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SPACE-STORABLE OXIDIZER VALVE

FINAL REPORT
NOVEMBER 1970

Prepared Under Contract No. NAS 3-12029

by
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McDonnell Douglas Astronautics Company—West
McDonnell Douglas Corporation
5301 Bolsa Avenue
Huntington Beach, California 92647
for
NASA Lewis Research Center
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R.E. Grey, Project Manager
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-WEST

NOTICE

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ABSTRACT

A program to design, fabricate, and test a space-storable oxidizer valve is described. The conceptual design and analysis of this valve configuration were completed on a previous contract (NAS 3-11195). The present program, carried out by McDonnell Douglas Astronautics Company—West for NASA-LeRC, comprised five major tasks:

- Valve Design
- Fabrication and Acceptance Testing
- Fluorine Compatibility Testing
- Valve Refurbishment and Testing
- Environmental Testing

Two similar configurations of a 2-in. (5.08×10^{-2}m) pneumatically-actuated poppet valve were evaluated. One version featured a hard-surface-on-hard-surface poppet/seat arrangement (1T32095-1 configuration), and the second version had a hard-surface-on-soft-surface poppet/seat arrangement (1T32095-501 configuration). Compatibility and cycle-life tests, consisting of more than 250 operating cycles at LF_2 flowrates of 12 lbm/sec (5.45 kg/sec) and supply pressures of 100 psig (6.90×10^5 pascals), were completed on each valve. After 571 additional cycles at an off-design (proof pressure) condition of 250 psig (1.73×10^6 pascals), the -1 valve developed a fatigue crack in the poppet-shaft bellows seal.

Acceleration loads of 12 g's applied to the -501 valve in several orientations did not degrade its performance, nor did a 532-g, 1.25-msec shock load applied along the poppet centerline.

The refurbished -1 valve was subjected to a rigorous series of random and sinusoidal vibration loads with 100 psig (6.90×10^5 pascals) LF_2 applied to the valve inlet. No adverse effects on valve operation were noted.

Throughout the program, internal valve leakage rates below 10^{-8} lbm/sec (4.54×10^{-9} kg/sec) of GHe at -320°F (77.9°K) and 100 psig (6.90×10^5 pascals) (equivalent to 10^{-7} lbm/sec [4.54×10^{-8} kg/sec] of GF_2 at -290°F [94.4°K] and 100 psig [6.90×10^5 pascals]) were consistently demonstrated.

FOREWORD

The work described herein was performed by the McDonnell Douglas Astronautics Company—West (MDAC-West) under National Aeronautics and Space Administration contract NAS 3-12029. The work was done under the direction of the NASA Project Manager, Mr. R. E. Grey, Liquid Rocket Technology Branch, NASA Lewis Research Center.

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Section 1

SUMMARY

A program to design, fabricate, and test a space-storable oxidizer valve was completed by the McDonnell Douglas Astronautics Company--West (MDAC-West) for the National Aeronautics and Space Administration, Lewis Research Center (NASA-LeRC). Conceptual design studies for this valve configuration were previously completed on Contract NAS 3-11195 and documented in NASA Report CR 72543. The design criteria generated on Contract NASw 1351 and documented in NASA Report CR 72063 were the basis for all valve design work. The assistance of the Systems Division of the Parker Hannifin Corporation, Los Angeles, was utilized in several key portions of the program.

The program included the following major tasks:

- Valve Design
- Fabrication and Acceptance Testing
- Fluorine Compatibility Testing
- Valve Refurbishment and Testing
- Environmental Testing

The 2-in. (5.08×10^{-2}m) pneumatically-actuated valve, designed for direct liquid fluorine (LF_2) service, incorporates a flat metal poppet and a compliant self-aligning flat metal seat. Two valve configurations, differing only in seat materials, were evaluated. One version (1T32095-1 configuration) featured a hard-surface-on-hard-surface poppet/seat arrangement, and the second version (1T32095-501 configuration) was a hard-surface-on-soft-surface poppet/seat arrangement. The -1 configuration utilized an A286 seat and an Inconel 718 poppet, while the -501 configuration had a 23+ carat gold-plated seat and an Inconel 718 poppet. The Systems Division of Parker Hannifin Corporation accomplished the detail design and fabrication using the basic MDAC-West preliminary design.

Compatibility and cycle-life tests, consisting of more than 250 operating cycles with average LF_2 flowrates of 12 lbm/sec (5.45 kg/sec) and system pressures up to 100 psig (6.90×10^5 pascals), were successfully completed on each valve configuration. In addition, the -1 valve was cycled in LF_2 at

the design-integrity proof pressure of 250 psig (1.73×10^6 pascals). A fatigue crack occurred in the poppet-shaft bellows seal after 571 cycles. The crack, caused by a ringing vibration of the poppet shaft when the actuator piston repeatedly reached the limit of its travel during valve closing, is an explainable failure at the stringent off-design pressure condition of the test. Subsequently, both valves were exposed to a series of environmental tests.

After disassembly, inspection, and reassembly the -501 valve was mounted on a centrifuge and subjected to 6-g and 12-g acceleration loads in several attitudes while leakage and response-time checks were made. The same valve was then exposed to a 532-g shock load for a duration of 1.25 msec. No visible damage was sustained in either test, and final GHe internal leakage rates were virtually zero.

The -1 valve was returned to Parker Hannifin Corp. for repair of the damaged bellows seal, and also for rework of the static seal recesses. The latter work was required in connection with a special test of external seal leakage. Although internal leakage rates for this valve were well within specification before rework, they became excessive after the rework. The difficulty, traced to imperfectly lapped poppet and seat sealing surfaces, was eventually solved by relapping the -1 seat and installing the -501 poppet assembly. A test to verify satisfactory external leakage characteristics of the static seals at LN_2 temperature was accomplished by installing the -1 valve in an evacuated tank and monitoring vacuum decay. External leakage rates of less than 1.2×10^{-5} ccs were measured with the valve inlet pressurized to 100 psig (6.90×10^5 pascals) and 2×10^{-4} ccs with both the inlet and outlet portions of the valve pressurized.

Finally, the valve was subjected to sinusoidal and random vibration loading profiles while exposed to 100 psig (6.90×10^5 pascals) LF_2. Posttest leakage checks and valve disassembly showed that the valve successfully withstood the imposed vibration loads, and demonstrated that the design is sound. Internal valve leakage rates below the NASA goal of 10^{-8} lbm/sec (4.54×10^{-9} kg/sec) of GHe at -320°F (77.9°K) and 100 psig (6.90×10^5 pascals) (equivalent to 10^{-7} lbm/sec [4.54×10^{-8} kg/sec] of GF_2 at -290°F [94.4°K] and 100 psig [6.90×10^5 pascals]) were consistently demonstrated for both valve configurations.

Section 2

INTRODUCTION

2.1 OBJECTIVE AND APPROACH

The overall objective of this program was to design, manufacture, and test a space-storable oxidizer shutoff valve. This valve is of a nominal 2-in. (5.08×10^{-2}m) line size, having a configuration (Figure 2-1) based on the preliminary design work previously accomplished under Contract NAS 3-11195 (Reference 1) and meeting the design criteria established under Contract NASw 1351 (Reference 2). Two different seat material combinations for this valve were evaluated. One version featured a hard-surface-on-hard-surface poppet/seat arrangement, and the second version had a hard-surface-on-soft-surface poppet/seat arrangement. Program objectives were fulfilled by completing the five tasks summarized below (Reference 3).

2.2 TASK I: VALVE DESIGN

The objective of this task was to perform the engineering operations necessary to produce a set of manufacturing drawings and supporting documentation

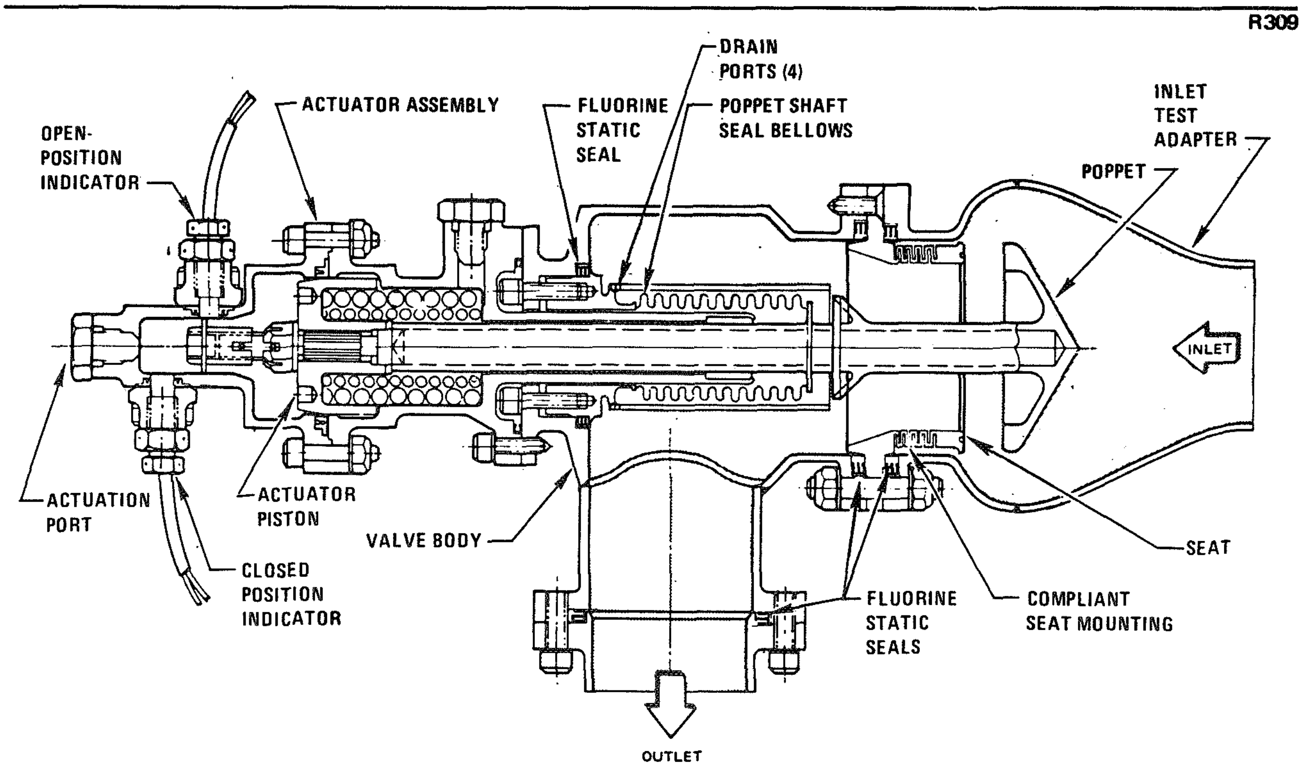

Figure 2-1. Space-Storable Oxidizer Valve Design

suitable for fabrication of the two test valves. These drawings and procedures consisted of detail design configurations and material lists, fabrication and assembly procedures, inspection requirements, and packaging and handling instructions.

The drawing set, including layout, assembly, and detail part drawings conforming to Military Specification MIL-D-1000, defined the dimensions, tolerances, finishes, material processes, and raw material specifications. Before the drawings and associated lists of materials were released for fabrication and procurement, a final design review was conducted with the NASA-LeRC Project Manager.

Analytical studies were conducted concurrently with, and in support of, the detail design activity. These studies verified design features such as valve response, dynamic stability, functioning capability, and proof and burst pressure ratings. A design study was made to insure ease of manufacturing, reasonable costs, and satisfactory component performance.

A manufacturing plan was prepared to identify critical items in the fabrication of the two valve assemblies, and to control the pacing items, so that the overall program objectives would be accomplished on schedule.

2.3 TASK II: FABRICATION AND ACCEPTANCE TESTING

The objectives of this task were to fabricate two complete oxidizer valve assemblies, and to perform acceptance tests on both units. The fabrication orders were placed in the subcontractor's prototype shop after final design approval was received from NASA-LeRC. All parts for the two valves were individually identified, and inspection records, deviations, reworks, and repairs were documented. A minimum number of spare parts was fabricated, and a complete history of all spare parts was maintained.

A test plan was prepared for the acceptance testing of the two valve assemblies. This plan included test conditions, facility requirements, instrumentation, documentation, variables, and types and number of tests. This test plan was submitted to the NASA Project Manager for his approval before the start of acceptance testing.

The acceptance testing was conducted by subcontractor personnel using the subcontractor's experimental facilities. These tests included proof tests, actuation tests, and internal and external leakage tests. After completion of the acceptance tests, the two valves were inspected, cleaned, packaged for shipment, and forwarded to the MDAC-West Fluorine Flow Facility.

2.4 TASK III: FLUORINE COMPATIBILITY TESTING

The objective of this task was to perform full-scale evaluation tests of the two valves in an oxidizer system. This testing was conducted at the MDAC-West Fluorine Flow Facility using LF_2 as a test medium. A comprehensive test plan for the Task III testing was prepared and forwarded to the NASA-LeRC Program Manager for his approval prior to the start of the test. This test plan specified test conditions, facility requirements, instrumentation, documentation, variables, and type and number of tests.

Testing under this task was performed to determine the capability, cycle life, and fluorine leakage characteristics of the two valve configurations. Each valve was subjected to a 250-cycle life test at representative system pressures. At the completion of the cycle life tests, the -1 valve was selected for additional testing. After NASA approval, an additional off-design high-pressure cycle test series was conducted on the selected valve at its nominal proof-pressure integrity rating of 250 psig (1.73×10^6 pascals).

2.5 TASK IV: VALVE REFURBISHMENT AND TESTING

The objective of this task was to prepare both valves for the environmental test series conducted under Task V. Because the -1 valve was damaged during the high-pressure cycle test portion of the Task III testing, it was returned to Parker Hannifin for complete refurbishing. The refurbishment included replacement of parts needed to return the valve to an acceptable condition for further testing, and a change in static seal groove dimensions to provide adequate sealing for GHe service, so that valid external leakage-rate measurements could be obtained. The refurbished -1 valve was acceptance tested at Parker Hannifin before delivery of the assembly to MDAC-West. The external leakage tests were conducted by MDAC-West in an LN_2-jacketed vacuum tank, using GHe as a test medium.

The -501 valve was disassembled, inspected, reassembled, and evaluated for baseline performance by MDAC-West. Since the -501 valve had not been exposed to high-pressure cycle testing during Task III, no rework was required.

2.6 TASK V: ENVIRONMENTAL TESTING

The environmental tests were performed to determine the test valves' ability to withstand the acceleration, shock, and vibration loads expected during a typical space vehicle launch. The -501 valve was exposed to acceleration loads in the MDAC-West Environmental Laboratory centrifuge facility. Loads of 6 g's and 12 g's were applied parallel to the valve centerline, perpendicular to the centerline, and at one intermediate position. Tests of internal valve leakage and actuator response times were made using inert test media. The same valve was installed on a shock machine and subjected to a 532-g, 1.25 msec half-sinusoidal shock pulse.

Vibration testing was accomplished on the reworked -1 valve at the MDAC-West Gypsum Canyon Test Site. Sinusoidal and random vibrations in the 5- to 2,000-Hz frequency range with loadings up to a 4.5-g level were applied, first in a plane perpendicular to the valve poppet shaft, then parallel to the poppet shaft. During these tests, the valve inlet was pressurized with 100 psig (6.90×10^5 pascals) LF_2.

At the conclusion of the environmental test series, both valves were leak checked, disassembled, inspected for damage, and reassembled.

2.7 SIGNIFICANCE OF PROGRAM RESULTS

The design of a flightweight valve, representative of fluorine feed system components for typical high-energy upper-stage propulsion system applications, was successfully accomplished, using the design criteria formulated by MDAC-West during a previous contract. The low leakage requirement of 10^{-7} lbm/sec (4.54×10^{-8} kg/sec) of fluorine at cryogenic temperature was met successfully in a 2-in. (5.08×10^{-2}m) shutoff valve using a flat-surface-on-flat-surface poppet valve configuration. The leakage rates measured during the test program are in good agreement with theoretically predicted values. The A286-Inconel material combination and the 23+ carat gold-Inconel combination exhibited acceptable cycle-life performance in the range of 1 to 900 cycles. Exposure to severe testing environments (acceleration, shock, and vibration) verified the valve's overall design integrity.

The difficulty in obtaining direct fluorine leakage rate measurements still exists, and correlations of GHe test data with predicted LF_2 leakage rates are still unreliable in the flow regime of interest. Additional work on both of these problems is indicated.

The material combinations selected for all parts of the test valves are acceptable for LF_2 service. No serious problems were encountered during the testing phase, even though a secondary failure during testing at a condition above the design operating pressure permitted fluorine to enter parts of the valve which would normally not be exposed to the oxidizer. Use of the component design criteria as guidelines appears to offer a high degree of confidence in producing successful fluorine feed systems. The reliability offered by the fluorine-compatible all-metal component configuration was aptly demonstrated. The features exhibited in the prototype design appear to be equally applicable for use with many other high-energy propellants.

2.8 RECOMMENDATIONS

The following recommendations are based on the results of the work completed on this contract:

A. The valve design evaluated on this program has successfully demonstrated its capabilities under all of the specified conditions. The ease with which the design requirements were met indicates that this valve design is capable of performing equally well under other design conditions. To evaluate the extent of potential additional valve capabilities, further testing is recommended. One of the recently defined mission requirements related to the state of the art of valve design is for shutoff valves in the Attitude Control Propulsion System (ACPS) of the proposed space shuttle vehicle. The shuttle requirements include extended cycle life (10^5 cycles) and low leakage in a GH_2/GO_2 environment. The design of the space-storable oxidizer valves lends itself to further use in evaluating changes in internal leakage rates with extended-duration cycle testing, and with the addition of system contamination. Since the contamination tolerance of this valve design was not established in a space-storable oxidizer system, a test program to obtain this information with a non-reactive cryogenic liquid would be worthwhile.

Specifically, it is recommended that the following tests be conducted:

1. Contamination tolerance testing in GH_2.
2. Contamination tolerance testing in LN_2.
3. Cycle life testing (to 10^5 cycles) in GH_2.

B. Testing should be conducted to correlate the leakage rates of propellants and inerts (in both the liquid and gaseous states) in the laminar, transitional, and molecular flow regimes.

C. Additional work should be done to provide better inspection methods for determining the flatness and surface finish of the type of lapped poppet and seat interface surfaces used in the valves tested.

D. The extended cycle-life testing program included in the first recommendation will be time consuming and costly. The testing time and cost would be reduced if a method can be developed to eliminate or minimize the downtime needed to make leakage measurements and to inspect the condition of the test article. Two possible methods for providing a continuous monitoring capability would utilize:

1. Acoustical signature principle (based on mechanical vibrational characteristics of test article).
2. Acoustical leakage measuring system (dependent on sound characteristics of leaking fluid).

It is recommended that these two test methods be investigated for suitability of use on future valve-cycle tests, and that verification testing be conducted in conjunction with the recommended extended cycle-life tests.

Section 3
TECHNICAL DISCUSSION

3.1 TASK I: VALVE DESIGN

The valve design phase of this program consisted of completing the engineering studies necessary to define the final valve configuration, and to convert the existing conceptual design to a set of detailed manufacturing drawings. This work was carried out jointly by MDAC-West and the Systems Division of Parker Hannifin Corporation of Los Angeles, California. The design activity included evaluation of the changes in the valve design specification that occurred between the conceptual design contract and the present contract, completion of additional valve dynamic studies, preparation of the detail drawing set, and evaluation of changes made to simplify the manufacturing process. The MDAC-West layout drawing (1T32095) served as the guideline for the Parker Hannifin design effort. The assembly drawing and all detail drawings were then made by Parker Hannifin using their own drawing format. This arrangement minimized the difficulty of processing drawings in the Parker Hannifin manufacturing facility. All design work was in compliance with the criteria delineated in References 4 and 5.

3.1.1 Analytical Studies

The basic analytical studies for this valve design were completed on the previous contract (Reference 1). Therefore, the analysis work on this contract emphasized the evaluation of changes to the original design specifications (Table 3-1). These changes include a lowering of the nominal flow and pressure drop requirements, increases in actuation pressures, and tightening of the internal leakage goal.

3.1.1.1 Flow Performance

The specified flowrate and pressure-drop requirements were calculated for the proposed valve design. The pressure drop through the valve at the maximum rated flow of 12 lbm/sec (5.45 kg/sec) of LF_2 at -320°F (77.9°K) was predicted to be less than 2.4 psid (1.66×10^4 pascals). The flowrate and pressure-drop calculations are based on the use of empirical constants derived from tests of similar valves. Table 3-2 summarizes the preliminary flow performance analysis.

3.1.1.2 Main Seat Leakage

The main seat leakage requirement of 10^{-7} lbm/sec (4.54×10^{-8} kg/sec) of fluorine is within the predicted range of values generated for the conceptual design; therefore, no separate calculations were required. A recheck of the original calculations was made, and no design change was indicated.

Table 3-1

VALVE DESIGN OBJECTIVES AND SPECIFICATIONS

	NAS 3-11195	NAS 3-12029
Fluid	LF_2, LOX, FLOX (MIL-P-27401)	Same
Fluid temperature	-320°F (77.9°K)	Same
Fluid pressure (gage)		
Maximum operating	100 psi (6.90×10^5 pascals)	Same
Proof	250 psi (1.73×10^6 pascals)	Same
Burst	375 psi (2.59×10^6 pascals)	Same
Flowrate	18 lbm/sec (8.18 kg/sec)	12 lbm/sec (5.45 kg/sec)
Pressure drop at rated flow (maximum)	10 psi (6.90×10^4 pascals)	5 psi (3.45×10^4 pascals)
Line size	2 in. (5.08×10^{-2}m) ID	Same
Actuator pressure (gage)		
Maximum operating	500 psi (3.45×10^6 pascals)	Same
Proof	600 psi (4.14×10^6 pascals)	750 psi (5.18×10^6 pascals)
Burst	750 psi (5.18×10^6 pascals)	1,125 psi (7.76×10^6 pascals)
Actuation time (maximum)	75 msec	Same
Failure mode	Closed	Same
Internal leakage		
Main seat (F_2)	10^{-6} lbm/sec (4.54×10^{-7} kg/sec)	10^{-7} lbm/sec (4.54×10^{-8} kg/sec)
Propellant cavity to actuator (GHe)	0 lbm/sec (0 kg/sec)	Same

Table 3-2

PRELIMINARY FLOW-PERFORMANCE SUMMARY

Pressure drop	<2.4 psi (1.66 x 10^4 pascals)
Rated flow	12 lbm/sec (5.45 kg/sec)
Temperature, fluorine	-320°F (77.9°K)
Density, fluorine	97 lbm/ft^3 (1.56 x 10^3 kg/m^3)
Flow velocity across seal (valve fully open)	6.1 fps (1.86 m/sec)
Equivalent flow area	3.14 $in.^2$ (2.03 x 10^{-3} m^2)
Resistance factor, K	6

3.1.1.3 Valve Response Time

The valve response time was calculated by Parker Hannifin using an existing computer program. The results of this study indicated that a 0.060-in. (1.52 x 10^{-3}m) -dia orifice would be required in the actuator pressurization line to keep the valve response in the 50 to 75-msec range. The results of this analysis are included in the Parker Hannifin Analysis Report (Appendix A).

3.1.1.4 Proof and Burst Pressure Determination

The proposed valve design was checked by Parker Hannifin to verify proof and burst pressures; the resultant safety factors are presented in Appendix A. No changes in material type or dimension were indicated by this study.

3.1.1.5 Manufacturing Feasibility Study

The Parker Hannifin Design Section completed a study to determine ease of manufacturing and relative cost of fabrication of the conceptual valve design. This study indicated that the selection of Conoseal-type flange seals would complicate the fabrication of the valves, and that the poppet-seat bellows design would require some modification. The basic problem was that the flange sizes selected were not standard Conoseal sizes. Therefore, special tooling and inspection fixtures would be required to utilize this type of seal. Instead of accepting the time and cost penalties associated with the nonstandard Conoseals, a change was made to a W seal configuration. The W seals were available in the sizes required for the valve design, and in addition, offered several advantages over the Conoseal type of seal. Both seal types were expected to provide the same leakage rates under the design conditions, but the W-seal flanges are easier to machine because the W-seal fits into a groove similar to an O-ring groove, and one of the mating flanges is a flat surface. The flat surface is easier to machine than the critical male and female mating flanges of the Conoseal design.

The W seals selected were made of Inconel and gold-plated. The seals were supplied by the Hydrodyne Division of the Donaldson Company, the same firm that supplied the machined-bellows poppet seat.

The stress analysis of the machined-seat bellows with the A286 seat material indicated that the original design configuration would be satisfactory for cryogenic conditions, but the seat would be overstressed under ambient test conditions. To correct this situation, the outside diameter of the bellows was decreased 0.050 in. (1.27×10^{-3}m) and the inside diameter was decreased 0.150 in. (3.81×10^{-3}m). This change provided a greater height for the bellows convolution, and lowered the stress levels to an acceptable value for the A286 seat material.

3.1.1.6 Hard-Surface-on-Soft-Surface Configuration

To obtain a greater amount of basic data for the flat-surface-on-flat-surface poppet/seat leakage characteristics, a variation of the basic valve was designed to employ a hard-surface-on-soft-surface poppet/seat. This second version (-501 configuration) was identical to the basic -1 configuration except for the addition of gold plating on the poppet seat. Although a gold plating was desirable for several reasons, a detailed study of the plating data available revealed that very little information existed on mechanical properties of thin gold plating, and no information existed for these platings in a fluorine environment.

To establish baseline performance of the gold plating in fluorine, a MIL-G-45204, Type II, Class 3 plating was selected. This plating is 23+ carat gold with a minimum thickness of 0.0003 in. (7.62×10^{-6}m). The actual plating tested was approximately 0.0004-in. (1.02×10^{-5}m) thick, which places it in the middle of the high Class 4 range. The plating was applied to a nickel strike underplating. The plating was performed by Metal Surfaces Co., Bell Gardens, California, using the Engelhard E-73 hard gold plating process.

3.1.2 Design Studies

Design studies were carried out jointly by MDAC-West and the Parker Hannifin Corporation.

3.1.2.1 Assembly Drawing

The final valve configuration is shown in the Attachment. This drawing reflects the final design changes incorporated into the MDAC-West 1T32095 valve.

3.1.2.2 Detail Manufacturing Drawings

The detail manufacturing drawings were completed by Parker Hannifin using their standard format. These drawings include all dimensions, tolerances, finishes, material processing, and raw material specifications, and conform to MIL-D-1000.

A formal design review was conducted by the NASA Project Manager, MDAC-West, and Parker Hannifin personnel, and design approval was obtained.

3.2 TASK II: FABRICATION AND ACCEPTANCE TESTING

Valve fabrication and acceptance testing were accomplished by Parker Hannifin under the surveillance of MDAC-West.

3.2.1 Valve Fabrication

The fabrication of the two test valves was completed in the Parker Hannifin prototype shop using both experimental and production personnel. Several of the key parts of the valves were subcontracted by Parker Hannifin to other manufacturing firms to insure early delivery. All parts for the two valves, including spares, were serialized, and complete logbooks were kept on each valve. In addition to this basic valve hardware, a complete set of assembly tools and test fixtures for the acceptance testing was designed and fabricated by Parker Hannifin. The two valves were manufactured to print except for the following deviations.

3.2.1.1 Body Weldment

The welding together of the two body parts causes a 0.040 to 0.050-in. (1.02×10^{-3} to 1.27×10^{-3}m) warpage of the outlet flange toward the inlet flange. This was not a serious problem since it occurred before final machining, and a total of 0.100 in. (2.54×10^{-3}m) of material was available for cleanup. It did result in a small change in the distance from the centerline of the outlet flange to the mounting plane of the inlet flange. A slight change in the chamfers of the weld joints is recommended for future valves.

3.2.1.2 Shaft Assembly

The plug weld on one of the poppet shafts was found to be open when the part was inspected. The plug was rewelded and ground flush with the shaft.

3.2.1.3 Shaft Bellows Seal

The shaft bellows seals received from the vendor were out-of-square, dirty, had an undersize ID, and had irregular convolution heights. A design review was held with the bellows supplier, and it was determined that none of these deviations would affect the required cycle life of the bellows. The out-of-squareness was corrected, and the bellows welded in place. The assemblies were x-rayed and no defects detected.

3.2.1.4 Poppet Seat

The main sealing surface diameter of both poppet seats was undersized; 2.0785 in. (5.28×10^{-2}m) (serial No. 001) and 2.0160 in. (5.12×10^{-2}m) (serial No. 002) instead of 2.100 in. (5.34×10^{-2}m) as ordered.

Since these items required a long procurement leadtime, and since the change in predicted leakage rate was very small, the two seats were accepted for testing. The smaller of the two (serial No. 002) was selected for gold plating because the relatively soft gold plating would be less sensitive to the change in seat loading resulting from the undersized condition. The change from a Class 3 gold plate to the thicker Class 4 plating was made on this part in an attempt to compensate for the lower apparent seat stresses obtained with the smaller seal diameter. In addition to the thicker plating, the seat was given a very light surface lapping prior to and after plating to insure the proper seat width dimension.

3.2.2 Valve Inspection

A complete quality control inspection was made of all valve parts. The out-of-specification parts utilized in the two valves were discussed in Section 3.2.1. The inspection records of a number of key parts which were within specification are also of special interest. These are discussed briefly below.

3.2.2.1 Poppet Seat

The unplated A286 poppet seat used in the -1 configuration had the sealing surface lapped to a finish less than 1μ in. (2.54×10^{-8}m) arithmetic average (AA). The photomicrograph of a typical section of seal is shown in Figure 3-1. The lapping technique used on this valve employed a hand-held lap moved in a circular pattern. This method of lapping produces a high-quality multidirectional lay, but not the specified circular lay. The differences between a multidirectional lay made in this manner and a theoretically circular lay were discussed with the Parker Hannifin Lapping Department personnel. Due to the anticipated difficulty in maintaining the required surface finish while lapping with a truly circular motion, a decision was made to approve the multidirectional finish for acceptance testing. The final inspection of the seal was conducted just prior to the assembly of the valve to ensure that no damage had occurred to the seat due to cleaning and handling of the part. This last inspection showed no scratches or other damage which would hinder proper valve sealing. The bumper height was 0.0002 to 0.00025 in. (5.08×10^{-6} to 6.35×10^{-6}m) (0.0003 ±0.0001 in. [$7.62 \times 10^{-6} \pm 2.54 \times 10^{-6}$m] specified). The spring rate of the bellows portion of the seat was measured and found to be 5,880 lbf/in. (10.30×10^5 N/m), which is well within the 5500 ±500 lbf/in. ($9.62 \times 10^5 \pm 0.88 \times 10^5$ N/m) specified. Since this value was near the upper end of the specified range, it tended to compensate for the undersized seat diameter discussed in Section 3.2.1.4. The poppet seat for the -501 valve had the same spring rate as the -1 valve part. This poppet seat was given a light surface lapping prior to gold plating because the surface was scratched, was not flat, and did not provide the proper bumper height. The seat was lapped to an acceptable flatness and surface finish before the gold plating was completed. A second lapping operation was completed after the gold-plating process. This second lapping was to eliminate slight irregularities of the gold plating with the removal of a minimum amount of material.

3.2.2.2 Poppet Sealing Surface

The shape of the poppet assembly prevented its installation into the optical device used to determine surface finish. Therefore, the poppet sealing surface was not completely inspected. Instead, a sample of the same dimensions and material as the poppet was lapped, using the same technique used on the valve poppet. The sample was then inspected and found acceptable. The photomicrograph of the Inconel 718 sample piece is shown in Figure 3-2. Based on the acceptable condition of the sample, the two poppets were accepted for testing.

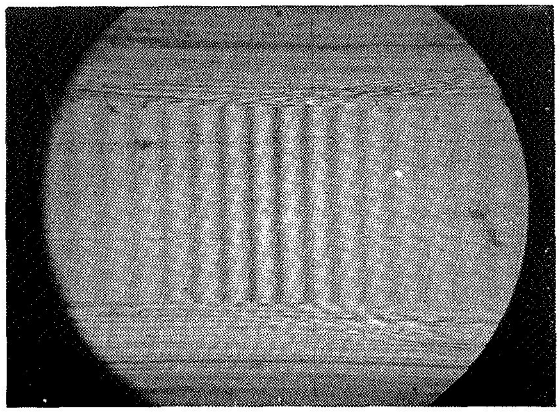

Figure 3-1. Photomicrograph of Typical Seat-Seal Section (100X)

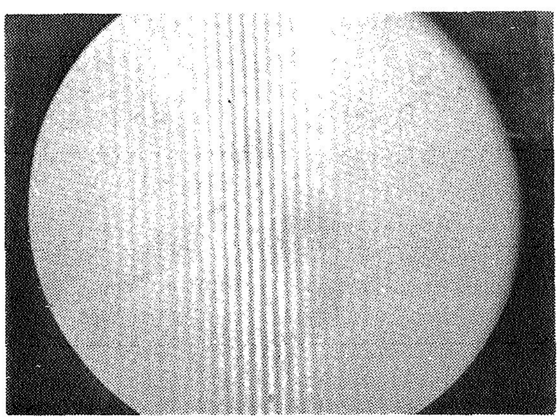

Figure 3-2. Photomicrograph of Inconel 718 Sample Piece (100X)

3.2.2.3 Valve Return Springs

The two valve return springs were designed to twist in opposite directions. The outer spring is a left-hand design, while the inner one is a right-hand design. This approach was incorporated to minimize the twisting motion of the shaft which occurs on valve closing, and which may be transmitted into the shaft bellows seal. The initial delivery was made with the springs in specification, except both inner and outer springs were left handed. This required replacement of the inner springs with new ones which had the proper right-hand twist. Both springs were then checked for spring rate and found acceptable. The outer springs had a 202 lbf/in. (3.54×10^4 N/m) rate (204 ±20 lbf/in. [$3.58 \times 10^4 \pm 0.35 \times 10^4$ N/m] required), and the inner springs had a 134 lbf/in. (2.35×10^4 N/m) rate (126 ±13 lbf/in. [$2.21 \times 10^4 \pm 0.23 \times 10^4$ N/m] required).

3.2.3 Valve Assembly

The unassembled valve parts are shown in Figure 3-3, and the completely assembled valve is shown in Figure 3-4. The two valves were assembled using the procedures presented in Appendix B. No serious difficulty was encountered during the assembly of the two valves. However, two minor problems occurred.

The design requires nine countersunk flat-head screws to install the seat flange to the main valve housing. These screws are situated on the side of the housing seal not exposed to fluorine. NAS1189E3P8 self-locking screws, made of high-strength A286 steel, were chosen for this application. After the original screw selection, it was determined that the self-locking provisions were obtained with nylon inserts. Since the nylon is incompatible with fluorine, an alternate screw was selected. Through an oversight, however, this change was not incorporated into the assembly drawing, and the two test valves were delivered to MDAC-West with the originally specified screws. This was not discovered until after the -501 valve was under LF_2 testing at the Fluorine Flow Facility. While no difficulty was encountered due to this error, both valves were reworked to replace the screws. As each screw was extracted, all traces of nylon were removed from the screw hole with a standard 10-32 tap, and a new copper-plated NAS514P1032-8 screw was installed. The copper plating was applied by a commercial plating company using the brush-plating technique.

A second assembly difficulty was encountered when the proximitor-type position indicators were installed. The position indicators in these valves utilize the outer surface of the variable reluctance detection coil as the sealing interface. This arrangement functions satisfactorily, provided the coil tip and the proximitor mounting threads are concentric. This concentricity callout was inadvertently omitted on the original purchase order, and two of the first four proximitors delivered were unacceptable for testing. The importance of the concentricity of the coil is illustrated in Figure 3-5. The lack of concentricity was discovered during the actuator leakage tests conducted as part of the valve acceptance tests. Excessive leakage occurred around one of the proximitor seals, and it was found that excessive side loads on the proximitor coil had broken the coil mounting joint. The defective units were returned to the supplier for replacement.

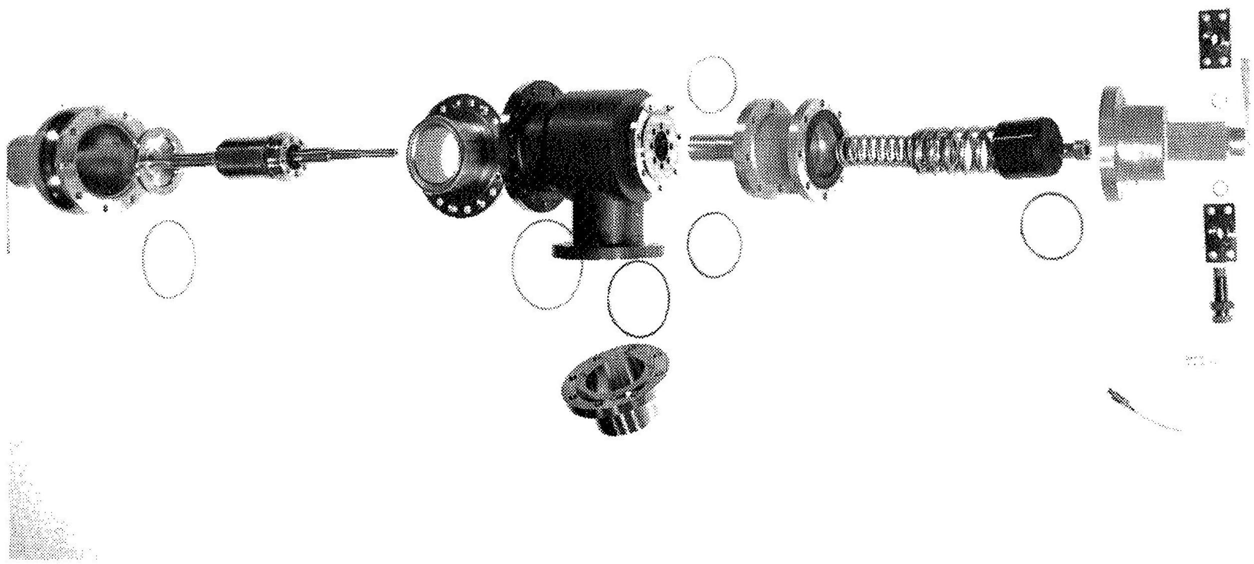

Figure 3-3. Space-Storable Oxidizer Valve (Disassembled)

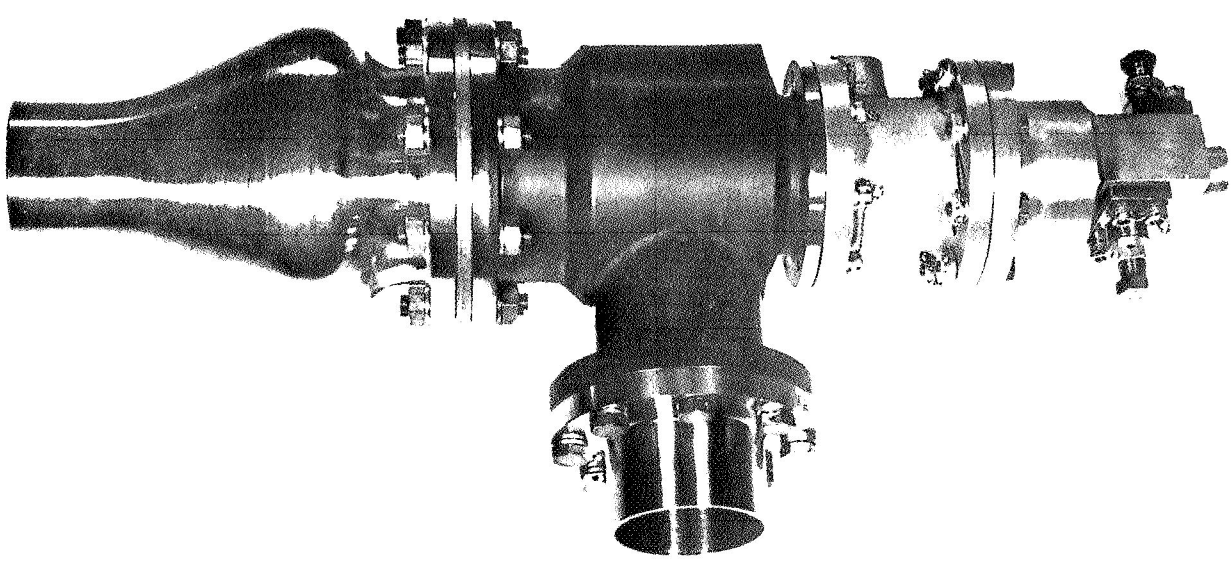

Figure 3-4. Space-Storable Oxidizer Valve

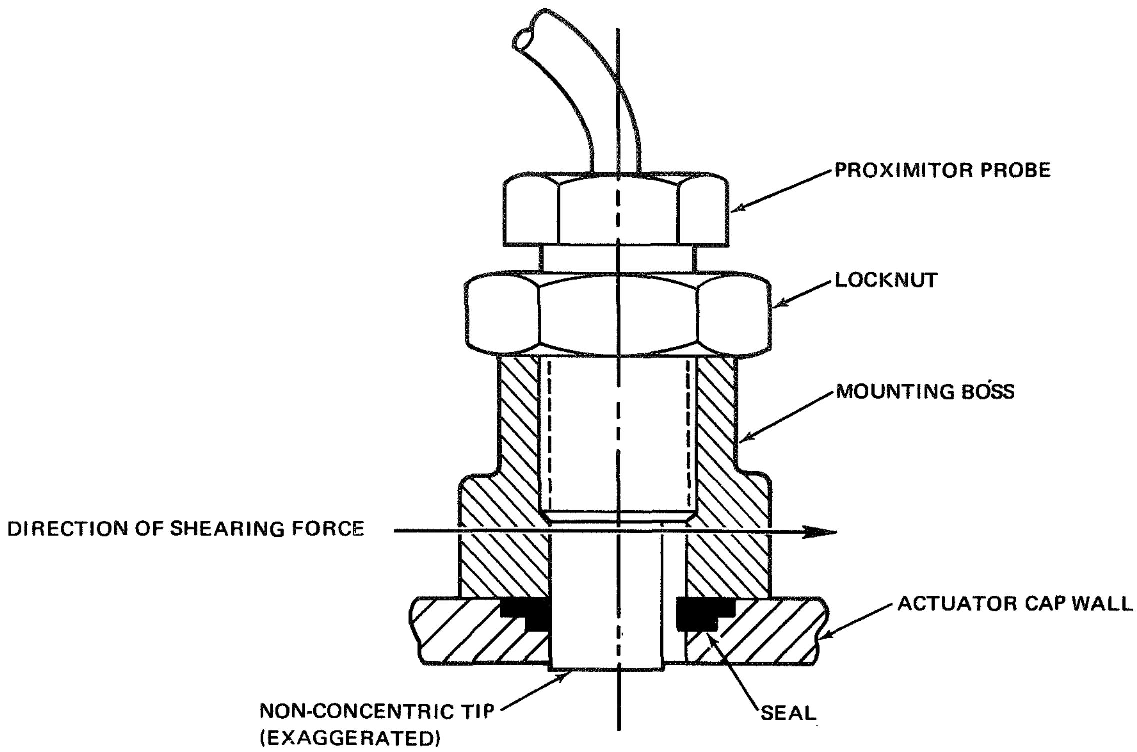

Figure 3-5. Proximitor-Seal Installation

3.2.4 Acceptance Testing

Both test valves were tested by the subcontractor under MDAC surveillance to verify compliance with specifications before delivery to MDAC-West.

3.2.4.1 Test Plans

The test plan for the acceptance tests was prepared by Parker Hannifin using inputs from both the Parker Hannifin and MDAC-West program groups. The acceptance testing included proof tests, actuation tests, and internal and external leakage tests. The complete test plan for this activity is presented in Appendix C. The detailed results are presented below.

3.2.4.2 Proof Tests

Proof tests were made on both the oxidizer cavity and actuator portions of the valve. The oxidizer cavity was pressurized with GHe at 250 psig (1.73×10^6 pascals) for 10 minutes (6×10^2 sec) and the actuator portion was pressurized at 750 psig (5.18×10^6 pascals) for 10 minutes (6×10^2 sec). No component damage was detected as a result of these tests. The tests were then repeated with the valve submerged in LN_2. Again, no damage was detected.

3.2.4.3 Internal Leakage Tests

Both valve configurations were tested for internal leakage over the pressure range of 50 to 250 psig (3.45×10^5 to 1.73×10^6 pascals) at ambient and

-320 °F (77.9 °K) temperature conditions using GHe as a test medium. The acceptance testing was conducted with the valves in the as-built condition, and neither valve required disassembly or rework.

Difficulty was encountered in obtaining good analytical correlation of LF_2 and GHe leakage rates. There is no reliable test method available for obtaining direct LF_2 leakage rate measurements. Until this problem can be solved, a correlation factor of 10^{-8} lbm/sec (4.54×10^{-9} kg/sec) GHe equals 10^{-7} lbm/sec (4.54×10^{-8} kg/sec) LF_2 will be used for component evaluation. This correlation factor is directly applicable to comparisons of cold GHe and cold GF_2; however, the validity of this method in comparing GHe with LF_2 is uncertain. The value of 10^{-8} lbm/sec (4.54×10^{-9} kg/sec) of GHe is equal to 1.7 sccm (2.84×10^{-2} sccs). This latter value is most useful for making direct comparisons of measured valve leakages with design objectives. The design point for internal leakage is the nominal maximum operating pressure of 100 psig (6.90×10^5 pascals). Additional testing was conducted at off-design conditions, up to the proof-pressure rating of 250 psig (1.73×10^6 pascals), to obtain additional information for valve evaluation. It should be noted (Table 3-3) that the -1 valve (unplated seat) met the design objective at the nominal 100 psig (6.90×10^5 pascals) level. Under higher, off-design pressures, the leakage rate was higher than that anticipated for the cryogenic test condition at proof pressure. Analysis indicates that these results were partly due to the off-design test conditions, and, therefore, do not necessarily represent true valve performance data. The gold-plated seat configuration (-501 valve) had an initial leak rate somewhat higher than predicted (Table 3-4). This appears to be because the 0.0004-in. (1.02×10^{-5}m) -thick plating of 23+ carat gold was too hard to permit plastic deformation of the sealing surface, and too soft to permit the same smoothness of surface finish. It should be noted that no mechanical design data were available for the very thin gold plating materials. Design data for 23+ and 24-carat gold in thick sections are available, but are not entirely applicable to thin-film situations. The gold plating used was selected on the basis of the properties of thick gold plating, and testing was required to correlate the performance of the thin-film plating for this application. This valve was accepted for compatibility testing to permit evaluation of the leakage rate over a larger number of valve cycles. Assuming that the 23+ carat plating is too hard for initial seating, it is softer than the poppet seat material, so an improvement in leakage control was expected (and achieved) with additional valve cycling.

