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SPACE STORABLE OXIDIZER VALVE

by

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Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA Lewis Research Center
Contract NAS 3-12035
R. E. Grey, Project Manager

NOTICE

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FOREWORD

This final report describes the work accomplished by the Aerojet Liquid Rocket Company, Sacramento, California, under Contract NAS 3-12035. It covers the period 14 March 1969 through 30 July 1971. The contract was sponsored by the Lewis Research Center of the National Aeronautics and Space Administration. It was administered under the direction of the Liquid Rocket Technology Branch with Mr. R. E. Grey as Project Manager.

The author wishes to acknowledge the significant technical support contributed by the following:

Materials Engineers:	Messrs. J. W. Chung and V. Hunt
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Development Engineer:	Mr. A. Solter

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ABSTRACT

The Space Storable Oxidizer Valve Program consisted of the design, fabrication, and testing of a 2.0-in., pneumatically-operated, metal-to-metal sealing, liquid fluorine shutoff valve. Two valve assemblies were subjected to liquid fluorine flow tests. These valves were identical in design and fabrication, but one incorporated a gold-plated CRES 304L main seal and the other had a beryllium nickel main seal. The beryllium nickel material transferred to the valve seat during testing. Of the two, the gold-plated seal proved to be more satisfactory in over-all performance.

I. SUMMARY

An Aerojet Liquid Rocket Company (ALRC) metal-to-metal sealing shutoff valve was evaluated by subjecting it to liquid fluorine testing. This design was developed in 1965 in a company-sponsored program. Its first use was an electrically-actuated all-metal valve in the Transtage Program.(1) The valve was adapted for the Space Storable Oxidizer Valve Program (SSOV) by replacing the electrical actuator with a pneumatic one.

Two main seal materials were evaluated by placing each in separate valve assemblies and testing them. Both seals were identical in design and fabrication except for the seal material itself which was beryllium nickel in one seal and gold-plated CRES 304L in the other seal.

Each valve was subjected to 250 liquid fluorine flow cycles; ten of these cycles at 25 psig (1.72×10^5 N/m^2, g) inlet pressure and the remaining 240 cycles at 100 psig (6.89×10^5 N/m^2, g) inlet pressure. After 250 cycles, the gold-plated CRES 304L seal demonstrated the superior performance and was subsequently subjected to an additional 756 liquid fluorine flow cycles at a proof inlet pressure of 250 psig (1.72×10^6 N/m^2, g). All the tests were conducted satisfactorily without damage to the test hardware.

Both valves operated satisfactorily throughout the test program. Valve pressure drop was under that required and valve actuation times were easily controlled by orificing the actuator helium supply and vent lines. The valve bellows, actuator assemblies, and the proximitor probes were in good condition at the end of testing. The gold-plated seal also was in good condition; however, seal standoff, which is a setting made during valve assembly to control the sealing load on the seal, decreased 48% during the testing. This caused the seal load to become relaxed and resulted in a final gold-plated seal leakage rate of 1.00×10^{-1} SCCS helium at 250 psig (1.72×10^6 N/m^2, g) and -320°F (77.6°K) after 1006 fluorine cycles.

All valve materials performed as anticipated except for the beryllium nickel seal material which transferred to the electrolized Inconel 718 seat. This occurred early in the program and resulted in increased leakage through the tenth fluorine cycle. At this point, the seal started to lap into the seat and leakage decreased steadily through the end of the program. The final beryllium nickel seal leakage rate of 2.44 SCCS helium at 250 psig (1.72×10^6 N/m^2, g) and -320°F (77.6°K) after 250 fluorine cycles was approximately one-half that measured after the tenth cycle.

The beryllium nickel material transfer and the loss of the gold-plated seal standoff caused the leakages noted during the program.

It was concluded that the CRES 304L material is not satisfactory for this type of seal because of material instability. A gold-plated beryllium nickel seal would incorporate the best features of both the seals tested and should provide excellent service in a fluorine valve. The beryllium nickel material would maintain the set standoff adjustment, as it did during the testing in this program, and the gold plating would prevent the transfer of the beryllium nickel material.

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(1) CCN 192, "Electrical Valve Development, Contract AF 04(695)-197, Transtage Program, 15 February 1967.

II. INTRODUCTION

The feasibility of using fluorinated oxidizers in space vehicles has been under investigation for almost 20 years. Recent programs(2)(3) established design criteria for a fluorine flightweight feed system with primary emphasis upon valve compatibility and leakage. These studies again showed the importance of achieving extremely low leakage rates throughout a fluorine system.

ALRC conducted a company-sponsored program in 1965 to develop a reliable all-metal shutoff seal for future space propulsion systems. Successful test results were obtained with the design evolved and served as the basis in selecting this configuration for use in an all-metal bipropellant valve developed under an Air Force contract.(4) It was this same basic valve design configuration that was tested in the SSOV Program.

The SSOV Program was conducted under Contract NAS 3-12035 for the purpose of evaluating the existing ALRC metal-to-metal seal design with regard to leakage and to determine which of two different seal materials is the better for fluorine service. The program consisted of the design, fabrication and test of the pneumatically actuated SSOV and was organized into three tasks.

The design task consisted primarily of adapting the pneumatic actuator to the existing ALRC valve design. The fabrication and acceptance test task covered the manufacture and acceptance testing of two valves while the fluorine compatibility test task consisted of flow testing the valves in liquid fluorine.

This report is organized on the basis of these three tasks with the information being presented in the order in which the tasks were accomplished. Appendix A presents the detailed test plan under which the fluorine compatibility testing was accomplished.

It is believed that the information presented in this report will be of value to others when further work on a flightweight fluorine feed system is pursued as the experience gained in this program and will give direction for future improvements in fluorine valve sealing and actuation.

III. TECHNICAL DISCUSSION

A. VALVE DESIGN

The Space Storable Oxidizer Valve (Figure 1) is a 2.0-in. (15.08×10^{-2} m) pneumatically-operated, liquid fluorine shutoff valve of right angle flow design. The inlet port is located at one end of the valve and the actuator is in-line opposite this port. A welded, nested-type bellows is welded to the valve body and seals the actuator cavity from the flow path. Actuator force is applied directly to the end of the bellows shaft by pressurizing the pneumatic actuator with helium. Two position indicators are used to monitor the full-open and full-closed positions of the valve. The valve was designed to meet the goals delineated on Table I. Figures 2 and 3 are the assembled and exploded views of the valve, respectively.

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(2) Contract NASw-1351, Development and Demonstration of Criteria for Liquid Fluorine Feed System Components, Douglas Aircraft Company, October 1967.

(3) Contract NAS 3-11195, Development and Demonstration of Criteria for Liquid Fluorine Feed System Components, McDonnell Douglas Astronautics Company, June 1969.

(4) CCN 192, Contract AF 04(695)-197, op. cit.

