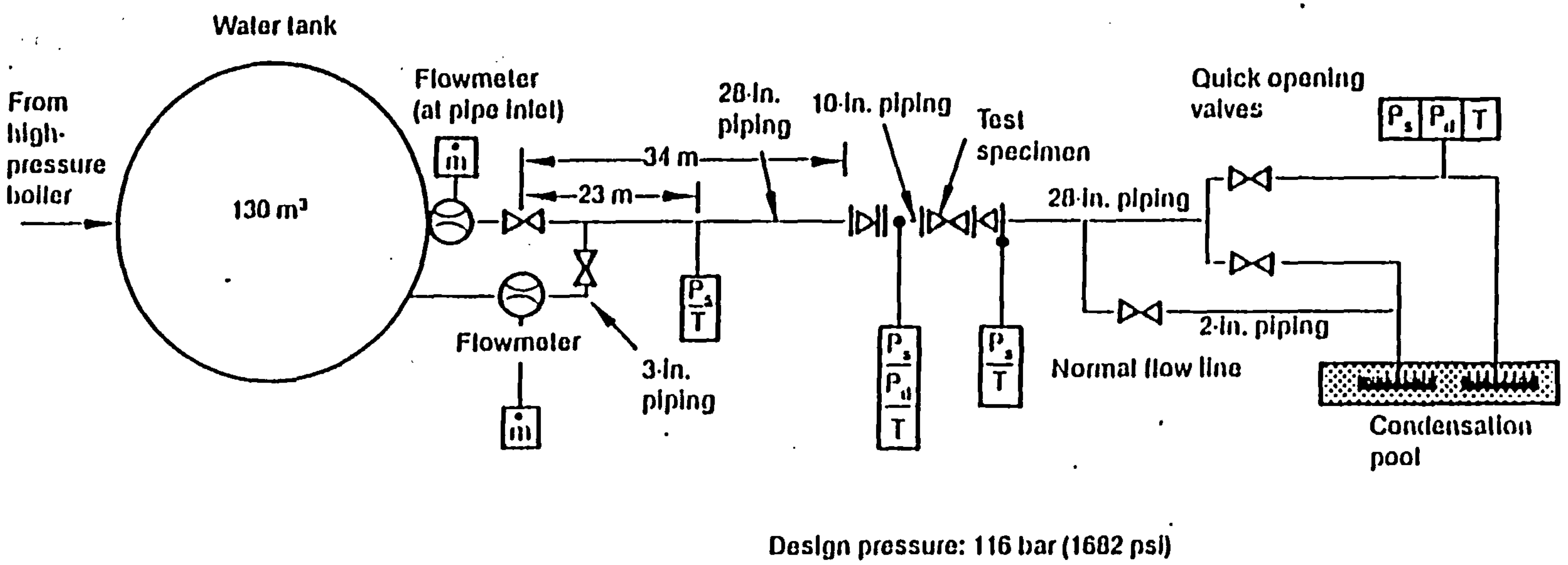

Figure 4. Simplified diagram of KWU 10-in. valve test loop, showing configuration, lengths, and pipe sizes. Legend is shown in Figure 5.