3.2.4.4 External Leakage Tests

A special jacketed vacuum chamber was designed and fabricated by Parker Hannifin for the external leakage tests. The valve assembly was mounted on a removable lid which suspended the valve inside the jacketed vacuum chamber. The first external leakage test was attempted with a mass spectrometer connected to the vacuum chamber, but the vacuum chamber would not maintain the required vacuum. Since it was necessary to energize the valve actuator to the open position, the leakage occurring at the proximitor seals was affecting the evacuation of the chamber. The concentric-tipped proximitors were not available at the time of this test, so it was decided to evaluate the external leakages using a standard leak check bubble solution. With the concurrence

Table 3-3

INTERNAL LEAKAGE-RATE SUMMARY--VALVE CYCLE-LIFE TEST SERIES, PART NO. 1T32095-1

	Checkout						Cycle Life			Proof Cycle	Checkout	Valve Inlet Pressure (Gage)	
	* Parker Accept	Parker Accept	Pretest Baseline	* Pretest Baseline	Pre-Pass	Post-Pass	Post-Run No. 2	Post-Run No. 4	Post-Run No. 6	Posttest Baseline	* Posttest Baseline	(psi)	(pascals)
Total Cycles	12	18	39	42	45	50	84	201	366	927	933		
LF_2 Cycles	0	0	0	0	0	0	16	121	280	851	851		
	--	--	0.00	0.24		0.08	0.04	0.05	0.09	0.01	0.48	25	1.73×10^5
	--	0.40	0.00	0.46		0.12	0.10	0.10	0.12	0.23	0.78	50	3.45×10^5
	0.20	0.60	0.00	0.90		0.19	0.18	0.18	0.30	0.21	0.93	100	6.90×10^5
	12.00	0.72	0.03	1.35		0.29	0.46	0.26	0.40	0.27	1.20	150	1.04×10^6
	24.00	1.10	0.12	6.45		0.40	0.68	0.39	0.57	0.38	3.63	200	1.38×10^6
	38.20	1.40	0.13	11.10		0.52	0.90	0.53	0.74	0.52	5.83	250	1.73×10^6

*Measurements at LN_2 temperature (all others at local ambient temperature)

NOTES:
1. The posttest baseline measurements were made following disassembly, inspection, and reassembly of the valve; the failed poppet-shaft bellows seal was not repaired.
2. All leakage rates in ccm

Table 3-4

INTERNAL LEAKAGE-RATE SUMMARY--VALVE CYCLE-LIFE TEST SERIES, PART NO. 1T32095-501

	Checkout					Cycle Life				Checkout		Valve Inlet Pressure (Gage)	
	Parker Accept	* Parker Accept	Pretest Baseline	Pre-Pass	Post-Pass	Post-Run No. 1	Post-Run No. 2	Post-Run No. 3	Post-Run No. 6	Posttest Baseline	* Posttest Baseline	(psi)	(pascals)
Total Cycles	8	12	16	28	36	44	50	115	367	379	373		
LF_2 Cycles	0	0	0	0	0	2	12	61	307	307	307		
	--	--	0.09	0.15	0.11	0.00	0.04	0.04	0.00	0.00	0.12	25	1.73×10^5
	--	--	0.17	0.19	0.15	0.00	0.09	0.06	0.00	0.00	0.23	50	3.45×10^5
	0.80	2.85	0.27	0.27	0.27	0.00	0.11	0.08	0.00	0.00	0.47	100	6.90×10^5
	1.50	3.00	0.49	0.31	0.28	0.04	0.15	0.10	0.00	0.16	0.84	150	1.04×10^6
	1.85	9.00	0.71	0.39	0.43	0.07	0.22	0.12	0.02	0.25	1.67	200	1.38×10^6
	2.55	13.80	1.03	0.51	0.56	0.10	0.30	0.18	0.02	0.33	4.00	250	1.73×10^6

*Measurements at LN_2 temperature (all others at local ambient temperature)

Note: All leakage rates in ccm

of the NASA Project Manager, the ambient external leak checks were completed with the bubble solution. No leaks were detected in any of the basic housing static seals; however, a slight fuzz leak was detected at the test-adapter-to-housing interface on the -501 valve. Since this adapter was not part of the basic valve assembly, the small leakage was accepted. This test adapter was later reworked by MDAC-West during the Task III testing discussed in Section 3.3.

The external leakage tests at cryogenic conditions were attempted by submerging the pressurized valve in an LN_2 bath and visually observing for leakage bubbles. It was determined that the heat absorbed by the valve body from the pressurizing gases prevented complete thermal stabilization after a 1-hour (3.6×10^3 sec) soak, and it was not possible to distinguish between bubbles from the heat input and potential leakages.

A recheck was made of the jacketed vacuum chamber to see if the vacuum condition required by the mass spectrometer could be met without the valve installed. The required vacuum condition could not be maintained by the chamber under these circumstances. It was determined that the welds on the chamber and the main chamber seal were leaking at an unacceptable rate. Since extensive redesign or rework could be required to provide a leak-tight chamber, thus causing a significant schedule delay, it was decided to accept the ambient external leakage results obtained with bubble solution.

3.2.4.5 Functional Tests

The LN_2 functional tests were conducted by mounting the -1 valve in the outlet line of a 1,500-gal ($5.69\ m^3$) LN_2 storage tank, and controlling the LN_2 blowdown flow with the test valve. A total of 17 cycles was accumulated in this series of tests. The time response for the valve was predicted analytically before the test, and suitable control orifices were installed in the test specimen. The predicted time response for the valve with an unrestricted 450-psig (3.10×10^6 pascals) pneumatic supply was less than 10 msec. Since it was desirable to operate in the 50 to 75-msec closing response range, drilled orifices were installed in the pneumatic actuator pressure and vent lines. These orifices were 0.050 and 0.060 in. (1.27×10^{-3} and 1.52×10^{-3}m) in diameter, respectively. The measured time responses were 31 msec for opening, and 63 msec for closing.

The valve functioning was found to be smooth and reliable during the LN_2 functional tests. A recheck of the internal leakage rates was made after the LN_2 functional tests, and the leakage was found to be within the limits of the design objective.

3.2.4.6 Water-Flow Test

Full-scale water-flow tests, funded by MDAC-West, were conducted to determine the flow characteristics of the valve configuration. A model was fabricated from clear plastic and aluminum parts and set up as shown in Figure 3-6. A good estimate of the losses through a valve is given by Darcy's equation,

$$\Delta P = 1.112 \times 10^{-5}\ K\rho(Q/A)^2$$

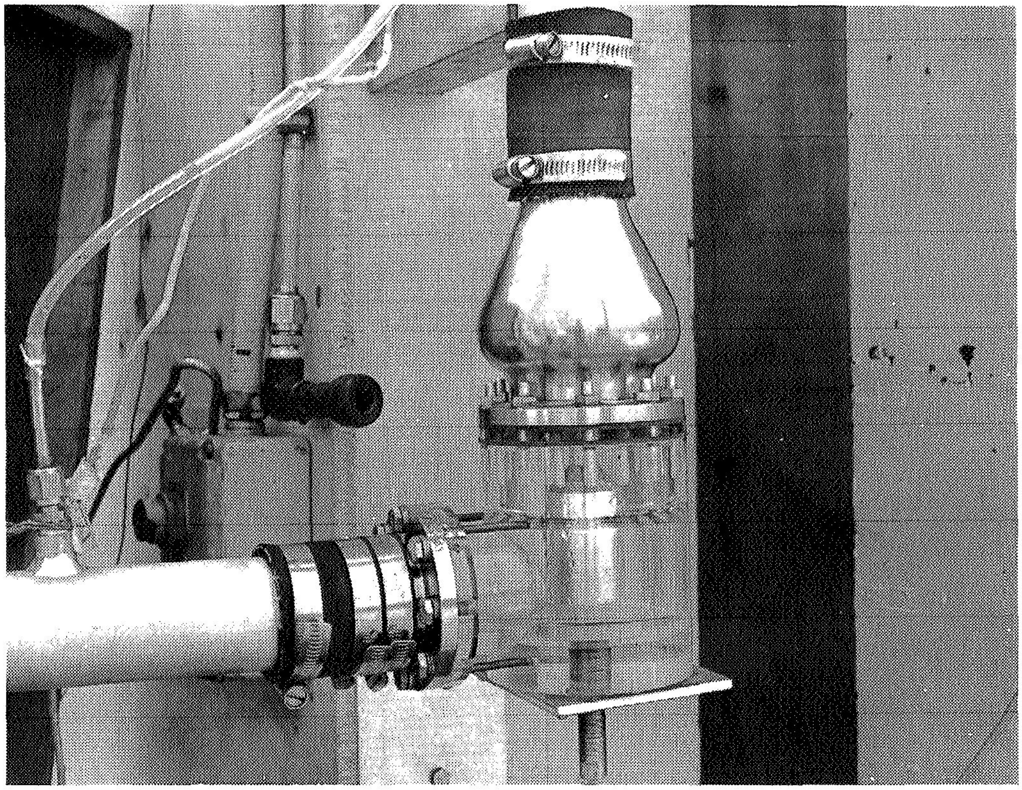

Figure 3-6. Water-Flow Model Test Setup

where

ΔP = pressure drop, psid (6.90×10^3 pascals)

K = resistance factor

ρ = fluid density, lb/ft^3 (1.60×10 kg/m^3)

Q = flowrate, gpm (6.31×10^{-5} m^3/sec)

A = equivalent flow area, in.^{2} (6.45×10^{-4} m^2)

A representative value for the flow factor K was found to be 3.3. This value indicates that the valve design has a very smooth flow passage, and the calculated pressure drop is well within the original target value of 5 psid (3.45×10^4 pascals) at 18 lbm/sec (8.18 kg/sec). The original pressure drop predictions were made with the conservative K value of 6, which corresponds to a ΔP of 2.4 psid (1.66×10^4 pascals) at 12 lbm/sec (5.45 kg/sec)of LF_2. The measured K value indicated that the pressure drop for the valve would be less than 1.5 psid (1.04×10^4 pascals) at the design flowrate of LF_2.

3.3 TASK III: FLUORINE COMPATIBILITY TESTING

The objective of this task was to perform full-scale evaluation tests of the two valves in an oxidizer system. The testing was conducted at the MDAC-West Fluorine Flow Facility (Figure 3-7) using LF_2 as a test medium. Testing was performed to verify the compatibility, cycle life, and leakage

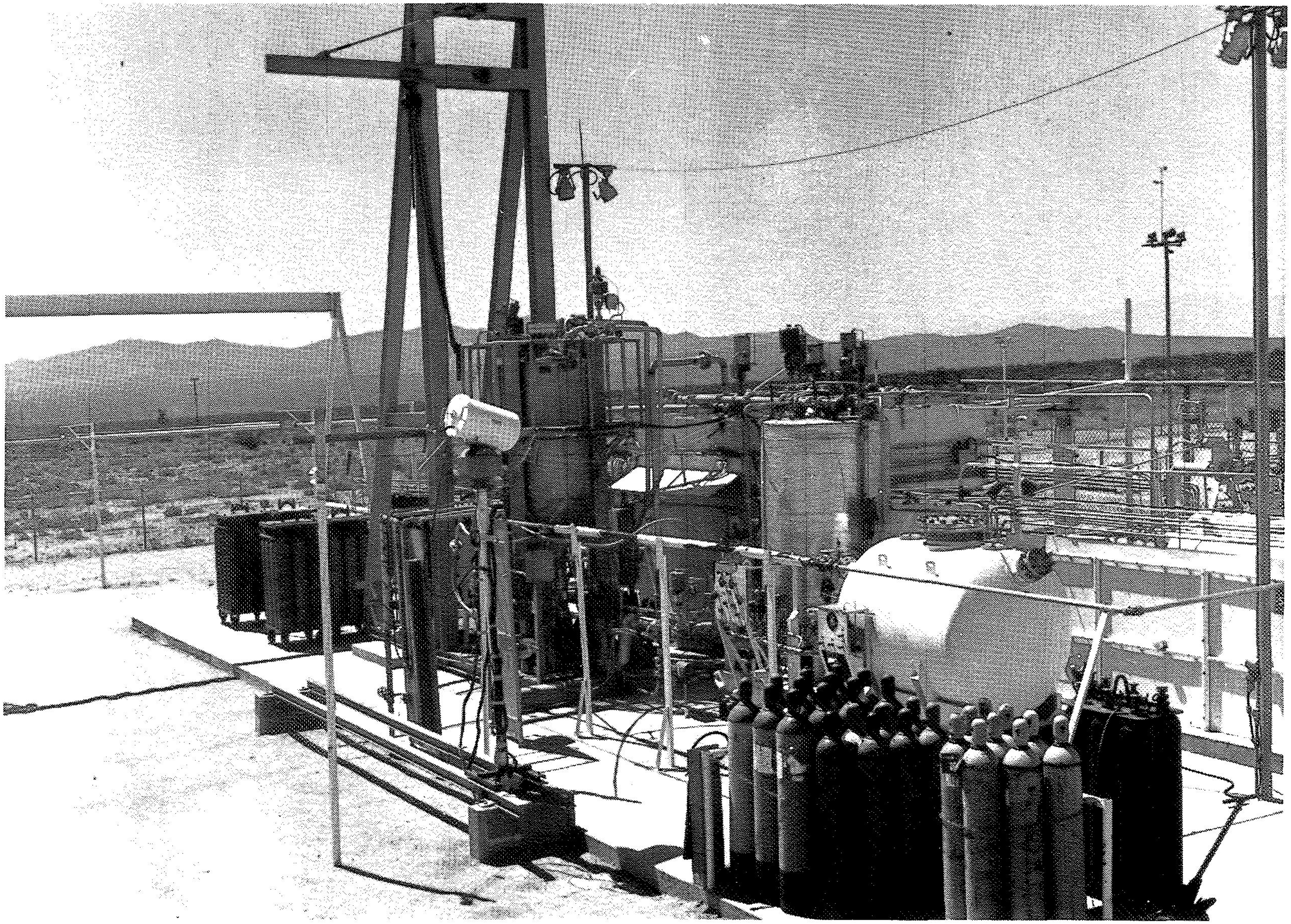

Figure 3-7. MDAC-West Fluorine-Flow Facility

characteristics of the two valve configurations in a fluorine environment. More specifically, it was desired to demonstrate that the valves could meet the NASA design and performance goals summarized in Table 3-1. Each valve was subjected to a 250-cycle life test at representative system pressures. The -1 valve was then cycled for an additional 570 cycles at its proof-pressure rating. At the completion of this task, the valves were cleaned and refurbished in preparation for the Task V environmental tests.

The -1 valve (hard-surface-on-hard-surface poppet/seat configuration) and the -501 valve (hard-surface-on-soft-surface poppet/seat configuration) were delivered to the test facility on 15 August 1969. Both valves were visually inspected for shipping damage, and the -501 valve, which was scheduled to be tested first, was given a preliminary internal leakage check.

Baseline functional and leakage checks of the -501 valve were performed in the clean room after correcting some initial test adapter leakage problems. The valve was installed in the LF_2 flow loop, leak checked, passivated with GF_2, and leak checked again. Six LF_2 cycle-life test runs were made during the period 16 through 23 October 1969. The test runs included steady-state and pulse-mode valve operation at system pressures of 25 psig (1.73×10^5 pascals) and 100 psig (6.90×10^5 pascals). Internal leakage of the valve was checked between runs, and at the conclusion of the test series. The valve was removed from the test stand and transferred to the clean room, where the baseline checks were repeated. A final check of the internal leakage rate was made with the valve immersed in LN_2. With 100 psig (6.90×10^5 pascals) applied to the valve inlet, leakage across the seat was less than 0.5 ccm (8.35×10^{-3} ccs) of GHe compared to the design goal of 1.7 ccm (2.84×10^{-2} ccs). This result was obtained after the valve had accumulated more than 300 operating cycles in direct LF_2 service.

Testing of the -1 valve was initiated on 27 October 1969 with the clean-room baseline checks. This was followed by pretest LN_2 cold-soak leakage checks, installation in the LF_2 flow loop, post-installation leakage checks, GF_2 passivation, and post-passivation leakage checks. Six LF_2 cycle-life test runs, paralleling those previously made on the -501 valve, were performed in the interval 31 October through 10 November 1969. The two initial attempts at Run 1 were aborted because of leaks at the interface between the test-valve inlet flange and the facility transfer-line adapter. Close examination of the installation disclosed that the tiedown and restrainer arrangement on the transfer-line bellows assembly permitted thermal contraction forces to decrease the preload on one side of the valve inlet seal, allowing the fluorine leakage to occur. Adjustments to the installation alleviated the problem, and the first six test runs were completed without further delay. At this time, the -1 valve had undergone 261 LF_2 cycles with no discernible degradation in performance. Before the Run 6 test operations were concluded, 19 additional valve cycles at 250 psig (1.73×10^6 pascals) were added to verify system integrity in preparation for Runs 7 and 8.

Runs 7 and 8 were performed on 12 November 1969 to determine valve cycle life at the proof-pressure level of 250 psig (1.73×10^6 pascals). Testing was terminated after 571 high-pressure LF_2 cycles when the valve failed to open. It was determined that leakage of fluorine into the actuator cavity had damaged the actuator piston seal, thereby preventing the valve from opening.

Subsequent disassembly and inspection revealed that the fluorine leakage originated in the poppet-shaft bellows seal which had developed a fatigue crack. The crack, caused by a ringing vibration of the poppet shaft when the actuator piston repeatedly reached the limit of its travel during valve closing, is an explainable failure at the stringent off-design pressure condition that was being tested.

Without attempting to repair the damaged bellows seal, the valve was reassembled and subjected to internal leakage checks of the poppet seat, both at ambient and at LN_2 cold-soak conditions. The final cold-soak leakage check yielded a leakage rate at 100 psig (6.90×10^5 pascals) of 0.93 ccm (1.55×10^{-2} ccs), still below the 1.7 ccm (2.84×10^{-2} ccs) design goal. By this time, the -1 valve had accumulated over 850 LF_2 operating cycles, 70 percent of them at the design proof-pressure level.

Table 3-5 summarizes the detailed test plan for satisfying the overall Task III test objectives. The plan calls for six test runs on each of the two test valves. The first two runs, conducted at a 25 psig (1.73×10^5 pascals) system pressure, involve only steady-state or low-frequency pulse-mode operation. The remaining four runs are all performed at the nominal valve-operating pressure of 100 psig (6.90×10^5 pascals), but require rapid pulse-mode operation, gradually increasing in pulse frequency. Each valve accumulates 260 operating cycles, equivalent to about 12 minutes (7.20×10^2 sec) of LF_2 exposure.

Two additional runs are performed on the -1 valve at the proof pressure condition of 250 psig (1.73×10^6 pascals). A maximum of 750 high-frequency pulse-mode operating cycles are scheduled, adding 6 minutes (3.6×10^2 sec) of LF_2 exposure time and bringing the total exposure time for the -1 valve to about 18 minutes (1.08×10^3 sec). All runs are made at an average LF_2 flowrate of 12 lbm/sec (5.45 kg/sec). The plan specifies internal leakage checks after Runs 1, 2, 3, and 6 for both valves, and after Run 8 for the -1 valve which is subjected to proof-pressure cycle-life testing. To provide a means of correlating possible valve performance degradation with the presence of LF_2 contaminants, periodic collection of LF_2 samples is also scheduled. The samples are taken during the final LF_2 test-tank loadings for Runs 1, 4, 6, and 8. Instances in which the actual testing deviated from the plan just described are discussed, if applicable, in the following paragraphs.

3.3.1 -501 Valve

By mutual agreement of the NASA and MDAC-West Project Managers, it was decided to initiate the LF_2 testing with the -501 valve, which had exhibited a somewhat high (but acceptable) low-temperature internal leakage rate at 100 psig (6.90×10^5 pascals) during the Parker Hannifin LN_2 cold-soak acceptance test (Table 3-4). In this way, the lower-leakage -1 valve would be reserved for the more stringent cycle-life test at proof pressure. Also, the -501 valve would be monitored for a possible improvement in internal leakage behavior with increasing poppet cycles.

3.3.1.1 Receiving Inspection Checks

The -501 test valve was delivered to the test facility on 15 August 1969, and found to be undamaged. A black-light check verified the cleanliness of the

Table 3-5

TASK III, FLUORINE COMPATIBILITY AND CYCLE-LIFE TEST CONDITIONS

Test Type	Run No.	No. of Cycles	Flow Time Per Cycle (sec)	Operating Pressure, Gage (psi)	Operating Pressure, Gage (pascals)	Leak Test	LF_2 Sample	Minimum Cumulative Flow Time (sec)	Minimum Total Run Time (sec)
Functional	1	2	60.0	25	1.73×10^5	X	X	120	120
Functional	2	8	15.0	25	1.73×10^5	X		240	120
Functional	3	40	3.0	100	6.90×10^5	X		360	120
Functional	4	50	2.5	100	6.90×10^5		X	485	125
Functional	5	75	2.0	100	6.90×10^5			635	150
Functional	6	85	1.5	100	6.90×10^5	X	X	763	128
Cycle Life	7	250	0.5	250	1.73×10^6			888	125
Cycle Life	8	500	0.5	250	1.73×10^6	X	X	1,138	250

NOTES:
1. Functional tests conducted with -1 and -501 valves.
2. Cycle-life tests conducted with -1 valve only.
3. Leak tests and LF_2 samples made for test runs indicated by X.
4. Leak tests performed after applicable test runs.
5. Collect LF_2 samples during loading for runs 1, 4, and 6, and during final loading for run 8.

component. To facilitate hookup of the valve in the clean room for a preliminary internal leakage check, it was necessary to install the inlet and outlet facility adapter fittings. A 0.050-in. (1.27×10^{-3}m) -dia control orifice was installed in the valve-actuation port, but had to be removed because it prevented normal valve actuation under hand-controlled pressure conditions. Apparently the gas leakage past the actuation seal counteracted the gradual increase in actuation pressure obtained by manually adjusting the clean room helium supply. A later check, in which the 0.050-in. (1.27×10^{-3}m) -dia orifice was reinstalled, and 450 psig (3.10×10^{6} pascals) helium was applied by a solenoid valve, provided proper valve actuation. Figure 3-8 shows the clean-room setup used in obtaining leakage rate data. One portion of the control and monitoring panel regulated the high-pressure gaseous helium (GHe) to 450 psig (3.10×10^{6} pascals) for test-valve actuation. Another portion, capable of supplying regulated GHe in the range from 25 psig to 250 psig (1.73×10^{5} to 1.73×10^{6} pascals) pressurized the test-valve inlet. Leakage past the poppet seat was directed to a volumetric leak detection apparatus consisting of a 10-cc graduated flask with 0.01-cc divisions, inverted in a container of water. The helium leakage rate was determined by noting the volume of water displaced in a 5-minute (3×10^{2} sec) time interval. Past experience had shown that this method provides reliable and reproducible results. The results of the preliminary leakage check were 15 to 30 percent lower than the corresponding Parker Hannifin ambient temperature acceptance values, but were within the expected cycle-to-cycle variation.

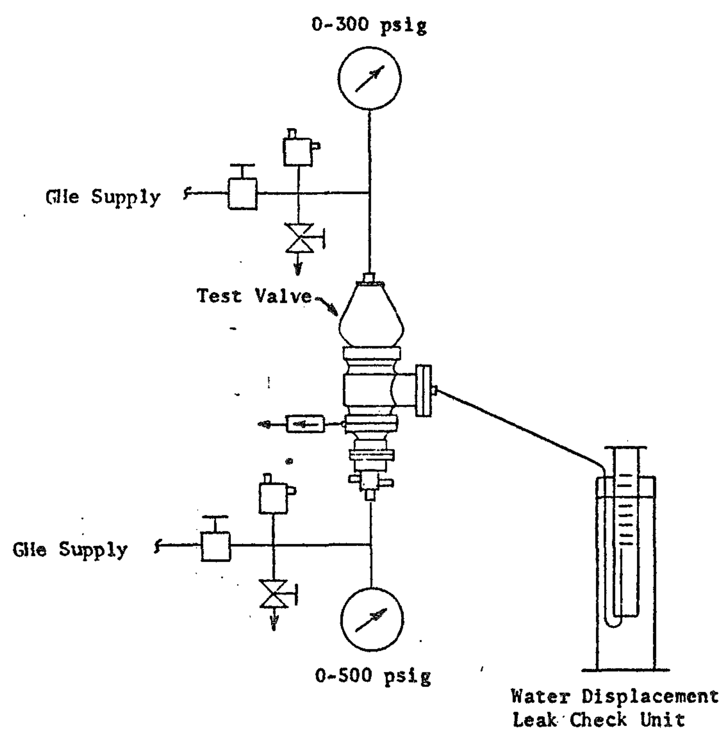

Figure 3-8. Schematic – Internal-Leakage Test Setup

3.3.1.2 Liquid Fluorine Delivery and Sampling

The LF_2 for the compatibility tests was obtained from the Allied Chemical Company of Metropolis, Illinois. The oxidizer was shipped as bulk liquid in a special liquid-nitrogen-jacketed tank truck, and arrived on 1 October 1969. Approximately 4,700 lbm (2.13×10^3 kg) of LF_2 were transferred from the tank truck to the 500-gal. ($1.90\ m^3$) storage tank.

A filter assembly was installed in the transfer line between the tank truck and the storage tank to intercept solid contaminants which, if present, would interfere with normal test-valve operation. The filter assembly consisted of the filter housing used on a previous contract (NAS 3-11195) to evaluate LF_2 filter elements, and a new MDAC-owned element. The housing assembly was used with the permission of the NASA-LeRC program group. The element was fabricated from sintered nickel wire using the criteria generated on the previous program. The element was similar to and interchangeable with the 60-μ (6.0×10^{-5}m) element tested before, but with a 10-μ (1.0×10^{-5}m) (18-μ [1.8×10^{-5}m] absolute) filter rating.

A slight modification of the filter housing permitted the installation of the fluorine sampling system shown in Figure 3-9. The upstream sample bottles were arranged to collect potential HF contamination, while the downstream bottles collected GF_2 samples (without HF). Non-volatile solid contaminants were trapped within the filter housing, and were recovered by disassembly of the filter.

To obtain a GF_2 sample, LF_2 flow was first established through the transfer line. The GF_2 sample isolation solenoid valve was opened, allowing LF_2 to flash into the previously evacuated sample bottles. After pressure equalization was complete, the sample isolation solenoid valve was closed. HF sample collection was initiated immediately after completion of the LF_2 transfer operation. Any HF present at this time would exist as a solid trapped in the upstream side of the filter assembly. First, the upstream and downstream filter isolation valves were closed. Then, residual fluorine was removed through the filter vent valve by means of a GN_2 ejector. Next, the HF sample isolation solenoid valve was opened and kept open until the filter-housing temperature probe indicated an ambient temperature reading. HF, if present, would melt and drain into the sample bottles where it would be trapped by closing the sample isolation solenoid valve. After closing the hand isolation valves, the GF_2 and HF bottles were disconnected from the system and sent to the chemical lab for analysis of their contents.

Using this sample method, no HF was detected during the storage tank filling operation, and analysis of the GF_2 samples indicated the presence of insignificant amounts of volatile impurities. However, a small amount of nonvolatile contaminate was obtained from the filter element after removal from the filter housing. The element was boiled in demineralized water, and back-flushed with demineralized water. The demineralized water was filtered with millipore paper, and the paper was oven-dried. This technique yielded 1.25 to 1.50 grams of particulate foreign material consisting of fluorinated iron, nickel, and calcium. Based on the results of all the sample analyses, it was concluded that the LF_2 was acceptable for the compatibility test series.

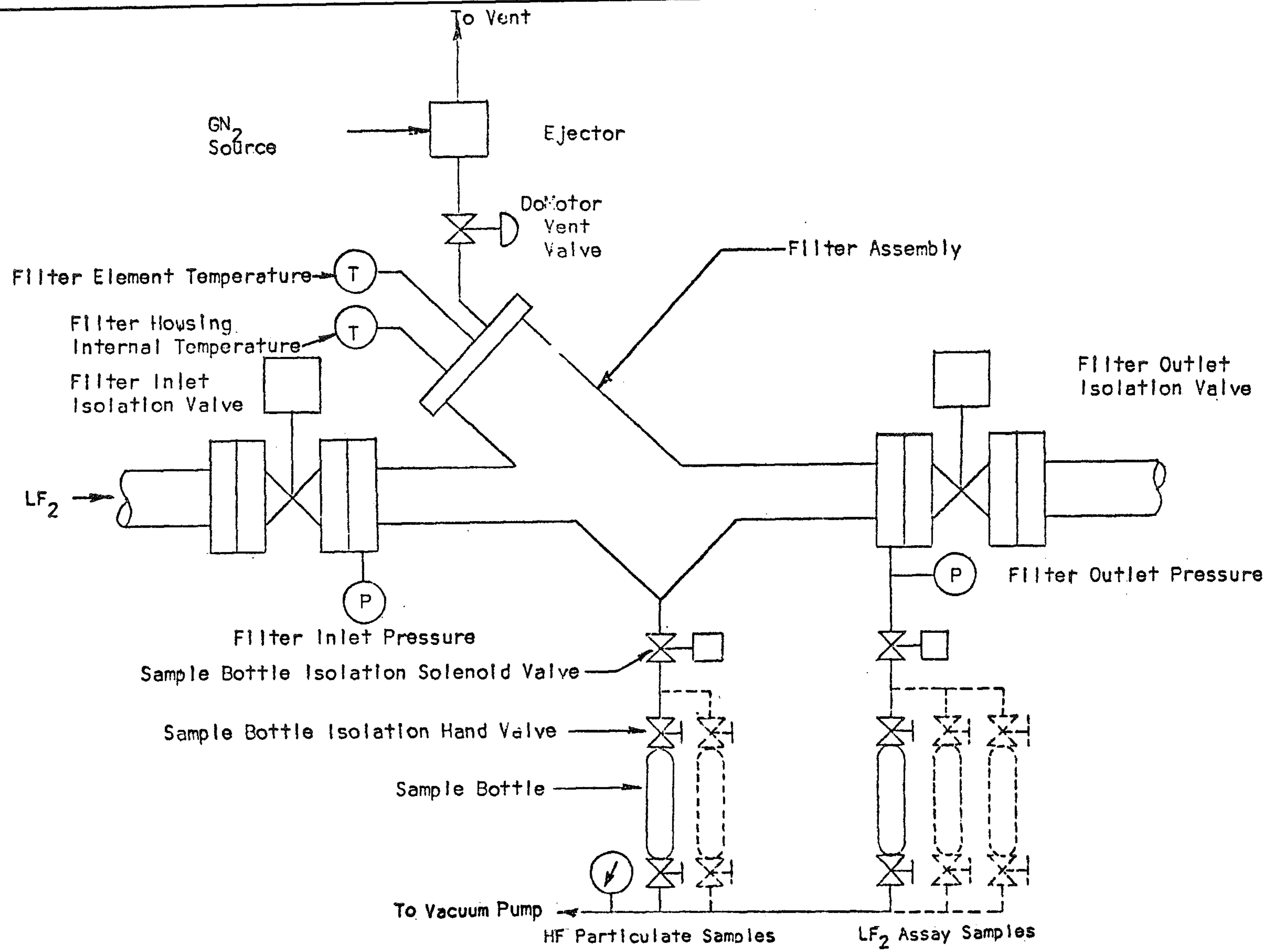

Figure 3-9. Schematic—Fluorine Sampler Setup

3.3.1.3 Clean Room Baseline Checks

In preparing for the pretest baseline checks of the -501 valve, leakage was encountered at both the inlet and outlet side of the valve at the static seal interface with the test adapters. These adapters included flightweight flanges at one end (to match the valve flanges) and massive facility flanges at the other end to mate with the heavy facility piping. In both cases, the leakage occurred where the flightweight adapter flanges mated with the valve body. These two interfaces were sealed with gold-plated W-section seals similar to the other static seals used in the construction of the valves. The leakage of these two seals was due to:

A. Slight warpage of the flanges caused by welding the adapter halves together.

B. Lack of compression on the seal element.

C. Marginal plating properties on the primary seal surfaces and tolerance stackup on the seal dimensions.

The seals are designed to seal properly by loading the primary seal area to a level of 2,500 to 5,000 psi (1.73×10^7 to 3.45×10^7 pascals). This arrangement is shown in Figure 3-10A. To obtain this loading, a groove depth of 0.096 in. (2.44×10^{-3}m) was specified by the seal supplier, and this value was used by Parker Hannifin in the design of the valves. All measurements made by MDAC-West indicated that the Parker Hannifin parts were properly machined to these dimensions. However, for critical applications, a redundant seal surface can be obtained by allowing the seal to compress as shown in Figure 3-10B. Although not required for normal liquid service, a redundant seal surface is recommended for sealing GHe at 250 psig (1.73×10^6 pascals), a test condition used routinely in evaluating valve poppet-seat leakage.

After leakage was detected at the inlet test adapter connection, the adapter was cryoshocked (i.e., submerged in LN_2) to relieve residual welding stresses, and then remachined to provide the specified 0.096-in. (2.44×10^{-3}m) groove depth. Leakage was still encountered after this rework, so a second rework was accomplished to reduce the groove depth to 0.092 in. (2.34×10^{-3}m). This provided an acceptable seal.

The outlet test adapter was then installed, and it was also found to leak. Unfortunately, this adapter contained a flexible bellows between the two flanges, so it could not be remachined on the available machine tools. Furthermore, the flightweight flanges were designed so that a pilot surface bottoms with a mating surface to control the groove depth (to prevent seal breakage from over-compression). Thus, over-torquing of the flange bolts has no effect on the seal compression, once the pilot bottoms. A special lapping tool was made, and the required 0.004 in. (0.10×10^{-3}m) was hand lapped from the pilot surface of the outlet test adapter flange. With the resultant 0.092-in. (2.34×10^{-3}m) groove depth, the outlet test adapter also sealed properly at 250 psig (1.73×10^6 pascals) when tested with GHe.

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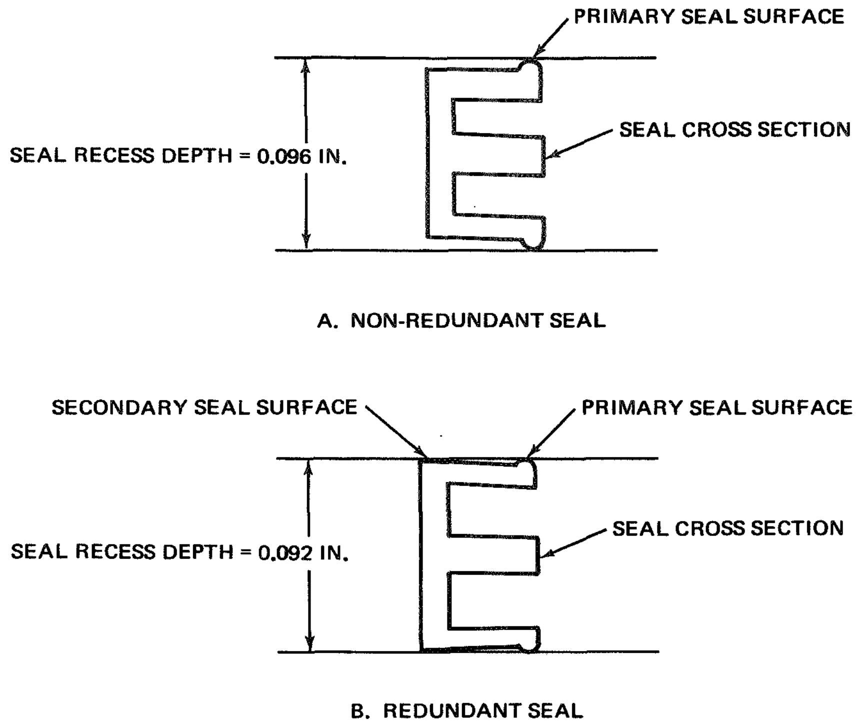

Figure 3-10. Effect of Loading on Static Seal Deflection

The pretest internal leakage checks of the -501 valve were completed in the clean room. These checks utilized the same leak detection apparatus described for the receiving inspection checks (as did all of the Task III leakage checks) and followed the same standardized procedure. Helium pressure at the valve inlet was increased in successive steps to 25, 50, 100, 150, 200, and 250 psig (1.73×10^5, 3.45×10^5, 6.90×10^5, 1.04×10^6, 1.38×10^6 and 1.73×10^6 pascals), and 5-minute (3×10^2 sec) readings of the stabilized leakage at the valve outlet for each pressure were recorded. The test valve was cycled before starting each series and three sets of readings were obtained. The three leakage rates at each pressure were then averaged arithmetically. The pretest baseline internal leakage rates for the -501 valve ranged from 0.09 ccm (1.50×10^{-3} ccs) at 25 psig (1.73×10^5 pascals) to 1.03 ccm (1.72×10^{-2} ccs) at 250 psig (1.73×10^6 pascals), with a value of 0.27 ccm (4.51×10^{-3} ccs) at the 100-psig (6.90×10^5 pascals) nominal operating pressure (Table 3-4). All leakage rates showed an improvement over those obtained during the receiving inspection checks. This improvement was probably because the sealing surface was cleaner for the pretest baseline checks than for the receiving checks, and because the gold-plated surface was becoming smoother as additional valve cycles were accumulated.

3.3.1.4 Valve Installation

The -501 valve was installed in the 3-in. (7.62×10^{-2}m) portion of the existing test section of the closed-loop fluorine flow facility using the inlet and outlet adapter spools designed for this purpose (Figure 3-11). The test installation (Figure 3-12) closely simulated the actual installation in a flight

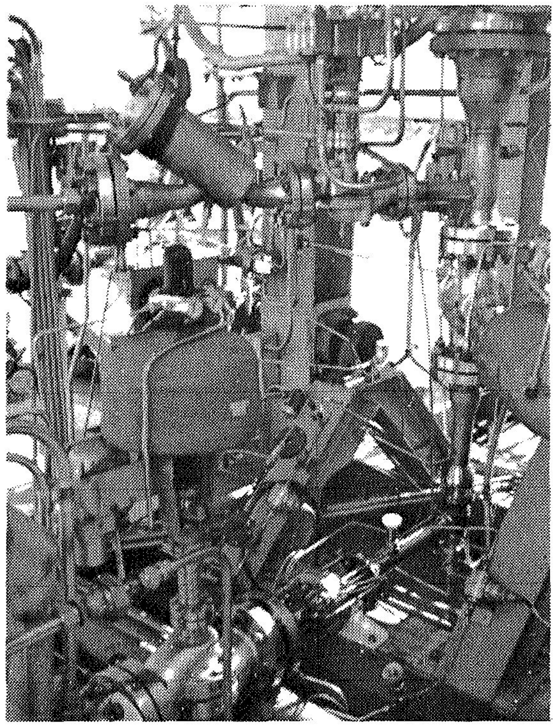

Figure 3-11. Test-Valve Installation in Fluorine Flow System

vehicle, with only a test tank isolation valve between the test valve and the tank to protect the facility in the event of a failure in the test section. The flow system test section was supplied by a liquid-nitrogen-jacketed, 120-gal (4.55×10^{-1} m^3), 700-psi (4.83×10^6 pascals) high-pressure test tank. The test tank was filled from the 500-gal (1.90 m^3) LF_2 storage tank through a line containing a 10-μ (10^{-5}m) filter assembly. This was the same filter assembly used during the LF_2 delivery and sampling operations. Its purpose was to minimize the danger of volatile or nonvolatile particulate matter entering the LF_2 flow loop where it could damage the test valve poppet seat. The filter assembly also retained the sampling features described earlier, permitting periodic monitoring of the LF_2 quality as the testing progressed. The LF_2 storage tank return line contained an orifice flowmeter and a throttleable control valve to allow the desired flowrate through the test section to be set and maintained.

The test valve actuation system consisted of a 500-psig (3.45×10^6 pascals) gaseous helium source, accumulator, and 3-way solenoid valve. Test valve cycling was automatically controlled by signals to the 3-way solenoid valve from a preset cycle timer located in the control trailer. A single 0.050-in. (1.27×10^{-3}m) -dia orifice installed in the test valve actuator pressurization port controlled the actuator response time for both opening and closing operations.

A gaseous helium source, offering accurate regulation and readout of pressures up to 250 psig (1.73×10^6 pascals) was connected immediately upstream of the test valve. When used in conjunction with the water

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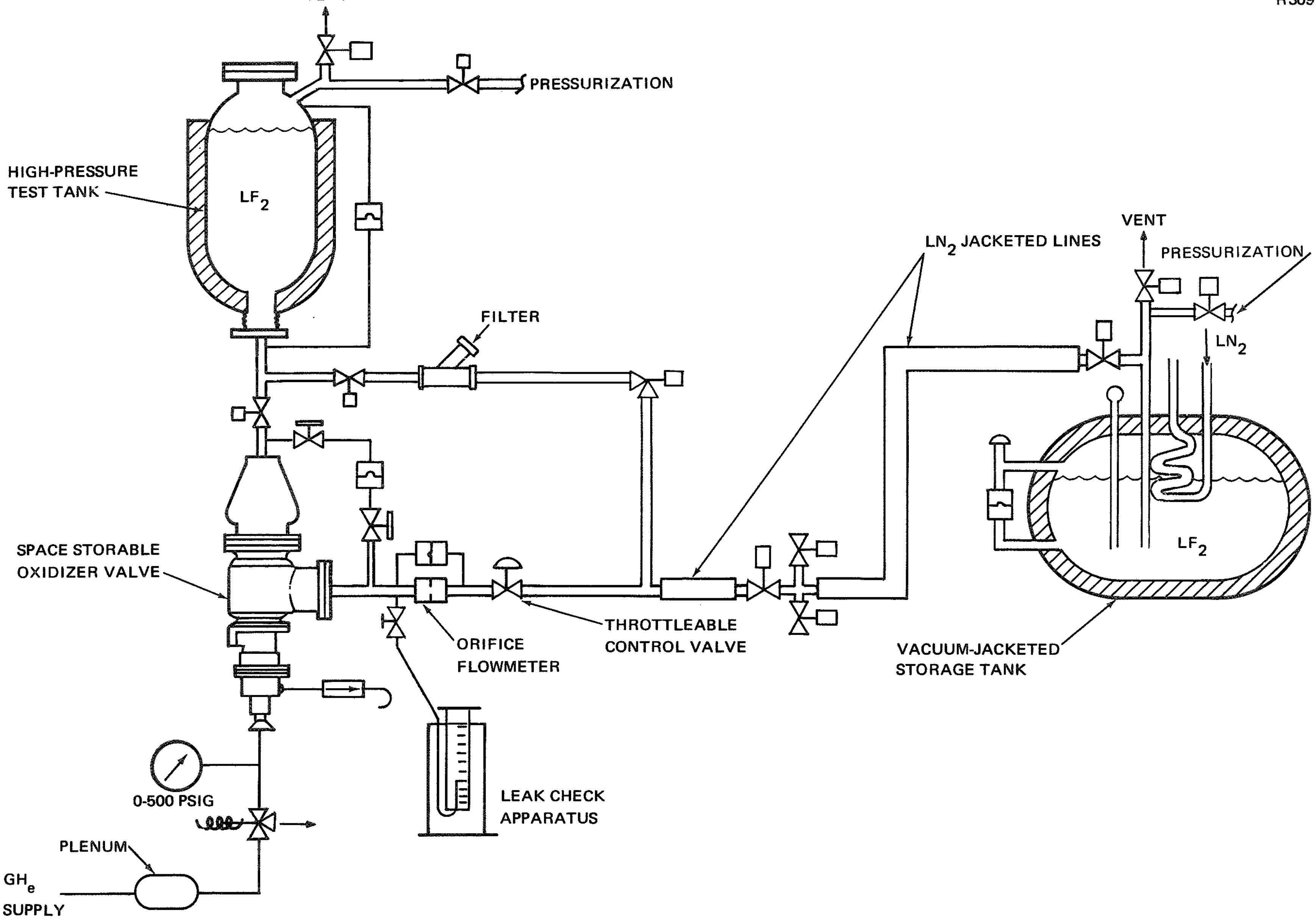

Figure 3-12. Fluorine Flow System Schematic

displacement leak check apparatus connected downstream of the test valve, it permitted on-the-spot internal leakage checks to be made between test runs.

Test instrumentation, in addition to that needed for routine facility operation, included the basic parameters used to evaluate test valve operation and performance, i.e., inlet and outlet pressures, pressure drop, actuator supply pressure, inlet and outlet fluid temperatures, body temperature, poppet position and response times, and fluid flowrate. These parameters, together with a suitable time code correlation, were recorded on a 36-channel oscillograph.