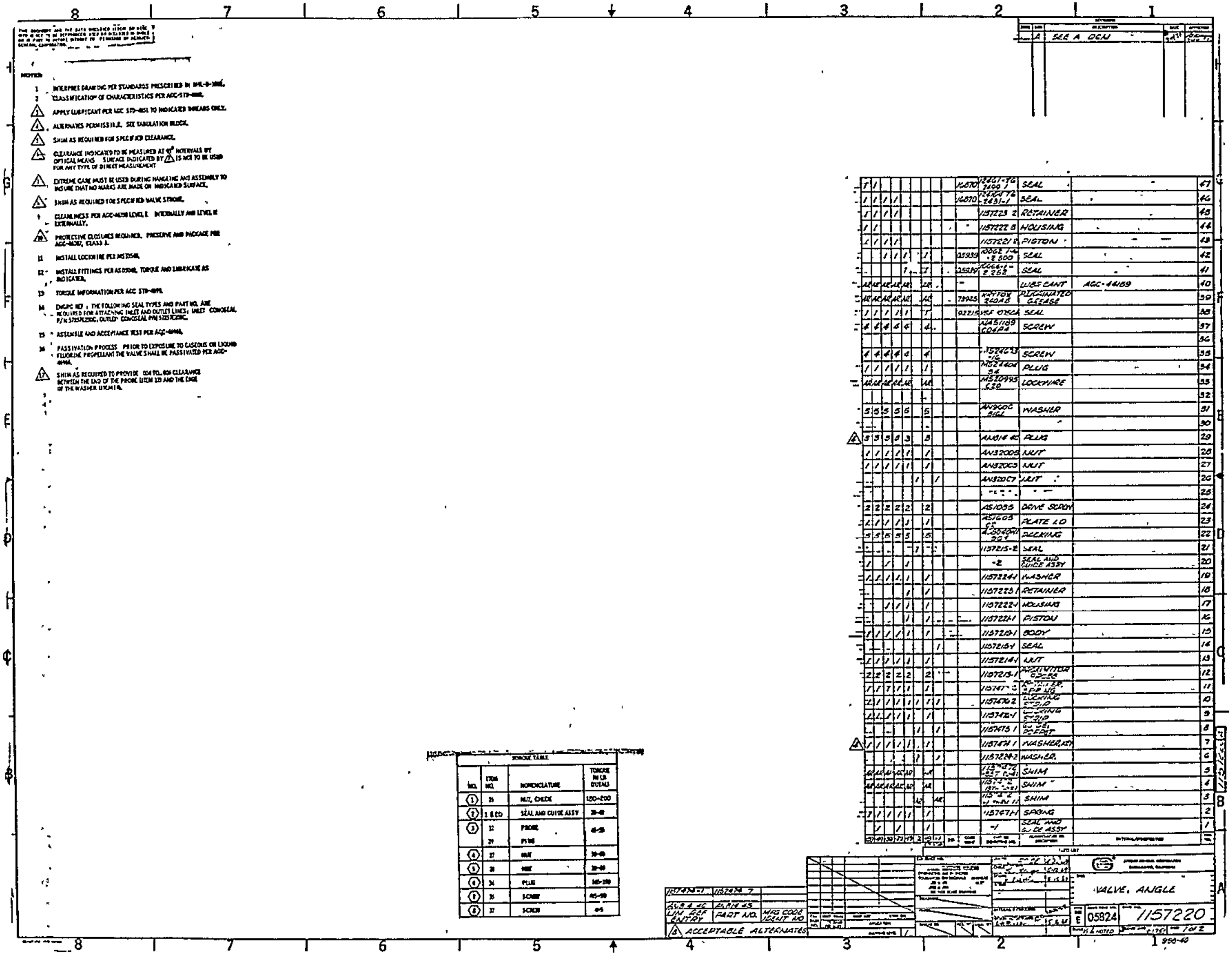

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Figure 1. Angle Valve
(Sheet 1 of 2)

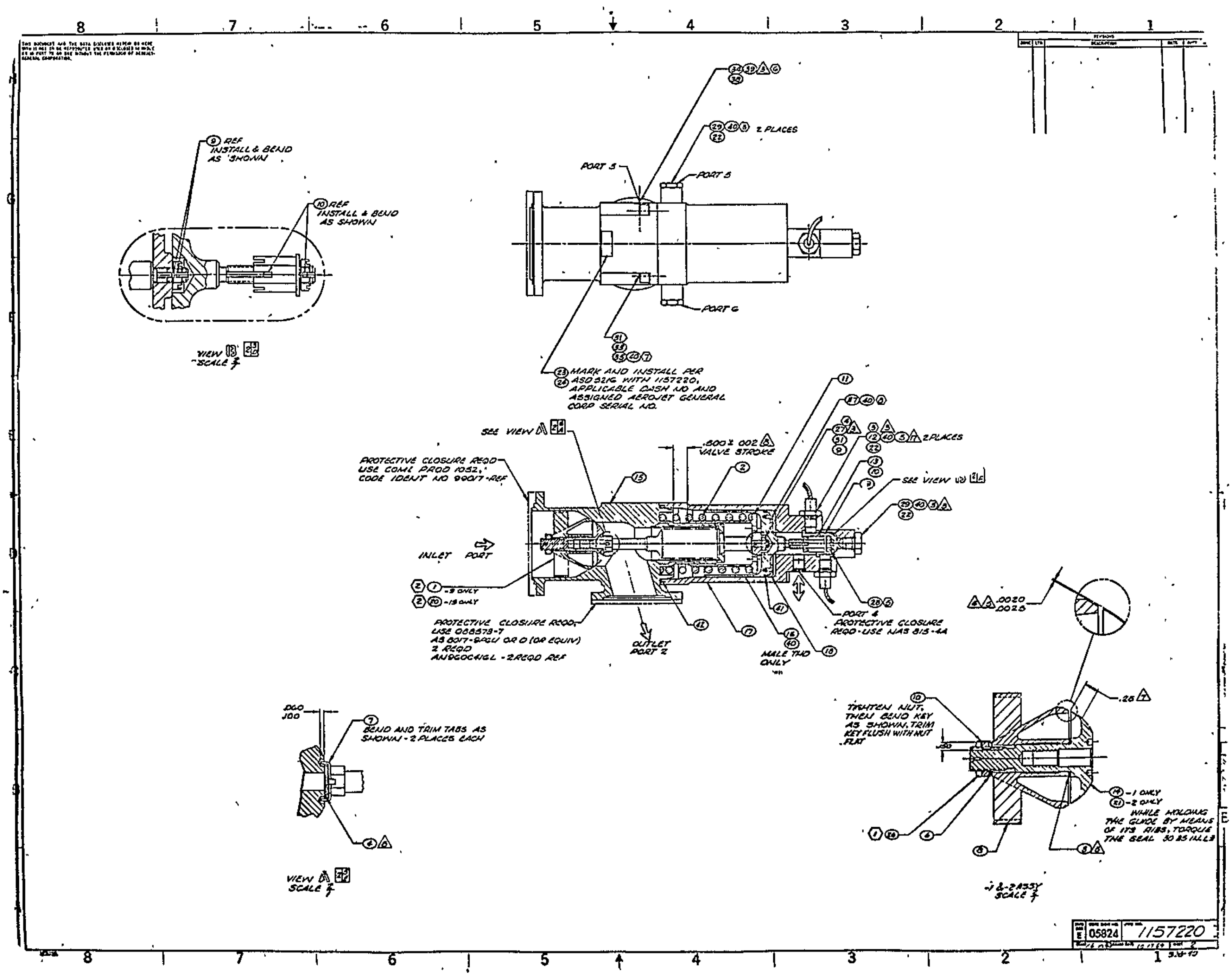


Figure 1. Angle Valve
(Sheet 2 of 2)

TABLE I. - SPACE STORABLE OXIDIZER VALVE DESIGN GOALS

FLUID SPECIFICATIONS:

1. Liquid Oxygen (MIL-0-25508)
2. Liquid Fluorine (98.7% LF_2, min)
   (0.3% [by wt.] max, HF, CH_4)
   (1.0% [by wt.] max O_2, N_2, other inerts)
3. Mixtures of (1) and (2)
4. Helium (Grade A Bureau of Mines)
5. Liquid Nitrogen (MIL-P-27401)

TEMPERATURE:

Inlet Fluid	-320°F (77.6°K)

FLUID PRESSURE:

Oxidizer	100 psig (6.89×10^5 N/m^2, g) max operating
	250 psig (1.72×10^6 N/m^2, g) proof
	375 psig (2.58×10^6 N/m^2, g) burst

ACTUATION:

Helium	500 psig (3.45×10^6 N/m^2, g) max operating
	750 psig (5.17×10^6 N/m^2, g) proof
	1125 psig (7.76×10^6 N/m^2, g) burst

FLOW RATE: 60 gpm (3.78×10^{-3} $meter^3$/second)

PRESSURE DIFFERENTIAL AT RATED FLOW: 5 psid (3.45×10^4 N/m^2)

LINE SIZES: 2 in. (5.08×10^{-2} m) ID

LEAKAGE RATE:

1. Between propellant and actuator	zero sccm He (1×10^{-6} SCCS He)
2. Main seat leakage	10^{-7} pps F_2 (2.50×10^{-2} SCCS F_2) (2.83×10^{-2} SCCS F_2)

TABLE I (cont.)

MATERIAL:

Only metallic fluoride lubricants to be permitted in the propellant cavities.

ACTUATION TIME (MAXIMUM): 75 millisec

ENVIRONMENTAL CONDITIONS:

1. This valve shall be designed to be functioning properly with ambient pressure from 0 psia to 14.7 psia (1.01×10^5 N/m^2), ambient temperature of -250°F (116.7°K) to + 140°F (333.3°K), humidity from 0% to 100%, vibrations $\pm$ 0.25 in. (6.35×10^{-3} m) amplitude from 5 cps to 31 cps, and 25 g's from 31 cps to 2000 cps. No test verification shall be required.

2. Accelerations:

   12.0 g's parallel and perpendicular.
   No test verification shall be required.

SPECIAL CONSIDERATIONS:

1. The valves shall be designed for maximum internal passivation with fluorine gas.
2. Positive isolation shall be provided between propellant and actuator. Redundancy shall be considered.
3. The valve shall fail safe closed under normal operating conditions.