PHASE II INSTRUMENTATION ACCURACY

Chan. ID	Measurement Description	Full Scale	Accuracy	Error	Units	Comments
CHAN 0	Bonnet Fluid Temperature	--	--	10	deg F	Steady State (Transient - Ref. Only)
CHAN 1	Shadow Fluid Temperature	--	--	10	deg F	Steady State (Transient - Ref. Only)
CHAN 2	Under Disc Fluid Temperature	--	--	10	deg F	Steady State (Transient - Ref. Only)
CHAN 3	Upstream 4D Fluid Temperature	--	--	10	deg F	Steady State (Transient - Ref. Only)
CHAN 4	Upstream 2D Fluid Temperature	--	--	10	deg F	Steady State (Transient - Ref. Only)
CHAN 5	Downstream 2D Fluid Temperature	--	--	10	deg F	Steady State (Transient - Ref. Only)
CHAN 6	Downstream 4D Fluid Temperature	--	--	10	deg F	Steady State (Transient - Ref. Only)
CHAN 7	Valve Body Surface Temperature	--	--	10	deg F	Steady State (Transient - Ref. Only)
CHAN15	Thermocouple Reference Temperature	--	--	10	deg F	
CHAN16	Motor Current, I1	20	0.14%	0.03	Amp	
CHAN17	Motor Current, I2	20	0.09%	0.02	Amp	
CHAN18	Motor Current, I3	20	0.12%	0.02	Amp	
CHAN19	Motor Voltage, L1-L2	575	0.09%	0.52	Volt	
CHAN20	Motor Voltage, L2-L3	575	0.10%	0.58	Volt	
CHAN21	KWU Accumulator Static Pressure	--	--	--	Psia	Reference Only (less than 2%)
CHAN22	KWU Upstream Dynamic Pressure	--	--	--	Psid	Reference Only (less than 2%)
CHAN23	KWU Upstream Static Pressure	--	--	--	Psia	Reference Only (less than 2%)
CHAN24	KWU Flowmeter Static Pressure	--	--	--	Psia	Reference Only (less than 2%)
CHAN25	KWU Flowmeter DP A	--	--	--	Psid	Reference Only (less than 2%)
CHAN26	KWU Flowmeter DP B	--	--	--	Psid	Reference Only (less than 2%)
CHAN27	Motor Speed	1000	0.11%	1.10	Hz	Converted to RPM (Valve Specific)
CHAN28	KWU Downstream Dynamic Pressure	--	--	--	Psid	Reference Only (less than 2%)
CHAN29	KWU Downstream Static Pressure	--	--	--	Psia	Reference Only (less than 2%)
CHAN30	Limit Switches	--	--	--		
CHAN31	Closed Torque Switch	--	--	--		
CHAN32	Stem Force	40000	0.40%	160	Lbs	
CHAN33	Bonnet Static Pressure	3000	0.50%	15	Psia	
CHAN34	Shadow Static Pressure	2000	0.50%	10	Psia	
CHAN35	Under Disc Static Pressure	2000	0.50%	10	Psia	
CHAN36	Upstream 4D Static Pressure	2000	0.50%	10	Psia	
CHAN37	Upstream 2D Static Pressure	2000	0.50%	10	Psia	
CHAN38	Downstream 2D Static Pressure	2000	0.50%	10	Psia	
CHAN39	Downstream 4D Static Pressure	2000	0.50%	10	Psia	
CHAN40	Upstream 4D Dynamic Pressure	1000	0.50%	5	Psid	
CHAN41	Upstream 2D Dynamic Pressure	1000	0.50%	5	Psid	
CHAN42	Downstream 2D Dynamic Pressure	2000	0.50%	10	Psid	
CHAN43	Downstream 4D Dynamic Pressure	2000	0.50%	10	Psid	
CHAN44	4D Valve Differential Pressure	2000	0.50%	10	Psid	
CHAN45	2D Valve Differential Pressure	2000	0.50%	10	Psid	
CHAN52	KWU Accumulator Temperature	--	--	--	deg F	Reference Only (less than 3 deg K)
CHAN53	KWU Upstream Fluid Temperature	--	--	--	deg F	Reference Only (less than 3 deg K)
CHAN54	KWU Flowmeter Fluid Temperature	--	--	--	deg F	Reference Only (less than 3 deg K)
CHAN55	KWU Downstream Fluid Temperature	--	--	--	deg F	Reference Only (less than 3 deg K)

PHASE II INSTRUMENTATION ACCURACY

Chan. ID	Measurement Description	Full Scale	Accuracy	Error	Units	Comments
CHAN56	Stem Force, General Physics	Validated Against CHAN32			Lbs	(Refer to Manufacturer for Actual)
CHAN64	Valve Stem Position	5	0.32%	0.02	Inch	
CHAN65	Spring Pack Deflection	0.75	0.50%	0.004	Inch	
CHAN69	Valve Body Acceleration, X	--	--	--	g	Reference Only
CHAN70	Valve Body Acceleration, Y	--	--	--	g	Reference Only
CHAN71	Valve Body Acceleration, Z	--	--	--	g	Reference Only
CHAN72	Motor Operator Acceleration, X	--	--	--	g	Reference Only
CHAN73	Motor Operator Acceleration, Y	--	--	--	g	Reference Only
CHAN74	Motor Operator Acceleration, Z	--	--	--	g	Reference Only