3.3.1.5 Postinstallation Leak Checks

Leakage rate measurements were repeated after the valve had been installed in the LF_2 flow system to verify that no damage had occurred to increase internal valve leakage. Table 3-4 shows that the leakage rates were comparable to or lower than the pretest clean-room baseline results. The leakage rate at 100 psig (6.90×10^5 pascals) remained unchanged at 0.27 ccm (4.51×10^{-3} ccs).

3.3.1.6 System Passivation

Simultaneous passivation of the facility plumbing and the test article was accomplished with GF_2 before permitting direct exposure of the hardware to LF_2. This was done by using GF_2 derived from LF_2 boiloff. Normally this would have been accomplished using three incremental pressure increases up to 150 psig (1.04×10^6 pascals) with a 10-minute (6×10^2 sec) hold at each pressure plateau. However, a malfunction in the isolation valve (FP-21) downstream of the test article resulted in a single pressure step to 150 psig (1.04×10^6 pascals), which was maintained for 30 minutes (1.8×10^3 sec). Monitoring of critical system temperatures during this time showed no abnormal behavior. The test valve remained open for the full 30-minute (1.8×10^3 sec) duration, assuring complete exposure of the operating parts.

3.3.1.7 Postpassivation Leak Checks

Another check of the internal leakage rates, performed after the GF_2 passivation operation, disclosed only minor deviations from the postinstallation checks. Therefore, the series was abbreviated to one set of 3-minute (1.8×10^2 sec) readings over the entire 25 to 250-psig (1.73×10^5 to 1.73×10^6 pascals) pressure range, plus several 5-minute (3×10^2 sec) readings at the upper and lower pressure extremes. Again, the leakage rate at 100 psig (6.90×10^5 pascals) was 0.27 ccm (4.51×10^{-3} ccs). The results are shown in Table 3-4.

3.3.1.8 Actuator Response Check

During the Parker Hannifin LN_2 functional tests (Section 3.2.4.5) the opening and closing response times were controlled by installing orifices of unequal sizes in the pressurizing and vent ports of a three-way solenoid valve that supplied helium to the test valve actuator. For LF_2 testing, MDAC-West utilized a single 0.050-in. (1.27×10^{-3}m) -dia orifice installed directly in the test valve actuator supply port. Before exposing the valve to LF_2, a response check with the revised control setup was made at ambient temperature conditions. With an actuation pressure of 450 psig (3.10×10^6 pascals) and 100 psig (6.90×10^5 pascals) GHe at the valve inlet, the opening response was 45 to 50 msec, and the closing response was 65 to 68 msec. This was accepted as a good compromise in opening and closing characteristics with a single control orifice.

3.3.1.9 Run 1

The first LF_2 compatibility test run on the -501 valve was initiated on 16 October 1969. After completing chilldown of the high-pressure test tank and transfer plumbing by flowing LN_2 through the cooling jackets, the test tank was filled to capacity with LF_2 from the storage tank. The contents of the test tank were transferred back to the storage tank through the test section. Flow took place under a system pressure of 25 psig (1.73×10^5 pascals), at an average LF_2 flowrate of 13 lbm/sec (5.90 kg/sec), and lasted 69 sec. The test tank was filled again. A second cycle of the test valve added another 30 sec of LF_2 flow, at an average flowrate of 13 lbm/sec (5.90 kg/sec), under a system pressure of 25 psig (1.73×10^5 pascals). The total flow time for Run 1 was about 21-sec short of the intended total, but valve operation and performance were satisfactory. Opening response was approximately 30 msec, and closing response was about 60 msec. Pressure loss through the valve was about 1.3 psid (8.98×10^3 pascals) at 12 lbm/sec (5.45 kg/sec). Ambient leakage checks made the next day indicated no leakage below 150 psig (1.04×10^6 pascals) and only 0.10 ccm (1.67×10^{-3} ccs) at 250 psig (1.75×10^6 pascals). GF_2 and HF samples collected during this run were later analyzed and found to contain negligible amounts of impurities.

3.3.1.10 Run 2

Run 2 was completed on 20 October 1969. Ten 15-sec flow cycles were made with an average flowrate of 11.3 lbm/sec (5.13 kg/sec) at a system pressure of 25 psig (1.73×10^5 pascals). Liquid fluorine was not maintained at the valve inlet for the final five seconds of the 10th cycle. Still, 145 additional seconds of flow time were accumulated, making up the flow deficit of Run 1. Performance was nominal. Ambient leakage rates obtained the next day were slightly higher than those taken after Run 1, but were substantially lower than the pretest baseline values. The leakage rate at 100 psig (6.90×10^5 pascals) was 0.11 ccm (1.84×10^{-3} ccs).

3.3.1.11 Run 3

Run 3, the first test completed at the 100-psig (6.90×10^5 pascals) nominal-design operating pressure level, was made on 21 October 1969. The run consisted of 49 cycles, with the cycle timer set for valve-open times of 2.25 sec. The average flowrates were 12 lbm/sec (5.45 kg/sec). Postrun internal leakage rates were generally lower than those observed after Run 2. The leakage rate at 100 psig (6.90×10^5 pascals) was 0.08 ccm (1.34×10^{-3}ccs).

3.3.1.12 Runs 4, 5, and 6

Runs 4, 5, and 6 were completed on 23 October 60. The three runs were treated as a single run requiring four fillings of the test tank. The test conditions were the same as those for Run 3, i.e., 2.25-sec cycles at an inlet pressure of 100 psig (6.90×10^5 pascals), and an average flowrate of 12 lbm/sec (5.45 kg/sec). A total of 258 cycles was accumulated. The only problem experienced was the failure of the valve differential pressure transducer after five cycles. The test was not delayed for the repair of this transducer, since the desired data were recoverable from the valve inlet and outlet pressures. Internal leakage rates measured after Run 6 were the lowest obtained to date. No leakage was detected in the 25 to 150 psig (1.73×10^5 to 1.04×10^6 pascals) range, and at 200 to 250 psig (1.38×10^6 to 1.73×10^6 pascals) leakage was only 0.02 ccm (3.34×10^{-4} ccs). A GF_2 sample was collected during the fourth filling of the test tank and an HF sample was obtained after the filter had warmed sufficiently. No significant contamination was found in the samples.

3.3.1.13 Posttest Clean-Room Baseline Checks

Following the successful completion of the -501 fluorine compatibility tests, the valve was removed from the test stand and taken to the clean room for a rerun of the baseline checks. No leakage could be detected at 100 psig (6.90×10^5 pascals) and below. At higher pressures, leakage rates fell between the postpassivation and post-Run 1 values, but were still approximately one-third of the pretest baseline values. The maximum leakage at 250 psig (1.73×10^6 pascals) was 0.33 ccm (5.52×10^{-3} ccs), compared to the pretest baseline value of 1.03 ccm (1.72×10^{-2} ccs).

3.3.1.14 Liquid Nitrogen Cold-Soak Checks

A final check of the -501 internal leakage was made on 24 October 1969, using the setup shown in Figure 3-13. The valve was immersed in a Dewar container filled with LN_2 and allowed to chill for approximately one hour (3.6×10^3 sec). During this time, the valve interior was purged with 3 to 5-psig (2.07×10^4 to 3.45×10^4 pascals) GHe which was precooled in a helical LN_2 heat exhanger. The valve body temperature stabilized at -312°F (82.2°K) as indicated by a thermocouple patch bonded to the external surface of the valve body. The leakage rates exhibited a dramatic drop from the original cold-soak acceptance values, and confirmed the definite downward trend evident in the ambient readings. After 307 LF_2 operating cycles, the cold-soak leakage rates ranged from 0.12 ccm (2.00×10^{-3} ccs) at 25 psig (1.73×10^5 pascals) to 4.00 ccm (6.68×10^{-2} ccs) at 250 psig (1.73×10^6 pascals), with 0.47 ccm (7.85×10^{-3} ccs) at the 100-psig (6.90×10^5 pascals) design point. Following these checks, the -501 valve was removed from the LN_2 bath, oven-dried in the clean room, packaged, and stored in anticipation of Task IV and V activities.

3.3.2 -1 Valve

After testing the -501 valve in LF_2, the -1 valve was subjected to a parallel test series.

3.3.2.1 Receiving Inspection Checks

The -1 and -501 valves were delivered to the Fluorine Flow Facility on 15 August 1969. When the valves arrived, both were given an initial visual inspection to confirm that no shipping damage had occurred. The -1 valve was then placed in temporary storage in the clean room until work could be completed on the -501 valve, which was scheduled to be tested first.

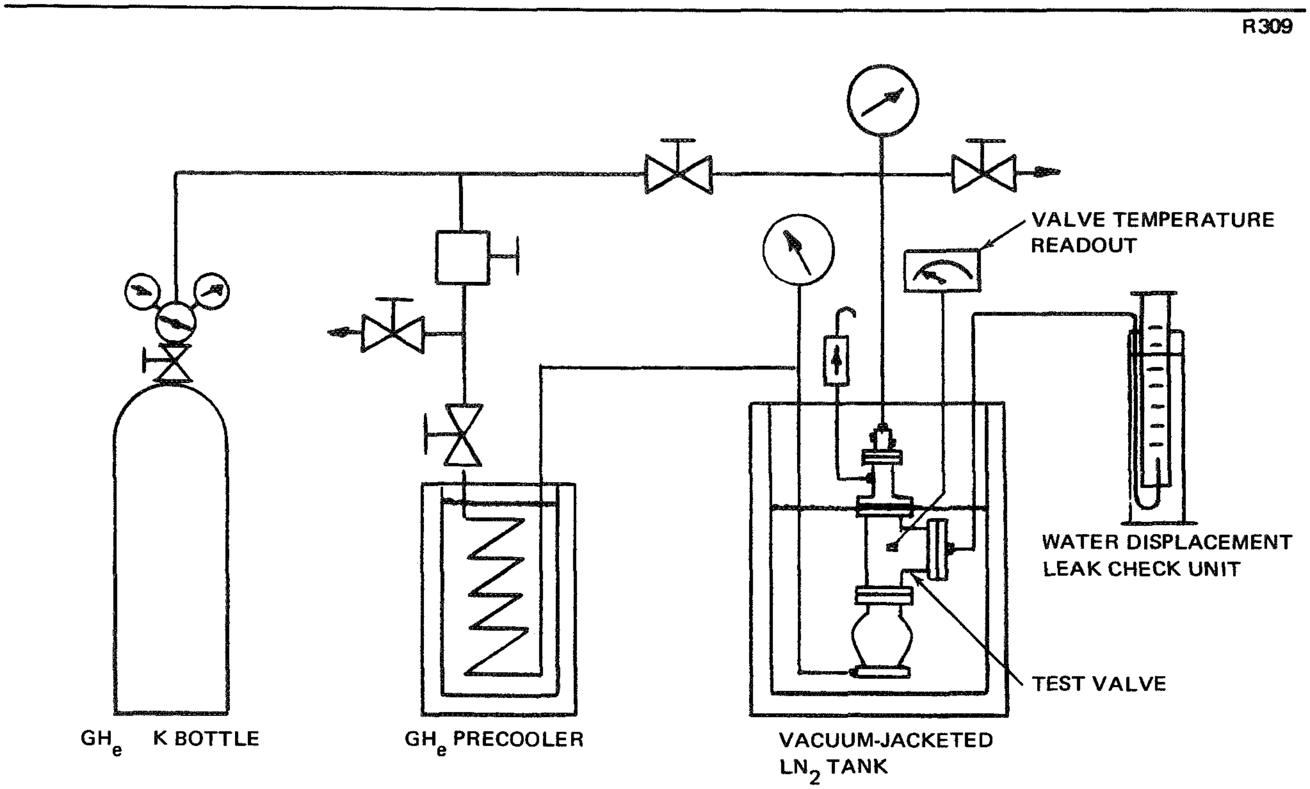

Figure 3-13. Schematic–Low-Temperature Internal-Leakage Test Setup

3.3.2.2 Clean-Room Baseline Checks

Clean-room baseline checks of the -1 valve were performed on 27 October 1969. After installing the test adapters, the valve was pressurized to 250 psig (1.73×10^6 pascals) and checked for external leakage. A leaking Omniseal in one of the position indicator mounting adapters was discovered and replaced to provide a leak-tight assembly. The internal leakage checks were made, using the same equipment and methods previously described for the -501 valve. Leakage (Table 3-3) was undetectable at 100 psig (6.90×10^5 pascals) and below, 0.03 ccm (5.01×10^{-4} ccs) at 150 psig (1.04×10^6 pascals), and 0.13 ccm (2.17×10^{-3} ccs) at 250 psig (1.73×10^6 pascals).

3.3.2.3 Pretest LN_2 Cold-Soak Checks

The -1 valve was also subjected to a series of pretest leakage checks under LN_2 cold-soak conditions using the setup shown in Figure 3-13. Readings ranged from 0.24 ccm (4.00×10^{-3} ccs) at 25 psig (1.73×10^5 pascals) to 11.1 ccm (1.85×10^{-1} ccs) at 250 psig (1.73×10^6 pascals), with 0.90 ccm (1.50×10^{-2} ccs) at the 100-psig (6.90×10^5) design point. The valve temperature during these tests stabilized at -312°F (82.2°K).

3.3.2.4 Valve Installation

The -1 valve was installed in the LF_2 test section on 29 October 1969. The installation was identical to that for the -501 valve (Figures 3-11 and 3-12). The 10-μ (10^{-5}m) filter was disassembled and inspected for particulate contamination. None was found, so the unit was reassembled for use during the remaining test runs.

3.3.2.5 Postinstallation Leak Checks

Postinstallation leak checks of the -1 valve were also made on 29 October 1969. During the external leakage checks at 250 psig (1.73×10^6 pascals), a small fuzz leak was noted at the valve inlet between the valve body and valve-seat flanges. The leakage was accepted without repair because the rate was extremely small, and because the initial test runs would be performed at an operating pressure of only 100 psig (6.90×10^5 pascals).

3.3.2.6 System Passivation

The -1 valve and the flow loop in which it was installed were simultaneously passivated with GF_2. With the test valve held in the open position, the system was evacuated to approximately 1 in. of mercury, absolute (25 torr, abs). Then the system was pressurized with GF_2, increasing the pressure incrementally at a rate of less than 25 psi/min. (2.88×10^3 pascals/sec) to 0, 75, 150, and 250 psig (0, 5.18×10^5, 1.04×10^6, and 1.73×10^6 pascals), and holding for 10 minutes (6×10^2 sec) at each pressure level.

3.3.2.7 Postpassivation Leak Checks

When the leak checks were repeated after the passivation operation, it was found that the fuzz leak at the valve inlet had disappeared. The internal leakage rates were somewhat higher than the pretest baseline values, but were still low, ranging from 0.08 ccm (1.34×10^{-3} ccs) at 25 psig (1.73×10^5 pascals) to 0.52 ccm (8.69×10^{-3} ccs) at 250 psig (1.73×10^6 pascals), with 0.19 ccm (3.18×10^{-3} ccs) at 100 psig (6.90×10^5 pascals).

3.3.2.8 Liquid Fluorine Compatibility Tests

The first six test runs planned for the -1 valve are identical to the corresponding -501 valve test runs. Two additional -1 valve test runs (Runs 7 and 8), not a part of the -501 testing, are to take place at the proof-pressure level of 250 psig (1.73×10^6 pascals). Table 3-5 shows the test program as planned. Details of the actual operations are discussed in the following paragraphs.

3.3.2.9 Run 1 (First Attempt)

Run 1 on the -1 valve was initiated on 31 October 1969. The first filling of the test tank was completed without incident, and the LF_2 was transferred back to the storage tank through the test section. This cycle provided 60 seconds of LF_2 flow through the test valve at 25 psig (1.73×10^5 pascals) and an average flowrate of 12 lbm/sec (5.45 kg/sec). The test tank was filled again, and the second flow cycle was started. Nineteen seconds later a fire warning light came on, and emergency shutdown operations were carried out. The fire detection system utilized several sensing wires strategically located in the immediate vicinity of the test article. If electrical continuity of any of the sensing wires was lost, a relay was tripped, and a warning light went on in the control trailer. Inspection of the test installation showed that there had been a small fire at the test valve outlet flange where it mates with the outlet test adapter. Except for some black sooty deposits from burned insulation on the fire detection sensor wires, the valve appeared to be undamaged externally.

The valve, with its adapters attached, was removed from the system and taken to the clean-room shop area where the soot deposits were removed. Torque readings were made on the valve outlet flange bolts and found to be within specification. The outlet adapter was removed and the seal and mating surfaces were carefully examined. There was no visible damage or evidence of leakage. The connection was reassembled, torqued, leak checked at 100 psig (6.90×10^5 pascals) and found to be leak free.

The test valve was moved to the clean room where it was thoroughly cleaned and oven-dried. After re-installing and leak checking the test adapters, an abbreviated set of baseline internal leakage checks (one reading at each pressure level) was performed. These leakage rates agreed closely with those taken just before the aborted Run 1 test (e.g., 0.20 ccm [3.34×10^{-3} ccs] at 100 psig [6.90×10^5 pascals] compared to 0.19 ccm [3.17×10^{-3} ccs] before Run 1).

After re-installation of the test assembly in the LF_2 flow loop, another set of internal leakage checks was made. These readings were also consistent with previous results (0.14 ccm [2.34×10^{-3} ccs] at 100 psig [6.90×10^5 pascals]. Repassivation of the test section was considered unnecessary and was therefore omitted.

GF_2 and HF samples taken during this run failed to show any significant LF_2 contamination.

3.3.2.10 Run 1 (Second Attempt)

Run 1 was attempted again on 4 November 1969. This time the test was aborted after only 10 seconds of LF_2 flow when a small fire was observed on the TV monitor screen. Shutdown was completed before the fire detection system sensing wires could fuse, so damage to the test installation was minor. The fire occurred around the top edge of the test valve outlet flange, just as it did in the previous test attempt. While the system was still cold, it was pressurized to 100 psig (6.90×10^5 pascals) and checked with a USON leak detector. A large leak in the vicinity of the valve outlet flange was discovered which disappeared as the system temperature returned to ambient. On the basis of this evidence, the cause of both fires was attributed to thermal contraction stresses in the facility plumbing, which unloaded the valve outlet seal. This problem was anticipated during the program planning stage, and was to have been solved by installing a braid-reinforced flexible bellows in the facility plumbing downstream of the test valve. However, schedule and budget constraints dictated the use of a plain bellows. This unit was adequate for relieving thermal stresses, but had a tendency to elongate and squirm under internal pressure. To correct these effects, a tie-rod restrainer assembly was permanently affixed to the test stand structure. Under test conditions, this arrangement allowed a buildup of thermal stresses which could unload the upper portion of the valve outlet seal. The problem was corrected by shimming the bellows support bracket and adjusting the tie-rod nuts to provide vertical and horizontal preloads that would compensate for thermal contraction. This compensation amounted to 0.125 in. (3.18×10^{-3}m) in both the vertical and horizontal directions.

3.3.2.11 Run 1 (Final Attempt) and Run 2

Runs 1 and 2 on the -1 valve were successfully completed on 6 November 1969. The requirement for Run 1 was changed to a single 60-sec cycle at 25 psig (1.73×10^5 pascals), since previous attempts had already accumulated 89 sec of LF_2 flow. The cycle was completed with no unusual occurrences. Run 2 was also completed without difficulty. This run required two loadings of the test tank and consisted of 11 cycles, each 15-sec long. The run was performed at a system pressure of 25 psig (1.73×10^5 pascals) and an average flowrate of 12 lbm/sec (5.45 kg/sec). A set of ambient leakage rates was obtained, but these measurements were taken on the day of the test rather than on the following morning, as was customary. The slightly higher leakages were probably due to the fact that the test assembly had not attained thermal equilibrium. The leakage rates ranged from 0.04 ccm (6.68×10^{-4} ccs) at 25 psig (1.73×10^5 pascals) to 0.90 ccm (1.50×10^{-2} ccs) at 250 psig (1.73×10^6 pascals), with a reading of 0.18 ccm (3.01×10^{-3} ccs) at 100 psig (6.90×10^5 pascals).

3.3.2.12 Runs 3 and 4

Runs 3 and 4 were completed on 7 November 1969. Run 3 consisted of 53 cycles, each 2.25 sec in duration, performed at a system pressure of 100 psig (6.90×10^5 pascals). An HF sample was collected during the test tank loading for Run 3. Run 4 consisted of 52 cycles carried out at identical test conditions. A GF_2 sample was also obtained from the Run 4 loading operation. Later analysis of both samples showed only trace quantities of contaminants.

Ambient internal leakage data collected after Run 4 were comparable to the postpassivation values. Leakage at 100 psig (6.90×10^5 pascals) was 0.18 ccm (3.01×10^{-3} ccs).

3.3.2.13 Runs 5 and 6

Runs 5 and 6 were successfully performed on 10 November 1969. Three fillings of the test tank were required. The tankings yielded, in succession, 54 cycles, 54 cycles, and 51 cycles, for a two-run total of 159 cycles. The cycles were performed at a system pressure of 100 psig (6.90×10^5 pascals) and each cycle was 2.25 sec in duration. No propellant samples were taken for these runs.

The original test plan was modified to add several high-pressure flow cycles at this time to verify the adequacy of the thermal contraction solution implemented after the unsuccessful Run 1 attempts. If the system leaked at the 250-psig (1.73×10^6 pascals) flow condition, it would be reworked before undertaking Runs 7 and 8. The cycle timer was reset to provide 1.5-sec pulses, and the instrumentation ranges were adjusted for the higher operating pressure. The test valve actuation pressure was increased to 550 psig (3.80×10^6 pascals) to permit operation with the higher back pressure. Nineteen cycles were then completed at 250 psig (1.73×10^6 pascals), with no indication of leakage.

Ambient internal leakage checks made the next day showed leakage rates somewhat greater than those observed after valve passivation. Leakages were 0.09 ccm (1.50×10^{-3} ccs) at 25 psig (1.73×10^5 pascals), 0.30 ccm (5.02×10^{-3} ccs) at 100 psig (6.90×10^5 pascals), and 0.74 ccm (1.24×10^{-2} ccs) at 250 psig (1.73×10^6 pascals).

3.3.2.14 Runs 7 and 8

In preparation for Runs 7 and 8, the valve cycle timer was set to provide a 0.5-sec open time, and a 1.5-sec closed time.

Runs 7 and 8 were performed on 12 November 1969. The first tanking yielded 193 valve cycles at 250 psig (1.73×10^6 pascals). A second tanking added 224 cycles. After 154 cycles of the third tanking (a total of 571 cycles for Runs 7 and 8), the test valve would not open. Counting the trial cycles after Run 6, this failure occurred after 590 LF_2 cycles at 250 psig (1.73×10^6 pascals). The actuator control pressure was increased to 600 psig (4.14×10^6 pascals) in an effort to make the valve actuate, but this was unsuccessful. However, when the system pressure was vented to 100 psig (6.90×10^5 pascals) the valve would still actuate. A heavy discharge of gas through the actuator vent line as opening pressure was applied, suggested a leaking actuator piston seal. Also, the presence of blackened areas where the vent gas impinged was a possible sign of fluorine leakage into the actuator cavity. The test was terminated at this time. After purging and securing were complete, the test valve was warmed up, removed from the system, and transferred to the clean room.

3.3.2.15 Disassembly, Inspection, and Reassembly

A preliminary visual inspection of the valve exterior showed some black deposits on the position indicator bosses and lock nuts (Figure 3-14). Otherwise, the valve's appearance was normal. The appearance of the valve's inlet and outlet flanges, internal cavities, and static seals after removal of the test adapters was also normal. The valve was disassembled, noting the tightening torque of each bolt or screw before removal. All torque values were found to be within specification. Removal of the actuator cap revealed black soot deposits around the entire circumference of the piston seal and the seal recess in the actuator cap (Figures 3-15 and 3-16). Also, two grooves were burned in the teflon seal where it contacted the piston (Figure 3-17). Later removal of the position indicator bosses and seals showed no evidence of damage or leakage. From this it is concluded that all external GF_2 leakage was through the actuator vent port. Next, the indicator nut, actuator piston, inner and outer springs, piston shims, and the actuator housing were removed. All of these parts were in good condition, showing no signs of fire damage. Minor impact marks on the actuator piston face, and spring scratches inside the actuator housing were the result of operation at the proof-pressure condition (Figures 3-18 and 3-19). At this time, the valve inlet was pressurized with 20 psig (1.38×10^5 pascals) GHe, producing audible leakage around the poppet shaft. The bellows adapter seal appeared to be leak-tight. Also, movement of the poppet shaft from side to side changed the intensity of the audible leakage, a strong indication that the poppet-shaft bellows seal was cracked. Finally, the poppet and the seat assemblies were removed (Figures 3-20 and 3-21). These parts and their associated static seals were in excellent condition. The mating flanges and seal recesses of the valve body and the seat showed some discoloration (Figures 3-22 and 3-23), but

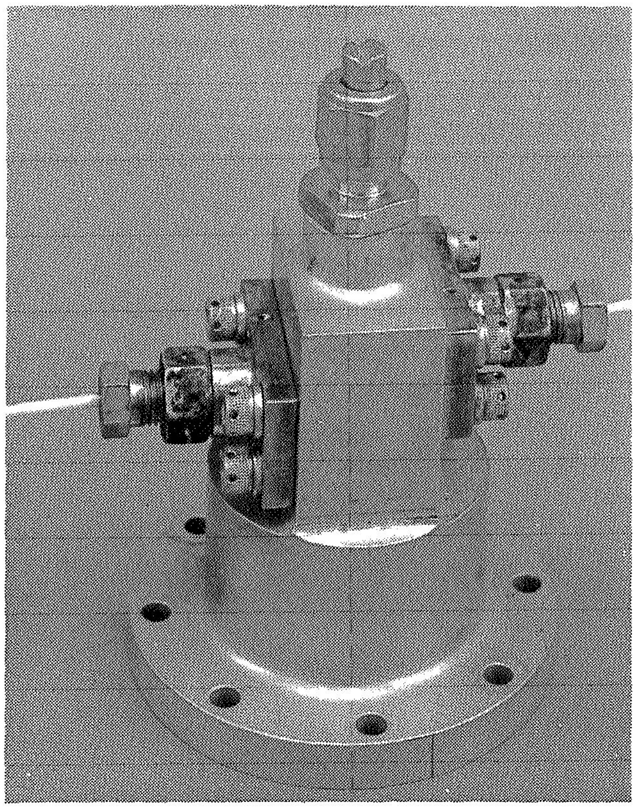

Figure 3-14. -1 Valve Actuator Cap After Task III Testing

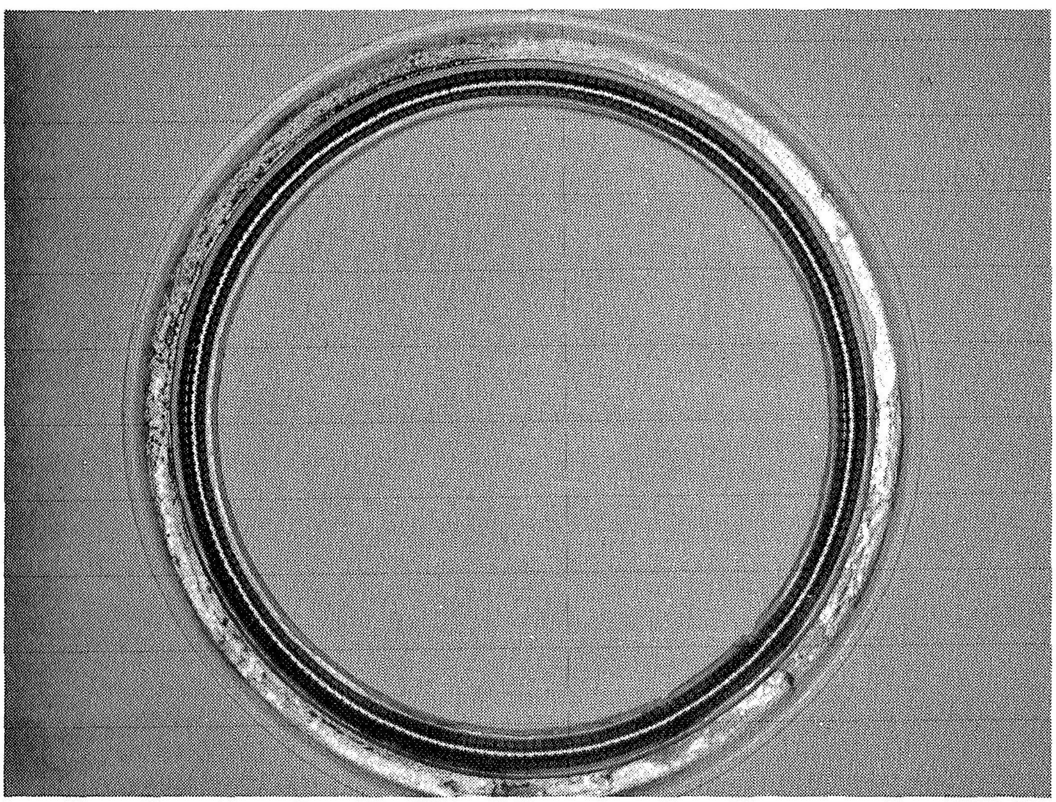

Figure 3-15. -1 Valve Actuator Piston Seal (Front Side) After Task III Testing

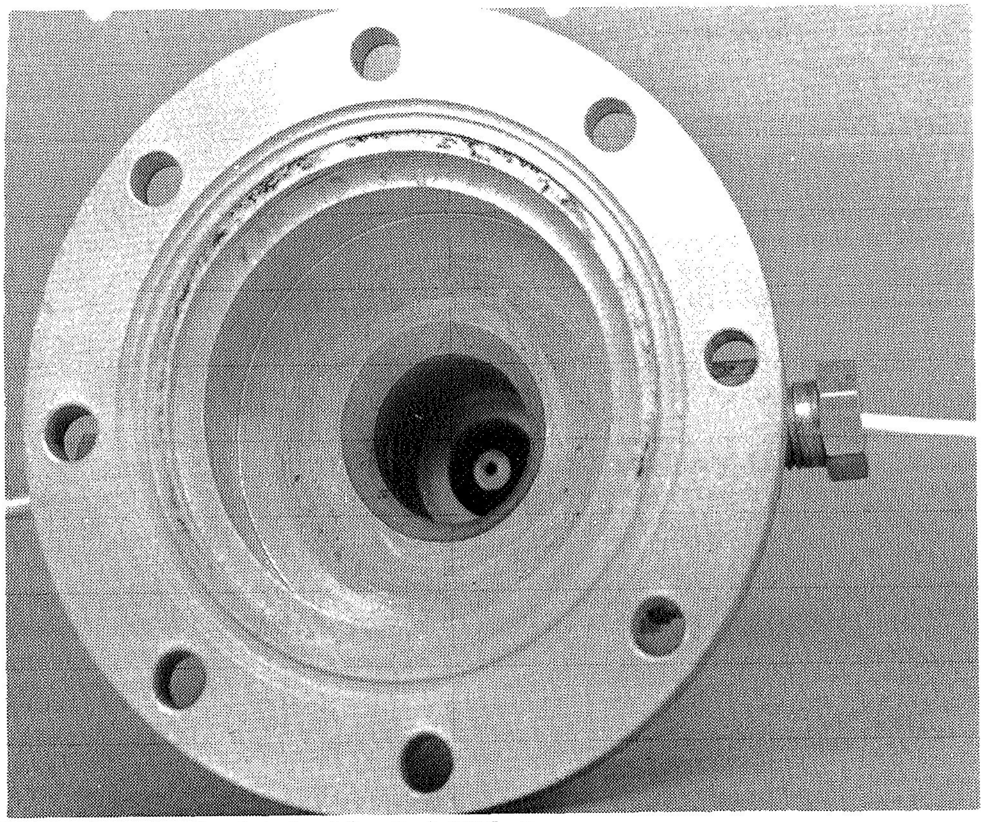

Figure 3-16. -1 Valve Actuator Cap Interior After Task III Testing

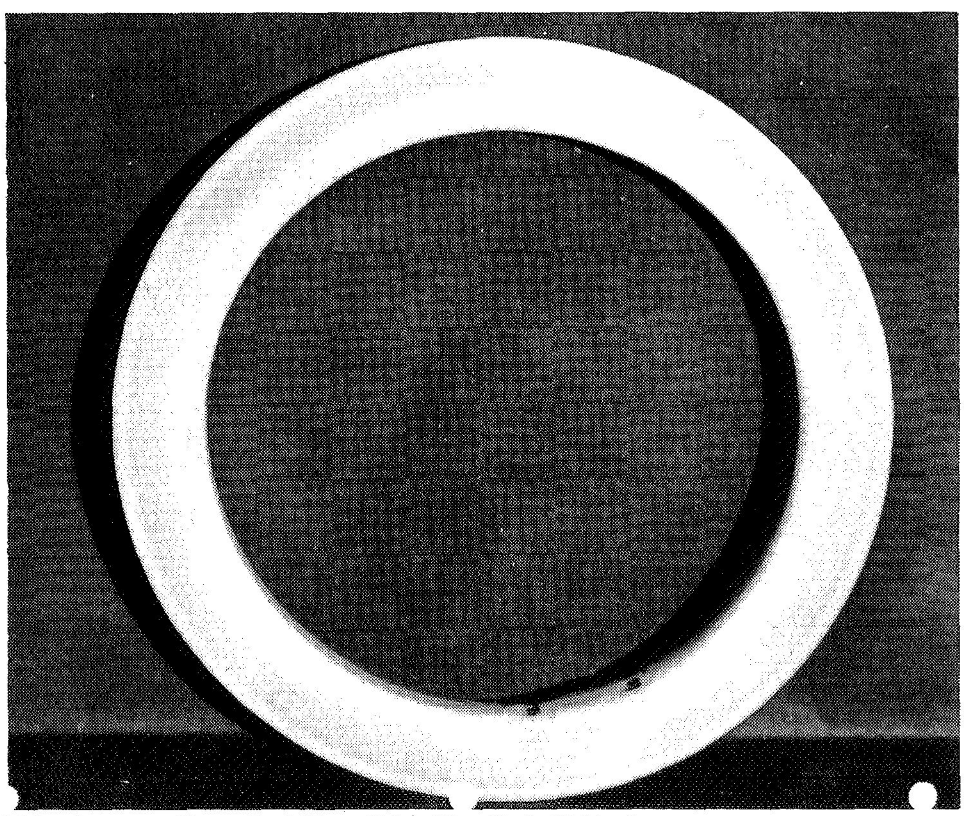

Figure 3-17. -1 Valve Actuator Piston Seal (Rear Side) After Task III Testing

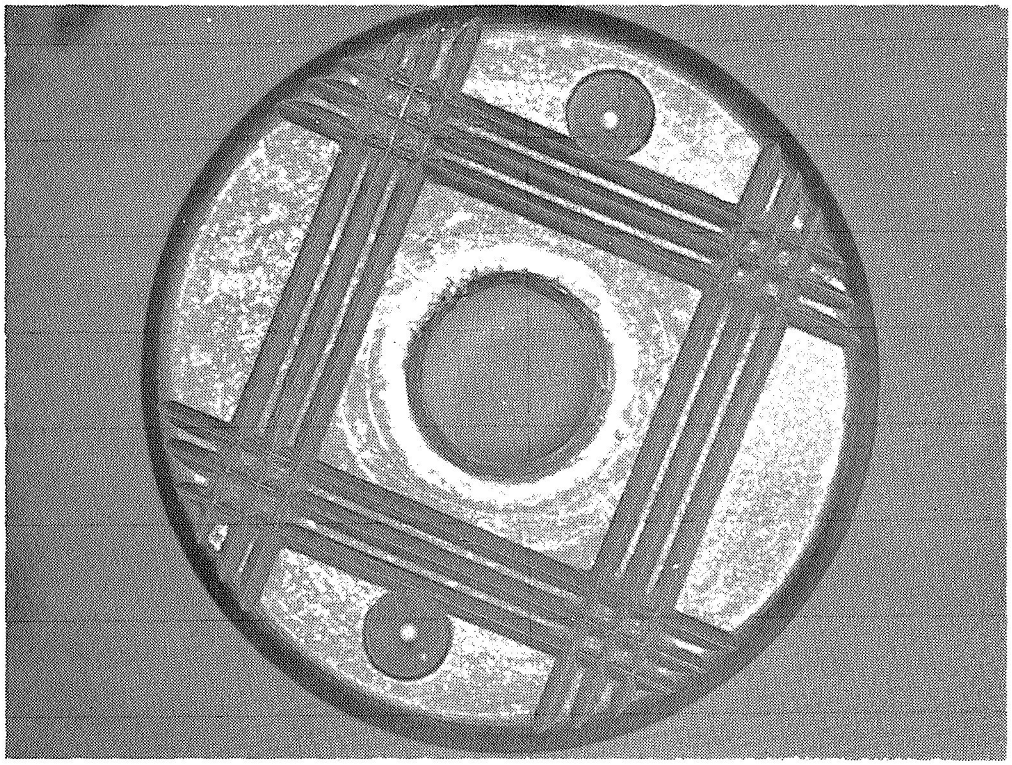

Figure 3-18. -1 Valve Actuator Piston After Task III Testing

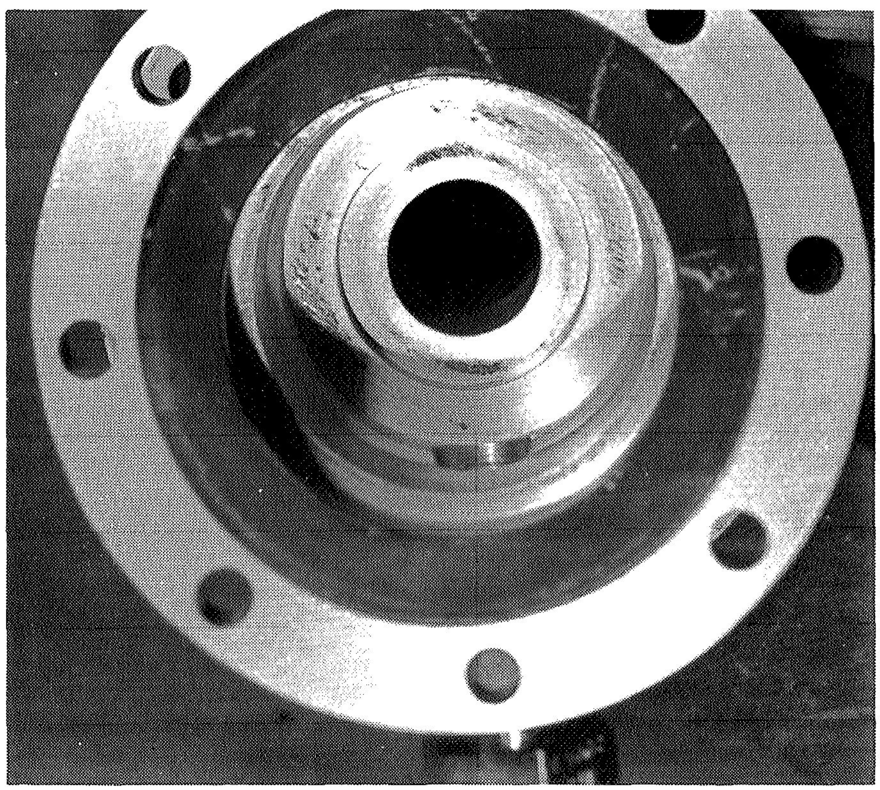

Figure 3-19. -1 Valve Actuator Body Interior After Task III Testing

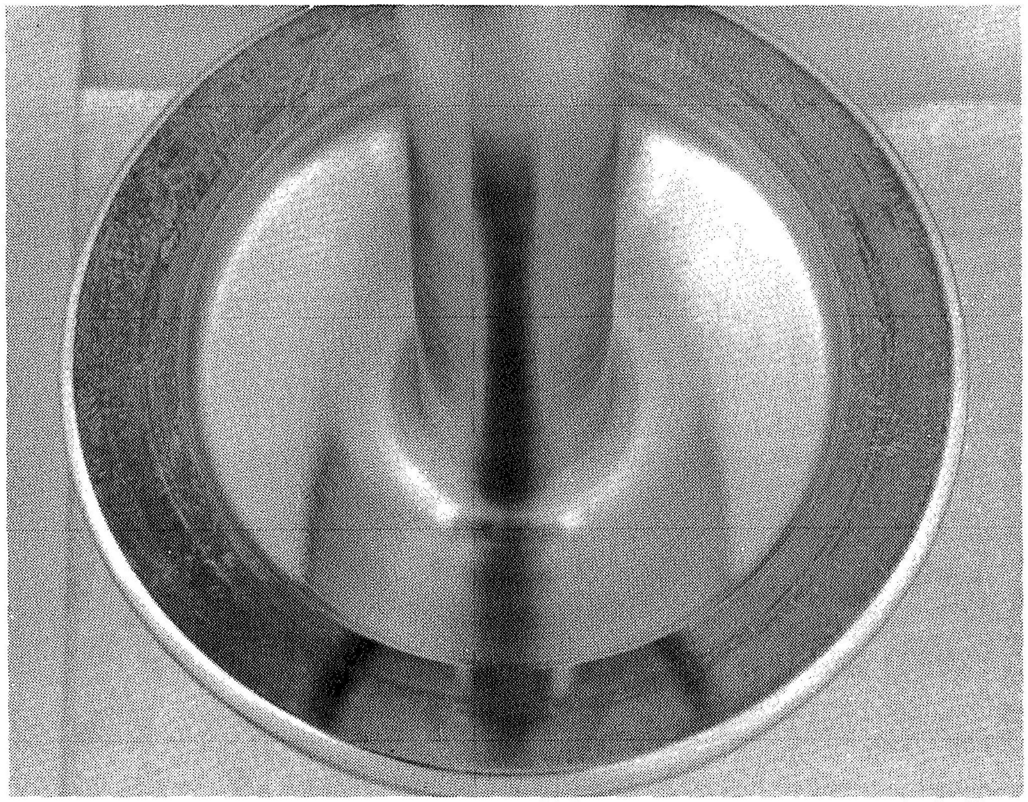

Figure 3-20. -1 Valve Poppet Face After Task III Testing

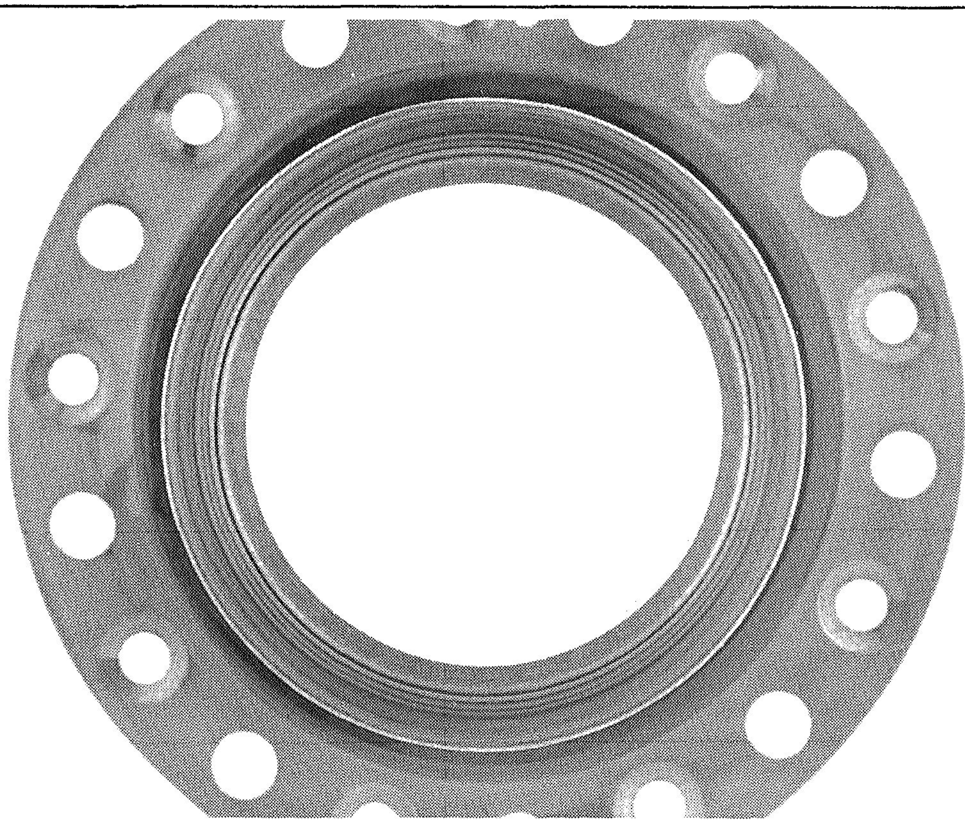

Figure 3-21. -1 Valve Seat (Front View) After Task III Testing

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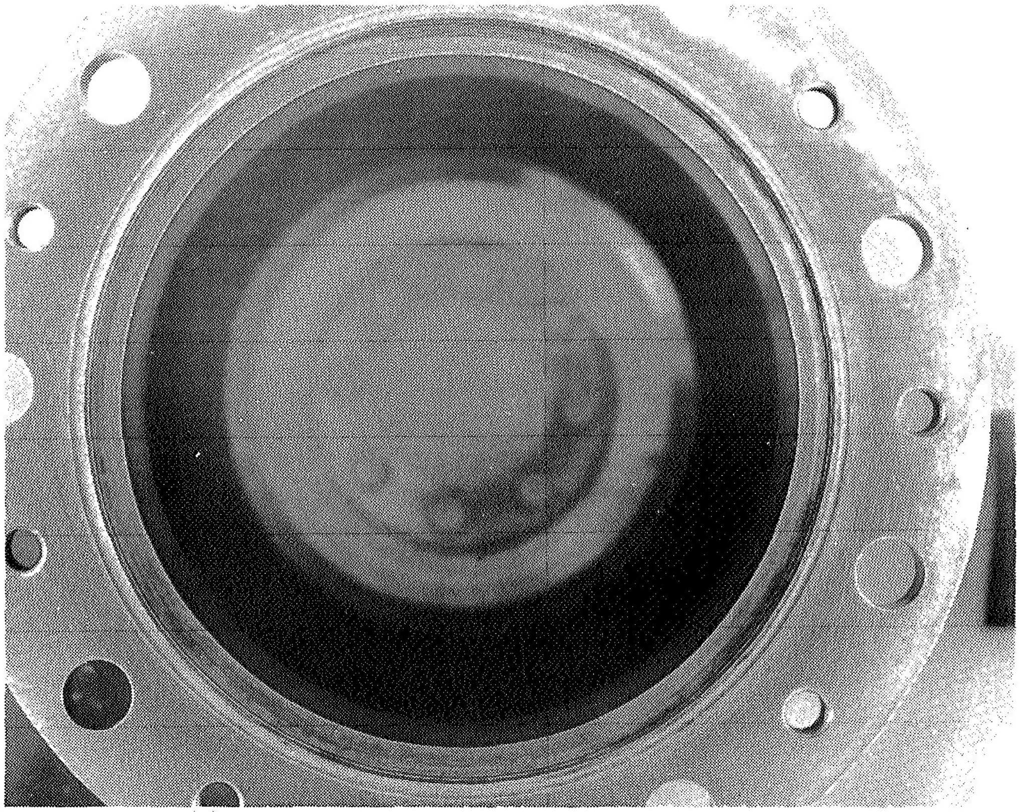

Figure 3-22. -1 Valve Body Inlet Flange After Task III Testing

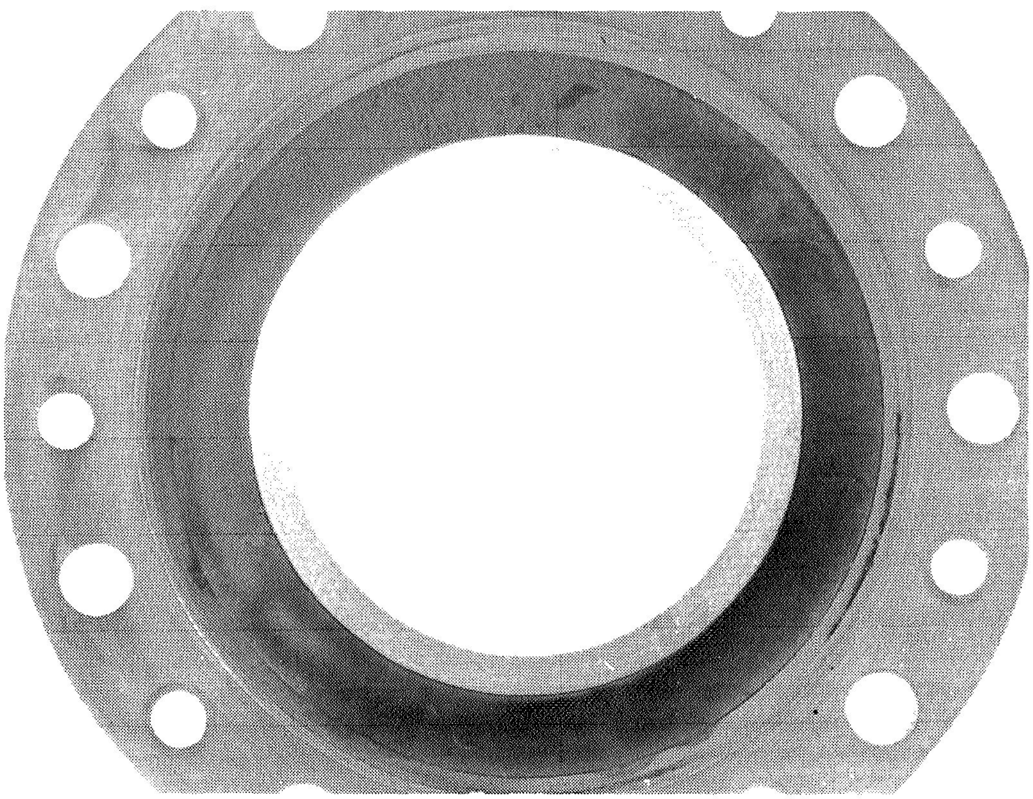

Figure 3-23. -1 Valve Seat (Rear View) After Task III Testing

this was later removed in a routine cleaning operation. Figure 3-24 shows the -1 valve completely disassembled.