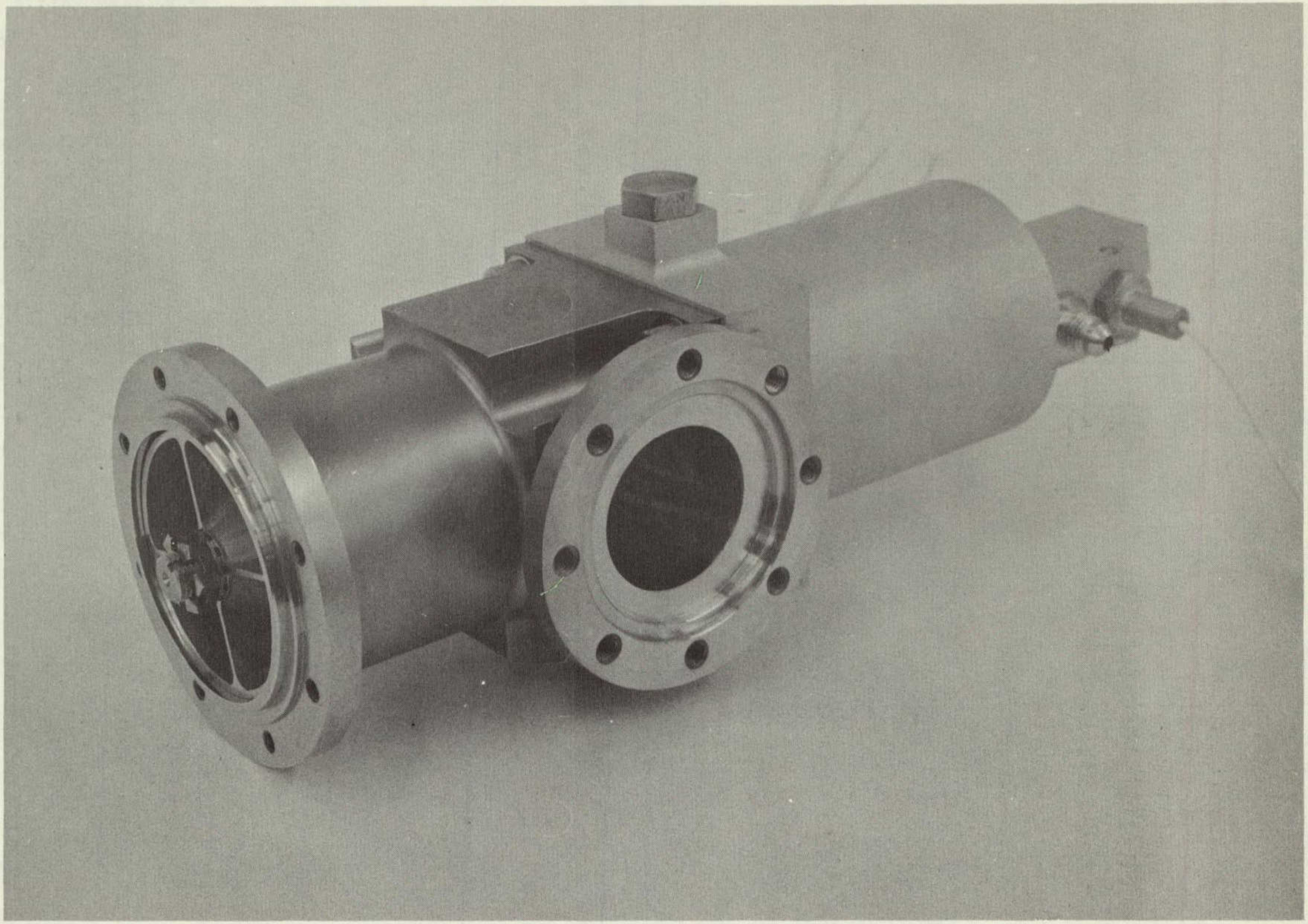


Figure 2. Assembled View of Space Storable Oxidizer Valve
(Poppet Illustrated in Open Position)

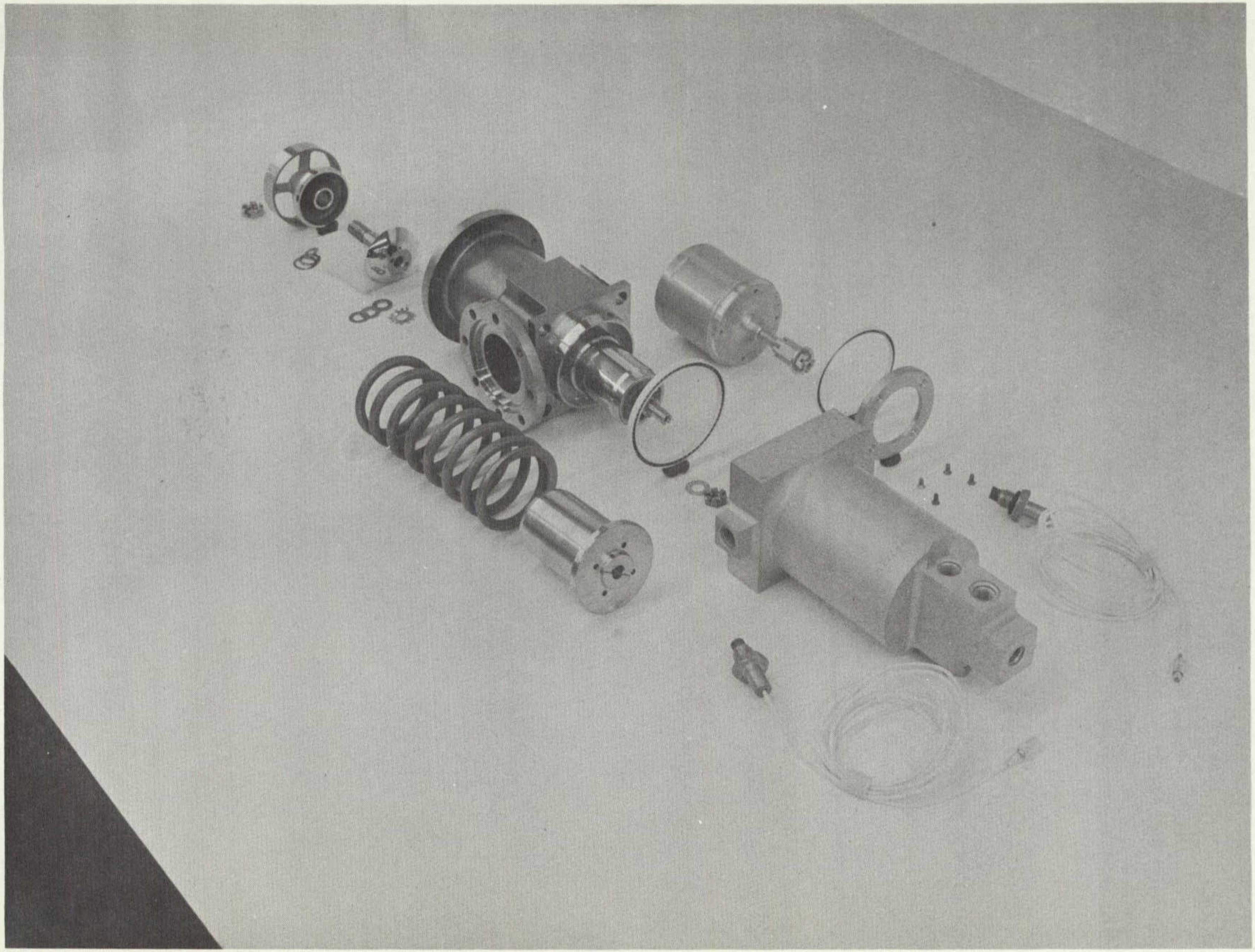


Figure 3. Exploded View of Space Storable Oxidizer Valve

1. Main Shutoff Seal

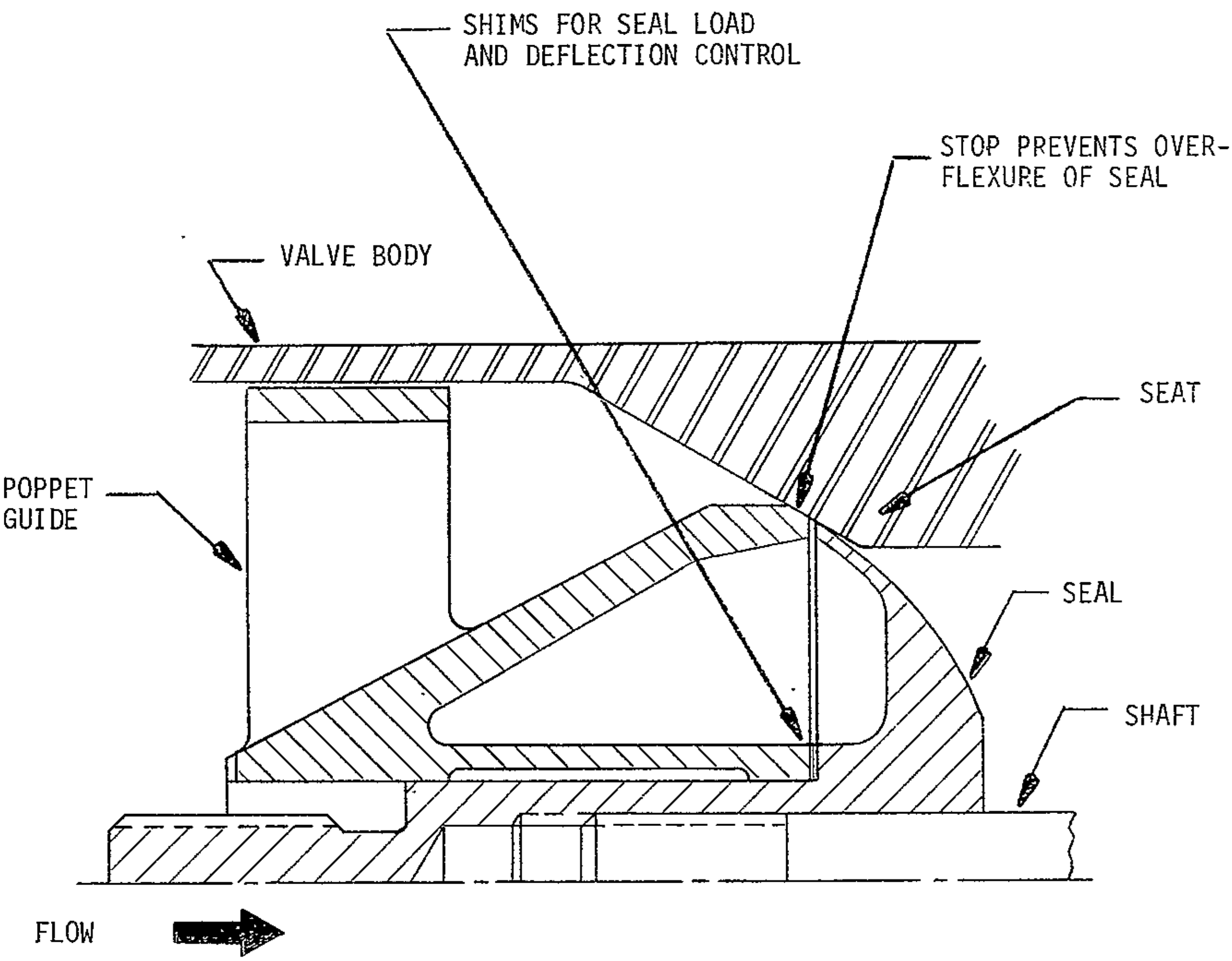
The valve features a metal-to-metal, hard-on-soft, seat-seal design (see Figure 4). The shutoff seal consists of a thin, spherical, metal shell which seats in a conical seat that is machined as an integral part of the valve body. In operation, the flexible seal contacts and centers itself in the valve seat as the valve closes. Then, the poppet assembly travels an additional distance (0.004-in. to 0.005-in.) (1.02×10^{-4} m to 1.27×10^{-4} m) into the seat until travel is halted by a conical metal stop provided on the poppet guide. This additional poppet travel provides a wiping, or lapping, action between the seal and seat to produce a microscopic conformation of the two sealing surfaces. At the same time, deflection of the seal provides the preload required to prevent leakage.

The seal and poppet guide are assembled prior to installation into the valve. Shims are installed between the guide and seal (see Figure 4) to adjust the relationship between the sealing edge and the stop on the guide. The amount that the seal projects beyond the surface of the stop in the free condition is the adjusted seal standoff, which is adjusted to a maximum of 0.002-in. (5.08×10^{-5} m) for 300 series CRES seals and 0.0025-in. (6.35×10^{-5} m) for beryllium nickel seals. Also, the guide can be installed in 12 different positions around the seal shaft to minimize any eccentricity in the assembly. This is accomplished by rotating the seal until the minimum eccentricity is obtained between the seal and guide stop. Then the assembly is locked with a locking strip installed between one of 12 slots in the end of the guide and a slot in the seal shaft.

One of the basic requirements in the design of the SSOV was the capability for eliminating all threads exposed to the flow stream. Threads would be acceptable in the demonstration valve but not in a production version. This requirement dictated that the materials utilized in the seal and poppet guide be weldable. Therefore, the final materials selected for the two test seals were CRES 304L and beryllium nickel 440 temper A. The poppet guide is made from CRES A286. Experience with the CRES 304L material made known that it could gall during usage if tested in the unprotected state. Consequently, the spherical surface of the CRES 304L seal was gold-plated using the electrodeposition process to 0.0015-in. (3.81×10^{-5} m) thick. Following plating, the gold was polished to a 2 microinch AA (5.08×10^{-8} m AA) surface finish with a minimum thickness of 0.0005-in. (1.27×10^{-5} m).

2. Bellows

The poppet shaft extends through the valve body and is sealed by a single ply (0.006-in. thick) (1.52×10^{-4} m) nesting type of welded bellows. One end of the bellows is welded to the shaft and the other end is welded to the valve body. Two keys are provided to prevent rotation of the bellows when the shaft attachment nuts are tightened or from the torque produced by compression of the valve springs. The keys also provide a stop to



SHUTOFF SEAL CONSISTS OF A THIN, SPHERICAL SHELL SEATED IN THE CONCICAL SEAT PORTION OF THE VALVE BODY.

DURING CLOSURE THE SEAL CONTACTS AND CENTEPS ITSELF IN THE SEAT.

A WIPING OR LAPPING ACTION BETWEEN SEAL AND SEAT PRODUCED MICROSCOPIC CONFORMATION OF THE SEALING SURFACES.

DEFLECTION OF THE SEAL PROVIDES THE SEALING PRELOAD.

EXCESSIVE SEAL DEFLECTION IS PREVENTED BY ACCURATELY LIMITING THE DEFLECTION WITH THE STOP.

Figure 4. Shutoff Seal/Seat Arrangement

prevent overextension of the bellows during inspection and fabrication assuring that the bellows convolutions are always in compression. These keys, which are an integral part of the bellows end fitting, ride in keyways in the valve shaft. Adverse pressure effects are minimized by externally pressurizing the bellows as well as locating it downstream of the shutoff seal.

A means for cleaning the bellows without disassembly of the valve is provided as an integral part of the valve. This is accomplished by introducing cleaning fluid into a cavity formed by the body and a thin stainless steel sleeve held in the body by a shrink-fit at each end. The fluid is sprayed onto the bellows through four rows of holes located 90-degrees apart in the sleeve. The holes in each row are arranged so that each convolution of the bellows passes at least one hole in the row when the valve is actuated. The fluid then passes out of the valve through the valve outlet port.

3. Actuator

A pneumatic actuator was designed to replace the electrical actuator used in the Transtage version of the valve. The poppet return spring and spring guide were retained. A piston and housing were added to complete the pneumatic actuator assembly. The piston bears against the spring guide and pushes the valve open when energized by helium pressure. This piston is guided in the actuator housing and is sealed by a spring-loaded Teflon dynamic seal. The valve stroke of 0.500 ± 0.002-in. ($1.27 \times 10^{-2} \pm 5.08 \times 10^{-5}$ m) is controlled by the end of the spring guide contacting against the valve body. Adjustment of the stroke is provided by shims installed between the main shutoff seal and the bellows shaft (View A on Figure 1).

4. Position Indicators

Proximitor probes are used as the valve position indicators. These devices sense the edge of a CRES 347 stainless steel washer as it passes the face of the probe at each end of the valve stroke. This concept was known to be practical at room temperature; however, the effect of a cryogenic environment upon the probe output signal was not known. Tests were conducted to establish a correlation between the output voltage at room temperature and the output at cryogenic temperature.

A test fixture (see Figure 5) was borrowed from the probe supplier (Bently Nevada Corporation of Minden, Nevada) and utilized for the tests. As the micrometer was turned, the washer moved from one side of the probe to the other, similar to the actual valve design. Tests were performed at ambient and cryogenic temperatures at gap settings of 0.0065-in. (1.65×10^{-4} m) to greater than 0.060-in. (1.52×10^{-3} m), and at input voltages of -18, -24, and -28 vdc. A Bently Nevada proximitor (P/N 3106) was used to provide energy to the probe.