Confirmation that the poppet bellows had failed required removal of the bellows shield by machining, which was accomplished at Parker Hannifin. The shield was separated from its adapter with a single lathe cut, exposing the bellows (Figures 3-25 and 3-26). Then, by use of shop air and bubble solution, the failure was determined to be a circumferential crack in the root of the first full convolution from the poppet end (Figure 2-27). Looking toward the poppet sealing surface, the crack extended approximately 50 degrees (8.73×10^{-1} rad) in a clockwise direction from the center of the shaft keyway.

On 10 December 1969 the -1 valve parts were transferred to the Gypsum Canyon facility. Here, the pieces were cleaned and reassembled. The reassembled valve duplicated as closely as practicable the configuration prior to disassembly. Exceptions were the replacement of the burned actuator piston seal, and the use of tape to hold the severed bellows shield in place.

3.3.2.16 Clean Room Baseline Checks

On 11 December 1969 the -1 valve was returned to the clean room for a final ambient check of the internal poppet seat leakage. The results were 0.01 ccm (1.67×10^{-4} ccs) at 25 psig (1.73×10^{5} pascals), 0.21 ccm (3.51×10^{-3} ccs) at 100 psig (6.90×10^{5} pascals), and 0.52 ccm (8.69×10^{-3}ccs) at 250 psig (1.73×10^{6} pascals). After 851 LF_2 cycles, 590 of which were performed at proof pressure, these leakage rates were approximately half of the design-goal values for ambient temperature.

3.3.2.17 Posttest LN_2 Cold-Soak Checks

Following the ambient checks, the LN_2 cold-soak configuration (Figure 3-13) was set up in an area adjacent to the clean room, and a final set of low-temperature leakage readings was obtained. The leakage rates were 0.48 ccm (8.01×10^{-3} ccs) at 25 psig (1.73×10^{5} pascals), 0.93 ccm (1.55×10^{-2} ccs) at 100 psig (6.90×10^{5} pascals), and 5.83 ccm (9.74×10^{-2} ccs) at 250 psig (1.73×10^{6} pascals). Leakage at the 100 psig (6.90×10^{5} pascals) design point was nearly identical to the pretest cold-soak value, while leakage at 250 psig (1.73×10^{6} pascals) had improved to a rate about half of the pretest value.

3.3.3 Test Results

The major results of Task III testing are discussed in the following paragraphs.

3.3.3.1 Internal Leakage

Internal leakage was one of the primary parameters used to evaluate valve performance during Task III testing. Leakage data were periodically collected as the testing of each valve proceeded according to the predetermined plan (Table 3-5). The leakage results are summarized in Tables 3-3 and 3-4.

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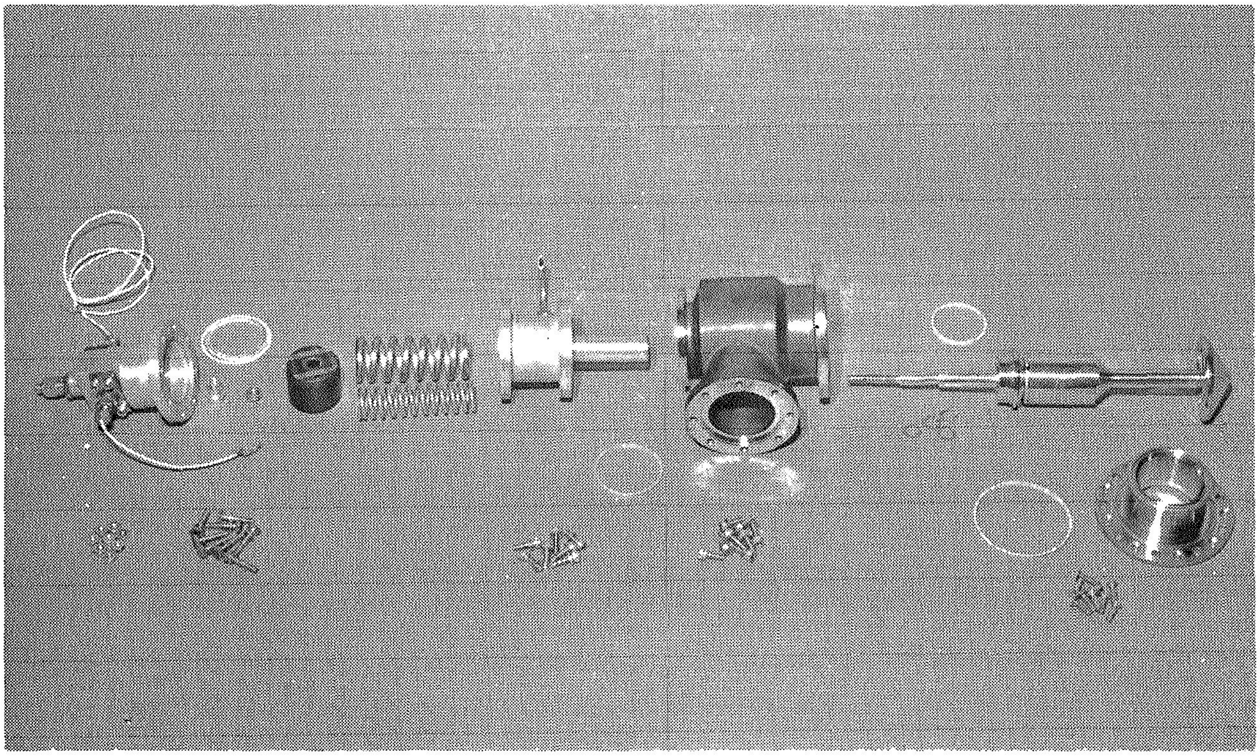

Figure 3-24. -1 Valve After Task III Testing (Disassembled)

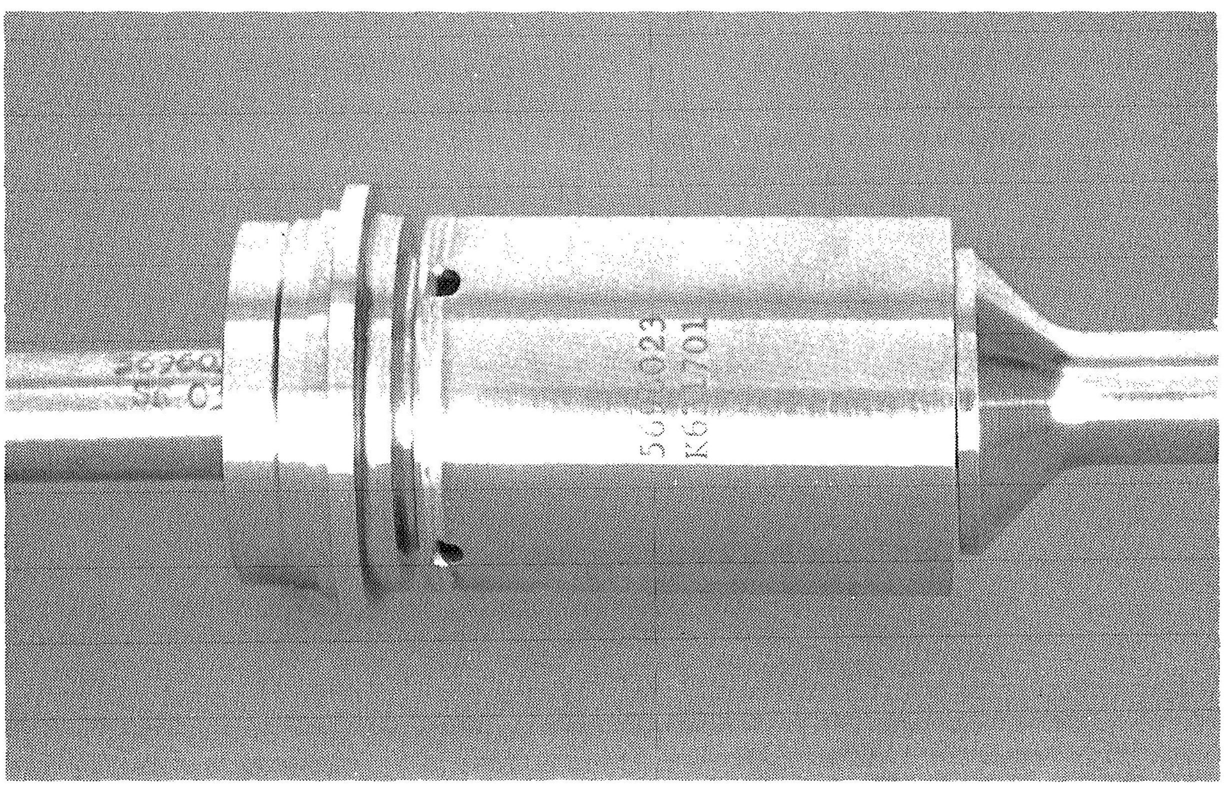

Figure 3-25. -1 Valve Poppet-Shaft Bellows Seal Assembly After Task III Testing.

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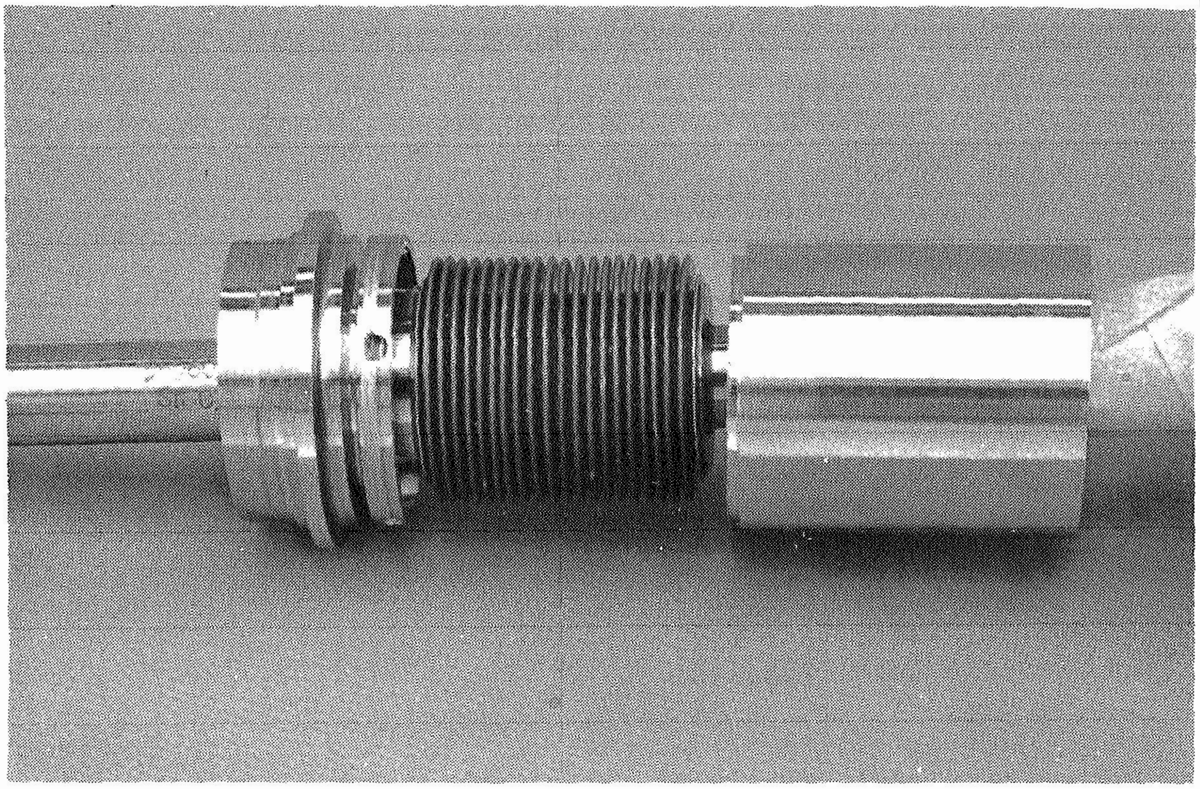

Figure 3-26. -1 Valve Poppet-Shaft Bellows Seal Assembly (With Shield Removed) After Task III Testing

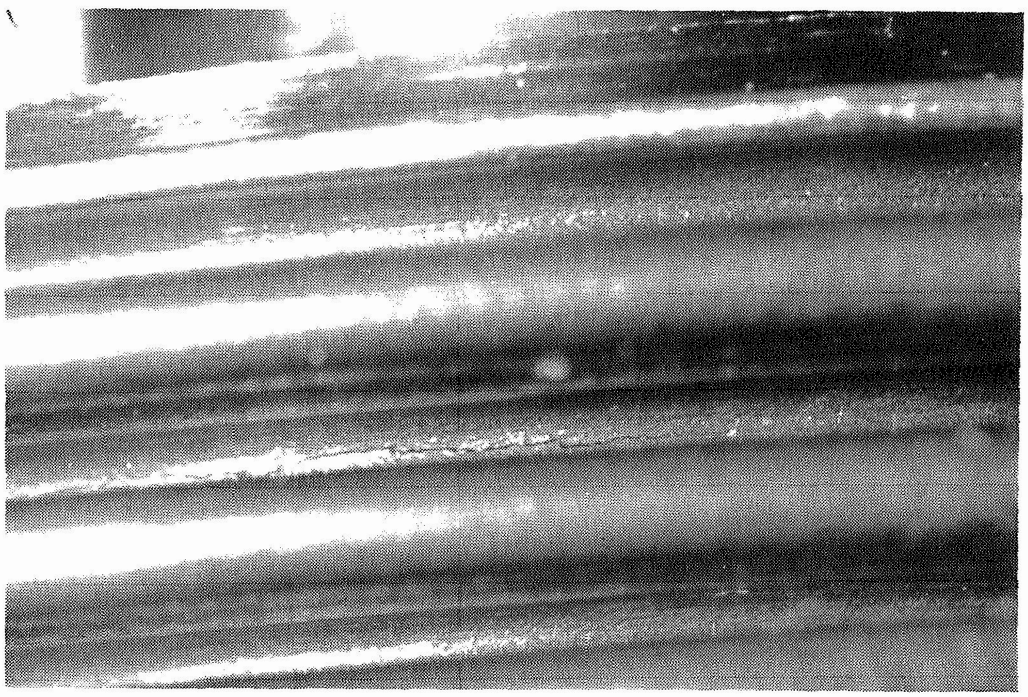

Figure 3-27. -1 Valve Poppet-Shaft Bellows Fatigue Crack

Since all internal leakage data were obtained volumetrically (Figures 3-8 and 3-13), the leakage results are given in volumetric units. These values can be converted to equivalent mass flow numbers by use of the conversions:

$$10^{-7} \text{ lbm/sec of } LF_2 \cong 1.7 \text{ sccm GHe at } -318°F$$
$$\cong 0.46 \text{ sccm GHe at } 60°F$$

$$(4.54 \times 10^{-8} \text{ kg/sec of } LF_2 \cong 2.84 \times 10^{-2} \text{ sccs GHe at } 78.9°K$$
$$\cong 7.69 \times 10^{-3} \text{ sccs GHe at } 289°K)$$

As mentioned earlier, the specified leakage limit of 10^{-7} lbm/sec (4.54×10^{-8} kg/sec) of LF_2 has been taken as equivalent to 10^{-8} lbm/sec (4.56×10^{-9} kg/sec) of GHe. Because of the uncertainty of this correlation, the volumetric conversion factors given above should be used with caution. Preferably, the data in Tables 3-3 and 3-4 should be regarded as representing leakage trends during the test series, rather than denoting absolute leakage rates at specific times.

Although the test valves are designed for operation at 100 psig (6.90×10^5 pascals), a complete leakage profile was made from 25 psig (1.73×10^5 pascals) to the proof-pressure condition of 250 psig (1.73×10^6 pascals). This wide spectrum of readings was taken to provide additional background data for evaluation of valve performance. Figure 3-28 compares -501 valve leakage observed after 373 cycles, with a theoretical plot of off-design leakage based on the 100 psig (6.90×10^5 pascals) design-point value. The theoretical curve shows the change in leakage due to both the change in pressure differential, and the change in apparent seat stress, that occurs with the pressure-balanced design. The seat stresses drop from 8,000 psi (5.53×10^7 pascals) at the 100-psig (6.90×10^5 pascals) level to 2,000 psi (1.38×10^7 pascals) at the 25-psig (1.73×10^5 pascals) level. The seat stress value at 150 psig (1.04×10^6 pascals) is 12,000 psi (8.30×10^7 pascals), and good correlations of test data with analytical data are obtained over the 25 to 150-psig (1.73×10^5 to 1.04×10^6 pascals) range. At slightly over 150 psig (1.04×10^4 pascals), the poppet shaft assembly bottoms on the actuator housing (at LN_2 temperature) and no further increase in seat stress is possible. With further increases in upstream pressure, the seat stresses will decrease as the pressure forces unload the seat. The test data indicate that the seat stresses have decreased from the peak value of about 12,000 psi (8.30×10^7 pascals) at 150 psig (1.04×10^6 pascals) to about 6,500 psi (4.49×10^7 pascals) at 250 psig (1.73×10^6 pascals). This condition can be corrected, if operation at the higher pressure is desired, by changing the spring rates of the actuator springs or the seat bellows assembly, and then adjusting the poppet seat area to return the apparent seat stresses to the desired conditions. Since no requirement for leakage control at 250 psig (1.73×10^6 pascals) existed on this program, the valve was not redesigned for the higher pressure.

As expected, the -501 valve showed an improvement in internal leakage with cycling. The initial leakage of 0.27 ccm (4.51×10^{-3} ccs) dropped to 0 at ambient temperature conditions at the end of the test (307 cycles), and the low-temperature data showed a drop from an unacceptable 2.85 ccm (4.76×10^{-2} ccs) to an acceptable 0.47 ccm (7.85×10^{-3} ccs) after cycling. This decrease in leakage appears to have occurred during the first few cycles in LF_2, with the leakage rate remaining fairly constant for the duration

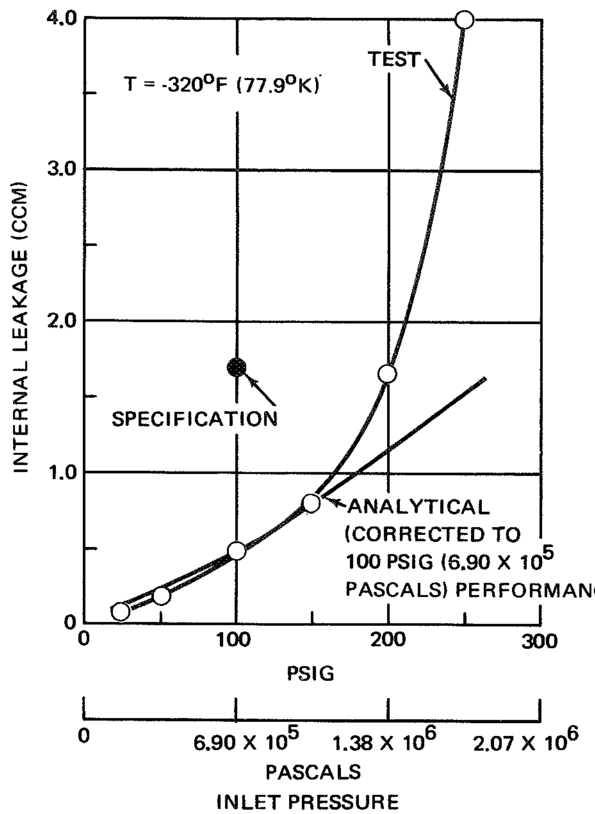

Figure 3-28. Low-Temperature Internal Leakage of -501 Valve After 373 Cycles

of the cycle-life testing. This change in leakage rate early in the testing could be due to several factors. It may have resulted from some flattening of the gold-plated surface from the loading of the seat; from a change in surface characteristics arising from exposure to LF_2; or from the removal of a small amount of contamination from the sealing interface by LF_2. Since a decrease in leakage from 0.80 ccm (1.34×10^{-2} ccs) to 0.27 ccm (4.51×10^{-3} ccs) occurred during the estimated 16 cycles of pretest checkout, it appears that a significant leakage decrease was due to a slight plastic deformation of the sealing surface because of seat loading. Comparison of pretest and posttest leak rate data indicates the change in leakage measured after cycling corresponds to a change in surface roughness to 0.6 μin. (1.52×10^{-8}m) arithmetic average (AA) from the initial 1.3 μin. (3.3×10^{-8}m) AA finish for the gold plating (Figure 3-29). The bandwidth shown for each test point indicates the probable range of uncertainty. No change in leakage was detected as a result of the passivation process, but a second significant decrease occurred with operation in LF_2.

The test results obtained with the -501 configuration during the cycle-life tests indicate that the 23+ carat gold plating is the proper plating for valves having long cycle-life requirements. A 24-carat gold plating would probably be better for valves with lower cycle-life requirements, since this material is softer and requires less cycling to achieve good conformance to the seal interface. Additional testing will be necessary to determine the upper limit of cycle-life for the harder 23+ carat gold plating, since the 307 cycles completed in this program were not sufficient to determine the point where surface deterioration occurs.

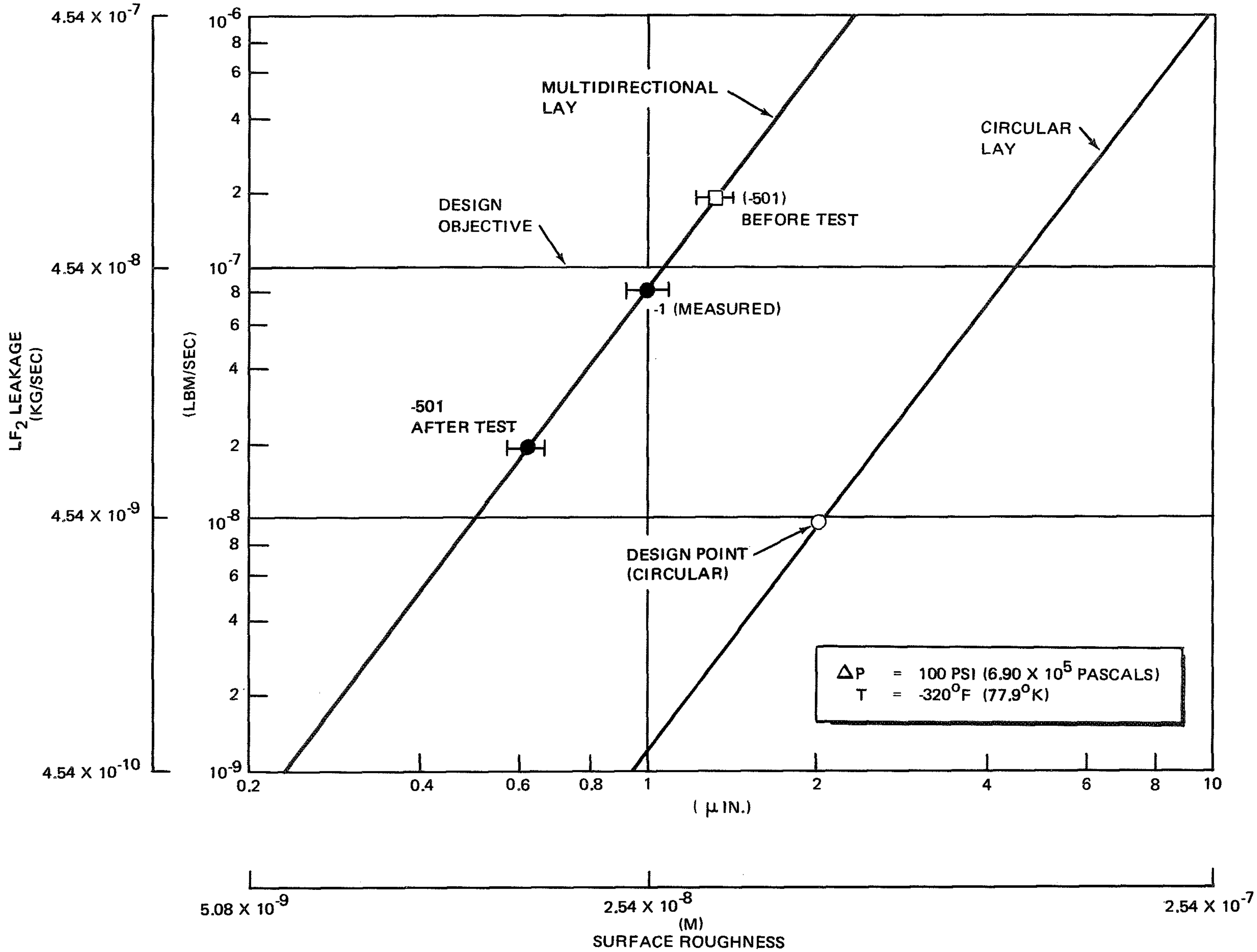

Figure 3-29. Effect of Surface Roughness on Low-Temperature LF_2 Leakage

The -1 valve incorporates an unplated A286 seat and an Inconel poppet. In this case, the sealing surfaces are relatively hard, and as would be expected, the changes in leakage during the cycle-life tests were very small (Table 3-3). The changes that did occur are probably a function of the leak-test method, and not necessarily an indication of a change in seal performance.

3.3.3.2 Pressure Drop

Figure 3-30 is a composite curve of pressure drop data for both test valves under a variety of flow conditions. Because all testing was performed at a nominal 12 lbm/sec (5.45 kg/sec) LF_2 flowrate, deviations from this value were obtained only during periods of flow adjustment. Consequently, there are few pressure-drop data points at off-nominal flowrates. Furthermore, when off-nominal conditions existed, they were usually transitory in nature and may have involved two-phase flow. These factors contribute to the spread in the data shown. The pressure drop of approximately 1.3 psid (8.98×10^3 pascals) at the design point is well below the design goal of 5 psid (3.45×10^4 pascals), and is in close agreement with water-flow test results. Extrapolation of the data to a flowrate as high as 30 lbm/sec (1.36×10^1 kg/sec) yields a pressure drop of only about 8 psid (5.53×10^4 pascals).

3.3.3.3 LF_2 Compatibility and Cycle Life

Testing of the -501 valve in LF_2 was successfully completed with no adverse effects on performance, and no evidence of hardware damage. The latter observation was based on an external examination of the valve; a complete inspection and evaluation of the disassembled valve would occur at a later date (Section 3.5.1.5).

The -1 valve was disassembled for failure isolation purposes after it failed during the high-pressure cycle-life test (Section 3.3.2.15). A thorough inspection was made of all the internal parts and surfaces not visible in the assembled valve. It was observed that the portion of the valve designed for direct LF_2 exposure was virtually unaffected. Although surface discolorations were present in a few areas on the static seals and static seal recesses, they were easily removed by use of the standard cleaning process for LF_2 components. There was no evidence of subsurface etching in the affected areas, and external leakage checks performed after valve assembly disclosed no loss in sealing efficiency. The fatigue crack in the shaft bellows seal allowed fluorine to enter the actuator cavity, an area normally not exposed to the oxidizer. Damage within the actuator was only superficial: two small grooves were burned in the actuator piston seal, depositing a sootlike film on the seal and adjacent surfaces within the actuator housing (Figures 3-15 and 3-16).

Cycle-life testing of the valves was tailored to the requirements of Table 3-5. Both valves completed over 250 operating cycles in LF_2 (307 cycles for the -501 valve and 280 cycles for the -1 valve) at the nominal 100 psig (6.90×10^5 pascals) design pressure with no indication of performance degradation.

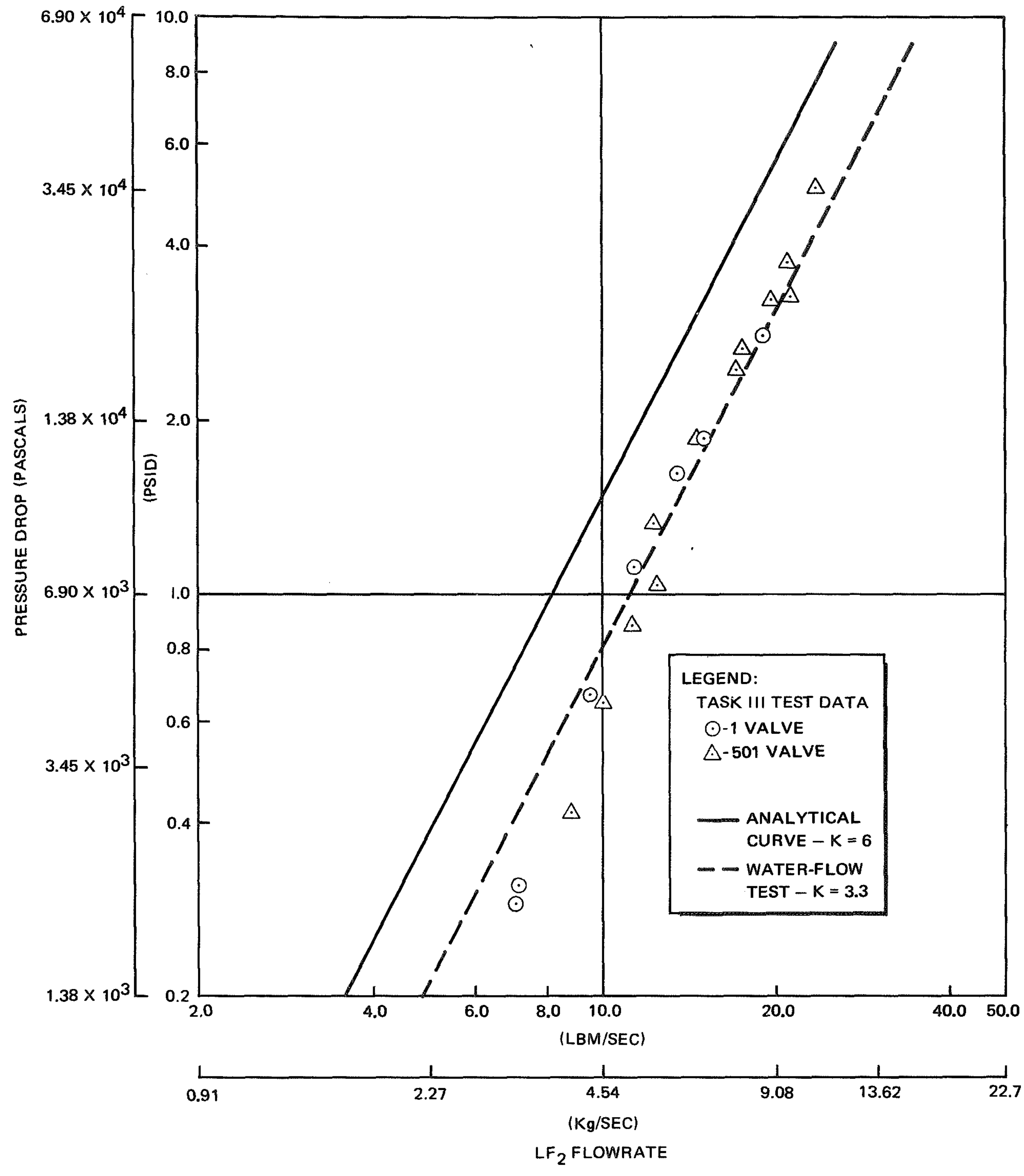

Figure 3-30. Summary of Valve Pressure Drop Data During Task III Testing

Additional cycle-life testing was performed at the proof-pressure condition of 250 psig (1.73×10^6 pascals) using the -1 valve. Although a cyclic test at proof-pressure has no direct relevance to one at the nominal design pressure, it was hoped that operation at the higher pressure would accelerate valve closure wear and provide a prediction of the internal leakage rates that might be expected after extended-duration testing at the nominal design pressure. After 590 of the scheduled 750 cycles were completed, testing was terminated because of the bellows seal fatigue failure. No sign of accelerated valve closure wear was apparent at the end of 590 proof-pressure cycles.

3.3.4 Conclusions

The goal of subjecting the two prototype valves to full-scale evaluation tests in LF_2 was accomplished. Measured in terms of compatibility with LF_2, low leakage, and low pressure drop, the results of these tests were successful. Further testing was performed to demonstrate the design integrity of the valves in severe vibration, shock, and acceleration environments. This latter testing is the subject of Task V.

3.4 TASK IV: VALVE REFURBISHMENT AND TESTING

The Space-Storable Oxidizer Valve contract with NASA-LeRC originally encompassed a 12-month program terminating with the completion of fluorine compatibility testing. A 4-month supplemental contract expanded the program scope to include environmental testing. This created a need for Task IV, the objective of which was to prepare the previously tested -1 and -501 valves for Task V, Environmental Testing. Specific work to be accomplished under Task IV included examination of both valves to determine the effects of storage after initial LF_2 exposure; repair of the -1 valve damage incurred during the Task III cycle testing at proof pressure; rework of the static seal recesses on the -1 valve; and evaluation of the resultant external seal leakage rates for the reworked -1 valve. The external leakage investigation was added by the NASA Program Office to provide an evaluation of the leakage control possible with W-type seals at cryogenic temperatures.

3.4.1 -1 Valve

The -1 valve was delivered to the Inglewood plant of Parker Hannifin for refurbishment and acceptance testing. The valve was disassembled and carefully inspected to determine if there were any storage effects on the various parts. This inspection took place on 12 May 1970, approximately 6 months after the unit's last exposure to LF_2. All parts were in excellent condition, with no changes apparent since the original disassembly (Section 3.3.2.15). The discolorations noted previously (Figures 3-22 and 3-23) in the seal recesses of the valve body and seat had not changed in appearance, and it was unlikely that they would affect the static seal efficiency. No discoloration was noted on the dynamic seal surfaces.

3.4.1.1 Rework and Refurbishment Details

A complete program plan for the valve refurbishment was prepared by Parker Hannifin. Because the Parker Hannifin facility was being relocated to Orange County, the refurbishment schedule was adjusted to accommodate the machine-shop downtime which would result from the move. A delivery date of 1 July 1970 was obtained by arranging for MDAC-West to provide the spare static seals (which were delivered with the original valve shipment) for Parker Hannifin to use in the -1 rebuild. New seals were ordered by Parker Hannifin to replace the MDAC-West spares.

Parker Hannifin reworked all the static seal recesses in the -1 valve, except the one on the actuator body, to provide a redundant seal surface, as explained in Section 3.2.3. The actuator body seal recess was not reworked because it is not critical in the control of LF_2 leakage. Concurrently with this rework, the poppet assembly was prepared for repair by machining off the damaged bellows seal. The bellows shield had been removed during the original failure inspection. A new bellows seal and shield were welded in place with an electron beam welder, and the welds were x-ray inspected.

The main poppet seal surface and the main seat surface were still in good condition, but were lightly relapped using the original multidirection lapping technique. The poppet shaft threads, slightly damaged during the posttest disassembly, were also repaired by lapping. All parts were recleaned for LF_2 service, and the valve was reassembled. A thicker nut was used on the poppet shaft to provide additional thread grip. Also, brush-copper-plated bolts were used where exposure to LF_2 was possible, and the studs at the inlet flange were replaced by bolts. The plating was applied by the Travis Plating Company, Santa Monica, California using the Selectron process.

3.4.1.2 Acceptance Test

Acceptance testing of the refurbished -1 valve was first attempted by Parker Hannifin on 3 June 1970. With the oxidizer cavity pressurized to 250 psig (1.73×10^6 pascals), there was no leakage through the static seals, indicating successful rework of the seal recesses.

The initial internal leakage rate of the uncycled poppet/seat was 6 ccm (1.00×10^{-1} ccs) at 100 psig (6.90×10^5 pascals), compared to a value of only 0.21 ccm (3.50×10^{-3} ccs) obtained under similar conditions before rework was initiated. The valve was disassembled, reshimmed, reassembled, purged with GN_2, and cycled 25 times. Another leakage measurement was made, yielding a lower, but still unacceptable, value of 2.5 ccm (4.18×10^{-2} ccs). The valve was again disassembled and thoroughly inspected for contamination particles, improper shimming, mechanical interference, and physical dimensions, but no cause for the excessive leakage could be found.

By this time, much of Parker Hannifin's equipment had been moved to their new Orange County facility, making it necessary to transfer the remaining -1 valve activities there, also. Further inspections of the poppet and seat were performed in the new lapping room. A partial seat track was noted on the poppet, a condition suggesting incomplete poppet closure because of the presence of a contamination particle. It was suspected that relapping of the poppet seat during refurbishment had decreased the height difference between bumper and seat to less than the acceptable minimum. With an undersize height difference, it would be possible for a particle of contamination to lodge under the bumper and prevent the seat from making contact around the complete circumference of the sealing area. Since it was known that the height difference was at or below the minimum of 0.0002 in. (5.08×10^{-6} m), the seat was reworked to bring the part back within the tolerance band. The bumper height was lapped down to the maximum permitted height difference, and the seat sealing surface was relapped using the technique employed during the original valve fabrication.

The valve was reassembled, and the internal leakage measurements were repeated. Still, there was no appreciable change in leakage rate. To determine if the leakage was occurring uniformly around the circumference of the seal, or at a single point, a special reverse pressure test was made. The inlet adapter was removed from the valve, and 10 psig (6.90×10^4 pascals) GHe was applied at the outlet flange. With this reverse pressure applied, the valve was submerged in Freon and visually checked for leakage bubbles at the poppet/seat interface. It was found that all of the leakage was occurring over an arc length about one-sixth of the seal circumference. Since this type of leakage would be expected if a contamination particle were caught under the seal face or bumper, the valve was again disassembled and inspected under a microscope. Although no contamination was visible, the valve was cleaned with Freon, and reassembled. It was determined during reassembly that a sheet of Kel F was being used between the poppet and the seat to prevent their contact while the actuator portion of the valve was assembled. The use of this protective sheet was immediately discontinued when it was determined that the seat stress from the return springs exceeded the compressive stress limit of the Kel F. At this time, funds allocated by the Parker Hannifin fixed-price purchase order had been expended, and the valve was delivered to MDAC-West in a disassembled condition.

Additional checks were made with a microscope to determine if any of the clear Kel F was embedded in the sealing surface. This determination proved to be impossible due to the clarity of the Kel F. However, a double row of optical marks could be detected on the face of the Inconel poppet when light was reflected from the poppet surface at a particular angle. An attempt was made to remove the optical marks using various organic solvents, including methylethylketone (MEK), but the surface appearance remained unchanged. The valve was reassembled at MDAC-West and a reverse leakage test was made. No change in leakage was detected. Next, a variation of the reverse leakage test was performed. This time, the seat was removed from the housing and reinstalled at several different positions relative to the poppet sealing surface. In all cases, the location of the leakage followed the A286 seat around the poppet surface, leading to the conclusion that the seat surface was causing the leakage, and not the poppet face, as originally suspected. The decision was made to again refinish the A286 sealing surface before making further checks.

After reviewing several possible approaches to the relapping, it was decided to perform this work at MDAC-West using special hand lapping tools. These tools were machined from copper disks in three configurations. The first tool was for the bumper surface, the second was for the main seal area of the seat, and the third was for the poppet sealing face. Using these three tools, the poppet and the seat were both lapped very lightly with 1,600-grit lapping compound. This procedure removed all visible scratches and surface imperfections from the poppet and the seat, but the measured valve leakage still did not change noticeably.

Clearly, a different approach to the problem was needed. Fortuitously, acceleration and shock testing of the -501 valve had just been completed, and it was now feasible to isolate the -1 valve problem through parts substitution. Accordingly, the poppet assembly from the -501 valve was removed and installed in the -1 valve. No appreciable change in leakage occurred with this arrangement when tested by submerging the seal interface in liquid Freon and observing the leakage bubbles. The leakage was observed in a single area about 1 in. (2.54×10^{-2}m) in length, or about one-sixth of the total circumference of the main sealing interface. The position of the leakage was marked on the valve, and the parts substitution was continued. The -501 poppet was replaced with the -1 poppet, and the -1 seat was replaced with the gold-plated -501 seat. When this combination was bubble tested, it was found that the amount and location of the leakage remained about the same.

It was known that the -501 poppet and the -501 seat combination gave no indicated leakage when mated together, so when these parts gave almost identical leakages when alternately exchanged for the -1 parts, it was concluded that the source of difficulty was located on both the seat and the poppet of the -1 valve, and about equally divided between them. Because no surface imperfections were detectable on either of the two key parts of the -1 valve, it was further reasoned that a low spot must exist on both the -1 seat and the -1 poppet, and at the same relative location on each. It was easier to relap the seat than to relap the poppet because of interference produced by the poppet-shaft bellows seal, so it was decided to continue the relapping of the seat enough to eliminate a potential low spot. This situation was discussed with Parker Hannifin, and they agreed to relap the -1 seat at no cost to the program. The maximum seat width specification of 0.012 in. (3.05×10^{-4} m) was waived for this rework, since there was no way of lapping to the proper flatness without exceeding the specification. The final surface was obtained with the seat width in the 0.012 to 0.014-in. (3.05×10^{-4} to 3.56×10^{-4} m) range, while the bumper-to-seat height was still in the specified 0.0002 to 0.0004-in. (5.08×10^{-6} to 1.02×10^{-5} m) range. To keep the bumper-to-seat height in the proper tolerance range, the bumper was lapped down by MDAC-West to provide a 0.0006 to 0.0008-in. (1.52×10^{-5} to 2.04×10^{-5} m) dimension before Parker Hannifin resurfaced the seat surface. This operation permitted the removal of 0.0002 to 0.0004 in. (5.08×10^{-6} to 1.02×10^{-5} m) of material from the seat, so that the final bumper-to-seat height was approximately 0.0004 in. (1.02×10^{-5}m), which is near the original maximum limit.