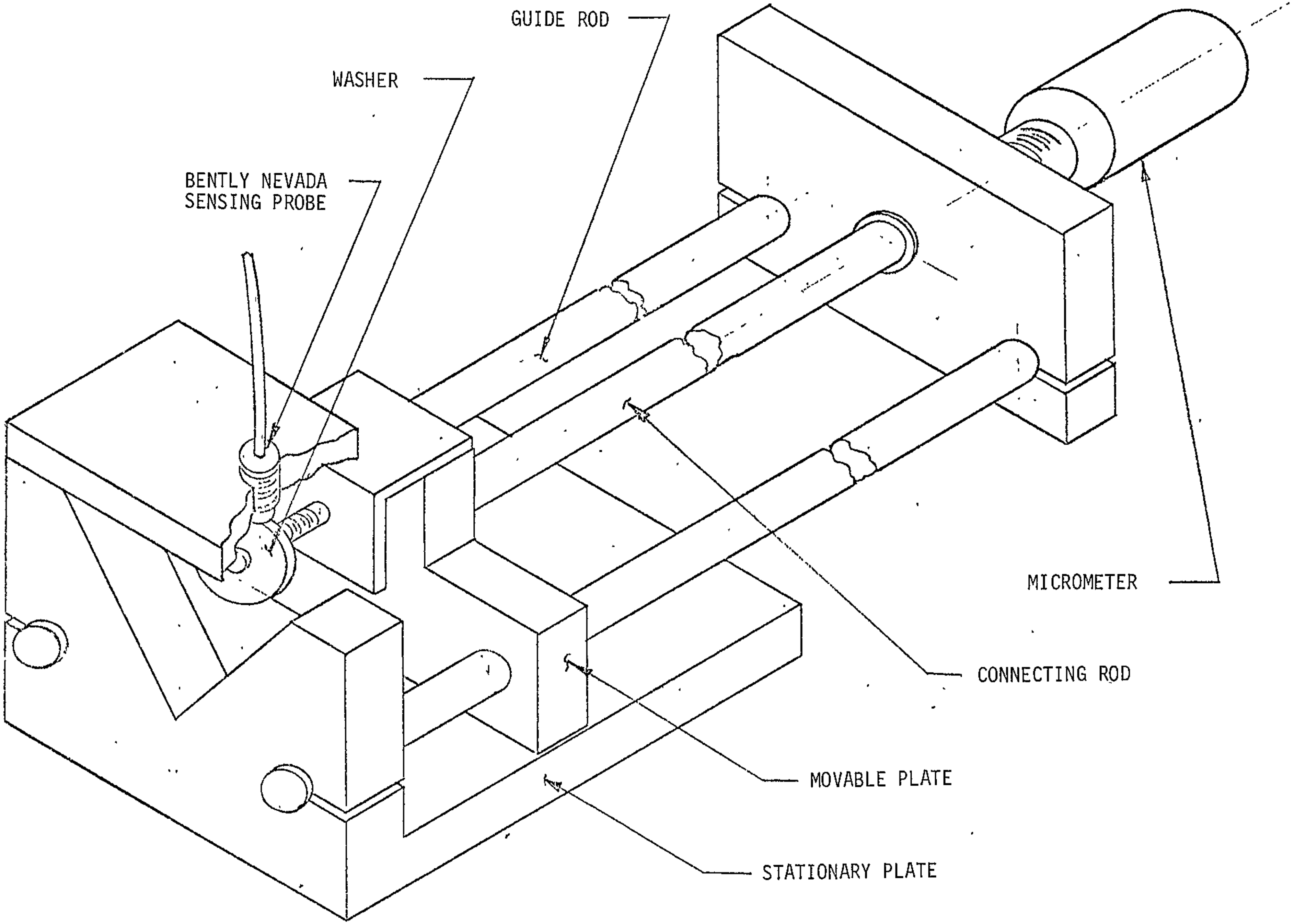


Figure 5. Proximitor Probe Test Fixture

Test results showed a definite reduction in the output signal when the probe was immersed in liquid nitrogen. A CRES 347 stainless steel washer and an input voltage of -18 vdc were used. The output reduction at low temperature ranged from 42% to 44% of the room temperature voltage output for large gaps greater than 0.060-in. (1.52×10^{-3} m) to 56% for a gap of approximately 0.010-in. (2.54×10^{-4} m). Figure 6 contains comparison curves between the room temperature and LN_2 tests conducted at -18 vdc. Curves from data taken at -18, -24, and -28 vdc are shown on Figure 7.

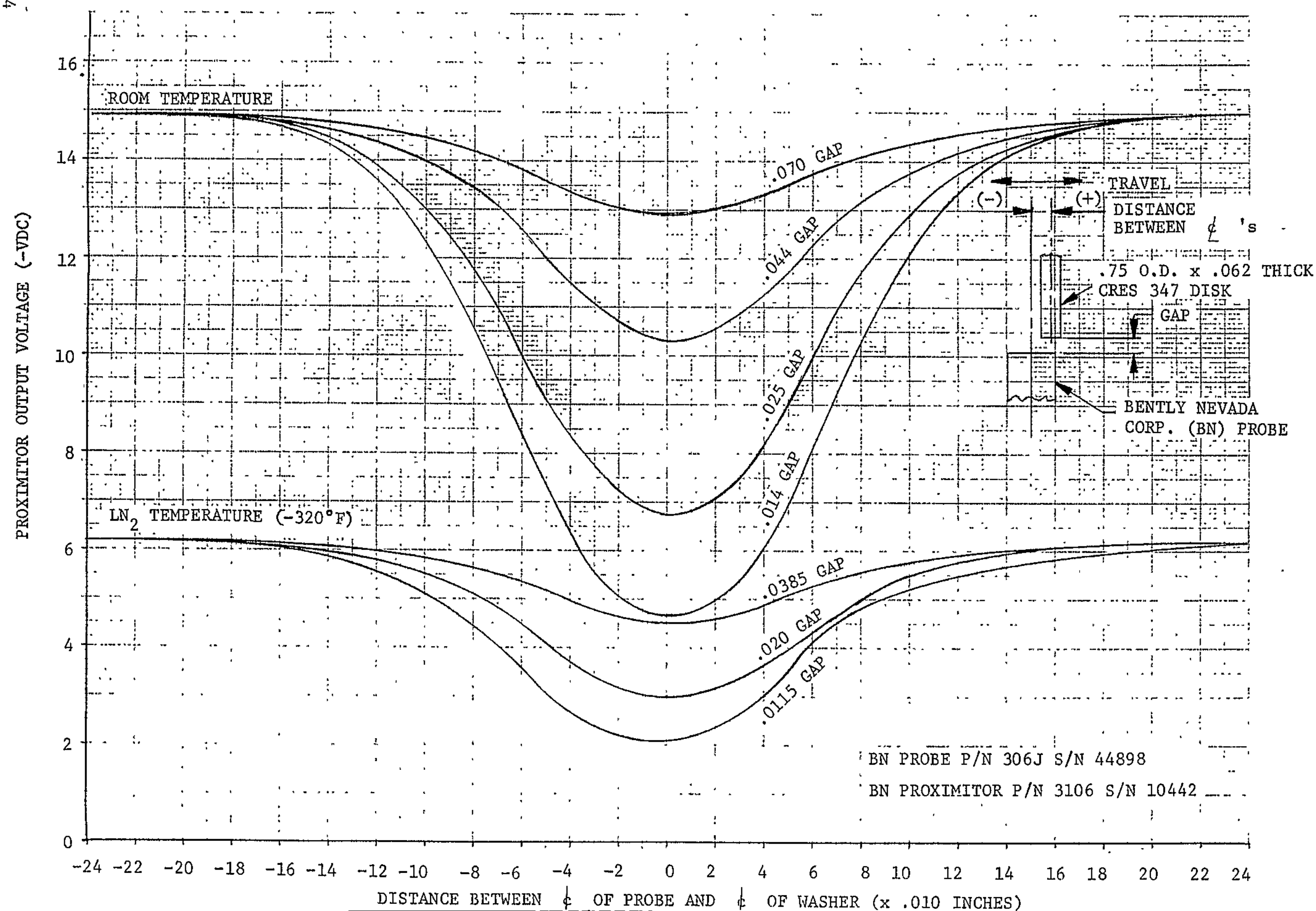
Comparison of the probe output signals indicated that the probe could not be adjusted to give consistent output voltage readings over the entire valve operating temperature ranging of +140°F to -320°F (33.1°K to 77.6°K). However, it was concluded that the standard design probe would give an adequate valve position trace at the ends of the valve stroke if the input voltage was set high and the gap setting between the probe and washer was kept as small as possible. In the SSOV design, the gap was specified as 0.004-in. to 0.006-in. (1.02×10^{-4} m to 1.52×10^{-4} m) and the voltage as -18 vdc minimum with -28 vdc preferred.

5. Materials

Fluorine is one of the most powerful oxidizing agents known and can react with practically all organic and inorganic substances. Therefore, the principal criteria for the selection of materials for liquid fluorine service are propellant compatibility and the retention of ductility as well as toughness at the service temperature. Materials must have the capability to be passivated through the formation of a protective fluoride film, a low uniform corrosion rate in the propellant, and high resistance to stress corrosion cracking. All of the materials that are exposed to liquid fluorine in the space storable oxidizer valve have the capability for meeting all of the above requirements.

The valve materials are listed on Table II. The mechanical property requirements of the valve materials exposed to fluorine were satisfied by selecting non-heat treatable as well as heat-treatable stainless steels and nickel base alloys. The 304L stainless steel and Inconel 600 have intermediate strength as well as excellent ductility along with toughness at ambient and cryogenic temperatures. The alloys A-286, Inconel 750, and Inconel 718 provide high yield strength in the range of 100 ksi to 160 ksi (6.89×10^8 N/m^2 to 1.10×10^9 N/m^2) with attendant good ductility at ambient and cryogenic temperatures.

Welding requirements include tungsten inert gas (TIG) weldments of Inconel 750 to itself and to Inconel 600 as well as electron-beam weldment of Inconel 600 to Inconel 718. All of these materials are readily weldable with the exception of Inconel 750, which is considered to possess good weldability in thin sections only. However, in the valve application, Inconel 750 is used as the bellows and good welding characteristics have been demonstrated.


PROXIMITOR OUTPUT VOLTAGE (-VDC)
ROOM TEMPERATURE
.070 GAP
.044 GAP
.025 GAP
.014 GAP
LN2 TEMPERATURE (-320°F)
.0385 GAP
.020 GAP
.0115 GAP
TRAVEL
(-)
(+)
DISTANCE BETWEEN ₵ 's
.75 O.D. x .062 THICK CRES 347 DISK
GAP
BENTLY NEVADA CORP. (BN) PROBE
BN PROBE P/N 306J S/N 44898
BN PROXIMITOR P/N 3106 S/N 10442
DISTANCE BETWEEN ₵ OF PROBE AND ₵ OF WASHER (x .010 INCHES)

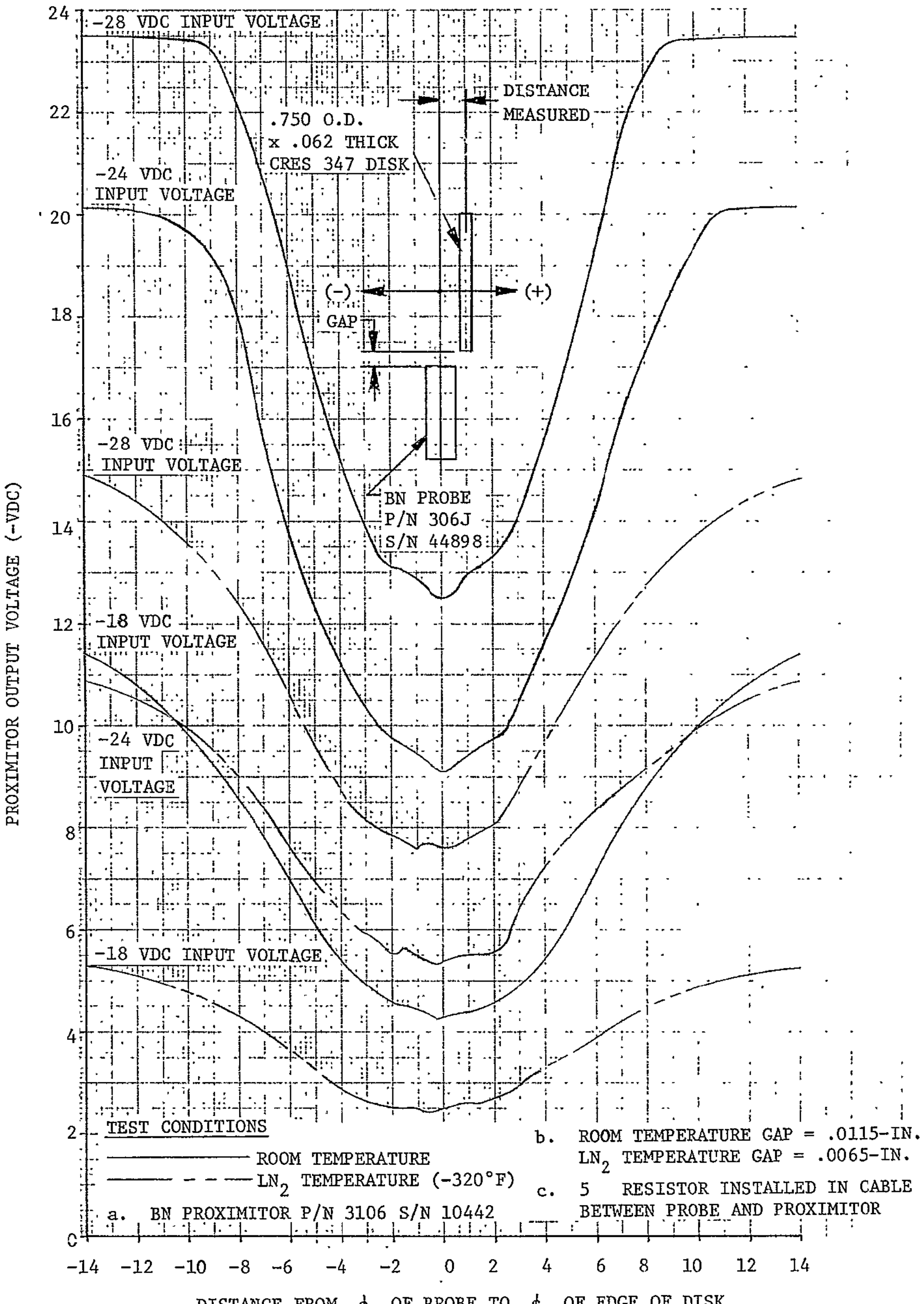


Figure 7. Proximitor Probe Output Voltage vs Input Voltage

TABLE II. - SPACE STORABLE OXIDIZER VALVE MATERIALS

Part No.	Nomenclature	Material
*1157214	Washer Positioning Nut	Aluminum Alloy 6061-T6**
1157215-1	Main Shutoff Seal	CRES 304L, gold plated
1157215-2	Main Shutoff Seal	Beryllium Nickel 440, Temper A
1157216	Bellows Cleaning Sleeve	CRES 304L
1157217	Push Rod (Bellows)	
	End Plate	Inconel Alloy 600
	Shaft	Inconel Alloy 718
	Bellows Disks	Inconel Alloy 750
1157218	Body	Inconel Alloy 718
	Seat	Electrolize chrome plating
*1157221	Actuator Piston	Aluminum Alloy 6061-T6
*1157222	Actuator Housing	Aluminum Alloy 6061-T6
*1157223	Actuator Seal Retainer	Aluminum Alloy 6061-T6
*1157224	Probe Sensing Washer	CRES 347
*1157471	Return Spring	CRES 17-7PH
1157472	Shims	CRES 301
1157474	Key Tab Washer	CRES 304
1157475	Poppet Guide	CRES A286
1157476	Locking Strip	CRES 304
*1157477	Spring Retainer	Inconel Alloy 718

*Not exposed to fluorine.
**Changed to Teflon (see Table III).

B. VALVE FABRICATION AND ACCEPTANCE TESTING

SSOV hardware was manufactured in the Mechanical and Optical Fabrication Shops, Aerojet Electronics Division, Azusa, California and at selected vendor facilities. Valve assembly and acceptance testing were accomplished in the ALRC Engineering Laboratories. Details of the fabrication, assembly, and acceptance test efforts are discussed below.

1. Fabrication

Two hardware anomalies were accepted prior to the start of assembly; one bellows shaft exhibited a low material hardness and two valve bodies had rough seat finishes. The bellows shaft hardness measured Rockwell C-35.5 instead of a specified R_C-38 minimum. Stress calculations were performed to verify the usability of the shaft, which had an adequate margin of safety, was accepted, and was used throughout the test program without incident.

Valve bodies were received at ALRC with seat finishes of 8 microinches AA (2.03×10^{-7} m AA) instead of the specified 2 microinches AA (5.08×10^{-8} m AA). The body supplier stated that he had measured the seat finish as 2 microinches AA (5.08×10^{-8} m AA) prior to plating but had not measured the finish after the electrolize operation. The effect of electrolizing on the surface finish was determined on a flat specimen. Plating increased the measurement a maximum of one microinch (2.54×10^{-8} m AA) when applied to a 2 to 3 microinch AA (5.08×10^{-8} to 7.62×10^{-8} m AA) surface. The supplier specified that this was his best effort and that any rework would have to be performed by a microfinished company.

Because of time and cost factors as well as the possibility that the seats might be damaged if rework was attempted, an investigation was conducted to determine the usability of the existing bodies. Calculations performed to determine the effect of the 8 microinch AA (2.03×10^{-7} mm AA) finish upon leakage verified that leakage would approach the specified rate; however, this was acceptable. The seat surface finish of one of the valve bodies that had performed satisfactorily in the Transtage program was measured at 7 microinches AA (1.78×10^{-7} m AA). Based upon this information and the knowledge that the seal finishes were much better than that specified, the bodies were accepted without rework.