After this relapping procedure was completed, the -1 valve was reassembled using the unplated relapped -1 valve seat, and the original -501 poppet assembly. This combination was leak checked, and the results were found to be well within the design specification range. The measured internal leakage was 0.1 ccm (1.67×10^{-3} ccs) at 100 psig (6.90×10^{5} pascals) at ambient temperature conditions. The equivalent design goal was 0.46 ccm (7.69×10^{-3} ccs) under these conditions. The valve assembly was then disassembled for final LF_2 cleaning prior to the start of the external leakage tests and the vibration tests. The valve and test equipment were shipped to the Gypsum Canyon Test Site for these final two tests.

3.4.2 -501 Valve

The -501 valve disassembly was carried out at the MDAC-West Santa Monica Plant Propulsion Laboratory on 11 June 1970. This valve's last exposure to LF_2 had been on 23 October 1969, when the Task III compatibility testing was completed. At that time, the valve was Freon-flushed, oven-dried, packaged, and placed in storage where it remained for approximately 8 months. The disassembly operation described here was intended to disclose any -501 valve abnormalities stemming from previous testing and storage, and to establish a firm baseline prior to acceleration and shock load exposure.

After removing all safety wires, disassembly began with the actuator portion of the valve. All breakaway torque values were within specification. Visual inspection of the removed proximitors showed an obvious nonconcentricity between the sensing tip and the mounting threads (Figure 3-5). This condition can result in excessive leakage and/or proximitor tip breakage, but is easily avoided by specifying the desired concentricity when ordering new parts. At this time, several correctly-specified spare units were on order. A small quantity of Teflon dust was observed in the actuator cap. This had been produced by friction between the actuator piston and Omniseal, and is considered normal. An imprint of the actuator piston face inside the end of the actuator cap and light impact marks on the piston face were probably produced during the 250-psig (1.73×10^6 pascals) GHe proof tests, and are also normal. Disassembly of the valve actuator disclosed a potential problem which can easily be eliminated by a minor revision to the assembly procedure. The cotter-key hole in the threaded portion of the poppet shaft should be aligned with its axis perpendicular to a plane passing through the position indicators. If it is not, the cotter key that retains the indicator nut can damage or interfere with the proximitor tips when the poppet moves. The alignment of the cotter-key hole is determined by the clocking of the bellows adapter to the main valve body when the poppet assembly is installed. During the original assembly of the -501 valve, the bellows adapter was misclocked by one bolt hole, resulting in a 45-degree (7.85×10^{-1} rad) error in cotter-key position. As a result, the bent end of the cotter key narrowly missed one of the proximitor tips during prior operation.

The LF_2 portion of the valve looked very clean, except for a few surface stains in the static seal recess areas. These stains were also observed in the -1 valve. The poppet and seat sealing surfaces were examined with a 50-power binocular microscope, and were found to be in good condition. A strong, unbroken optical track of the poppet seat seal area was observed.

3.4.2.1 Rework and Refurbishment Details

The -501 valve disassembly disclosed no abnormalities requiring repair or rework. Therefore, the refurbishment operation required only routine LF_2 cleaning, seal replacements, and reassembly using fasteners conforming to the revised Parker Hannifin assembly drawing. The latter changes included a thicker poppet shaft nut, brush-copper-plated screws and bolts in locations of potential LF_2 leakage, and bolts and nuts at the inlet flange to replace the original studs and nuts. The final assembly included installation of the inlet and outlet test adapters needed in the forthcoming acceleration tests. All fasteners were torqued to the high-side of the specified range and secured with safety wires.

3.4.2.2 Acceptance Testing

A preliminary acceptance test of the -501 valve showed excessive leakage around one of the proximitors, at the inlet flange, and at the outlet flange. The proximitor leak was caused by a broken tip, undoubtedly caused by non-concentricity of the tip and mounting threads noted earlier. The other leaks were the result of aberrations in the test adapter sealing surfaces. No internal leakage was detectable over the 25 to 250-psig (1.73×10^5 to 1.73 to 10^6 pascal) range in 3-minute (1.8×10^2 sec) checks using the water displacement method. After replacing the damaged proximitor and hand-lapping the test adapter sealing surfaces, the acceptance test was repeated. Internal leakage was still zero over the entire 25 to 250-psig (1.73×10^5 to 1.73×10^6 pascal) pressure range with 7-minute (4.2×10^2 sec) holds at each pressure level. Fifteen-minute (9×10^2 sec) checks at the 25- and 250-psig (1.73×10^5 and 1.73×10^6 pascals) pressure extremes confirmed this result. External leakage was cured, except at the inlet flange where it was reduced to an acceptable level. Leakage during the acceleration test was not a safety hazard because the test medium was water.

3.4.3 External Leakage Testing

The refurbished -1 valve was transferred to the Gypsum Canyon Test Site for completion of the remaining test activities. In the clean room, the disassembled valve was cleaned for LF_2 service and reassembled. The final assembly consisted of the -1 body and seat, and the -501 poppet and actuator. Shims installed on the poppet shaft totalled 0.050 in. (1.27×10^{-3} m) in thickness, and the overall piston travel amounted to 0.448 in. (1.14×10^{-2} m). A preliminary external leakage check of the valve with a USON helium leak detector disclosed slight leakages at three of the four oxidizer static seals (inlet flange, outlet flange, and seat), and gross leakage at one of the two position indicator mounting flanges on the actuator assembly. Leakage in the oxidizer portion of the valve was cured by installing new Hydrodyne seals, and by relapping the sealing surfaces of the inlet and outlet test adapters. It was decided to accept the actuator leakage when it was learned that the new seals would not be available to support the MDAC-West testing schedule.

3.4.3.1 Test Setup

Figures 3-31 and 3-32 show the test apparatus utilized in evaluating external leakage of the -1 valve. All equipment was installed on Pad 2 at the test site. The test setup centered around a small vacuum test chamber in which the test article was sealed. Cooling of the test chamber was achieved by immersing it in an LN_2-filled Dewar container. Ports in the test chamber lid provided for connections to the supporting subsystems (Figure 3-33). A mechanical vacuum pump established a rough vacuum in the test chamber and leak sensing subsystem, while the final evacuation was accomplished by the diffusion pump

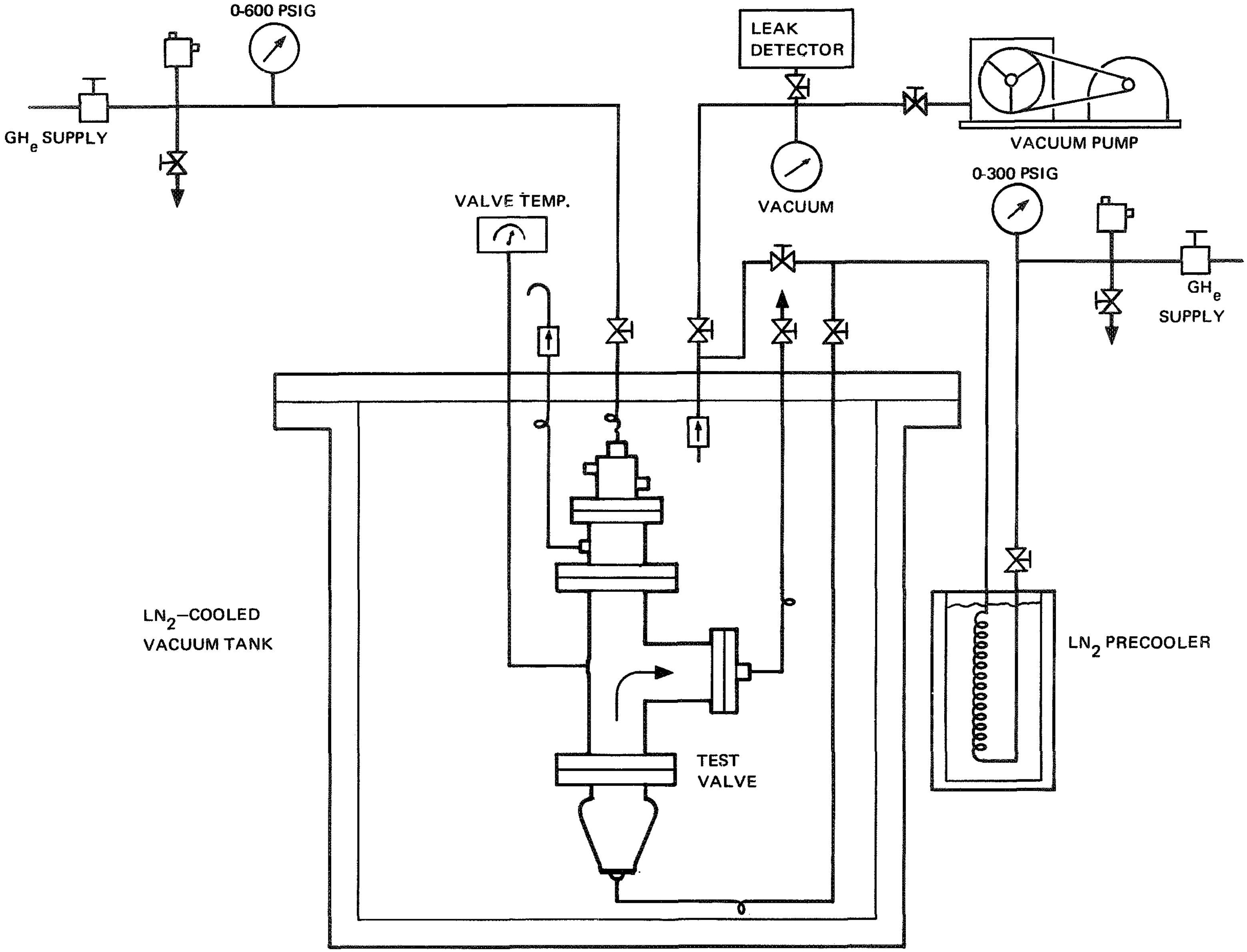

Figure 3-31. Schematic—External-Leakage Test Setup

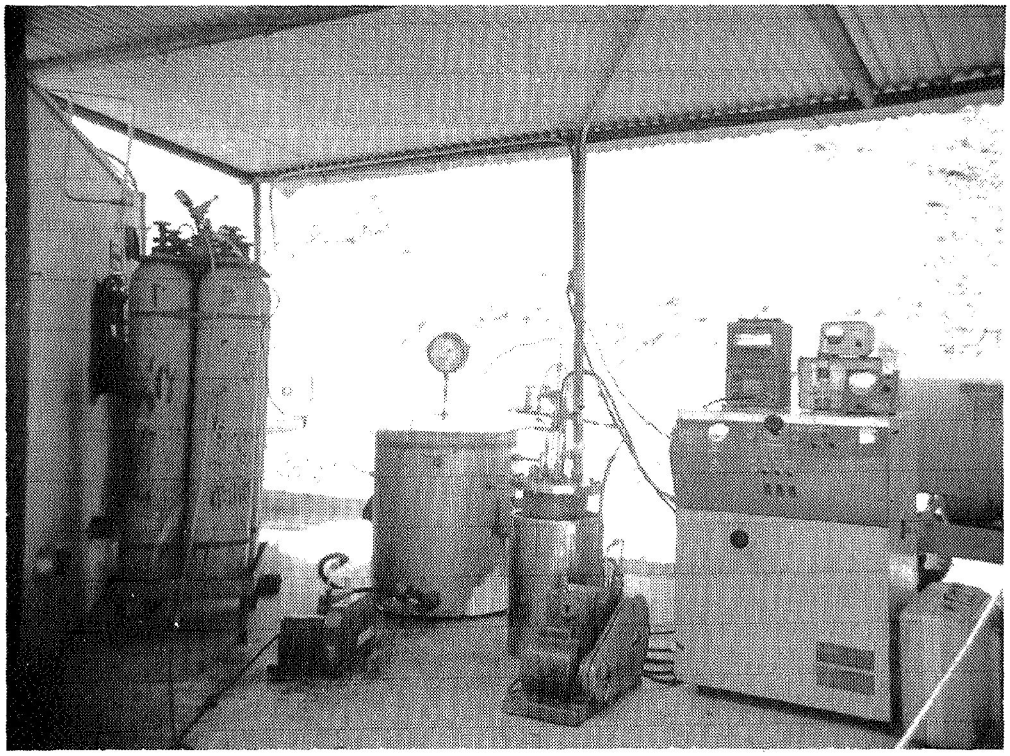

Figure 3-32. External-Leakage Test Apparatus

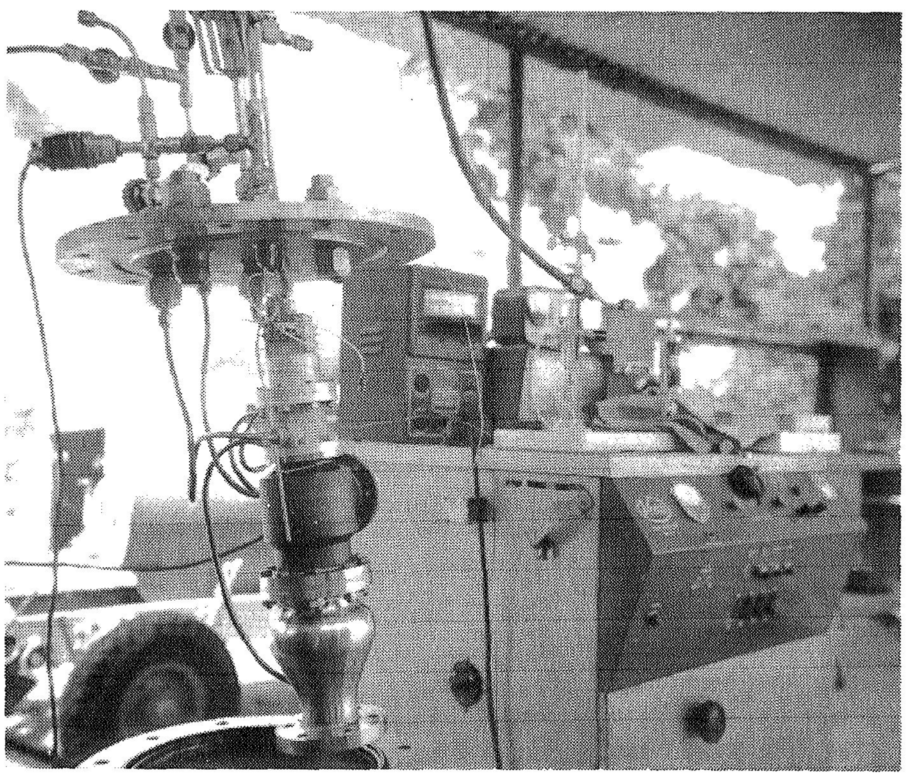

Figure 3-33. Test Chamber Lid Assembly with Test Valve Installed

housed in the Veeco leak detection unit. Pressure-regulated GHe was supplied to the test valve through an LN_2-cooled heat exchanger. Another subsystem provided the GHe pressure required for valve actuation. The actuator-bleed gas was dumped overboard from the test chamber via a small check valve, and a thermocouple skin patch provided an indication of the test-valve body temperature.

3.4.3.2 Test Procedure

Ideally, the procedure for determining external test-valve leakage would start with evacuation of the test chamber to the pressure required for proper functioning of the Veeco leak detector (normally, about 1μ Hg, absolute). Next, the test valve would be opened, and cold GHe flow maintained until the valve surface temperature stabilized at approximately -300°F (88.9°K). Then, after closing the test valve and pressurizing the valve inlet, leakage into the test chamber would be indicated directly by the Veeco unit. This reading would correspond to external leakage through the inlet flange static seal. A repetition of the foregoing with inlet and outlet connections both pressurized would yield the total external leakage for all four oxidizer static seals. Similarly, the simultaneous application of valve actuation pressure would result in a value for total external leakage, including the actuator assembly.

When the valve was opened to establish chilldown flow, GHe leakage from the actuator pressurized the test chamber, and the initial vacuum was quickly lost. To overcome this problem, a modified procedure was tried. Cold GHe was flowed through the valve until the body temperature stabilized at -300°F (88.9°K). The chilldown flow was then stopped, and an auxiliary vacuum roughing pump was utilized to reduce the test chamber pressure to 48μ. Meanwhile, the valve body temperature had increased to -237°F (123.9°K) and the time delay associated with additional pumping to permit use of the Veeco leak detector would have resulted in even higher temperatures. Therefore, the auxiliary vacuum pump was isolated, the test valve inlet was pressurized with 100-psig (6.90×10^5 pascals) cold GHe, and the test chamber vacuum was monitored for a pressure rise. The pressure increased from 48μ to 78μ in 6 minutes (3.6×10^2 sec), and valve surface temperature increased to -230°F (127.8°K) in the same period (Run 1). These data reflect the GHe leakage through the valve inlet flange seal. The vacuum pump was again used to evacuate the system, this time to a pressure of 50μ. The corresponding valve body temperature was -221°F (132.7°K). With the test-valve inlet and outlet both pressurized to 100 psig (6.90×10^5 pascals), the vacuum decay check was repeated, producing a pressure rise from 50μ to 98μ in 6 minutes (3.6×10^2 sec) and an increase in valve temperature to -216°F (135.5°K) (Run 2). These data are the result of leakage through all four oxidizer seals. After the entire system warmed to ambient temperature, the free volume of the test chamber was measured with Freon by the positive displacement method (with the test valve installed) and found to be 1,183 cu in. (1.94×10^{-2} m^3).

The test setup was modified to allow manual actuation of the test valve through the test chamber lid. This modification eliminated the problem of GHe leakage into the test chamber during valve actuation, and minimized valve warmup during the test. The manual actuator consisted of a long threaded rod passing through the chamber lid and entering the valve actuator through an internally-threaded union which replaced the normal actuator pressurization orifice fitting. A special tube assembly containing a teflon packing arrangement shrouded the actuator rod and prevented leakage into the vacuum test chamber. As the rod was rotated clockwise, its free end contacted the end of the poppet shaft and created an opening force. Conversely, counterclockwise rotation allowed the poppet to close.

Additional external-leakage test runs were performed with the modified test setup. A run was attempted after obtaining an initial system vacuum reading of 0μ with the Veeco diffusion pump. However, a malfunction in the Veeco electronic circuitry made it impossible to obtain a stabilized reading, and a decision was made to continue testing with the previous vacuum decay approach. The test valve was opened with the mechanical actuator, and after 3 hours (1.08×10^4 sec) of cold GHe flow, the valve body temperature was -260°F (111.2°K). As the actuator rod was screwed out to close the valve, the system vacuum was lost because of a leak in the actuator rod seal. By the time the leak was isolated and repaired, the system pressure had increased to an unacceptable value. The system was repumped to 15μ and the leak check was started. With the valve inlet pressurized to 100 psig (6.90×10^5 pascals), the chamber pressure remained at 15μ for a period of 5 minutes (3×10^2 sec), while the valve temperature increased from -230°F to -226°F (127.8°K to 130.0°K) (Run 3). The procedure was repeated with the valve inlet and outlet both pressurized to 100 psig (6.90×10^5 pascals). The pressure rose from 14μ to 30μ in 5 minutes (3×10^2 sec) as the valve temperature changed from -230°F (127.8°K) to -228°F (128.9°K) (Run 4).

Two final tests were performed at ambient temperature to serve as a baseline. With the valve inlet pressurized to 100 psig (6.90×10^5 pascals), the chamber pressure changed from 20μ to 23μ in 5 minutes (3×10^2 sec) (Run 5). When the valve inlet and outlet were both pressurized to 100 psig (6.90×10^5 pascals), the pressure rose from 19μ to 33μ in 5 minutes (3×10^2 sec) (Run 6). The valve body temperature was constant at 53°F (285°K) for these checks.

3.4.3.3 Test Results

The test chamber pressure, temperature, and free volume data given in the previous section were converted to the equivalent weight and volume leakage rates by using the Ideal Gas Law. Table 3-6 summarizes the values computed.

Because the data for Runs 1 and 2 were obtained while the valve body temperature was increasing, the resultant leakage rates were somewhat higher than those for Runs 3 and 4, in which the temperature was more nearly stabilized.

The results of Runs 3 and 4 indicate that the gold-plated W seals are capable of leakage rates of less than 10^{-5} ccs under the conditions tested. In a thermally stabilized system, slightly lower leakage rates would be anticipated.

As expected, the ambient-temperature leakage rates are consistent with the low-temperature results, if density changes are considered. These results indicate that the seals tested are mechanically stable over the temperature range tested, and are completely acceptable for the intended usage.

Table 3-6

EXTERNAL LEAKAGE RATE SUMMARY--REWORKED PART NO. 1T32095-1 VALVE

Run No.	No. of Seals	Pressure-Rise Rate	Initial Temperature		Final Temperature		Leak Rate		Leak Rate
		(μHg/min.)	(^oF)	(^oK)	(^oF)	(^oK)	(lbm/sec)	(kg/sec)	(ccs)
1	1	5	-237	123.9	-230	127.8	1.8×10^{-9}	8.2×10^{-10}	3.0×10^{-4}
2	4	8	-221	132.7	-216	135.5	2.8×10^{-9}	1.3×10^{-9}	4.8×10^{-4}
3	1	<0.2	-230	127.8	-226	130.0	7×10^{-11}	3.2×10^{-11}	$<1.2 \times 10^{-5}$
4	4	3.4	-230	127.8	-228	128.9	1.2×10^{-9}	5.5×10^{-10}	2.0×10^{-4}
5	1	<0.6	53	285.0	53	285.0	9×10^{-11}	4.1×10^{-11}	1.6×10^{-5}
6	4	2.8	53	285.0	53	285.0	4.3×10^{-10}	2.0×10^{-10}	7.4×10^{-5}

With the completion of the external leakage tests, the -1 valve was returned to the clean room for final cleaning prior to the vibration test series.

3.5 TASK V: ENVIRONMENTAL TESTING

The environmental testing program was conducted to determine the mechanical integrity, functional capability, and sealing characteristics of the test valves when exposed to acceleration, shock, and vibration loads representative of a space vehicle application.

Acceleration and shock testing were accomplished in the Santa Monica Plant Environmental Laboratory using the -501 valve. Acceleration loads of 6 and 12 g's were applied parallel to the valve centerline, perpendicular to the centerline, and at one intermediate position, while the valve was pressurized with inert test media. The same valve was then subjected to a single shock pulse having a one-half-wavelength sinusoidal shape, a 500-g amplitude, and a duration of approximately 1 msec.

Vibration testing was performed at the Gypsum Canyon Test Site using the refurbished -1 valve. Sinusoidal and random vibrations over a 5 to 2,000 Hz range, with loadings up to a 4.5-g level, were applied in two different planes while the valve was pressurized with LF_2.

Internal leakage rates were monitored as the testing progressed, and both valves were completely disassembled and inspected at the conclusion of the testing.

The -501 valve was installed on a centrifuge and subjected to 6-g and 12-g acceleration loads applied parallel to the valve centerline, perpendicular to the centerline, and at one intermediate position. In no instance did the acceleration loading affect the internal leakage rate, or interfere with normal poppet actuation. A 532-g shock applied for 1.25 msec along the valve axis had no harmful effect. Pre and posttest internal leakage checks revealed virtually zero leakage, and posttest disassembly and inspection disclosed no detectable hardware damage.

The -1 valve was subjected to random and sinusoidal vibration programs over the frequency range of 5 to 2,000 Hz with loadings up to 4.5 g's in two different planes. Vibration of the valve with 100 psig (6.90×10^5 pascals) LF_2 at the inlet had no effect on internal leakage. Posttest disassembly revealed no hardware damage or abnormalities. Pre and posttest leakage rates at ambient temperature were constant at 0.44 ccm (7.35×10^{-3} ccs). The posttest leakage rate at -318°F (78.9°K) was 1.02 ccm (1.70×10^{-2} ccs).

3.5.1 -501 Valve

The -501 valve passed an acceptance test following disassembly, inspection, and reassembly. At that time, the test adapter fittings were also installed and leak checked. These activities were described in Section 3.4.2.2. No additional pretest operations were performed.

3.5.1.1 Acceleration Test Setup

The acceleration test was performed on a 36-ft (1.10×10^1 m)-dia Model 58-3189 Rucker centrifuge located in the MDAC-West Santa Monica Plant Environmental Lab. Figure 3-34 shows the basic test setup. The test valve, with inlet and outlet test adapter fittings installed, was rigidly mounted in a special holding fixture. The holding fixture, in turn, was affixed to a mounting plate located at the end of the centrifuge arm. Various orientations of the valve in the plane of centrifuge rotation were possible by selecting the appropriate bolt holes in the mounting plate (Figure 3-35). A high-pressure GHe K bottle pressurized the valve inlet and the valve actuator through separate pressure regulators. These regulators were mounted near the centrifuge pivot point to negate g effects (Figure 3-36). A solenoid valve in the actuator supply line permitted test-valve actuation while the centrifuge was in motion. Evacuation of the valve outlet cavity was accomplished with a mechanical vacuum pump located on the upper floor level. The instrumentation setup consisted of valve inlet, outlet, and actuator supply pressures; applied acceleration, proximitor talkback (open and close), and actuation control solenoid signature; a total of seven parameters. The transducer outputs were recorded on a 36-channel oscillograph.

3.5.1.2 Acceleration Test Procedures and Results

Two types of tests were conducted: internal leakage, and time response. For each of these test types, the valve was oriented on the centrifuge mounting plate to provide the worst-case condition. That is, the valve inlet pointed away from the centrifuge pivot point for internal leakage tests, and toward the pivot point for time-response tests. Therefore, during the internal-leakage tests the acceleration loads tended to unload the poppet from the seat, thus reducing the apparent seat stresses, and increasing the tendency to produce a higher leakage rate. During the time-response tests, the acceleration loads tended to move the poppet in the closed direction, requiring a greater force to open the valve, thereby increasing the valve-opening time interval.

The first test series was to determine the effect of acceleration loads on internal valve leakage. With the centrifuge arm stationary, the valve inlet pressure was adjusted to 100 psig (6.90×10^5 pascals). The valve outlet cavity was evacuated to a pressure below 100μ of Hg, absolute, the outlet cavity was isolated, and the vacuum pump was disconnected. Internal valve leakage was determined by measuring the vacuum decay rate of the valve downstream pressure with the centrifuge at rest, and comparing this rate with those obtained during 6-g and 12-g centrifuge operation. The measured baseline decay rate was 0.8 psig (5.52×10^3 pascals) in a 30-minute (1.8×10^3 sec) period. In a single centrifuge run, the acceleration was stabilized for two 15-minute (9×10^2 sec) periods, first at 6 g's, then at 12 g's. In both cases, the vacuum decay rate was identical to the baseline value, and no rapid fluctuations in outlet pressure were observed. A second test run was made, in which the test valve was remounted so that the poppet shaft was aligned at a 45-degree (7.85×10^{-1} rad) angle with the centerline of the centrifuge arm, and the valve inlet was directed away from the centrifuge pivot point. In a third run, the poppet shaft was positioned at a 90-degree (1.57 rad) angle with the centerline. As in the first run, the two succeeding runs failed to disclose any indication of internal leakage. Static internal leakage checks made after each run with the water displacement apparatus also indicated zero leakage.

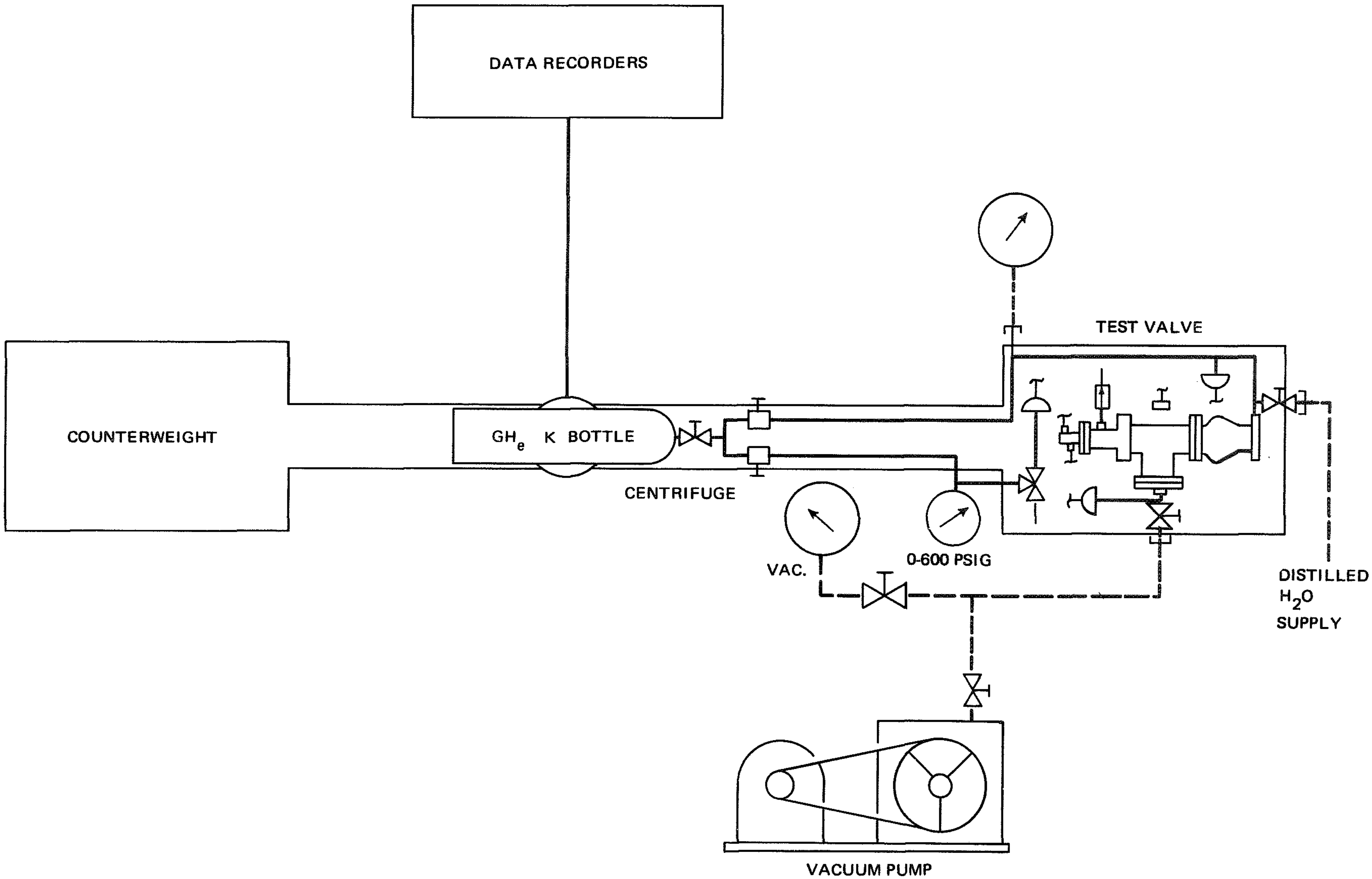

Figure 3-34. Schematic — Acceleration-Test Setup

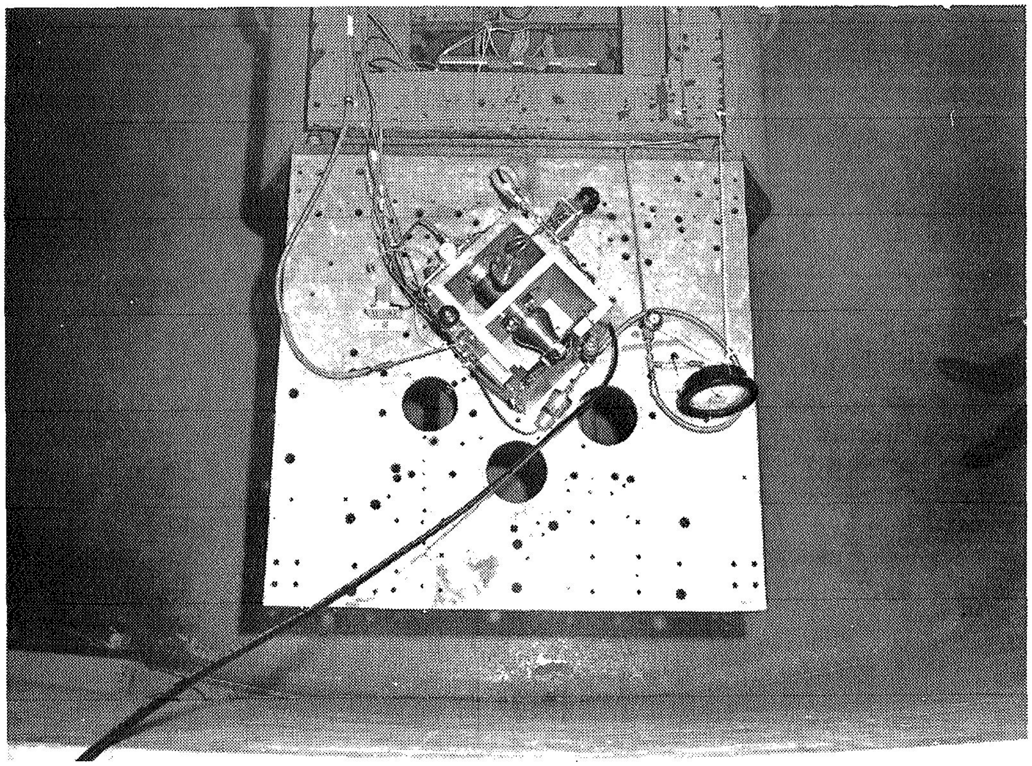

Figure 3-35. Centrifuge Mounting Plate Installation

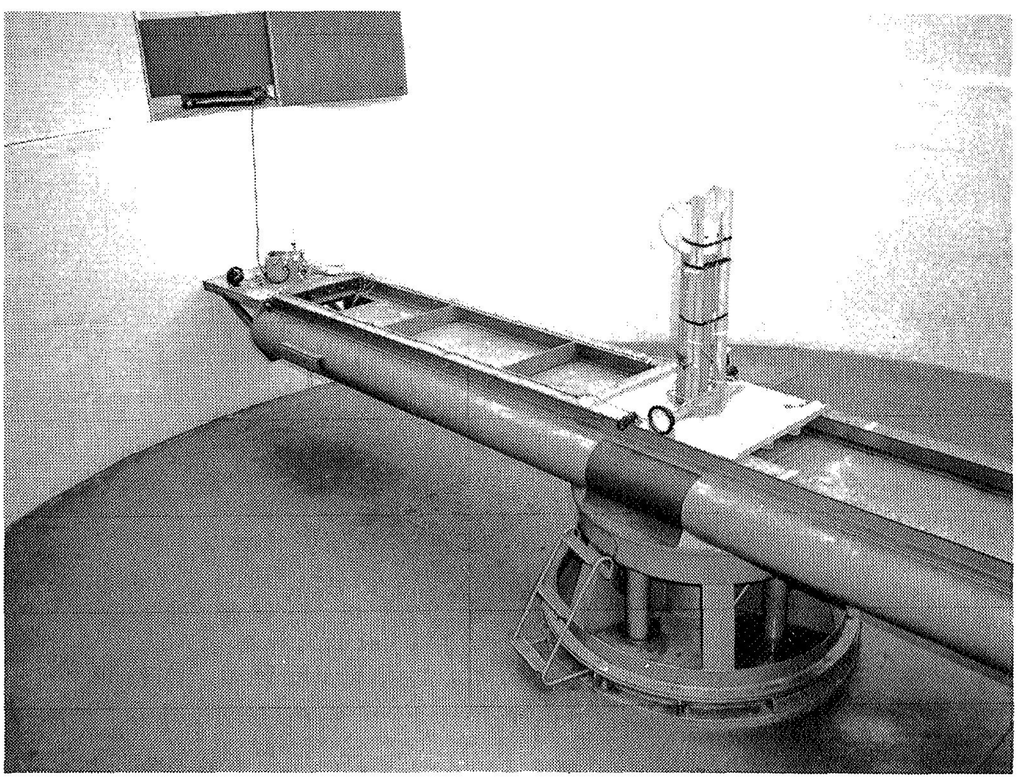

Figure 3-36. Centrifuge Test Installation

The test valve was repositioned to the time response position, i.e., with the poppet shaft parallel to the centrifuge arm centerline, and the valve inlet facing the centrifuge pivot point. The time response tests were made with the valve inlet section filled with distilled water and pressurized to 100 psig (6.90×10^5 pascals) with GHe, and the outlet vented to ambient conditions. The opening and closing time responses were measured, first with the centrifuge arm at rest, and then with the centrifuge operating at a 12-g load value.

The results of the tests, conducted with the 0.059-in. (1.27×10^{-3} m)-dia orifice at the actuator inlet and a supply pressure of 450 psig (3.10×10^6 pascals), were:

	Stationary		12 g's	
	Opening	Closing	Opening	Closing
Time from electrical signal to start of pressure rise/decay (msec)	25	73	64	65
Time for pressure rise/decay to 290 psig (2.00×10^6 pascals) (msec)	25			
Total valve response (msec)	10	45	13	40
Total system response (msec)	60	118	77	105
Actuator pressure at full open (psig)	340 (2.35×10^6 pascals)			

The theoretical value of actuator pressure needed to provide a complete force balance on the poppet assembly under static conditions was computed to be 290 psig (2.00×10^6 pascals). This value was confirmed during the tests when the valve shaft started its opening travel as the internal actuator pressure reached 290 psig (2.00×10^6 pascals). The measured time response values are well within the predicted limits, and in all cases the performance was equal to or better than the originally specified design goals.

Because the time response tests indicated that valve travel started at very nearly the time when the actuator cavity reached 290 psig (2.00×10^6 pascals) (thus indicating a very small amount of mechanical friction in the unit), a second series of tests was conducted. In the first special test, the actuator-supply pressure was set to a value less than 290 psig (2.00×10^6 pascals), and an attempt was made to open the valve against a 12-g acceleration load. As expected, the valve would not open. The actuator supply pressure was then adjusted to 300 psig (2.07×10^6 pascals) (290 psig [2.00×10^6 pascals] theoretical + 10 psig [0.07×10^6 pascals]) and the 12-g test was repeated. The valve opened as expected, with the valve travel occurring in the normal 10 msec. The pressure rise rate in the actuator cavity was much slower at this pressure level than the rate obtained at the specified 450-psig (3.10×10^6 pascals) level. The time response data for the 300-psig (2.07×10^6 pascals) run were:

	12 g's	
	Opening	Closing
Time from electrical signal to start of pressure rise/decay (msec)	24	40
Time for pressure rise/decay to 300 psig (2.07×10^6 pascals) (msec)	88	
Total valve response (msec)	10	40
Total system response (msec)	122	80

These results indicate excellent correlation between the analytical data and the observed test data. They also verify that the valve has successfully met all of the original design goals under accelerative loads up to the 12-g level.

Internal leakage tests performed at the conclusion of the acceleration test series still showed zero leakage.

3.5.1.3 Shock-Test Setup

The -501 valve inlet adapter flange was bolted to a flat plate fixture which, in turn, was installed on the mounting face of a Type SM 110-3 AVCO shock machine (Figure 3-37). This arrangement provided a shock load parallel to the valve poppet shaft in a direction tending to force the poppet down onto the seat.

The data for this test were recorded on a Hewlett Packard 141A Memoscope, using an Endevco 2242C accelerometer. An Ampex SP700 tape recorder was used as a backup device so that the tape recording could be replayed to re-input the signal to the recorder; Figure 3-38 illustrates the test setup.

3.5.1.4 Shock-Test Procedure and Results

The shock test machine was calibrated for this test by installing a dummy weight equal to the valve weight (about 12 lbm [5.55 kg]) and adjusting the table travel height to produce the desired 500-g shock level. It was found that the 500-g shock value was obtainable without difficulty, but the desired 0.4 msec shock duration could not be met. The shock duration could be reduced to slightly less than 1.5 msec, but no further. Although the longer time duration provided a test more severe than originally planned, it was proposed to conduct the testing with the shock duration obtainable. This proposal was approved by the NASA-LeRC program office. The shock test was completed with a measured amplitude of 532 g's and a duration of 1.25 msec (Figure 3-39). The output signals were obtained directly on the Memoscope as planned, so the backup tape recording was not required for this test.

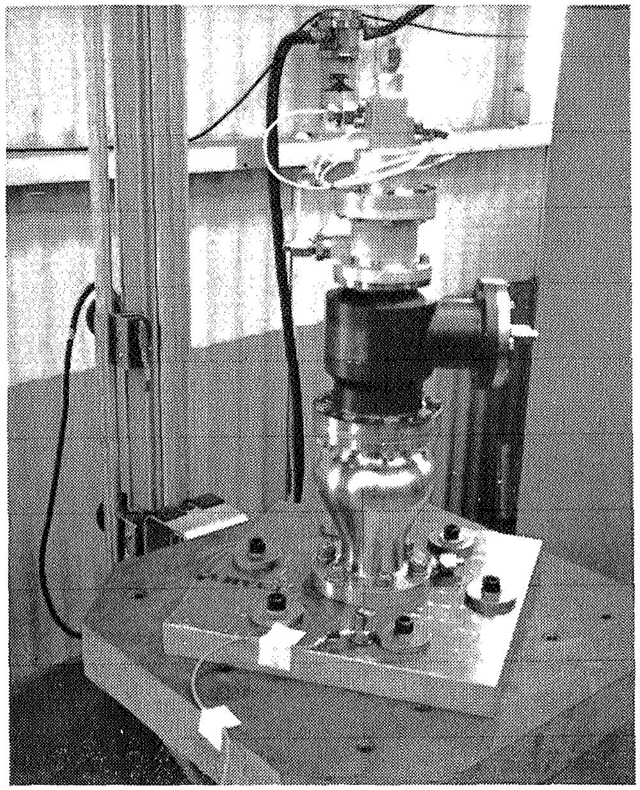

Figure 3-37. -501 Valve Mounted on Shock Tester

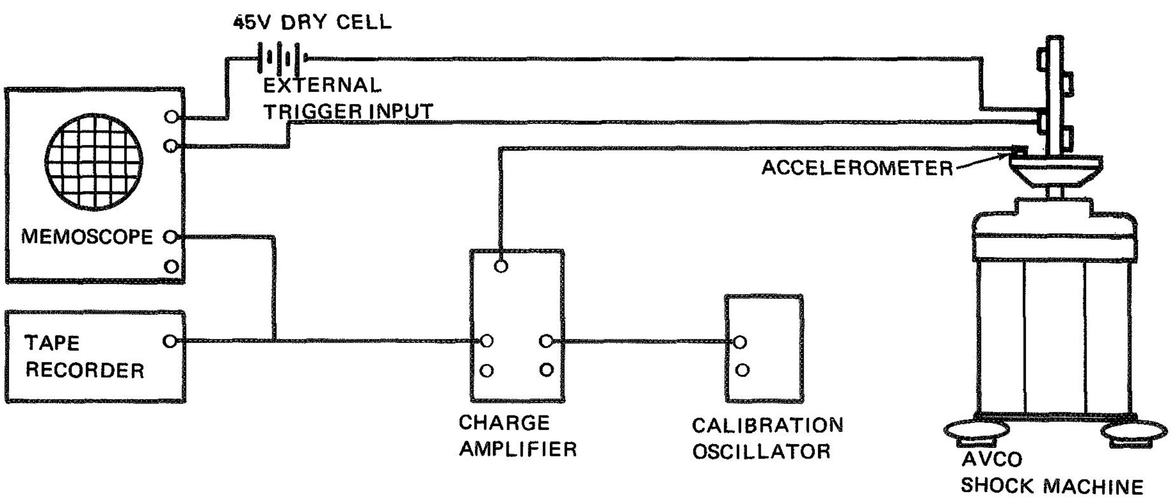

Figure 3-38. Schematic—Shock-Test Setup

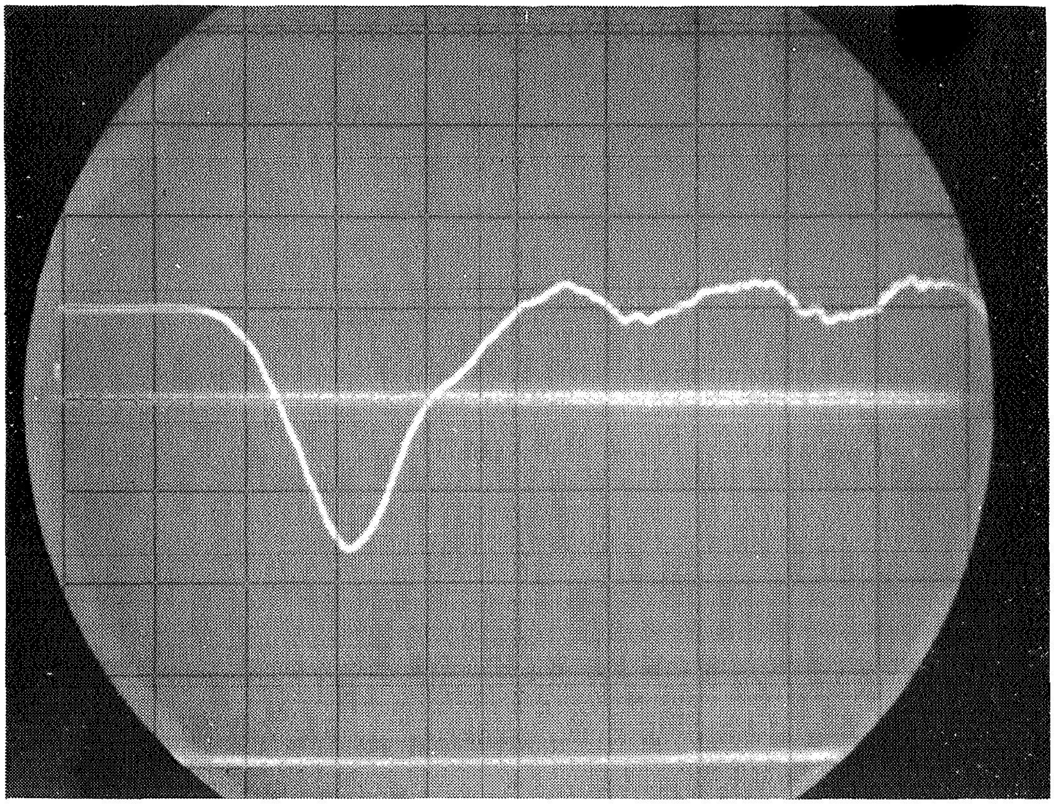

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Figure 3-39. Shock Impulse Signal

3.5.1.5 Post-Shock-Test Operations

The valve was removed from the shock machine after the test was completed, and tested for internal leakage. No detectable leakage was obtained for the 25 to 250-psig (1.73×10^5 to 1.73×10^6 pascals) range, just as during the pretest evaluation. After the leakage tests were completed, the valve was completely disassembled for visual inspection. No damage was found in any of the valve parts (Figure 3-40).