2. Valve Assembly and Acceptance Testing

Valve assembly was initiated by electron-beam welding the bellows assembly into the valve body. All subsequent assembly operations were accomplished on a laminar flow bench in the Engineering Controls Laboratory. All hardware was cleaned to Level "E" (oxidizer clean) in accordance with Specification AGC-46350[5] prior to any assembly work, including the

(5) ALRC Process Specification AGC-46350, "Levels of Cleanliness," 20 February 1964.

electron-beam welding operation. Clean, lint-free gloves were worn during all assembly operations. Two identical valve assemblies were built for the seal in each except a beryllium nickel seal (Valve S/N 0000001) was used in one and a gold-plated CRES 304L seal (Valve 0000002) was used in the other.

Several minor changes were made to the valve hardware during initial assembly and testing. Most involved the addition of chamfers to facilitate assembly and seal installation. All the changes made are shown on Table III. One revision required a change in the shape and material of the large nut utilized to position the proximitor probe washer on the end of the actuator piston. Aluminum chips were discovered in the smaller bore of the actuator housing during the disassembly needed to reposition the washer. The washer had contacted the housing during valve actuation and could not be positioned accurately enough to prevent this rubbing.

The positioning nut, P/N 1157214-1, was replaced with a round teflon nut that was a close fit (0.002-in. to 0.007-in. [5.08×10^{-5} in. to 1.78×10^{-4} m] on the diameter) in the actuator housing. The outside diameter of the washer was reduced to a size 0.003-in. to 0.008-in. (7.62×10^{-5} m to 2.03×10^{-4} m) smaller than the nut. During assembly, the washer was positioned in a manner assuring that no portion extended beyond the edge of the nut. This change eliminated the rubbing between the washer and housing while permitting an accurate adjustment of the proximitor probes.

Acceptance tests were conducted at both ambient and cryogenic temperatures (see Tables IV and V for test results). The valve actuation system consisted of two, two-way pilot valves with one of the pilot valves connected to each leg of a tee at the actuator. The opening orifice was installed immediately upstream from the opening pilot valve in the pressurization line and the closing orifice was installed upstream from the closing pilot valve, between the closing pilot valve and the tee. This arrangement gave a hard system with the orifices pressurized before the actuation of the respective pilot valve. Both pilot valves were actuated simultaneously by the same signal. This system resulted in more predictable and repeatable valve actuation times than was possible with a single, three-way pilot valve with the closing orifice mounted downstream from the pilot valve.

The gold-plated seal leaked in excess of the specified rate at cryogenic temperature during the main seal internal leakage test. It was not known at the time, but the seal had not yet "seated" into the body. The valve was accepted for test and installed in the flow facility for fluorine testing. After numerous test set-up and instrumentation checkout cycles, the seal "seated" and leakage was within the specified rate of 2.5×10^{-3} SCCS when the post-facility installation leakage test was conducted.

The actuation piston seal in both valve assemblies leaked in excess of the original value specified, but in no way affected valve actuation during acceptance testing or the fluorine test cycles. It is believed that

TABLE III. - HARDWARE CHANGES REQUIRED DURING MANUFACTURE AND INITIAL ASSEMBLY*

Part	Part No.	Change
Nut, Positioning	1157214-1 (Item No. 13 on 1157220)	Add -2 part made from Teflon FEP with an OD of 0.747/0.744-in. ($1.897 \times 10^{-2}/1.889 \times 10^{-2}$ m), notched for free helium flow.
Seal	1157215-1, -2 (Item Nos. 14 and 21 on 1157220)	Add a thermal stabilization process to rough machine within 0.020-in. (5.08×10^{-4} m), then conduct 10 thermal cycles of immersing the seal in LN_2 for 5 minutes, then in tap water until the seal is warm. The seals shall then be finish machined.
Housing, Actuator	1157222-1, -3 (Item Nos. 17 and 44 on 1157220)	Add a 0.045-in. (1.14×10^{-3} m) x 45° chamfer on the inner corner of the seal groove at the large end of the housing. Add a 0.015-in. (3.81×10^{-4} m) radius at the intersection of the 0.751/0.749-in. ($1.907 \times 10^{-2}/1.902 \times 10^{-2}$ m) diameter bore (small bore in the housing) and the 30-degree chamfer into the large bore.
Washer	1157224-1 (Item No. 19 on 1157220)	Change OD to 0.741/0.739-in. ($1.882 \times 10^{-2}/1.877 \times 10^{-2}$ m).

*See Figure 1 for the location of each part.

TABLE IV. - ACCEPTANCE TEST SUMMARY, VALVE S/N 0000001 INCORPORATING BERYLLIUM NICKEL SEAL

Operation	Conditions	Objectives	Results
Proof Test	400 psig LN_2 (2.76×10^6 N/m^2, g) 750 psig HE (5.17×10^6 N/m^2, g)	No permanent deformation	No permanent deformation
Bellows Proof Test	250 psig LN_2 (1.72×10^6 N/m^2, g) 500 psig HE (3.45×10^6 N/m^2, g)	75 actuations 1×10^{-6} scc/sec	75 actuations 1.24×10^{-9} scc/sec
Functional Test	250 psig LN_2 (1.72×10^6 N/m^2, g) 500 psig HE (3.45×10^6 N/m^2, g)	50-75 msec Open and Close	70 msec open 50 msec close
Internal Leak Test Main Seal	250 psig HE (1.72×10^6 N/m^2, g) Ambient Temperature	25×10^{-3} scc/sec	2.66×10^{-3} scc/sec
Main Seal	250 psig HE (1.72×10^6 N/m^2, g) LN_2 Temperature	25×10^{-3} scc/sec	3.40×10^{-3} scc/sec
Piston Seal	500 psig HE (3.45×10^6 N/m^2, g)	25×10^{-3} scc/sec	1.20×10^{-1} scc/sec
External Leak Test	250 psig HE (1.72×10^6 N/m^2, g) Ambient Temperature	25×10^{-4} scc/sec	Zero scc/sec inlet and outlet flanges
	250 psig HE (1.72×10^6 N/m^2, g) LN_2 Temperature	25×10^{-4} scc/sec	Zero scc/sec inlet and outlet flanges

TABLE V. - ACCEPTANCE TEST SUMMARY, VALVE S/N 0000002 INCORPORATING GOLD-PLATED 304L SEAL

Operation	Conditions	Objectives	Results
Proof Test	400 psig LN_2 (2.76×10^6 N/m^2, g) 750 psig HE (5.17×10^6 N/m^2, g)	No permanent deformation	No permanent deformation
Bellows Proof Test	250 psig LN_2 (1.72×10^6 N/m^2, g) 500 psig HE (3.45×10^6 N/m^2, g)	75 actuations 1×10^{-6} scc/sec	75 actuations 1.4×10^{-10} scc/sec
Functional Test	250 psig LN_2 (1.72×10^6 N/m^2, g) 500 psig HE (3.45×10^6 N/m^2, g)	50 - 75 msec Open and close	70 msec open 50 msec close
Internal Leak Test Main Seal	250 psig HE (1.72×10^6 N/m^2, g) Ambient Temperature.	25×10^{-3} scc/sec	1.70×10^{-2} scc/sec
Main Seal	250 psig HE (1.72×10^6 N/m^2, g) LN_2 Temperature	25×10^{-3} scc/sec	1.50×10^{-1} scc/sec
Piston Seal	500 psig HE (3.45×10^6 N/m^2, g)	25×10^{-3} scc/sec	6.70×10^{-2} scc/sec
External Leak Test	250 psig HE (1.72×10^6 N/m^2, g) Ambient Temperature	25×10^{-4} scc/sec	1.16×10^{-6} scc/sec (out) 2.32×10^{-7} (scc/sec (in)
	250 psig HE (1.72×10^6 N/m^2, g) LN_2 Temperature	25×10^{-4} scc/sec	2.15×10^{-7} scc/sec (out) 1.44×10^{-7} scc/sec (in) Out = outlet flange In = inlet flange

the leakage objective of this seal was too rigid in view of the particular installation and the cryogenic conditions to which the seal was subjected. If the actuator was redesigned for flight use, this plastic seal would be replaced with a metal seal (i.e., a bellows).

C. FLUORINE COMPATIBILITY TESTING

The two space storable oxidizer valves were tested in the fluorine test facility, Test Stand J-4A, at Sacramento, California. This stand, which is used primarily for the performance testing of valves, pumps, bearings, and seals with liquid fluorine or Flox, is equipped with a conventional, pressure-fed, remote-controlled, flow loop. It also has a charcoal pit for the disposal of vented fluorine and fluorine-compounds as well as deluge systems to protect the stand from any fire damage resulting from spillage. Visual observation of the stand and flow system during testing is accomplished by means of closed-circuit television.

1. Facility Preparation

The facility flow loop was modified for SSOV testing by installing a 2.0-in. (5.08×10^{-2} m) fluorine filter, adding a parallel flow loop for concurrent testing of both valves, and adding a surge dampener upstream from the valves. The filter, a Wintec Model No. 54241-508, is shown on the lower left-hand corner of Figure 8. The jacketed and insulated surge dampener is installed vertically immediately downstream from the filter. The fluorine system is jacketed up to the filter inlet; these jackets and the jacket around the surge dampener were filled with LN_2 prior to each flow test. Figure 9 is the test schematic.