3.5.2 -1 Valve

Before the -1 valve was removed from the external-leakage test fixture (Section 3.4.2.1), internal leakage checks were made with the water displacement apparatus. At 100 psig (6.90×10^5 pascals), the average leakage rate was 0.22 ccm (3.69×10^{-3} ccs). Removal of the external leakage apparatus from the valve was completed, and the previously unavailable replacement actuator seals were installed. The associated fasteners were tightened to the specified torque values and safety wired. A repetition of the internal leakage test, performed after the valve was oven-dried, yielded a somewhat higher average value of 0.55 ccm (9.19×10^{-3} ccs) at 100 psig (6.90×10^5 pascals).

3.5.2.1 Vibration-Test Setup

The vibration-test equipment was set up on Pad 2 of the Gypsum Canyon Unit 1 test area (Figure 3-41). The setup employed a Calidyne vibration unit

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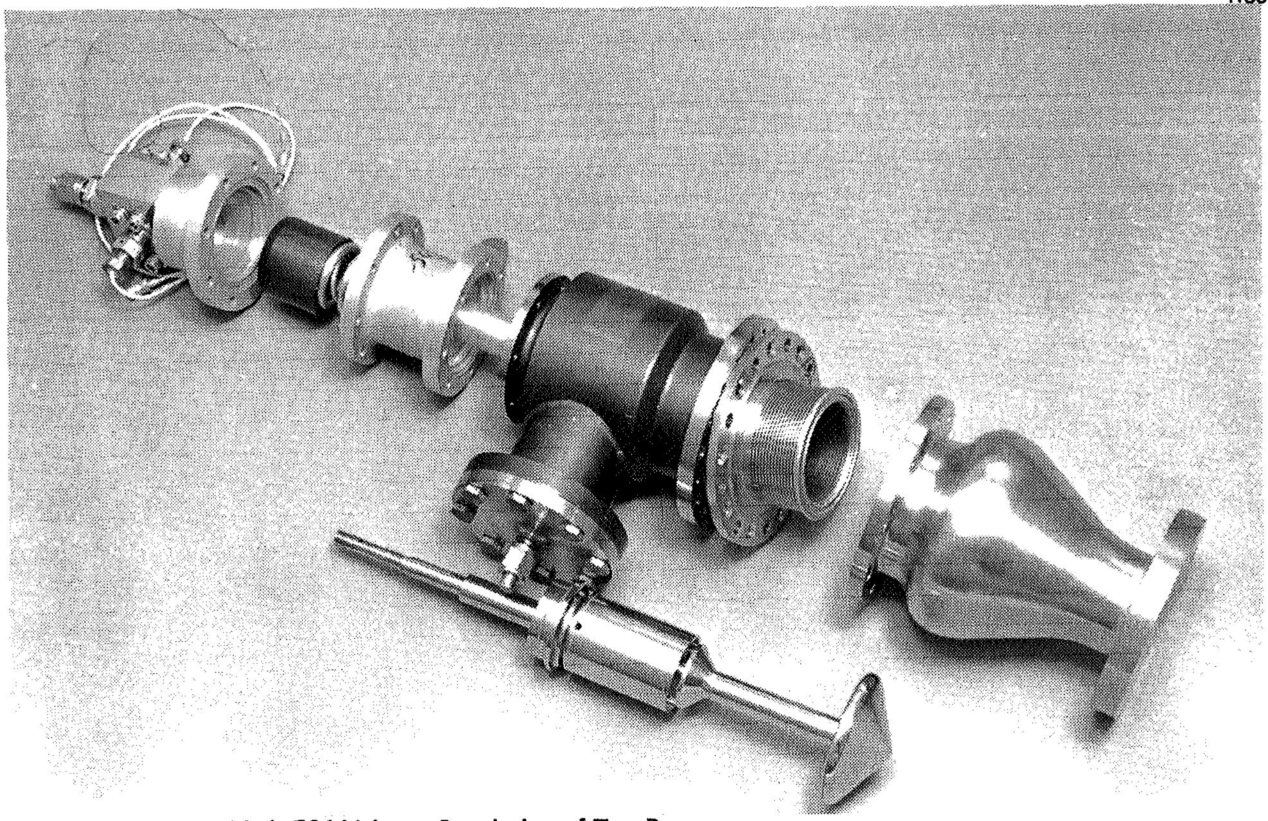

Figure 3-40. Disassembled -501 Valve at Conclusion of Test Program

driven by a Ling Electronics amplifier. Rigid attachment of the test valve to the shaker table was provided by a specially-designed test fixture. This fixture permitted mounting of the valve in either of two attitudes, allowing the vibration loads to be applied either perpendicular to or parallel with the poppet shaft. The fixture also served as a container for the LN_2 used in chilling the test valve inlet section. Thus, vibration testing was performed with the valve inlet bathed in LF_2 formed by the condensation of pressurized GF_2 supplied to the inlet adapter. Other features of the setup were: a GN_2 ejector to evacuate the test valve outlet, and to rid the system of unwanted GF_2; a scrubber for safe disposal of vented GF_2; a GH_e actuation supply for the test valve; a water displacement leak check apparatus; and a GN_2 purge supply. The instrumentation setup consisted of valve inlet and outlet pressures, actuator supply pressure, valve inlet and body housing temperatures, open and closed position talkback, and applied acceleration.

3.5.2.2 Vibration-Test Procedures and Results

The first test run was made with the test valve mounted horizontally and the shaker table positioned for vertical movement (Figure 3-42). A pretest internal leakage check using the water displacement technique gave a baseline value of 0.36 ccm (6.02×10^{-3} ccs) at 87 psig (6.00×10^5 pascals) and ambient temperature. The valve was then chilled with LN_2 until the oxidizer inlet cavity was at -300°F (88.9°K). When this temperature was reached, the GF_2 supply to the valve inlet section was opened, GF_2 at 50 psig (3.45×10^5 pascals) was allowed to pressurize the inlet cavity, and the LF_2 condensation

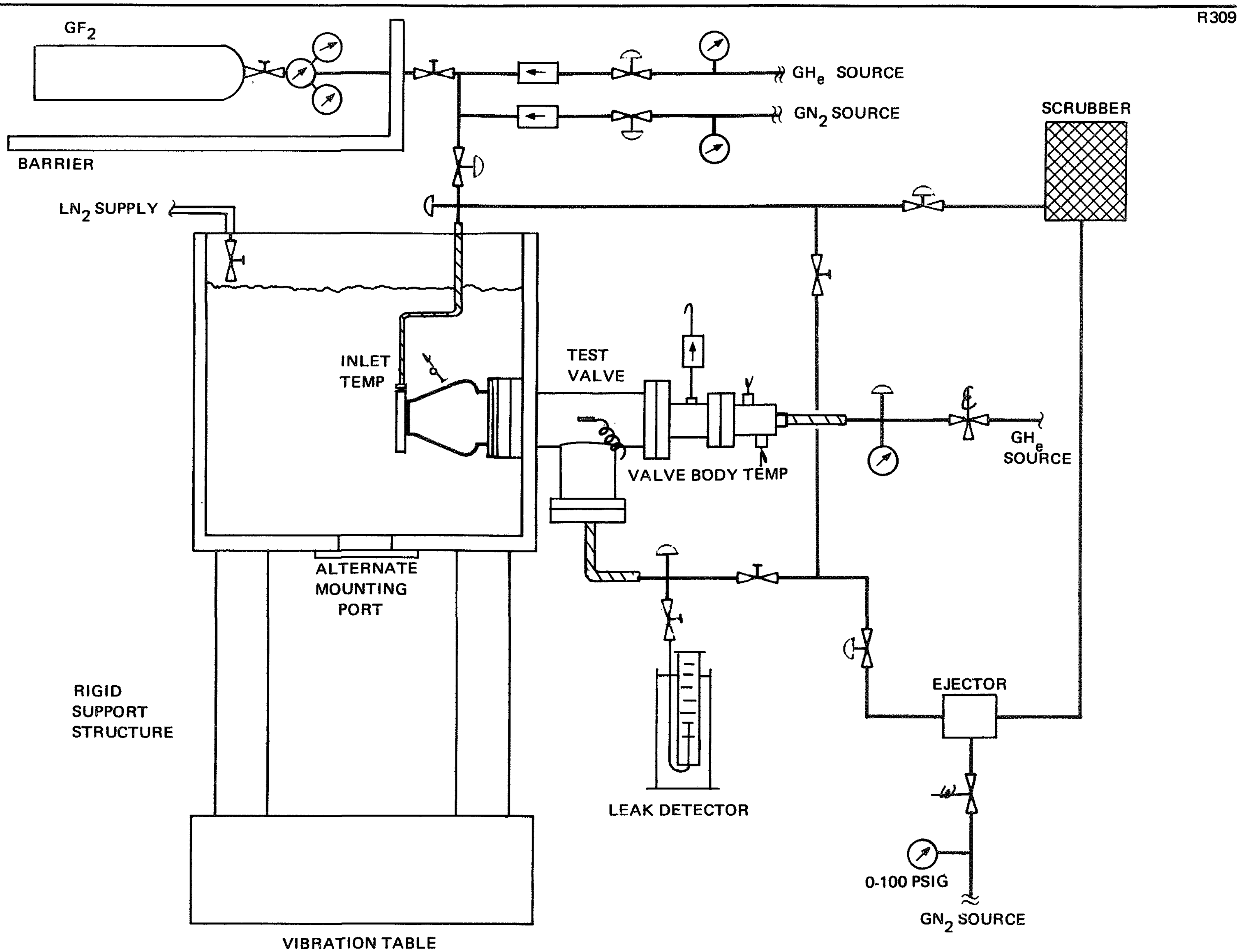

Figure 3-41. Schematic—Vibration-Test Setup

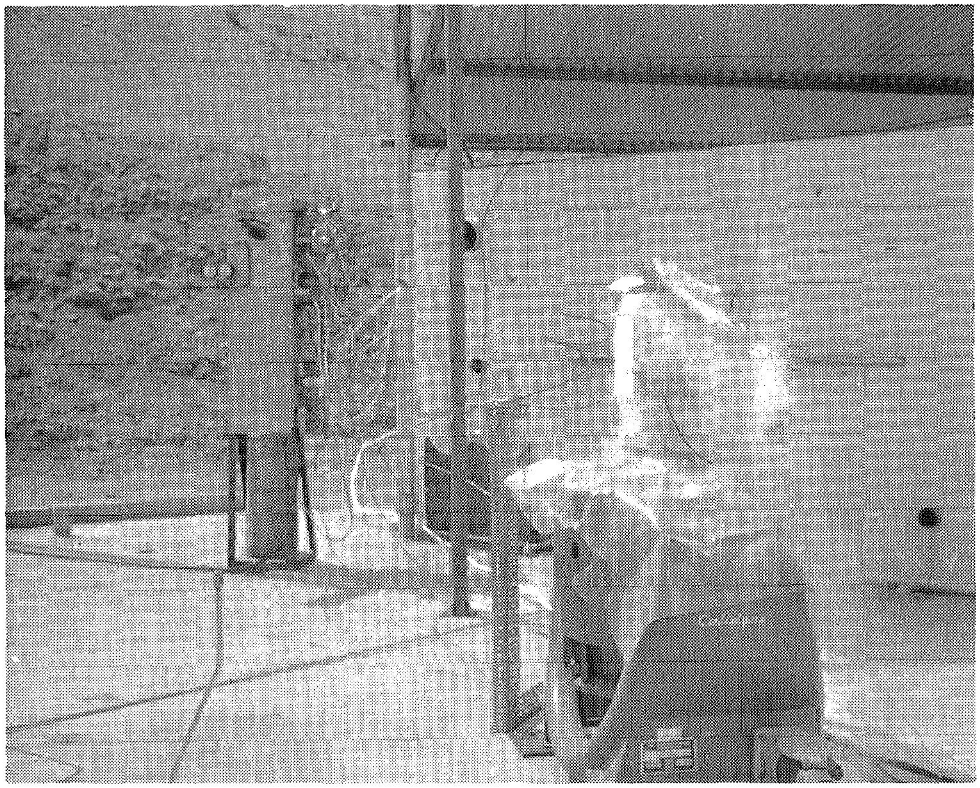

Figure 3-42. Transverse Vibration Test Installation

process began. The GF_2 supply pressure dropped from 435 psig (3.00×10^6 pascals) to 380 psig (2.62×10^6 pascals) during the 2-hour (7.2×10^3 sec) condensation period. The system stabilized at the 380-psig (2.62×10^6 pascals) level after the first 1-1/2 hours (5.4×10^3 sec), and no additional F_2 was condensed during the last half-hour (1.8×10^3 sec) period. This process succeeded in condensing 0.55 lbm (2.50×10^{-1} kg) of LF_2 in the valve inlet cavity. The amount of condensed LF_2 was enough to half fill the cavity throat.

A partial vacuum of 9 psia (6.21×10^4 pascals) was maintained at the outlet portion of the valve during the entire condensation process. This vacuum was monitored during the vibration portion of the testing to determine if a change in leakage occurred. When the condensing process had stabilized, the GF_2 supply was isolated. The valve inlet was pressurized with GHe at 100 psig (6.90×10^5 pascals), and the vibrational loading was started. A sinusoidal sweep was made over the frequency range of 5 to 2,000 Hz (upsweep) at the rate of one decibel per minute (1.67×10^{-2} db/sec). This test required approximately 8.5 minutes (5.10×10^2 sec). A shaker circuit breaker opened at 1,500 Hz, and had to be reset before the sweep could be continued. This behavior was identified as a shaker characteristic, and did not indicate a resonance condition in the valve assembly. After completing the upsweep run, the vibration sweep was repeated for a 2,000 to 5-Hz (downsweep) run. The circuit breaker required an additional reset at 1,500 Hz on the downsweep portion of the test. After completing the sinusoidal portion of the test, a 3-minute (1.80×10^2 sec) random vibration test was completed in a series of short runs. The circuit breaker would not permit a continuous run with the load levels programmed for the 1,500 Hz portion of the random vibration. The vibration schedule that was programmed, and the measured vibration traces are shown in Figures 3-43 and 3-44. No change in internal leakage was detected during this test run. The LN_2 coolant flow to the test fixture was then shut off, and GF_2 was removed from the valve assembly with the ejector system. A posttest internal leakage check showed that internal leakage through the valve did not change appreciably during the first vibrational test. Therefore, the valve was not disassembled before running the second vibrational test. The valve and test fixtures were removed from the shaker table, the shaker was rotated through a 90 degree (1.57 rad) angle (vibrational loading in the horizontal direction) and the valve and fixture were remounted with the valve shaft in the same plane as used for the first test (Figure 3-45). This change in relative position of the shaker with respect to the test valve resulted in the vibrational loading being applied in a direction parallel with the main poppet shaft. With this arrangement, the vibrational impulses would tend to shake the poppet off the poppet seat and produce the worst condition with respect to valve internal leakage. The test was conducted using the same procedure used during the first vibrational test. The condensed LF_2 was measured at approximately 0.6 lbm (2.72×10^{-1} kg), still approximately the one-half full condition. For this run, the LN_2 flow was increased to a higher rate to improve the cooling capability of the system, the pressure of the GF_2 was increased to 75 psig (5.18×10^5 pascals), and a greater portion of the fluorine test loop was evacuated prior to the start of the condensation process. These changes had little or no effect on the weight of LF_2 that could be condensed in the upstream side of the test valve. The vibration loading cycle was completed using the same shaker control program that was used in the first test. With the shaker on its side, the previous difficulty at 1,500 Hz did not occur (Figures 3-46 and 3-47) and the frequency sweeps up and down were completed without the circuit breaker opening. The random portion of this test reflected the improvement in shaker loading, and an 8-minute (4.8×10^2 sec) random test was completed without difficulty. No change in the valve outlet pressure (vacuum) was noted for this test series, indicating that no change in internal leakage occurred.

3.5.2.3 Post-Vibration-Test Operations

The posttest internal leakage was found to be 0.52 ccm (8.67×10^{-3} ccs) at 100 psig (6.90×10^5 pascals). After the internal leakage tests were made, the -1 valve was completely disassembled and inspected for mechanical damage. No damage of any type was found. The undamaged seat sealing surface is shown in Figure 3-48.

After completion of the posttest inspection and reassembly of the valve, a liquid displacement measurement was made to determine the size of the oxidizer inlet cavity. A value of 24 in.^{3} (3.95×10^{-4} m^3) was measured using Freon as the displaced fluid. This figure indicates that the maximum capacity of the inlet cavity would be about 1.3 lbm (5.90×10^{-1} kg) of LF_2. Since the measured quantity of LF_2 was 0.55 lbm (2.50×10^{-1} kg) on the first test, and 0.6 lbm (2.72×10^{-1} kg) on the second test, the estimate of one-half full appears to be essentially correct for both vibrational tests. The one-half full level was sufficient to ensure that the poppet and seat were exposed to

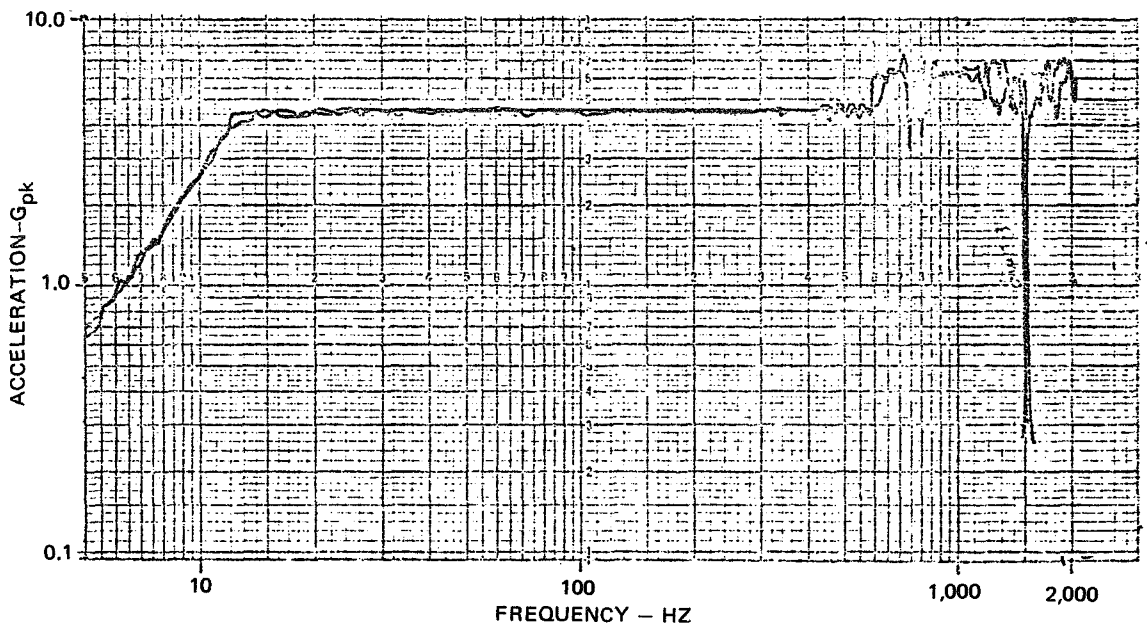

Figure 3-43. Lateral Sinusoidal Vibration Profile, Task IV

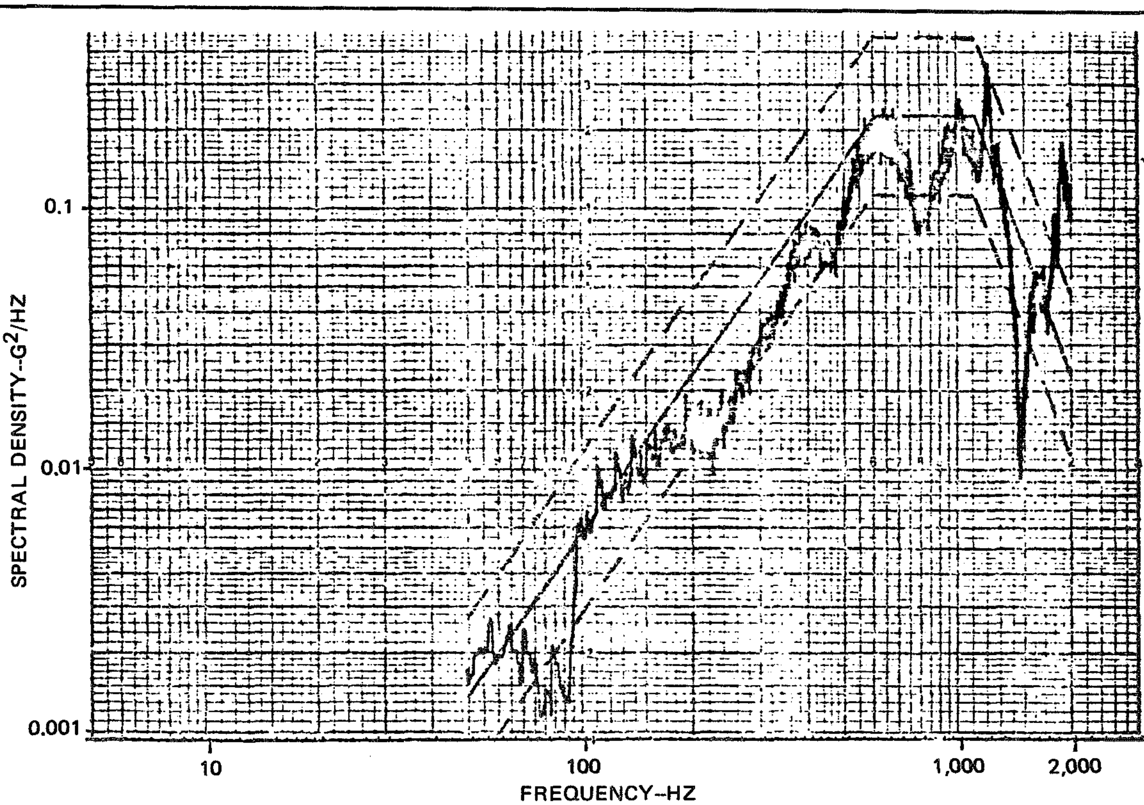

Figure 3-44. Lateral Random Vibration Profile, Task IV

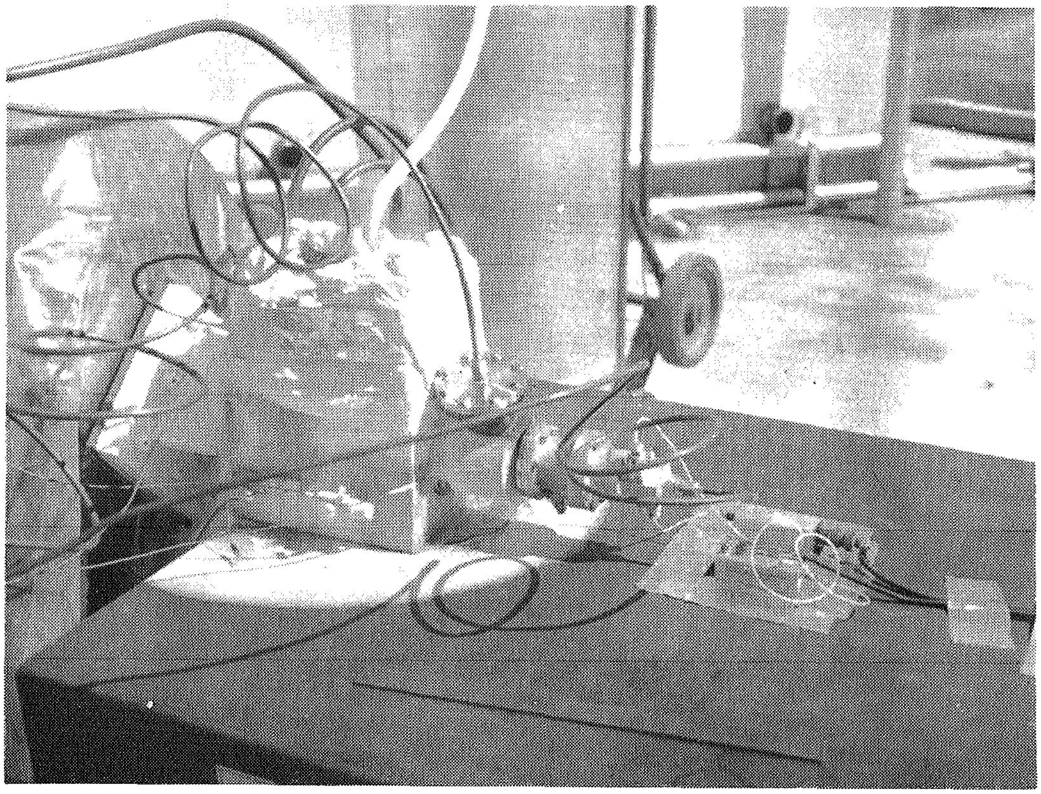

Figure 3-45. Longitudinal Vibration Test Installation

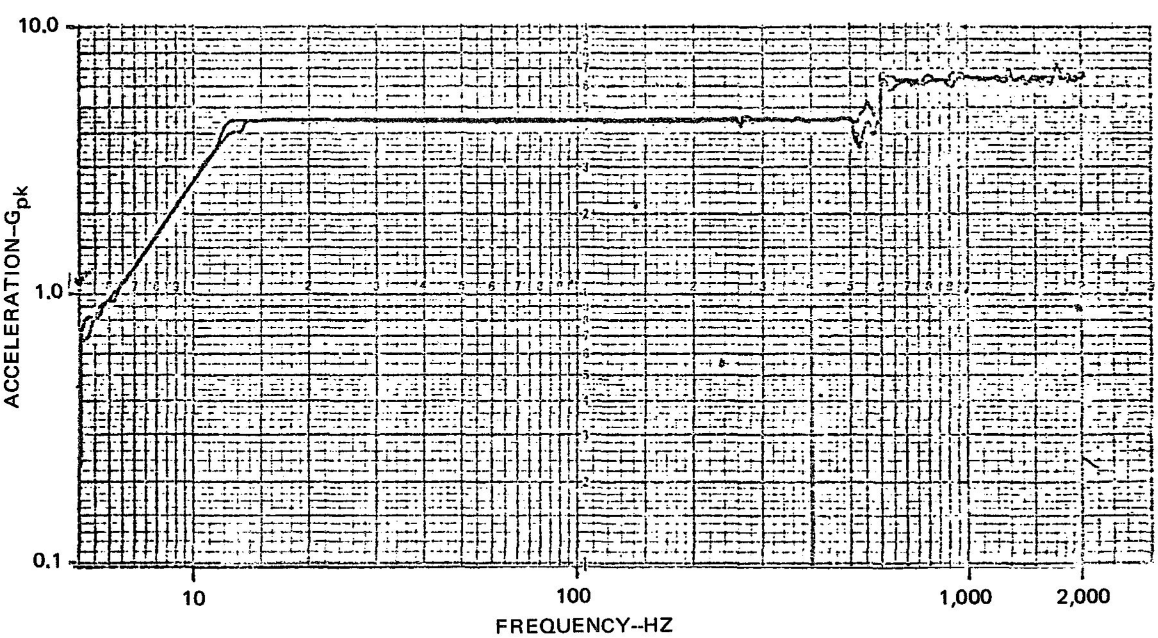

Figure 3-46. Longitudinal Sinusoidal Vibration Profile, Task IV

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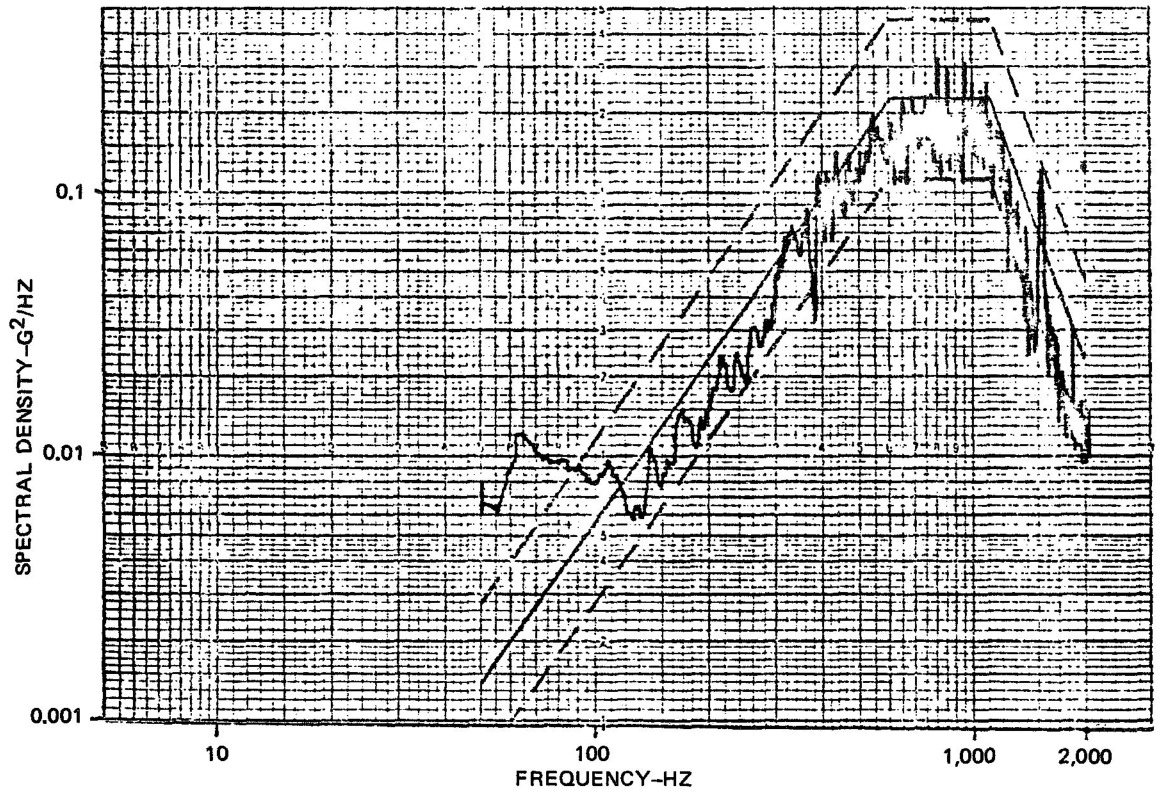

Figure 3-47. Longitudinal Random Vibration Profile, Task IV

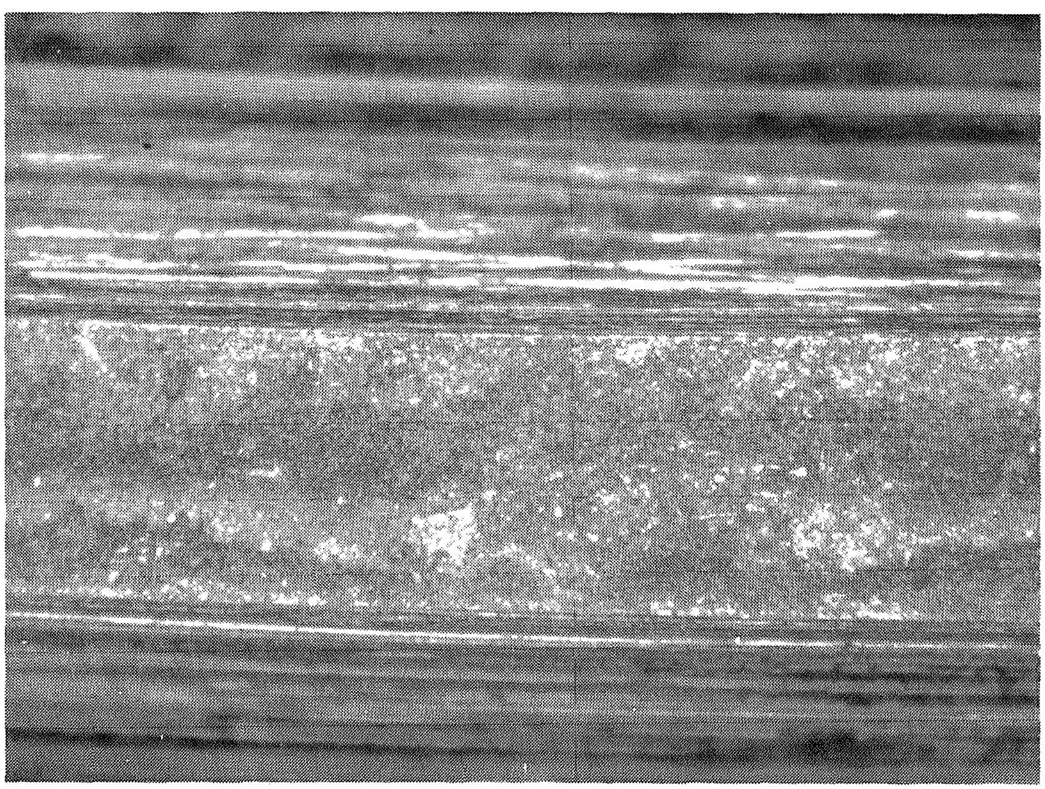

Figure 3-48. Sealing Surface of -1 Valve Seat After Vibration Tests (100X)

LF_2 during the testing completed on this program. To test with the cavity at a 90 to 95-percent full condition, it would be necessary to eliminate the heat leak, which is occurring through the outlet portion of the test valve, by chilling the entire test assembly. With the complete valve chilled to LN_2 temperature, the internal leakage of fluorine would remain in the liquid state in both the inlet and outlet portions of the valve, and this condition would prevent the monitoring of internal leakage during the test runs. Since monitoring of internal leakage during the vibration-test frequency sweeps was a requirement for this series of tests, no changes in the test setup were made. The -1 valve was reassembled, and final internal leakage checks made at ambient and LN_2 temperatures. The results at 100 psig (6.90×10^5 pascals) were 0.44 ccm (7.35×10^{-3} ccs) at ambient temperature, and 1.02 ccm (1.70×10^{-2} ccs) at -318°F (78.9°K). Following these checks the valve was oven-dried, packaged, and placed in storage.

3.5.3 Environmental-Test Conclusions

Exposure of the -1 and -501 valves to severe acceleration, shock, and vibration environments failed to produce any discernible deleterious effect on valve condition or performance. This conclusion is based on the consistency of pre and posttest internal leakage measurements, the singular lack of in-test anomalies, and the absence of breakage, wear, or other abnormality during the final disassembly and inspection operations.

3.6 CONCLUSIONS

The following paragraphs summarize the conclusions drawn from the five individual program tasks.

3.6.1 TASK I: Valve Design

Task I demonstrated that a conceptual LF_2 valve design, such as that resulting from Contract NAS 3-11195, in conjunction with the design principles and criteria for fluorine feed system components formulated under Contract NASw 1351, can be translated into a practical hardware design meeting the requirements of satisfactory component performance, ease of manufacture, and reasonable cost.

3.6.2 TASK II: Fabrication and Acceptance Testing

Fabrication of the prototype LF_2 valves involved the same precision manufacturing operations and techniques that are utilized in the routine production of high-quality, high-performance spacecraft components. The greatest difficulty encountered during the fabrication of the two test valves consisted of inspecting the poppet and seat sealing surface flatness and finish with sufficient accuracy. The method of inspection used by the valve supplier on this program is one of the most accurate methods in use at this time, yet even more accurate methods should be investigated.

Both valve configurations were fabricated, assembled, and successfully acceptance tested without the need for disassembly or rework of either valve. This type of performance confirms the merits of the basic design criteria approach to component design.

3.6.3 TASK III: Fluorine-Compatibility Testing

Compatibility and life-cycle tests, consisting of more than 250 cycles on each of the valves at LF_2 flowrates of 12 lbm/sec (5.45 kg/sec) and supply pressures of 100 psig (6.90×10^5 pascals), were completed during Task III. An additional 571 cycles on the -1 valve at an off-design (proof pressure) condition of 250 psig (1.73×10^6 pascals) produced a fatigue failure in the poppet-shaft bellows seal. The results of this testing show that the prototype valves met all design performance objectives (i.e., pressure drop at rated flow, response time, internal leakage, mode of failure, and material compatibility) when exposed directly to LF_2. Additional testing is needed to reveal the performance degradation effects of additional cycling, and the ultimate cycle life of the valves at the nominal 100 psig (6.90×10^5 pascals) operating condition. The investigation should also be extended to evaluate valve performance with fluids having grossly different chemical and physical properties, e.g., GH_2 and LH_2, so that additional basic design criteria can be generated for valves operating in different, but related service.

3.6.4 TASK IV: Valve Refurbishment and Testing

The refurbishment of the two test valves consisted primarily of the replacement of the failed poppet-shaft bellows seal of the -1 valve. Since the shaft and the seal are combined in a completely welded assembly, extensive work was required to replace the seal. After the seal was replaced, additional difficulty was experienced in relapping the original sealing surfaces. This difficulty was due to the lack of special tooling needed to permit lapping of the seal surface after assembly is completed, and due to the inability to properly inspect the lapped surface because the shaft extends through its center.

The external leakage test at cryogenic conditions was repeated at MDAC with better reading accuracy than had been obtained during the Task II effort. With the MDAC test system, a high vacuum could be obtained at ambient temperature conditions, but difficulty was experienced in maintaining the vacuum during the temperature chilldown period. The external leakage values measured on this program were obtained with the pressure rise (vacuum decay) technique, and are accurate within the accuracy of the pressure measuring instruments on the mass spectrometer (±10% approximately). The true leakage value will always be equal to or less than the reading presented due to the possibility of system leakage affecting the measured leakage value. To provide greater accuracy under the desired test conditions, i.e., -320°F (77.9°K) and 10^{-6} sccs leakage, it will be necessary to provide a more extensive space environment test setup which can supply uniform thermal conditioning of the complete test setup (as well as the test specimen) so that vacuum leakage from thermal gradients can be avoided.

It should be noted that the external leakage rates measured were all less than the specified 10^{-3} sccs for total oxidizer cavity leakage, and are in the order of the originally specified 2×10^{-4} sccs.

The 10^{-6} sccs value for one seal (oxidizer inlet) was not verified because it was beyond the lower readability limit of the test pressure gage.

3.6.5 TASK V: Environmental Testing

Task V extended the previous Task III fluorine-compatibility and cycle-life testing to include environmental testing. The results indicate that acceleration, shock, and vibration loads representative of those expected in a space stage application will not induce mechanical failure, or adversely affect the response times and internal leakage rates of the valve.

APPENDIX A

ENGINEERING ANALYSIS

PARKER HANNIFIN

SYSTEMS DIVISION
ENGINEERING DOCUMENT

PRODUCTION PRINT

OCT 28 1970

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Jay Katz

CONCURRENCE: ______

CONCURRENCE: ______

APPROVED BY: E. Johnson
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LIST OF EFFECTIVE PAGES

This document consists of 38 pages as follows:

Page	Rev Ltr
Cover.	NC
i	NC
1 thru 12	NC
A-1 thru A-24 . . .	NC

1.0 INTRODUCTION AND SUMMARY

1.1 Introduction - This report summarizes the calculations and engineering analysis conducted by Systems Division, Parker Hannifin on the Space Storable Oxidizer Valve, Parker PN 5690000-101 (Douglas PN 1T32095). The report is prepared in compliance with Program Task 3.1 of Parker Program Plan E137-500, dated 27 December 1968. The items considered in the analysis are as listed below. Appendix A of this report contains detailed analysis, where applicable, and computer printouts of the dynamic analysis.

a. Calculations for the sizing and manufacture of the:

(1) Shaft seal bellows
(2) Actuator springs
(3) Compliant seat

b. Determine acceptable range of seat stress as a function of pressure and static loads.

c. Determine required stroke limits.

d. Force diagram showing minimum and maximum conditions to determine force margin - all tolerances and sizing completed.

e. Structural calculations to determine flange and wall thickness for proof, burst, shock and vibration requirements.

f. Determine required bolt torques.

g. Computer valve simulation program to determine:

(1) Total system opening and closing response.
(2) Verification of selection of design elements and system volumes to obtain desired functional performance.

1.2 Summary - The design analysis utilizing manufacturing tolerances has verified valve performance. The two required performance changes are listed below:

a. Minimum actuator operating pressure has been raised from 250 psig to 300 psig.

b. Maximum pressure drop at minimum stroke has been raised from 2.4 psi to 3.5 psi.

1.2.1 The selected design elements and basic valve design appear sufficient to meet performance requirements. Only slight changes (such as the increase in the bellows effective area) were made to facilitate manufacturing.

2.0 CALCULATIONS

2.1 Shaft Seal Bellows - The bellows calculations were furnished by Gardner Bellows Company. The design parameters were computer calculated and correspond to an existing Gardner design. These design parameters, as furnished to Parker by Gardner are as follows:

a.	Rate:	100 ±20 lb/in
b.	Preload (Design Requirement):	50 lb
c.	Effective Area:	0.96 ±0.05 in^2
d.	Material:	Inconel 718
e.	Material Thickness:	0.008 inch (single ply)
f.	Number of Plys:	1
g.	Number of Convolutions:	20.0
h.	Stroke*:	0.600 inch max compression
i.	Maximum Stress (at full stroke and pressure of 250 psi):	94,100 psi (max allowable stress = 188,000 psi for 10,000 cycles)
j.	Bellows OD:	1.32 ±0.03 inches
k.	Bellows ID:	0.89 ±0.02 inches
m.	Proof Pressure, External:	250 psig
n.	Free Length:	1.70 ±0.02 inches

* Gardner Bellows Company does not recommend tention-compression type loading. All deflection should be in compression.

2.2 Actuator Springs - The two springs installed in parallel provide the necessary seat stress for sealing. The springs were calculated with a spring calculator and agree with the Douglas calculations. Upon release of the drawings for manufacturing, the spring company will re-check the parameters, however, the designs appear well within the fabrication tolerance range. The detail requirements are as follows:

a. Required Combined Performance

Preload:	189 ±19 lb
Stroke:	0.500 inch
Spring Rate:	230 ±23 lb/in
Maximum Compression:	1.32 inches

b. Spring I (Outer)

Wire Diameter:	0.192 inch
Maximum OD:	1.400 inches
Minimum ID:	1.050 inches
Mean Diameter:	1.183 inches
Spring Rate:	153 ±15.3 lb/in
Installed Load:	126 ±12.6 lb at installed length
Number of Active Coils:	7.8
Solid Height:	1.88 inches
Minimum Installed Length:	2.38 inches
Maximum Stress:	85,000 psi
Material:	316 CRES

c. Spring II (Inner)

Wire Diameter:	0.135 inch
Maximum OD:	0.970 inch
Minimum ID:	0.625 inch
Mean Diameter:	0.800 inch
Spring Rate:	77 ±7.7 lb/in
Installed Load:	63 ±6.3 lb at installed length
Number of Active Coils:	12.0
Solid Height:	1.89 inches
Minimum Installed Length:	2.39 inches
Maximum Stress:	82,000 psi
Material:	316 CRES

2.3 Compliant Seat - The square-wave bellows in the seat assembly will be manufactured by Hydradyne. The design parameters for the bellows were calculated by Hydradyne and are as follows:

a.	OD:	2.350 ±.003
b.	ID:	1.850 ±.003
c.	Rate:	5000±500 lb/in.
d.	Material:	A286
e.	No. of Convolutions:	13.5
f.	Maximum Stress:	130,000 psi at 520 lb axial load
g.	Maximum Allowable Stress:	160,000 psi fully heat treated

2.4 Seat Stress - Seat stresses are as follows:

a.	Maximum Seat Stress at 100 psi Inlet Pressure:	9,540 psi
b.	Minimum Seat Stress at 100 psi Inlet Pressure:	5,880 psi
c.	Maximum Seat Stress at 0 psi Inlet Pressure:	3,000 psi
d.	Minimum Seat Stress at 0 psi Inlet Pressure:	1,570 psi

2.5 Valve Opening Limits - For a 0.500 inch minimum actuator piston stroke, the poppet stroke (away from seat) is 0.478 inch maximum at 0 psi inlet pressure to 0.388 inch minimum at 100 psi inlet pressure.

2.6 Force Diagram - The valve force diagram is shown in Figure 1. All the nominal forces contributing to opening and closing are represented. For clarity, the minimum conditions for opening and closing are discussed in the computer valve simulation program.

2.7 Structural Calculations - Figure 2 shows the elements considered in the analysis. Table I summarizes the various thicknesses selected. In nearly all cases, the thickness was chosen for manufacturing reasons rather than structural requirements.

TABLE I. THICKNESS SELECTION SUMMARY

Section	Required Thickness (in.)	Selected Thickness (in.)	Safety Factor
T_1	0.014	0.070	5.06
T_2	0.003	0.070	26.0
T_3	0.057	0.125	4.8
T_4	0.019	0.090	4.8
T_5	0.103	0.150	2.3
T_6	0.151	0.350	5.3
T_7	0.134	0.250	3.5
T_8	0.036	0.188	27.0
T_9	0.173	0.300	7.0

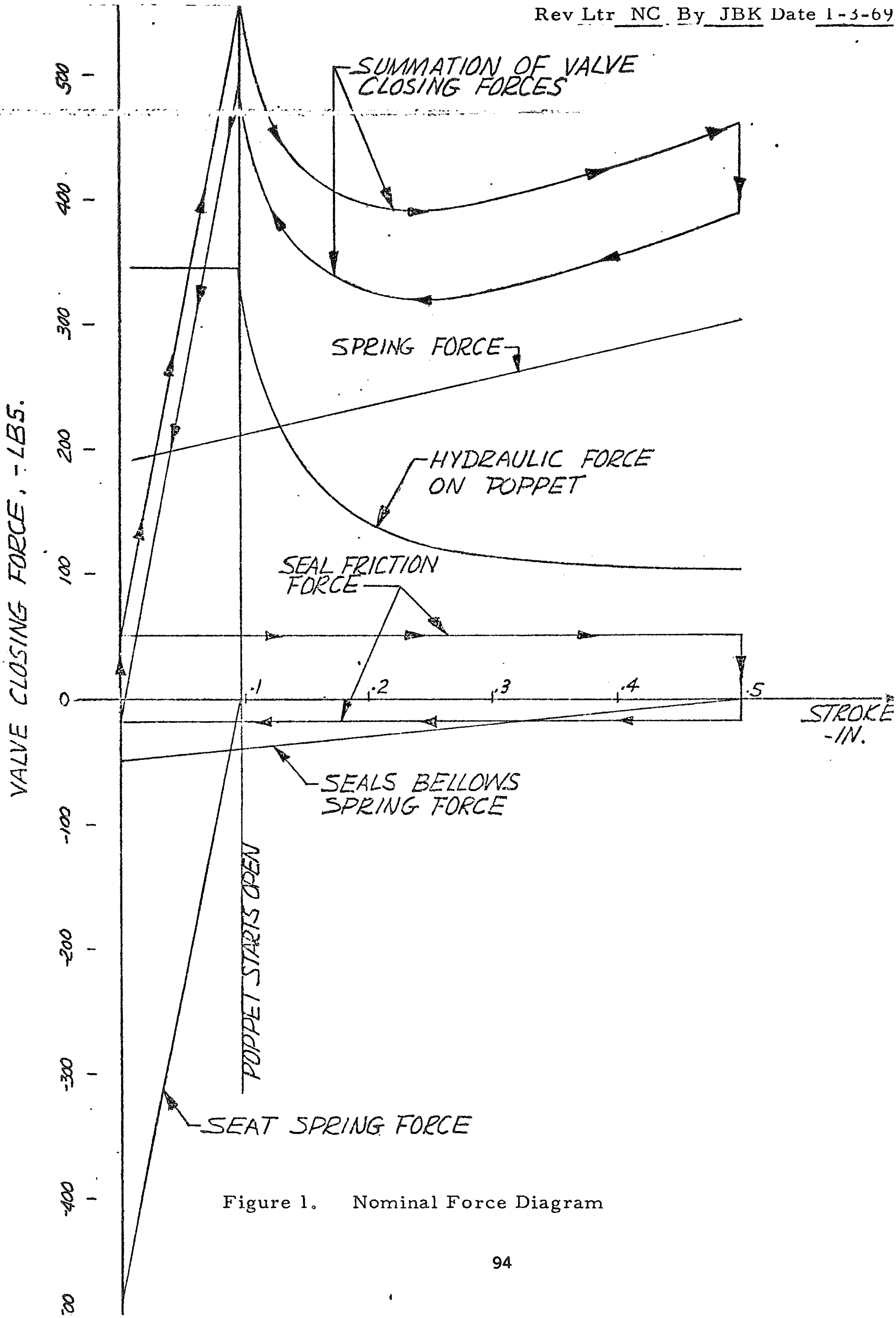


Figure 1. Nominal Force Diagram

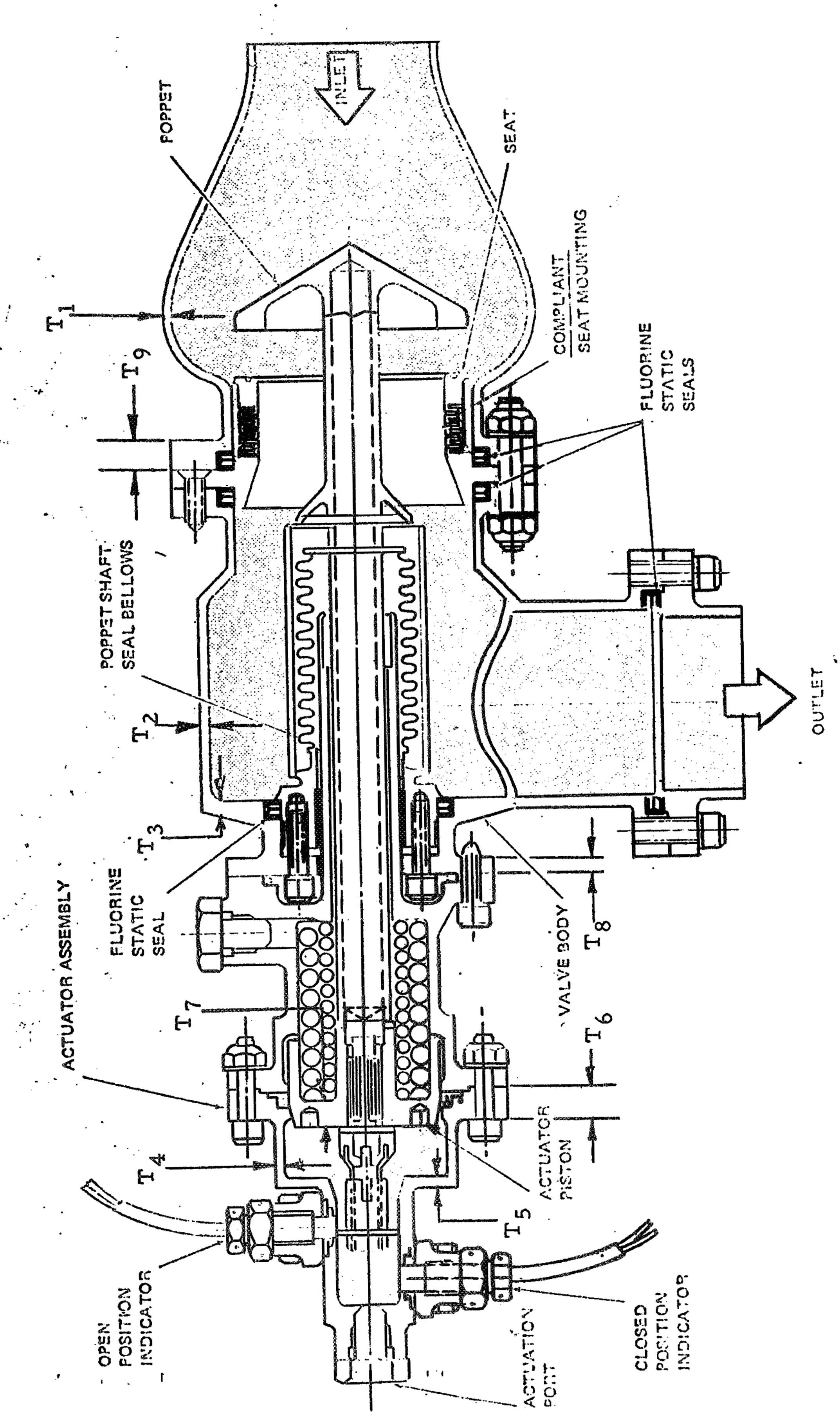
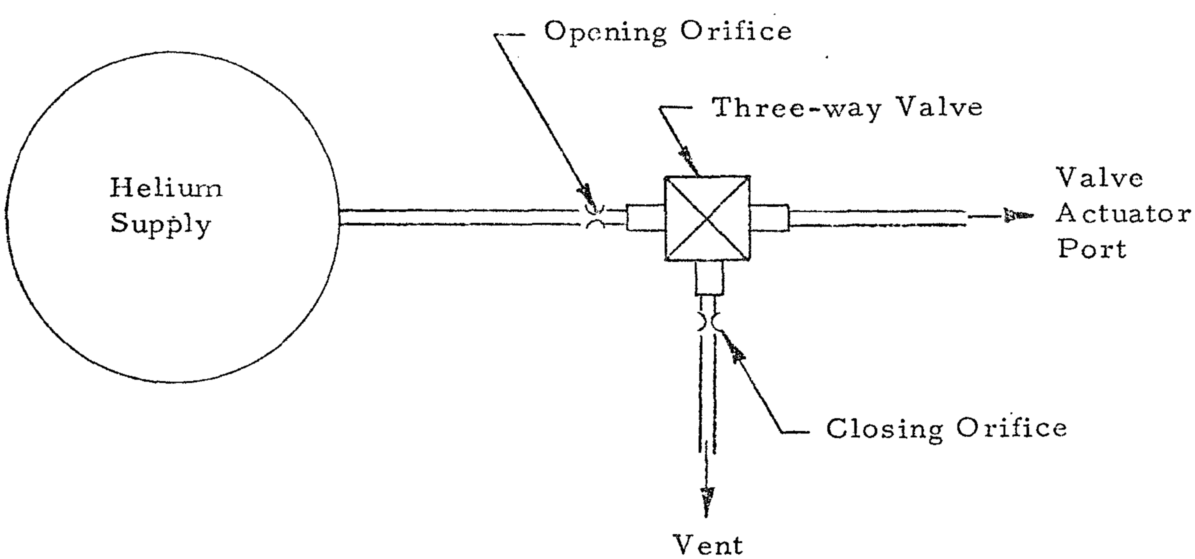


Figure 2. Structural Calculation Elements

2.8 Bolt Torques - The static seals selected for application in the subject design are manufactured by Hydradyne, Donaldson Division, located in San Fernando, California, Hydradyne PN 9100 series seals.

2.8.1 Five seals are required per valve. The minimum load required for sealing is shown in figure 3. The selected seal sizes are -29, -30, -32 and -37 (2 required). The required bolt torque will be the total load required for sealing divided by the number of bolts (determined during layout of the valve).

2.9 Opening and Closing Response Times - A computer program was written which dynamically simulates the performance of the valve during the opening and closing phases of operation. Response times were considered for a pressurization system consisting of a three-way valve containing orifices for opening and closing (see below). Orifice sizes considered were 0.060 and 0.100 inch.



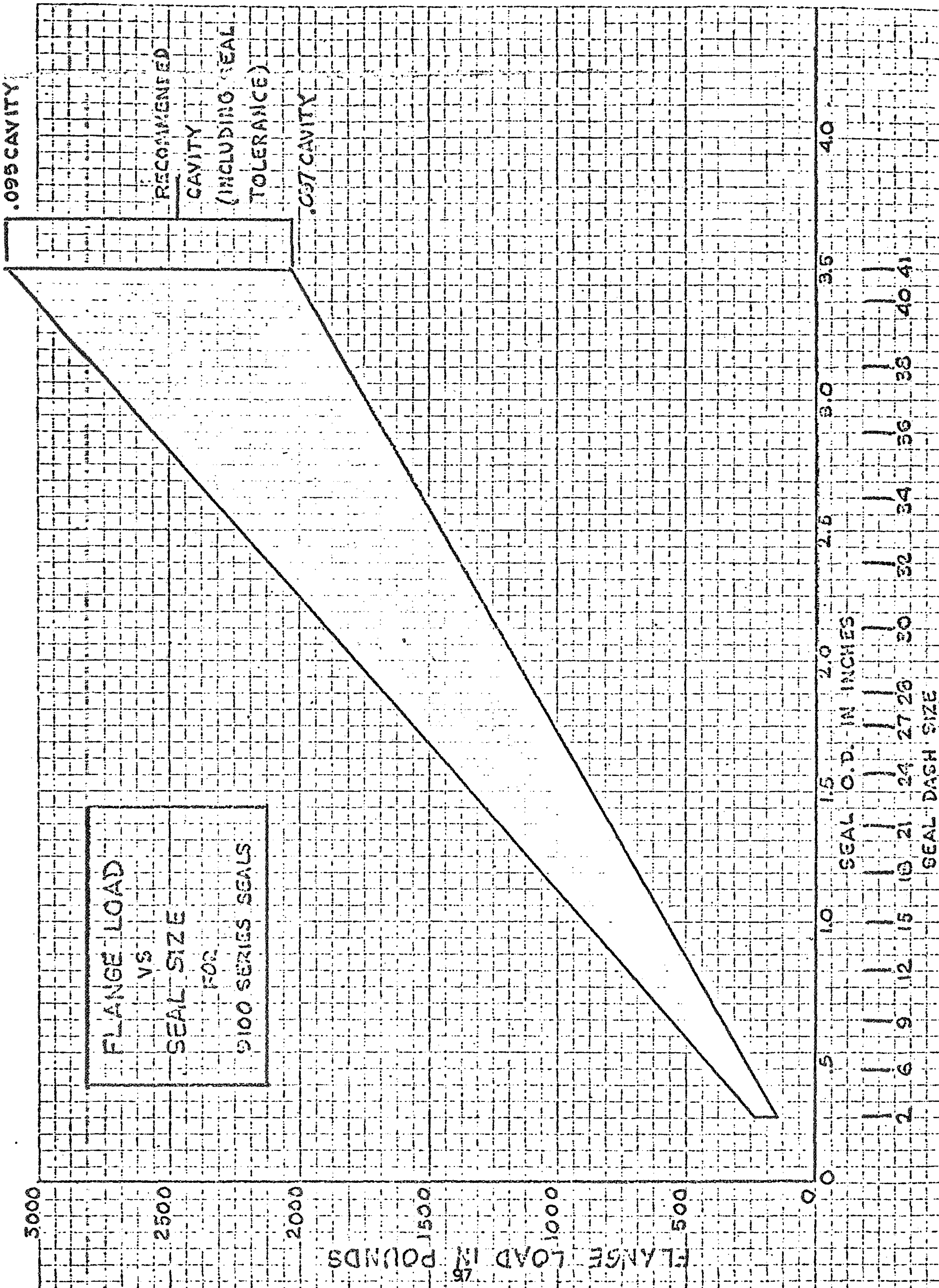

.095 CAVITY
RECOMMENDED CAVITY (INCLUDING SEAL TOLERANCE)
.057 CAVITY
FLANGE LOAD
VS
SEAL SIZE
FOR
9100 SERIES SEALS
FLANGE LOAD IN POUNDS
0
500
1000
1500
2000
2500
3000
SEAL O.D. IN INCHES
0
.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
SEAL DASH SIZE
2 6 9 12 15 18 21 24 27 28 30 32 34 36 38 40 41

Figure 3

2.9.1 Minimum conditions were used in the computer program to verify the opening and closing ability of the valve with the design elements and tolerances selected. Figures 4 and 5 are computer plotted curves representing the opening and closing traces. Response times for the two selected orifices are shown along with a summary of the parameters used in the program.

2.9.2 To avoid high-impact loading during valve operation, it is recommended that the smaller orifice sizes (0.060 inch or less) be used during testing.

2.9.3 The actual computer printouts for the program (for the 0.060 inch orifice) are attached to this report (Appendix A) to provide detailed information on the performance of the valve during the opening and closing transient periods. A nomenclature sheet is attached for parameter definition.

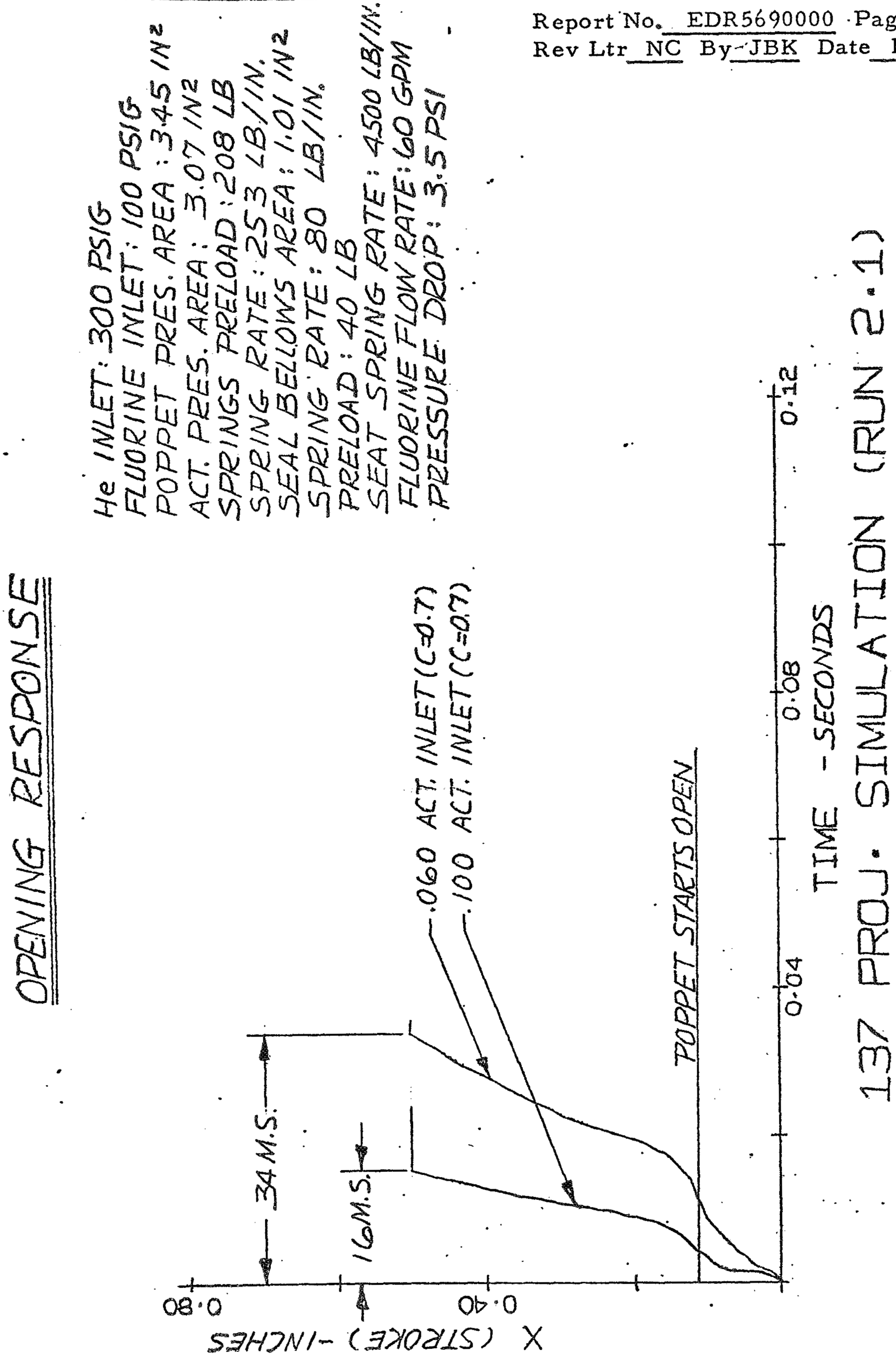

OPENING RESPONSE
He INLET: 300 PSIG
FLUORINE INLET: 100 PSIG
POPPET PRES. AREA: 3.45 IN²
ACT. PRES. AREA: 3.07 IN²
SPRINGS PRELOAD: 208 LB
SPRING RATE: 253 LB/IN.
SEAL BELLOWS AREA: 1.01 IN²
SPRING RATE: 80 LB/IN.
PRELOAD: 40 LB
SEAT SPRING RATE: 4500 LB/IN.
FLUORINE FLOW RATE: 60 GPM
PRESSURE DROP: 3.5 PSI
.060 ACT. INLET (C=0.7)
.100 ACT. INLET (C=0.7)
POPPET STARTS OPEN
34 M.S.
16 M.S.
0.80
0.40
X (STROKE) - INCHES
0.04
0.08
0.12
TIME - SECONDS
137 PROJ. SIMULATION (RUN 2.1)

Figure 4.

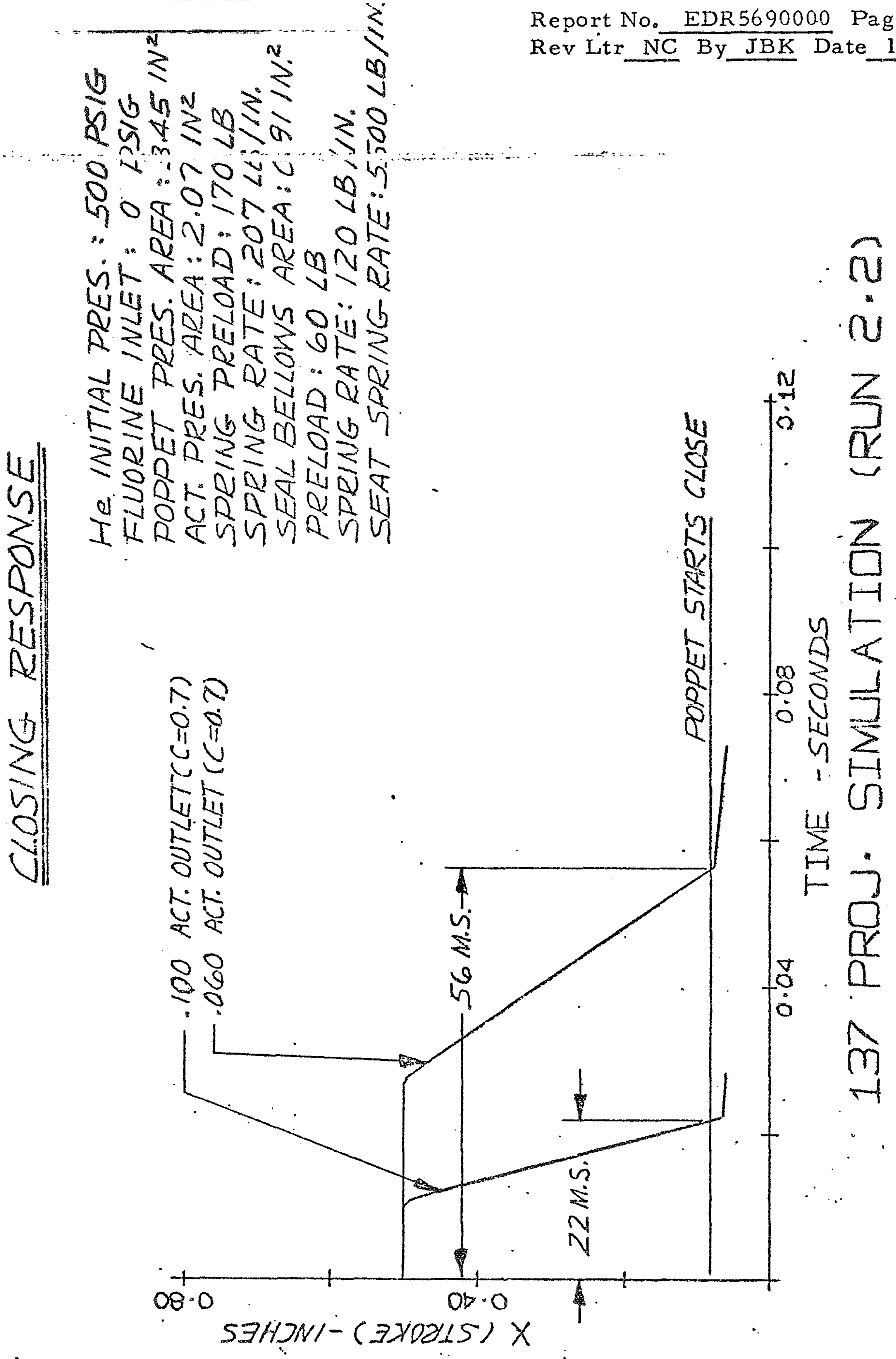

CLOSING RESPONSE
He. INITIAL PRES.: 500 PSIG
FLUORINE INLET: 0 PSIG
POPPET PRES. AREA: .345 IN²
ACT. PRES. AREA: 2.07 IN²
SPRING PRELOAD: 170 LB
SPRING RATE: 207 LB/IN.
SEAL BELLOWS AREA: 0.91 IN²
PRELOAD: 60 LB
SPRING RATE: 120 LB/IN.
SEAT SPRING RATE: 5500 LB/IN.
POPPET STARTS CLOSE
.100 ACT. OUTLET (C=0.7)
.060 ACT. OUTLET (C=0.7)
56 M.S.
22 M.S.
0.04
0.08
0.12
TIME - SECONDS
0.40
0.80
X (STROKE) - INCHES
137 PROJ. SIMULATION (RUN 2.2)

Figure 5.

APPENDIX A

DETAILED ENGINEERING ANALYSIS
AND
COMPUTER SIMULATION PROGRAM

SEAT STRESS

CONDITION I ~ MAX INLET PRESSURE OF 100 PSIG

CLOSING FORCES +
OPENING FORCES −

$$\sum \text{FORCES} = 0$$

SHAFT SEAL BELLOWS PRELOAD = −50 LB
SPRING FORCE (COMBINED) = 189 ± 19 LB
FORCES DUE TO PRESSURE = 345 LB (SMALL VARIATION ONLY WITH SEAT TOLERANCE)

SEATING FORCE MAX = (189+19) + 345 − 50 = 503 LB
MIN = (189−19) + 345 − 50 = 465 LB

MIN SEAT AREA: $\frac{\pi}{4}(2.104^2 - 2.096^2) = 0.0528\ in^2$
MAX SEAT AREA: $\frac{\pi}{4}(2.106^2 - 2.094^2) = 0.0792\ in^2$

MAX SEAT STRESS = $\frac{503}{.0528}$ = 9540 PSI

MIN SEAT STRESS = $\frac{465}{.0792}$ = 5880 PSI

CONDITION II ~ MIN INLET PRESSURE ~ 0 PSIG

SEATING FORCE MAX = (189+19) − 50 = 158 LB
SEATING FORCE MIN = (189−19) − 50 = 120 LB

MAX SEAT STRESS = $\frac{158}{.0528}$ = 3000 PSI

MIN SEAT STRESS = $\frac{120}{.0792}$ = 1570 PSI

STROKE LIMITS

SPRING RATE OF SEAT = 5000 ± 500 PSI

SEATING FORCES MAX = 503 LB } AT 100 PSI MAX INLET PRESS.
MIN = 465 LB

MAX SEAT COMPRESSION = $\frac{503}{5000-500}$ = 0.112 IN.

MIN SEAT COMPRESSION = $\frac{465}{5000+500}$ = 0.0845 IN.

SEAT COMPRESSION WITH 0 INLET PRESSURE

SEATING FORCE MAX = 158 LB
MIN = 120 LB

MAX SEAT COMPRESSION = $\frac{158}{4500}$ = 0.0351 IN.

MIN SEAT COMPRESSION = $\frac{120}{5500}$ = 0.0218 IN.

FOR A 0.500 MIN-ACTUATOR PISTON STROKE, THE OPENING OF THE POPPET WOULD RANGE FROM 0.478 TO 0.388 IN.

PRELIMINARY CALCULATIONS OF WALL THICKNESS

1. T_1

MATERIAL: 347 S/S
YIELDING STRESS: 35,000 PSI
PROOF PRESSURE: 250 PSI
INSIDE DIAMETER: 3.875 IN.

$$T_1 = \frac{(250)(3.875)}{2(35000)} = 0.01384 \text{ IN.} \quad \text{SAY } 0.070 \text{ IN.}$$

SAFETY FACTOR = 5.06

2. T_2

MATERIAL: INCONEL 718
YIELDING STRESS: 174,000 PSI
PROOF PRESSURE: 250 PSI
INSIDE DIAMETER: 3.750 IN.

$$T_2 = \frac{(250)(3.75)}{2(174,000)} = 0.0027 \text{ IN.} \quad \text{SAY } 0.070 \text{ IN.}$$

SAFETY FACTOR = 26.0

3. T_3

$$T_3 = (3.75)\sqrt{\frac{(0.162)(250)}{174,000}} = 0.0572 \text{ IN.} \quad \text{SAY } 0.125 \text{ IN.}$$

SAFETY FACTOR = 4.3

WALL THICKNESS CALCULATIONS (CONT)

4. T_4

MATERIAL: AL 6061-T6
YIELDING STRESS: 35,000 PSI
PROOF PRESSURE: 750 PSI
INSIDE DIAMETER: 1.75 IN.

$$T_4 = \frac{(750)(1.75)}{2(35,000)} = 0.01875 \text{ IN.} \qquad \text{SAY } 0.090 \text{ IN.}$$

SAFETY FACTOR = 4.8

5. T_5

$$T_5 = (1.75)\sqrt{\frac{(0.162)(750)}{35,000}} = 0.103 \text{ IN.} \quad \text{SAY } 0.156 \text{ IN.}$$

SAFETY FACTOR = 2.3

6. T_6

BOLTS D.B.C = 2.563 IN.

$$T_6 = (2.563)\sqrt{\frac{(0.162)(750)}{35,000}} = 0.151 \text{ IN.} \quad \text{SAY } 0.350 \text{ IN.}$$

SAFETY FACTOR = 5.3

WALL THICKNESS CALCULATIONS (CONT)

7. T_7

$$T_7 = \sqrt{\frac{3}{16} P \frac{D^2}{S}}$$

MATERIAL: AL 6061-T651
YIELDING STRESS: 35,000 PSI
PROOF PRESSURE: 750 PSI
D = 2.125 IN.

$$T_7 = \sqrt{\frac{3(750)(2.125)^2}{16(35,000}} = \sqrt{0.0181} = 0.1344 \text{ IN.}$$

SAY 0.250 IN.

SAFETY FACTOR = 3.46

8. T_8
MATERIAL: INCONEL 718
YIELDING STRESS: 174,000 PSI
PROOF PRESSURE: 250 PSI
D.B.C = 2.375 IN.

$$T_8 = 2.375\sqrt{\frac{(0.162)(250)}{174,000}} = 0.0362 \text{ IN.} \quad \text{SAY } 0.188 \text{ IN.}$$

SAFETY FACTOR = 27.0

9. T_9
MATERIAL: 347 S/S

$$T_8 : 3.313\sqrt{\frac{(0.162)(250)}{35,000}} = 0.178 \text{ IN.} \quad \text{SAY } 0.500 \text{ IN.}$$

SAFETY FACTOR = 7.0

SIMULATION PROGRAM NOMENCLATURE

NAME	UNIT	DESCRIPTION
XO	in.	VALVE INITIAL STROKE
XDO	in/sec	VALVE INITIAL VELOCITY
PCO	psi	ACTUATOR CHAMBER INITIAL PRESSURE
POUTO	psi	INITIAL VALVE OUTLET PRESSURE
ATM	psi	ATMOSPHERIC PRESSURE
AC	in^2	ACTUATOR AREA
AB	in^2	SEALING BELLOWS EFFECTIVE AREA
PLSF1	lb	OUTER SPRING PRELOAD FORCE
PLSF2	lb	INNER SPRING PRELOAD FORCE
KS1	lb/in	OUTER SPRING RATE
KS2	lb/in	INNER SPRING RATE
PLFB	lb	SEALING BELLOWS PRELOAD FORCE
KB	lb/in	SEALING BELLOWS SPRING RATE
ASEAT	in^2	VALVE SEATING AREA
PIN	psi	LIQUID FLUORINE INLET PRESSURE
FRIC1	lb	FRICTIONAL FORCE WHEN VALVE OPENS
FRIC2	lb	FRICTIONAL FORCE WHEN VALVE CLOSES
MASS	$\frac{lb\text{-}sec^2}{in.}$	MASS OF MOVING PARTS
XMAX	in.	MAX VALVE STROKE
XMIN	in.	MIN VALVE STROKE
VCO	in^3	INITIAL ACTUATOR CHAMBER VOLUME
PGAS	psi	ACTUATOR GAS INLET PRESSURE
CAGAS	in^2	ACTUATOR EFFECTIVE FLOW AREA
R	in/R°	SPECIFIC GAS CONSTANT
TEMP	°R	ACTUATING GAS ABSOLUTE TEMPERATURE
G	dimensionless	SPECIFIC HEAT RATIO
DFST	in.	VALVE SEAT DEFLECTION

SIMULATION PROGRAM NOMENCLATURE (CONT)

NAME	UNIT	DESCRIPTION
DSEAT	in.	VALVE SEAT DIAMETER
C	dimensionless	FLOW DISCHARGE COEFFICIENT
RHO	lb/in^3	LIQUID FLUORINE DENSITY
CADNS	in^2	DOWNSTREAM SHUTOFF VALVE EFFECTIVE FLOW AREA
BETA	psi	COMPRESSIBILITY OF LIQUID FLUORINE
VR	in^3	VOLUME BETWEEN VALVE SEAT TO DOWNSTREAM SHUTOFF VALVE
VISCD	$\frac{lb\text{-}sec}{in}$	VISCUOUS DAMPING COEFFICIENT
FS	lb	SEATING FORCE VS DEFLECTION

APPENDIX B

VALVE-ASSEMBLY PROCEDURE

PARKER HANNIFIN

SYSTEMS DIVISION
ENGINEERING DOCUMENT

NUMBER: PTS5696040

TITLE: Acceptance Test Procedure
Liquid Fluorine Shutoff Valve
PN 5696040

RELEASE HISTORY				CUSTOMER APPROVAL	
DATE	REVISION	E.O. NO.	MICROFILM	APPROVAL NO.	DATE
	NC	01			
4-14-69	A	02		D L Eudaly [illegible]	4/14/69
7-17-69	B	03		J R de Donna [illegible]	7/29/69

REFERENCE: S137

PREPARED BY: Erwin Johnson
Erwin Johnson
Project Engr

CONCURRENCE:

CONCURRENCE: Frank Throssell
Frank Throssell
Lab Supervisor

APPROVED BY:

5827 WEST CENTURY BOULEVARD, LOS ANGELES, CALIFORNIA 90009

PHS 1P31 10-68

LIST OF EFFECTIVE PAGES

This document consists of 15 pages as follows:

Page	Rev Ltr
Cover	B
i	B
1 thru 13	B

1.0 TEST OBJECTIVES

The liquid fluorine shutoff valve, PN 5696040, shall be acceptance tested to determine:

a. Structural integrity at proof pressure in both the oxidizer and actuator cavities at ambient and cryogenic temperatures.

b. The actuation/deactuation characteristics of the valve at both ambient and cryogenic temperatures.

c. The internal leakage obtainable from the poppet/seat design at both ambient and cryogenic temperatures.

d. That external leakage is within acceptable limits at ambient temperatures.

2.0 DETAIL TEST PROCEDURE

2.1 Pre-Test Inspection - Visually inspect the test specimen for proper identification, all bolts properly lockwired, and no noticeable damage. Weigh and record specimen.

2.2 Proof Pressure

2.2.1 Actuator (Ambient)

2.2.1.1 Test Setup - Install test specimen in setup as shown in figure 1. Oxidizer ports and actuator vent to be open but protected from contamination.

2.2.1.2 Test Procedure - Pressurize actuator inlet with 750 + 25, -0 psig helium for 10 minutes.

2.2.1.3 Test Requirement - There shall be no evidence of damage to specimen as a result of the proof pressure application.

2.2.2 Actuator (Low Temperature)

2.2.2.1 Test Setup - Immerse test specimen in LN_2 bath as shown in figure 1. Oxidizer ports and actuator vent to be open to atmosphere but protected from contamination and moisture.

2.2.2.2 Test Procedure - Immerse test specimen in liquid nitrogen bath. After boiling has ceased (or a minimum of 15 minutes) pressurize the actuator inlet with 750 +25,-0 psig helium for 10 minutes.

2.2.3 Oxidizer Cavity (Low Temperature & Ambient)

2.2.3.1 Test Setup - While maintaining valve at low temperature change test setup to as shown in figure 2.

2.2.3.2 Test Procedure - Pressurize oxidizer inlet and outlet to 250 +25, -0 psig helium for 10 minutes. Warm up valve and repeat test at ambient temperature.

2.2.3.3 Test Requirement - There shall be no evidence of damage to specimen as a result of the proof pressure application.

2.3 Valve Actuation/Deactuation

2.3.1 Ambient Actuation/Deactuation

2.3.1.1 Test Setup - Purge all ports with helium and cap to prevent entrance of air. Test lines and fixtures to be purged also. Install test specimen in test setup as shown in figure 3.

2.3.1.2 Test Procedure - At ambient temperature, pressurize actuator inlet using helium at a maximum pressurization rate of 100 psi/sec. Oxidizer inlet to have 2-5 psig helium pressure applied, outlet to be vented. Record pressure required to crack and reseat the valve (as indicated by flow from outlet and position indicators). Repeat test with 100 +10, -0 psig helium applied to the oxidizer inlet.

2.3.2 Cold Temperature Actuation/Deactivation

2.3.2.1 Test Setup - Test specimen to be setup as shown in figure 4.

2.3.2.2 Test Procedure - Actuate valve (with 2-5 psig oxidizer pressure) by increasing helium pressure at actuator inlet (do not exceed 100 psi/sec) and record pressure that valve cracks and reseats (as described in Para. 2.3.1.2). Pressurize oxidizer inlet to 100+10, -0 psig helium with oxidizer outlet open and repeat above test.

2.4 Leakage

2.4.1 Ambient Leakage (External)

2.4.1.1 Test Setup - Test setup as shown in figure 5.

2.4.1.2 Test Procedure - Pressurize oxidizer inlet and outlet to 250 +25, -0 psig helium (ambient). Bubble leak check all pressurized joints. No bubbles permitted.

2.4.2 Ambient Leakage (Oxidizer to Actuator) - Pressurize oxidizer inlet and outlet with 250 psig helium. Measure and record leakage at actuator port using water displacement graduated cylinder method.

2.4.3 Ambient Leakage (Seat)

2.4.3.1 Test Setup - per figure 5.

2.4.3.2 Test Procedure - Pressurize oxidizer inlet to 100, 150, 200 and 250 psig ambient helium. Measure and record seat leakage at oxidizer outlet port using water displacement graduated cyclinder method. 3 min min at each test pressure.

2.4.4 Low Temperature Leakage (Oxidizer to Actuator)

2.4.4.1 Test Setup - per figure 5.

2.4.4.2 Test Procedure - Do not allow moisture to enter valve. Pressurize oxidizer inlet and outlet with 250 psig chilled helium. Measure and record leakage at actuator vent port using water displacement graduated cylinder method.

2.4.5 Low Temperature (Seat Leakage)

2.4.5.1 Test Setup - per figure 5.

2.4.5.2 Test Procedure - While maintaining valve at low temperatures, apply 100, 150, 200 and 250 psig helium to oxidizer inlet. Measure and record leakage at oxidizer outlet using water displacement graduated cyclinder method. 3 Minutes min at each test pressure.

2.6 Liquid Nitrogen Blowdown (One Unit Only)

2.6.1 Test Setup - Install test specimen in setup as shown in figure 6.

2.6.2 Test Procedure - Pressurize liquid nitrogen supply tank to 100 psig. Pressurize normally closed inlet port of the three-way solenoid valve to 450 ±25 psig regulated helium pressure. Valve to be opened for 5±1 seconds, then closed by actuation and deactuation of the three-way solenoid valve. If liquid is not observed at valve outlet, repeat test while valve is still chilled. Liquid must be present in oxidizer cavity, when the valve closes. Opening and closing traces from the position indicators are to be recorded on a recording oscillograph.

WARNING

Due to the high flowrate of LN_2 during the test, the oxidizer outlet must be vented to an area clear of equipment and personnel.

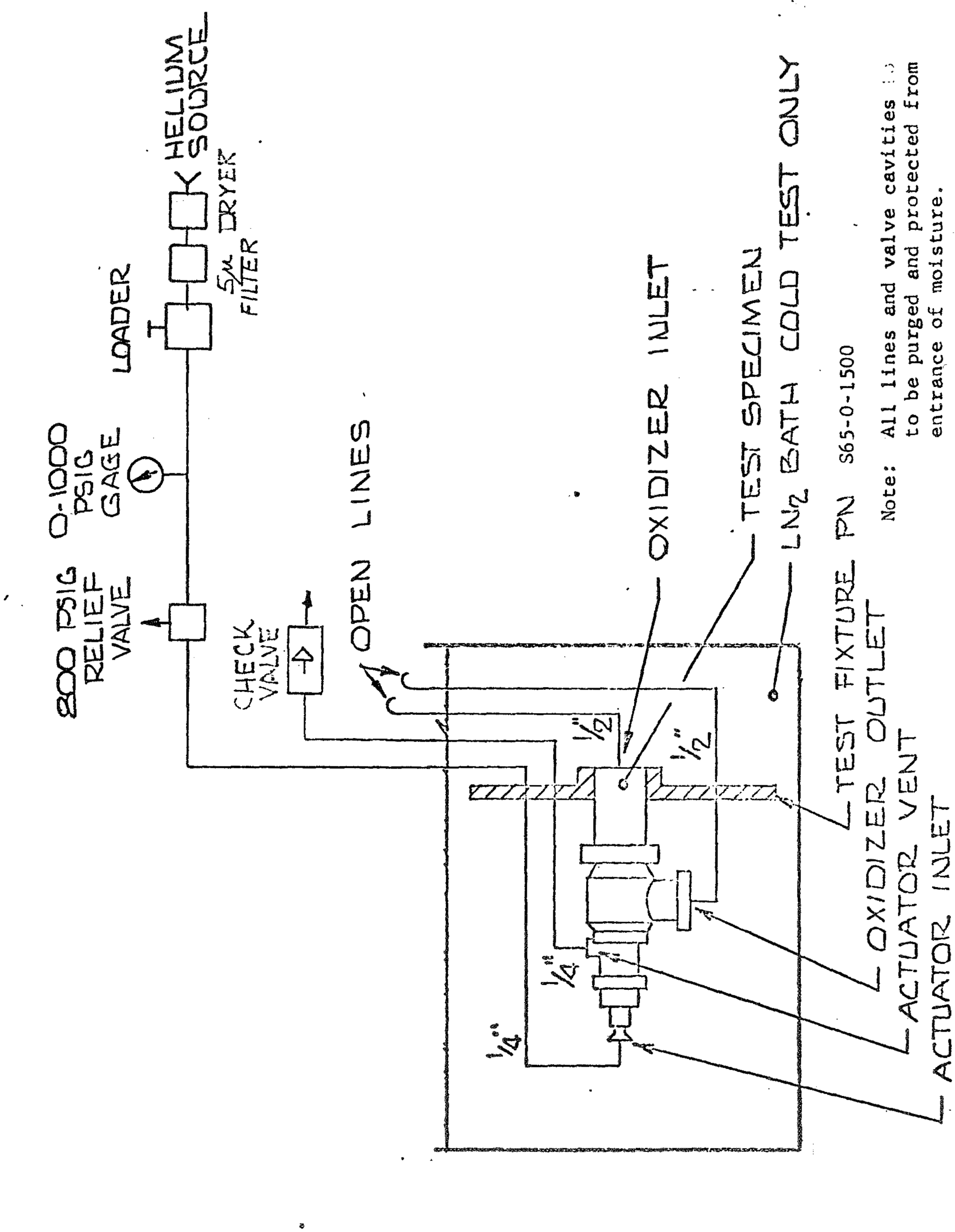


Figure 1. Proof Pressure Actuator Ambient & Cold

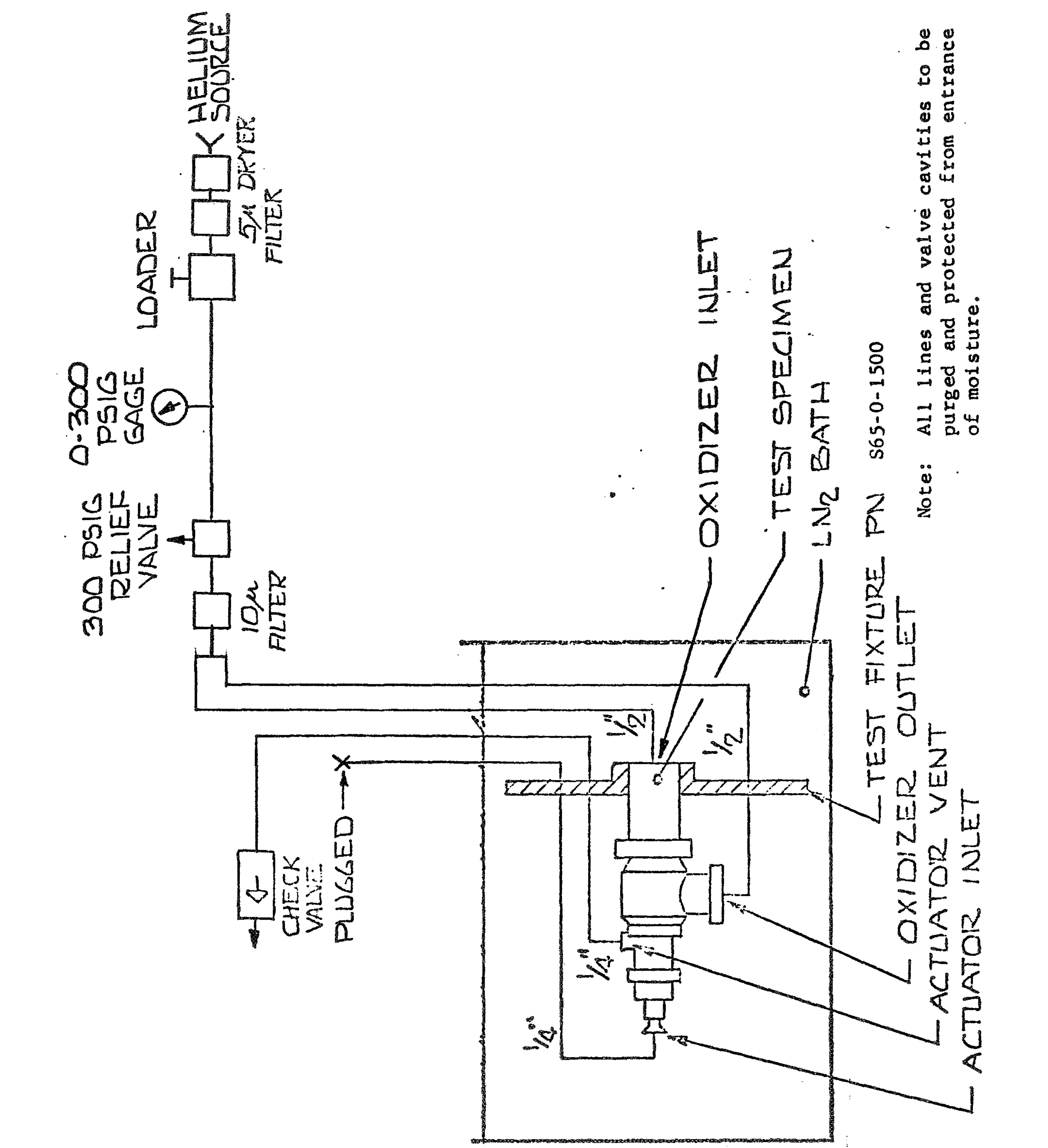


Figure 2. Proof Pressure Oxidizer Cavity Ambient & Cold.

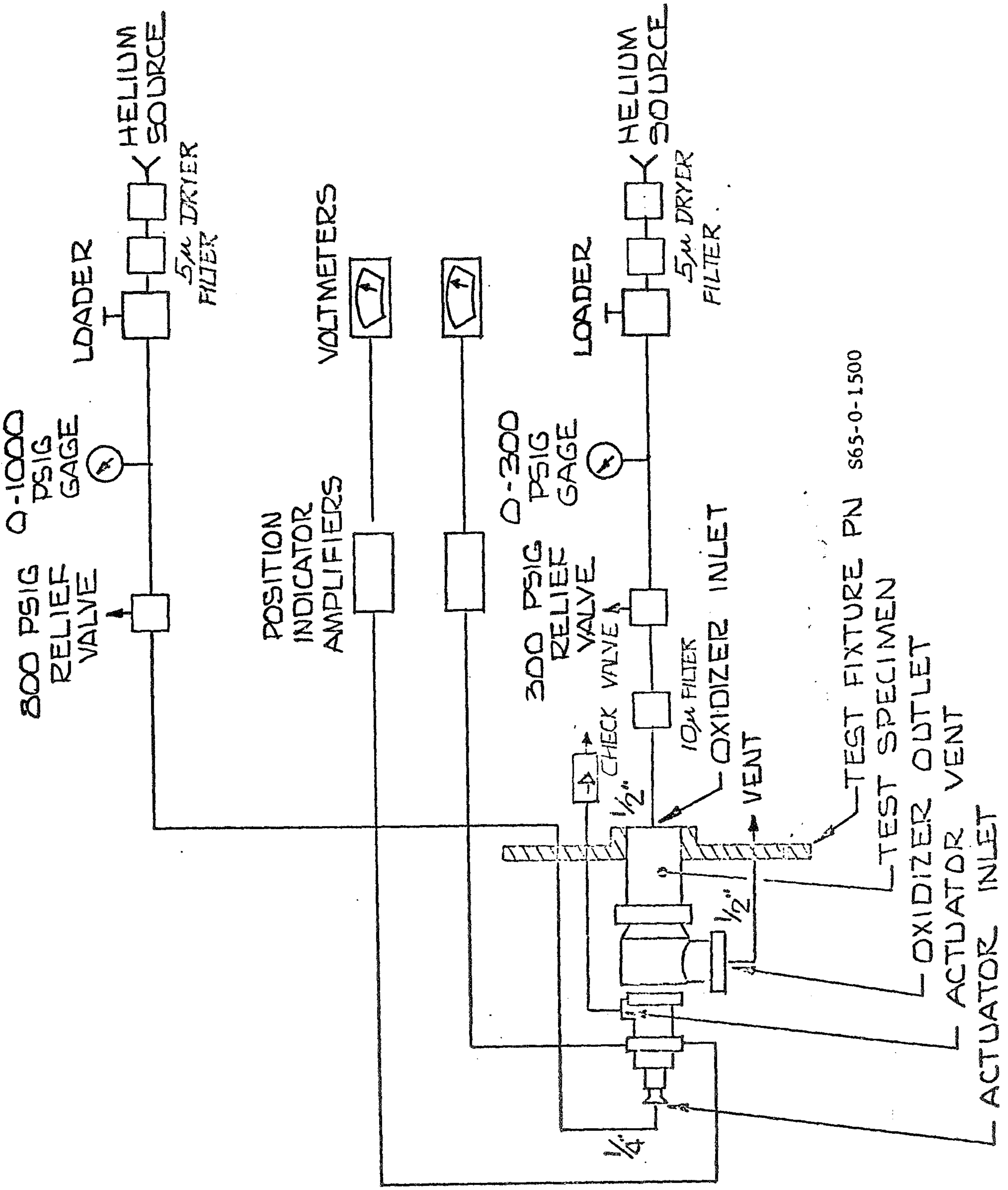


Figure 3. Ambient Actuation/Deactuation

REV LTR	NC	A	B		
DATE	3-28-69	4-9-69	7-17-69		

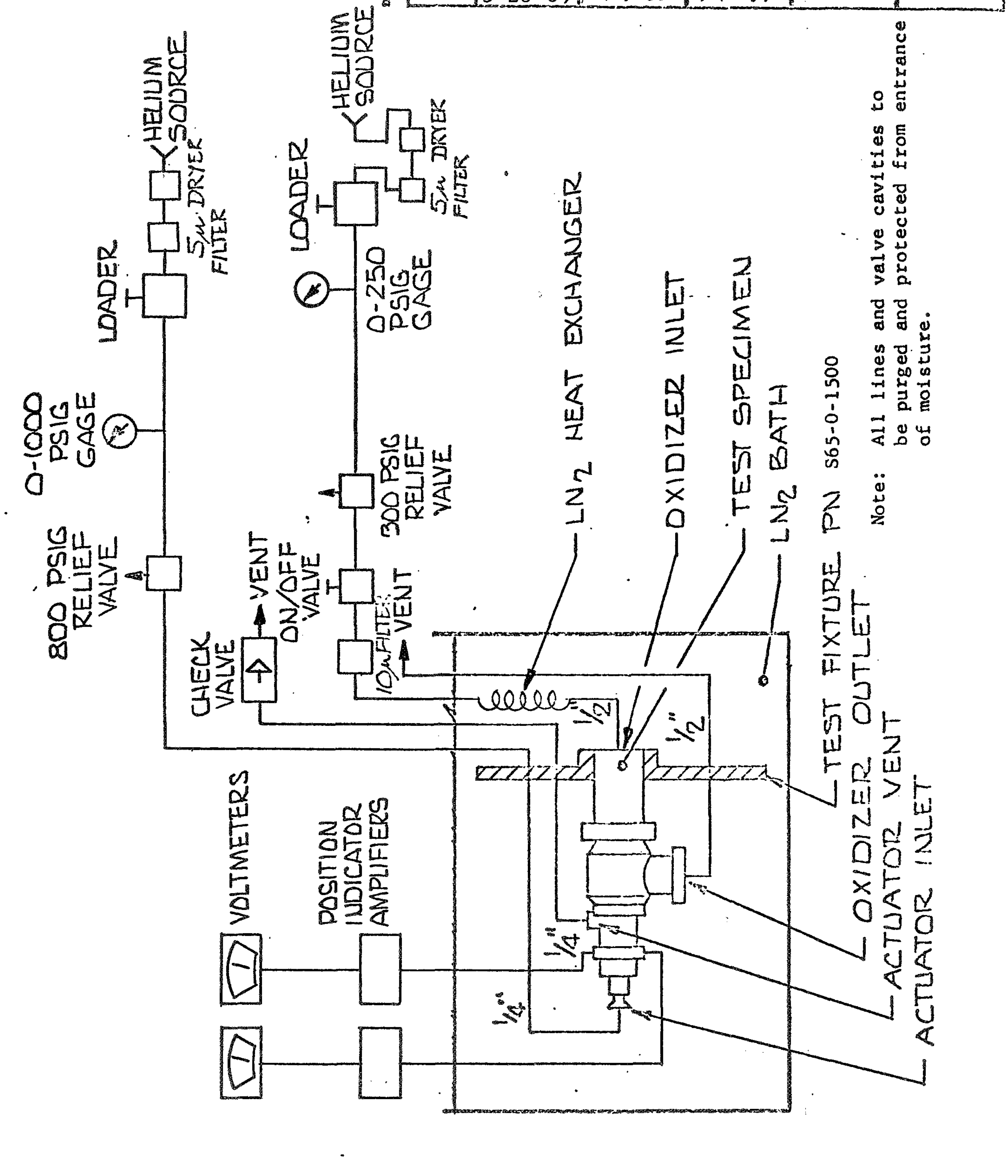


Figure 4. Cold Temperature Actuation/Deactuation

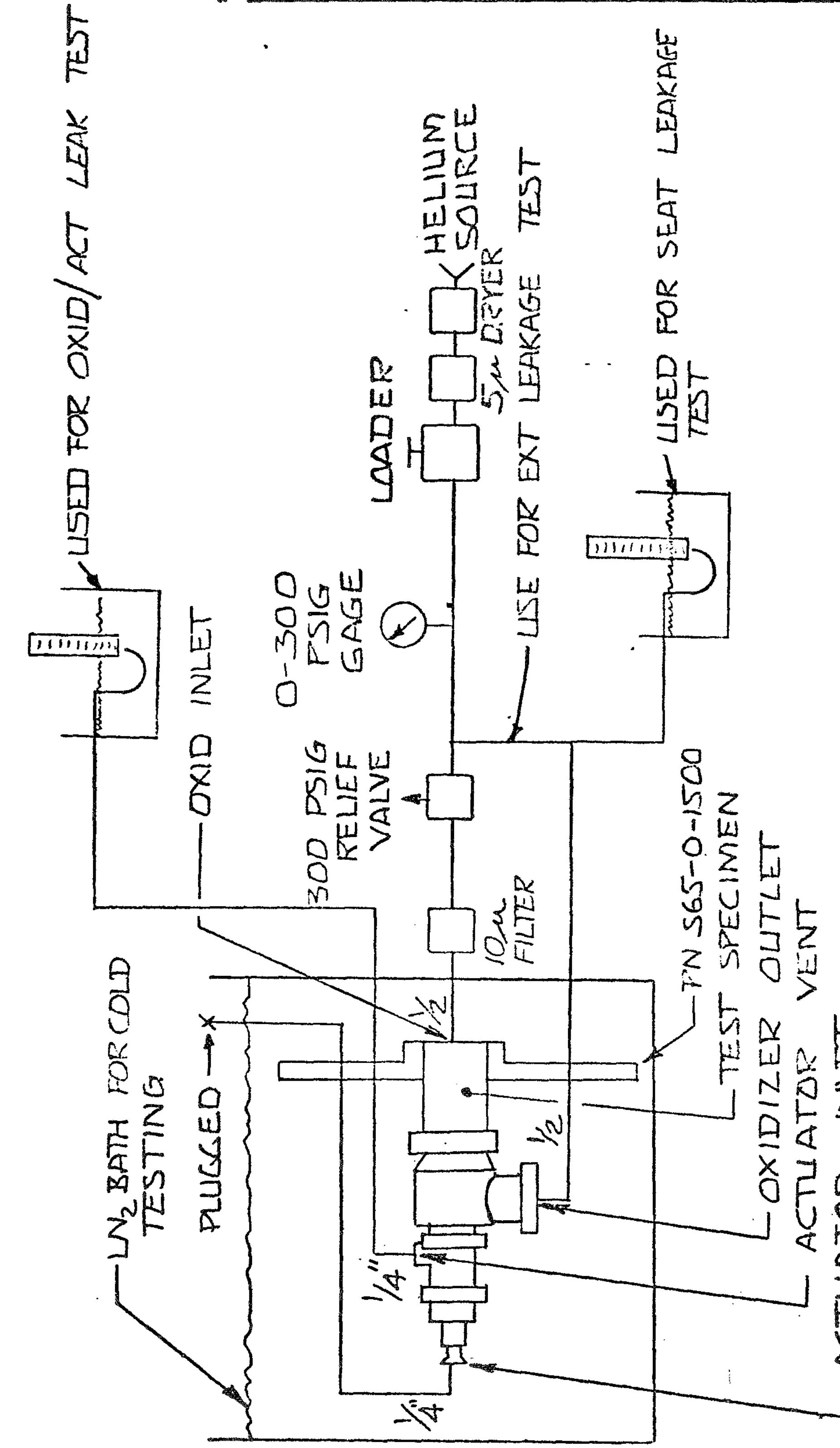


Figure 5. Leakage Tests

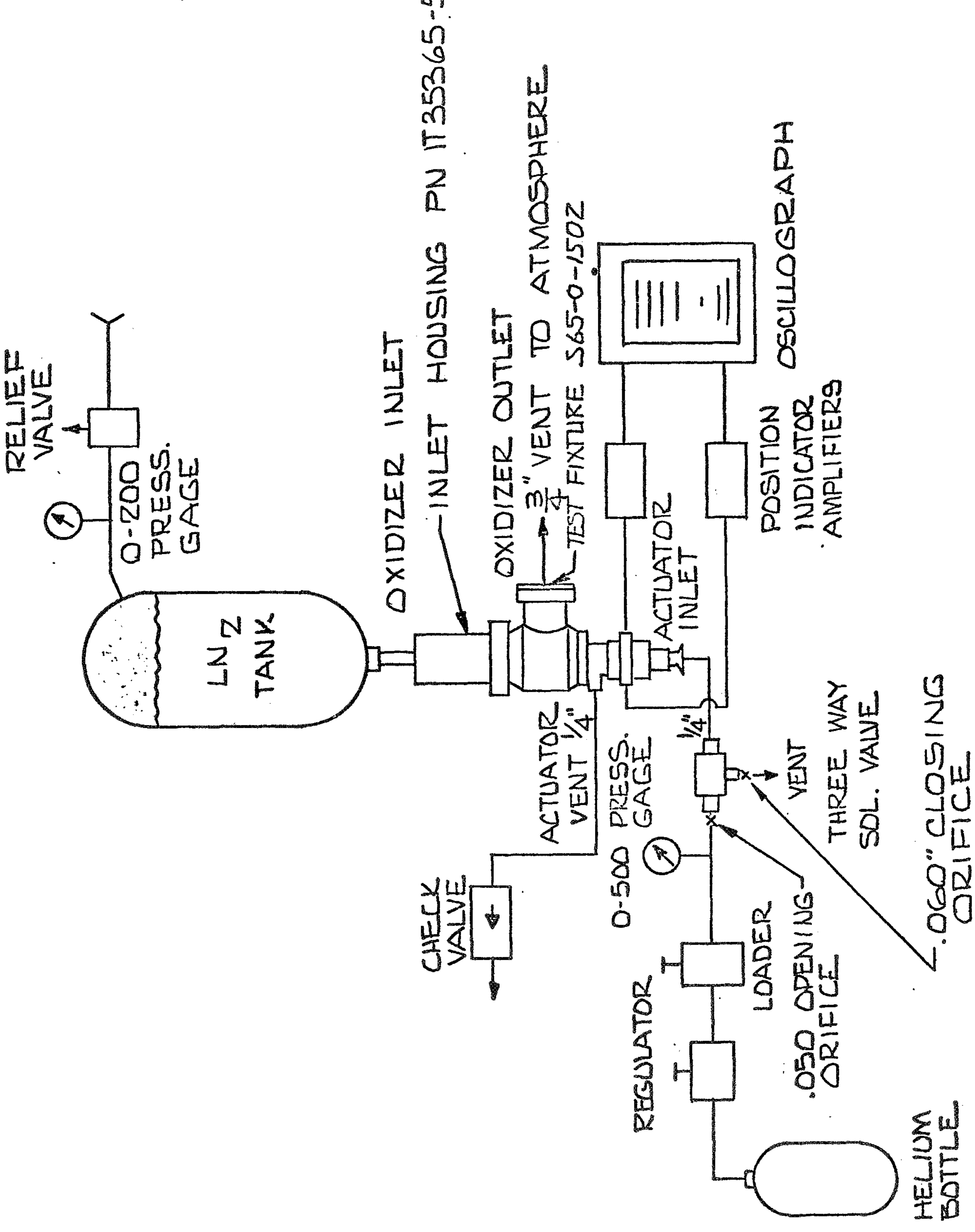


Figure 6. LN_2 Blowdown Test

PARKER PN ____________

MDAC PN ____________

Valve Serial Number: ____________

3.0 DATA SHEET

Pre-Test Inspection (Paragraph 2.1)

Proper identification Yes ________ NO ________

Bolts lockwired Yes ________ No ________

Noticable damage Yes ________ No ________

Valve Weight ________ pounds

Comments: ____

____

Approval: Parker ________ date ________

MDAC ________ date ________

Proof Pressure (Paragraph 2.2)

Actuator Cavity Ambient - Helium pressure used ________ psig

Actuator Cavity Low Temp - Helium pressure used ________ psig

Oxidizer Cavity Low Temp - Helium pressure used ________ psig

Oxidizer Cavity Ambient Temp - Helium pressure used ________ psig

Is there evidence of damage as a result of proof pressure application: Yes ______ No ______

Comments: ____

____

Approval: Parker ________ date ________

MDAC ________ ________

Valve Actuation/Deactuation (Paragraph 2.3)

The pressure required to open and reseat the valve with ____ psig on the oxidizer inlet was:

Ambient			Low Temperature		
Crack	Reseat		Crack	Reseat	
____	____	psig	____	____	psig

The required pressure to open and reseat the valve with ________ psi helium pressure applied to the oxidizer inlet was:

Ambient			Low Temperature		
Crack	Reseat		Crack	Reseat	
____	____	psig	____	____	psig

Comments: ____

____

____

Approval: Parker ________ date ________

MDAC ________ date ________

Leakage (Paragraph 2.4)

External Leakage

With ________ psig (ambient) helium applied at the oxidizer inlet for ________ minutes the external leakage was:

Bubbles observed Yes ________ No ________

Fuzz leakage observed Yes ________ No ________

Joints where leakage was observed ________

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Oxidizer to Actuator Leakage

With oxidizer inlet and outlet pressurized to ________psig helium for ________ minutes the leakage from the vent port was measured as:

Ambient cc/min	Cold cc/min

Seat Leakage

With _____, _____, _____, _____psig (ambient) and _____, _____, _____, _____ psig (low temp) helium applied to the oxidizer for ________minutes (ambient and ___________minutes (low temp), the seat leakage was:

Press.	Ambient cc/min	Cold cc/min

Comments:____

____

____

____

Approval: Parker_______________ date_____________

MDAC _______________ date_____________

Liquid Nitrogen Blowdown (Paragraph 2.6)

Liquid nitrogen tank pressure__________psig

Helium actuator regulated pressure ___________psig

Opening response _________milliseconds

Closing Response _________milliseconds

Comments:____

____

____

Approval: Parker_______________ date_____________

MDAC _______________ date_____________

EQUIPMENT & INSTRUMENT LIST

Name	Model No.	Serial No.

APPENDIX C

ACCEPTANCE-TEST PROCEDURE

Erwin Johnson

program 137

6/25/69

Revised 8/1/69

S/N 001

VALVE ASSEMBLY PROCEDURE FOR

5696040 FLUORINE VALVE

The following procedure shall be followed to assemble the valve:

1. Orient the valve by hand with the inlet end up. Prepare for installation of the valve seat (5696013), poppet (5696037) and their static seals by visually inspecting all of the sealing surfaces to ascertain that no damage is evident and no loose particles are present. Place a static seal (9100-27-0103) in the recess at the bottom of the valve body cavity and static seal (9100-36-0103) in the recess on the top side of the valve inlet flange. Carefully insert the valve seat through the seal and attach to the valve body with screws (NAS 1189E3P8). Tighten all screws until the heads just contact the seat, then torque each screw one-half turn in a sequence which will compress the seal in a uniform manner. Continue this tightening procedure until the seal is compressed and all of the screws have been torqued 20 to 25 in.-lb above running torque. Screw heads must not extend above flange face when installed and torqued.

2. Carefully insert the poppet shaft through the seat and the static seal previously placed at the bottom of the valve cavity, using care not to damage any of the sealing

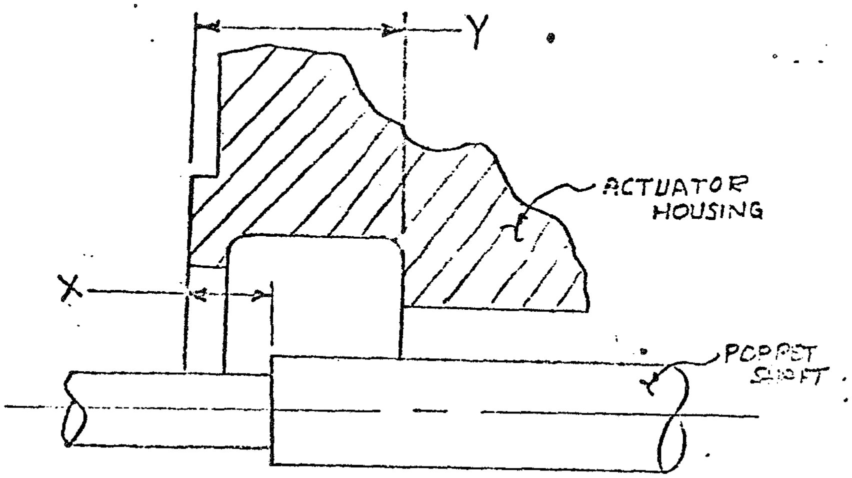
surfaces. The poppet must be installed in a position which precludes contact between the sealing surfaces of the poppet and seat so that the poppet can be rotated for alignment of the static seal bolt circle without marring the sealing surfaces. Align the bolt-hole pattern in the bellows adapter with the hole pattern in the valve body and install the eight cap screws and washers (NAS135 1C3H10 and NAS 620C10). Tighten all screws initially finger tight. Install inlet fixture S80-0-765-2 to hold poppet centered.

3. Invert the valve by hand to orient the valve inlet down. Torque each of the eight screws installed in the previous step one-half turn in a sequence which will compress the seal in a uniform manner. Continue this tightening procedure until the seal is compressed and all of the screws have been torqued 20 to 25 in.-lb. Lockwire the screw heads together with No. 25 stainless steel lockwire.

4. Install the static seal (9100-29-0103) and the actuator housing (5696024) using the seven screws and washers (NAS 1351C3H10 and NAS 620C10). Torque screws in sequence as described above 20 to 25 in.-lb. Lockwire the screw heads

togehter using No. 25 stainless steel lockwire.

5. Measure and record the dimension shown below:



Shim requirements will be determined from these dimensions as follows:

$$\text{Required shims} = .430\begin{smallmatrix}+.020\\-.000\end{smallmatrix} + X - Y - T_t - \underset{}{\text{seat deflection}}\ (.020)$$

Where T_t = Thickness of Teflon seat protection dics.
= .020

ACTUAL
X = .3120
Y = .6495

$$\begin{array}{r} .4400 \\ +.3120 \\ \hline .7520 \\ -.6495 \\ \hline .1025 \\ -.0400 \\ \hline .0625 \end{array}$$

$$.430\begin{smallmatrix}+.020\\-.000\end{smallmatrix} = \text{required stroke}$$

REQ'D SHIMS = ~~.~~ .0625
STROKE = ~~.~~ .440

6. Install inlet fixture to prevent rotation and to align poppet. Insert the two actuator springs (5696015 and 5696014) into the actuator housing and place the required shims

(5696039) on the shaft. Install the piston (5696027). During this step care must be exercised to prevent torsional overstressing of the bellows seal. Use four bolts with long threads with nuts to secure the piston support fixture S80-0-765-1 to the actuator housing. Tighten the bolts uniformly one-half turn each in sequence, compressing the actuator springs, until the fixture contacts the actuator housing at each bolt location. Install inlet assembly fixture S80-0-765-2. Install the lock washer and nut (NAS 460-516 and AN 316C5) and torque the nut 60 to 70 in.-lb above running torque.

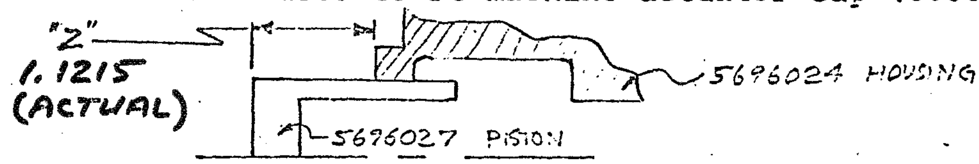
7. Remove the piston support fixture, initially unscrewing the attaching bolts uniformly one-half turn each in sequence until all loads in the bolts are removed. This causes the seat and poppet to engage on the plastic spacer. Remove the inlet assembly fixture. Bend up the tabs of the lockwasher. Install S80-0-765-1 fixture as described above, until poppet lifts above seat. Remove plastic guard on seat. Unscrew the attaching bolts uniformly one-half turn each in sequence, until all loads in the bolts are removed. The poppet and seat are now in metal-to-metal contact.

* ACTUAL REWORK DIM OF 5696019 CAP = 1.1215
+ .0600
1.1815 ± .005

CHAMFER = .875 ± .005 × 20°

.060 STOP

* 8. Measure distance that piston protudes from housing. Dimension will be used to re-machine actuator cap (5696019).



9. Install indicator nut approx flush with end of poppet shaft.

10. Make a trial installation of the actuator cap, securing with a minimum of two screws and check the position of the indicator nut flange through the position detector mounting hole nearest to the outborad end of the cap. The larger diameter of the indicator nut flange should appear in approx. the center of the hole.

11. If the indicator nut is not in the required location noted in step 9, remove the actuator cap and readjust the nut. Repeat steps 9 and 10 until the indicator nut is properly located within the specified tolerance.

12. Remove the actuator cap and secure the indicator nut with a cotter pin.

13. Install the position detectors (model 304CJXF) on the actuator cap as a subassembly. First install the jam nuts

(MS-9360-12) on the detectors, then screw the detectors into the seal retainers (5696018) until the detectors project approximately 0.200 in. through the bases of the retainers. Install the Omniseals (AR10108-011A1Q) over the projecting detector tips then install the detector assemblies on the actuator cap with their mounting screws and washers (NAS1351C3H8 and NAS 620C10). Torque to 20-25 in.-lb above running torque and lockwire. Adjust each detector until its tip is flush with the inner wall of the actuator cap then tighten the jam nuts with 120 to 150 in.-lb torque and lockwire together.

14. Install the Omniseal (AR10110-223A1Q) over the piston then install the actuator cap assembly and secure with the eight screws and washers (NAS 1003-7A and NAS 620C10) and nuts (MS 9360-09). Torque the nuts 20-25 in.-lb.

15. Install test fixtures to inlet (S65-0-1503) with seal (9100-36-010; and outlet (S65-0-1502) with seal (9100-32-0103) with nuts and bolts as specified on drawing. Torque bolts to drawing requirements in the sequence or torquing as previously discussed.

16. Scribe all common flanges to indentify assembly position of components to comply with 5696040 note 5.

VALVE ASSEMBLY PROCEDURE FOR

5696040 FLUORINE VALVE

The following procedure shall be followed to assemble the valve:

1. Orient the valve by hand with the inlet end up. Prepare for installation of the valve seat (5696013), poppet (5696037) and their static seals by visually inspecting all of the sealing surfaces to ascertain that no damage is evident and no loose particles are present. Place a static seal (9100-27-0103) in the recess at the bottom of the valve body cavity and static seal (9100-36-0103) in the recess on the top side of the valve inlet flange. Carefully insert the valve seat through the seal and attach to the valve body with screws (NAS 1189E3P8). Tighten all screws until the heads just contact the seat, then torque each screw one-half turn in a sequence which will compress the seal in a uniform manner. Continue this tightening procedure until the seal is compressed and all of the screws have been torqued 20 to 25 in.-lb above running torque. Screw heads must not extend above flange face when installed and torqued.

2. Carefully insert the poppet shaft through the seat and the static seal previously placed at the bottom of the valve cavity, using care not to damage any of the sealing

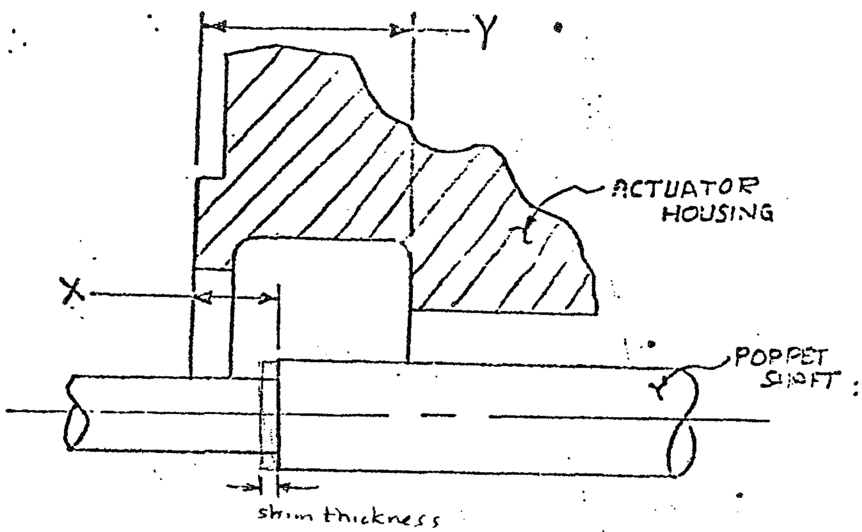
surfaces. The poppet must be installed in a position which precludes contact between the sealing surfaces of the poppet and seat so that the poppet can be rotated for alignment of the static seal bolt circle without marring the sealing surfaces. Align the bolt hole pattern in the bellows adapter with the hole pattern in the valve body and install the eight cap screws and washers (NAS1351C3H10 and NAS 620C10). Tighten all screws initially finger tight. Install inlet fixture S80-0-765-2 to hold poppet centered.

3. Invert the valve by hand to orient the valve inlet down. Torque each of the eight screws installed in the previous step one-half turn in a sequence which will compress the seal in a uniform manner. Continue this tightening procedure until the seal is compressed and all of the screws have been torqued 20 to 25 in.-lb. Lockwire the screw heads together with No. 25 stainless steel lockwire.

4. Install the static seal (9100-29-0103) and the actuator housing (5696024) using the seven screws and washers (NAS 1351C3H10 and NAS 620C10). Torque screws in sequence, as described above, 20 to 25 in.-lb. Lockwire the screw heads

together using No. 25 stainless steel lockwire.

5. Measure and record the dimension shown below:



Shim requirements will be determined from these dimensions as follows:

(.020)

Required shims = $.430^{+.020}_{-.000} + X - Y - T_t -$ seat deflection

Where T_t = Thickness of Teflon seat protection discs.

X = .3060
Y = .6470

$$\begin{array}{r} .4500 \\ +.3060 \\ \hline .7560 \\ -.6470 \\ \hline .0090 \\ -.0400 \\ \hline .0690 \end{array}$$

$.430^{+.020}_{-.000}$ = required stroke

REQ'D SHIMS = .0690
STROKE = .450

6. Install inlet fixture to prevent rotation and to align poppet. Insert the two actuator springs (5696015 and 5696014) into the actuator housing and place the required shims

(5696039) on the shaft. Install the piston (5696027). During this step care must be exercised to prevent torsional overstressing of the bellows seal. Use four bolts with long threads with nuts to secure the piston support fixture S80-0-765-1 to the actuator housing. Tighten the bolts uniformly one-half turn each in sequence, compressing the actuator springs, until the fixture contacts the actuator housing at each bolt location. Install inlet assembly fixture S80-0-765-2. Install the lock washer and nut (NAS 460-516 and AN 316C5) and torque the nut 60 to 70 in.-lb above running torque.

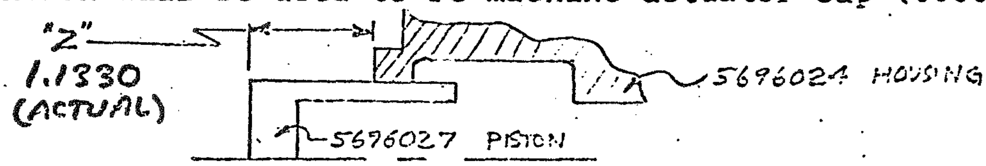
7. Remove the piston support fixture, initially unscrewing the attaching bolts uniformly one-half turn each in sequence until all loads in the bolts are removed. This causes the seat and poppet to engage on the plastic spacer. Remove the inlet assembly fixture. Bend up the tabs of the lockwasher. Install S80-0-765-1 fixture as described above, until poppet lifts above seat. Remove plastic guard on seat. Unscrew the attaching bolts uniformly one-half turn each in sequence, until all loads in the bolts are removed. The poppet and seat are now in metal-to-metal contact.

.0605
1.1930 ±.005

CHAMFER = .875±.005 × 20°

.060 STOP

* 8. Measure distance that piston protudes from housing. Dimension will be used to re-machine actuator cap (5696019).



9. Install indicator nut approx flush with end of poppet shaft.

10. Make a trial installation of the actuator cap, securing with a minimum of two screws and check the position of the indicator nut flange through the position detector mounting hole nearest to the outborad end of the cap. The larger diameter of the indicator nut flange should appear in approx. the center of the hole.

11. If the indicator nut is not in the required location noted in step 9, remove the actuator cap and readjust the nut. Repeat steps 9 and 10 until the indicator nut is properly located within the specified tolerance.

12. Remove the actuator cap and secure the indicator nut with a cotter pin.

13. Install the position detectors (model 304CJXF) on the actuator cap as a subassembly. First install the jam nuts

(MS-9360-12) on the detectors, then screw the detectors into the seal retainers (5696018) until the detectors project approximately 0.200 in. through the bases of the retainers. Install the Omniseals (AR10108-011A1Q) over the projecting detector tips then install the detector assemblies on the actuator cap with their mounting screws and washers (NAS1351C3H8 and NAS 620C10). Torque to 20-25 in.-lb above running torque and lockwire. Adjust each detector until its tip is flush with the inner wall of the actuator cap then tighten the jam nuts with 120 to 150 in.-lb torque and lockwire together.

14. Install the Omniseal (AR10110-223A1Q) over the piston then install the actuator cap assembly and secure with the eight screws and washers (NAS 1003-7A and NAS 620C10) and nuts (MS 9360-09). Torque the nuts 20-25 in.-lb.

15. Install test fixtures to inlet (S65-0-1503) with seal (9100-36-0103) and outlet (S65-0-1502) with seal (9100-32-0103) with nuts and bolts as specified on drawing. Torque bolts to drawing requirements in the sequence or torquing as previously discussed.

16. Scribe all common flanges to indentify assembly position of components to comply with 5696040 note 5.

REFERENCES

1. D. L. Endicott and L. H. Donahue. Development and Demonstration of Criteria for Liquid Fluorine Feed System Components. NASA Report No. CR72543. McDonnell Douglas Astronautics Company--West, June 1969.

2. Advance Propulsion Staff. Development and Demonstration of Criteria for Liquid Fluorine Feed System Components. NASA Report No. CR72063. Missile and Space Systems Division, Douglas Aircraft Company, October 1967.

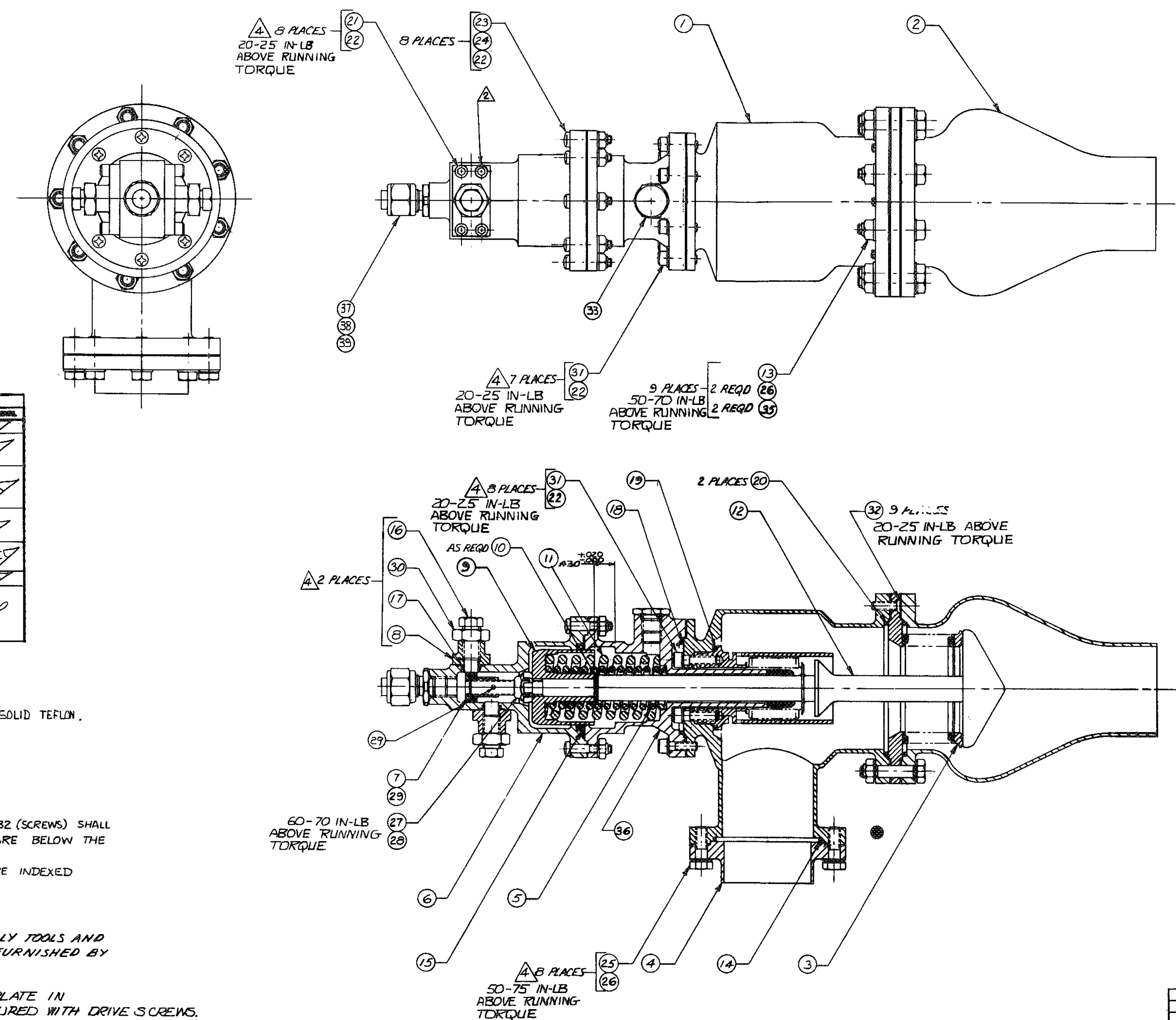
3. D. L. Endicott, P. L. Klevatt, and F. F. Stecker. Liquid Fluorine Feed System Component Design Criteria. AIAA Paper No. 70-705. AIAA 6th Propulsion Joint Specialist Conference, San Diego, California, 15 to 19 June, 1970.

4. Advance Propulsion Staff. Fluorine Systems Handbook. NASA Report No. CR72064. Missile and Space Systems Division, Douglas Aircraft Company, 1 July 1967.

5. H. W. Schmidt. Handling and Use of Fluorine and Fluorine-Oxygen Mixtures in Rocket Systems. NASA Report No. SP-3037. National Aeronautics and Space Administration, 1967.

REVISIONS

E.C.O. NO.	SYM	DESCRIPTION	DATE	APPROVAL
01	NC	RELEASED FOR SPECIAL PROJECT	3/27/9	EJ
02	A	1) LOCK WSHR WAS COTTER PIN, 2) NUT WAS AN310CS, 3) STUD WAS A286, 4) REV NAMEPLATE LOCATION, 5) REV NOTE 2	3/21/5	EJ
03	B	MODIFIED ITEMS 13,21,23,24,30,31,32,33, 34 + 35 ADDED LOCKWIRE + TORQUE CALLOUTS ADDED STROKE CALLOUT	4/11/5	EJ
04	C	ITEM 30: MS 9360-12 WAS AN395C6/6 MS 9360-09 WAS AN345C10 ADDED NOTES 5 & 6	4/28/9	EJ
05	D	ITEM 33 WAS MS24404-4 ADDED ITEM 29 ITEM 23 WAS NAS1003-5H	6/23/9	EJ
06	E	ITEM 32 WAS NAS1189E3P8	3/16/70	EJ
7	F	REVISED PN ITEMS 13,21,23,24, 25, 27, 30, 31, 32 & 35 DELETED NOTE 7, ADDED NOTES 8 & 9, ADDED ITEMS 37,38 & 39 QTY REQD ITEM 33 WAS '2'	11 Jun 70	



9. PART NO. OF Mc DONNELL-DOUGLAS CO. DIMENSIONALLY SIMILAR TO MS 28778-4, EXCEPT SOLID TEFLON.

8. PART NO. OF DEL MFG CO. 5711 E. SHEILA, LOS ANGELES, CALIF. 90022

7

6. DURING ASSEMBLY THE INSTALLATION OF ITEM 32 (SCREWS) SHALL BE VERIFIED BY INSPECTION THAT THE HEADS ARE BELOW THE FLANGE SURFACE.

5. DURING ASSEMBLY ALL MATING SURFACES SHALL BE INDEXED BY SCRIBE LINES IN NON-CRITICAL AREAS.

4. LOCKWIRE PER MS33540

3. ASSEMBLY SEQUENCE, REQUIRED ASSEMBLY TOOLS AND SPECIAL HANDLING INSTRUCTIONS TO BE FURNISHED BY RESPONSIBLE ENGINEER

2. VALVE ASSY TO BE IDENTIFIED BY NAMEPLATE IN AREA SHOWN. NAMEPLATE TO BE SECURED WITH DRIVE SCREWS.

1. ALL DETAIL PARTS TO BE CLEANED PER IEPS 5696040 PRIOR TO ASSEMBLY

LIST OF MATERIAL

ITEM NO.	DWG SIZE	QTY REQD	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	MATERIAL SPECIFICATION	HEAT TREAT	FINISH	FINISH SPECIFICATION
39	-	1	AN929-4S	CAP ASSY	CRES				
38	-	1	S0139-4	SEAL	TEFLON				
37	-	1	DO4-0.050D	ORIFICE	CRES				
36	E	1	5696024	HOUSING, ACTUATOR	AL ALLOY, 6061-T6				
35	C	18	5706016-10, OR-11, OR-12	NUT	CRES				
34									
33		1	MS24391C4	PLUG	CRES				
32	C	9	5706016-9	SCREW	CRES				
31	C	15	5706016-8	SCREW, CAP	CRES				
30	C	2	5706016-7	NUT	CRES (A286)				
29			MS24665-151	COTTER PIN	CRES				
28		1	NAS460-516	WASHER, LOCK	CRES				
27	C	1	5706016-6	NUT	CRES				
26		26	NAS620C416L	WASHER	CRES				
25	C	8	5706016-5	BOLT	CRES (A286)				
24	C	8	5706016-4	NUT	CRES (A286)				
23	C	8	5706016-3	BOLT	CRES (A286)				
22		31	NAS620C10	WASHER	CRES				
21	C	8	5706016-2	SCREW	CRES				
20		2	9100-36-0103	SEAL	DONALDSON CO INC, HYDRODYNE DIV				
19		1	910F27-0103	SEAL	DONALDSON CO INC, HYDRODYNE DIV				
18		1	9100-29-0103	SEAL	DONALDSON CO INC, HYDRODYNE DIV				
17		2	AR10108-011 AIQ	OMNISEAL	AEROQUIP CORP				
16		2	MODEL 304 CJXF	POSITION DETECTOR	BENTLY-NEVADA				
15		1	AR10110-223 AIQ	OMNISEAL	AEROQUIP CORP				
14		1	9100-32-0103	SEAL	DONALDSON CO INC, HYDRODYNE DIV				
13	C	9	5706016-1	BOLT	CRES (A286)				
12	D	1	5696037	POPPET ASSY	INCONEL 718				
11	B	1	5696014	SPRING, OUTER	316 CRES				
10	B	AS REQD	5696039	SHIM, PISTON	CRES				
9	D	1	5696027	PISTON, ACTUATOR	AL ALLOY, 6061-T6 OR T651				
8	C	2	5696018	RETAINER, SEAL	321 CRES				
7	C	1	5696028	INDICATOR NUT	AL ALLOY, 2024-T351				
6	E	1	5696019	CAP, ACTUATOR	AL ALLOY, 6061-T6				
5	B	1	5696015	SPRING, INNER	316 CRES				
4	D	1	5696021	FLANGE, OUTLET	347 CRES				
3	D	1	5696013	VALVE SEAT	A286 CRES				
2	E	1	5696026	HOUSING, INLET	347 CRES				
1	E	1	5696036	BODY, VALVE	INCONEL 718				

UNLESS OTHERWISE SPECIFIED DO NOT SCALE DRAWING. DIMENSIONS ARE IN INCHES. TOLERANCES: FRACTIONS ± 1/32, DEC ± .03, DEC ± .010. TOLERANCES OF HOLES SPECIFIED "DRILL" PER AND 10387. MUST CONFORM TO ES 1-1. MACHINED SURFACE 125 PER MIL-STD-10. CLASSIFICATION OF CHARACTERISTICS PER SPI-822-5 & MIL-STD-105. REF 137

WELDED JOINT SYMBOLS PER MIL-STD-22. DIMENSIONAL SYMBOLS PER MIL-STD-8.

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CHK BY	E Johnson	3/21/9
PROJ ENG	E Johnson	3/21/9

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TITLE: VALVE, SHUTOFF-POPPET, LIQUID FLUORINE

SIZE E — CODE IDENT NO. 92003 — DWG NO. 5696040 — SCALE 1/1 — SHEET 1 OF 1

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