Sheet metal containers were fabricated and installed around the two test valves. These containers were sealed at the inlet and outlet flanges as well as around the actuator covers. They were filled with liquid nitrogen prior to each cryogenic leak test to maintain a valve temperature of -300°F (88.7°K) maximum. This method of chilling the valve was effective as long as the liquid nitrogen level was maintained with the valve assembly submerged. One of the containers with the lid removed is shown on Figure 10. A closed container is visible on Figure 11, which is an over-all view of the flow test set-up.

The pilot valves shown mounted on the small blastshield between the SSOV's on Figures 8, 10 and 11 were relocated to be close-coupled with the SSOV actuators. The long line lengths shown delayed valve opening and closing as compared to the times obtained during acceptance testing. Also, the potentiometers projecting from the ends of the valve actuators were affected by the cold when the valves were thoroughly chilled. The potentiometers were wrapped with heater blankets and then operated satisfactorily. These potentiometers were added test equipment used to supplement and verify the proximitor probe readings.

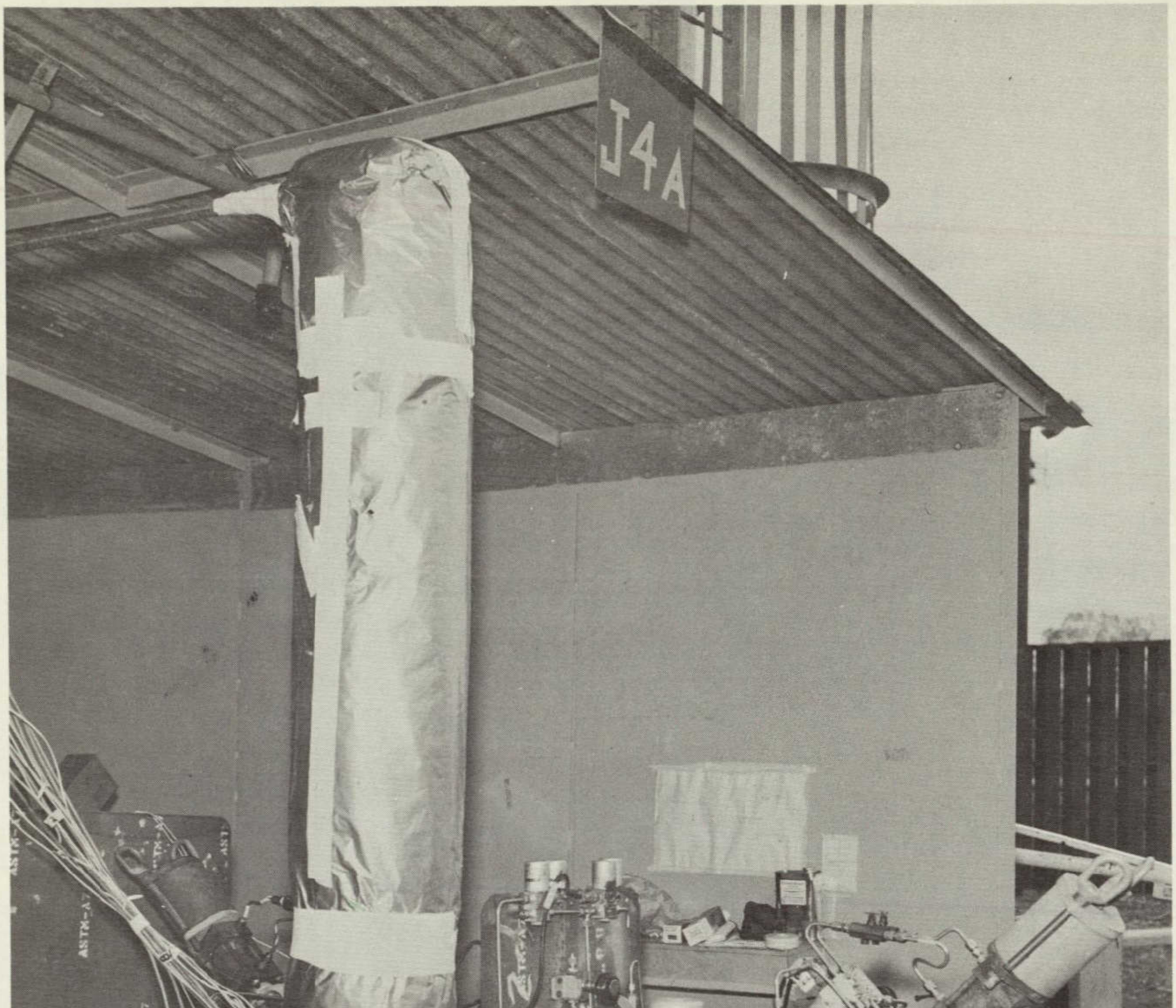


Figure 8. View of Flow Facility Showing Filter and Surge Dampener

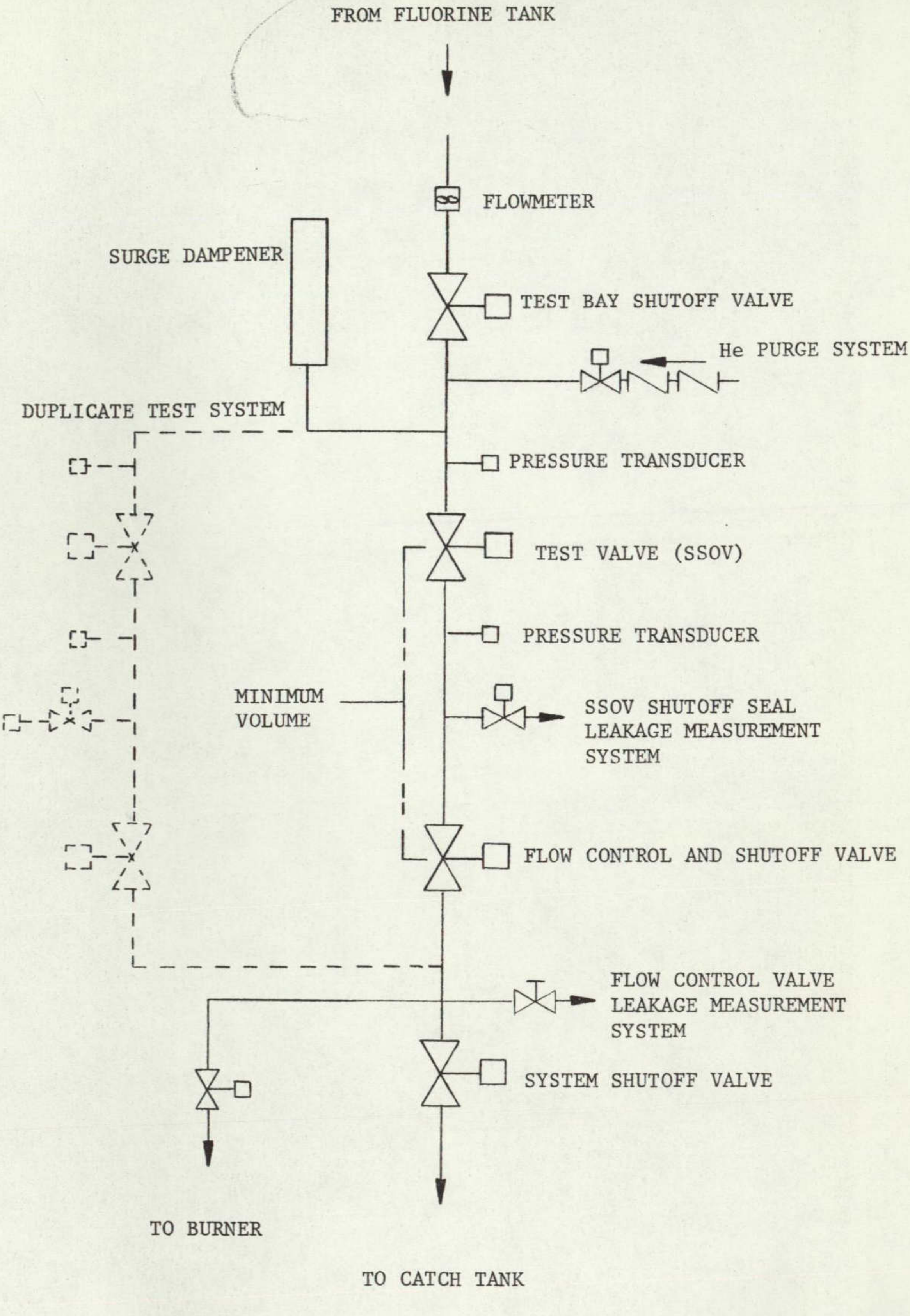


Figure 9. Test Set-Up

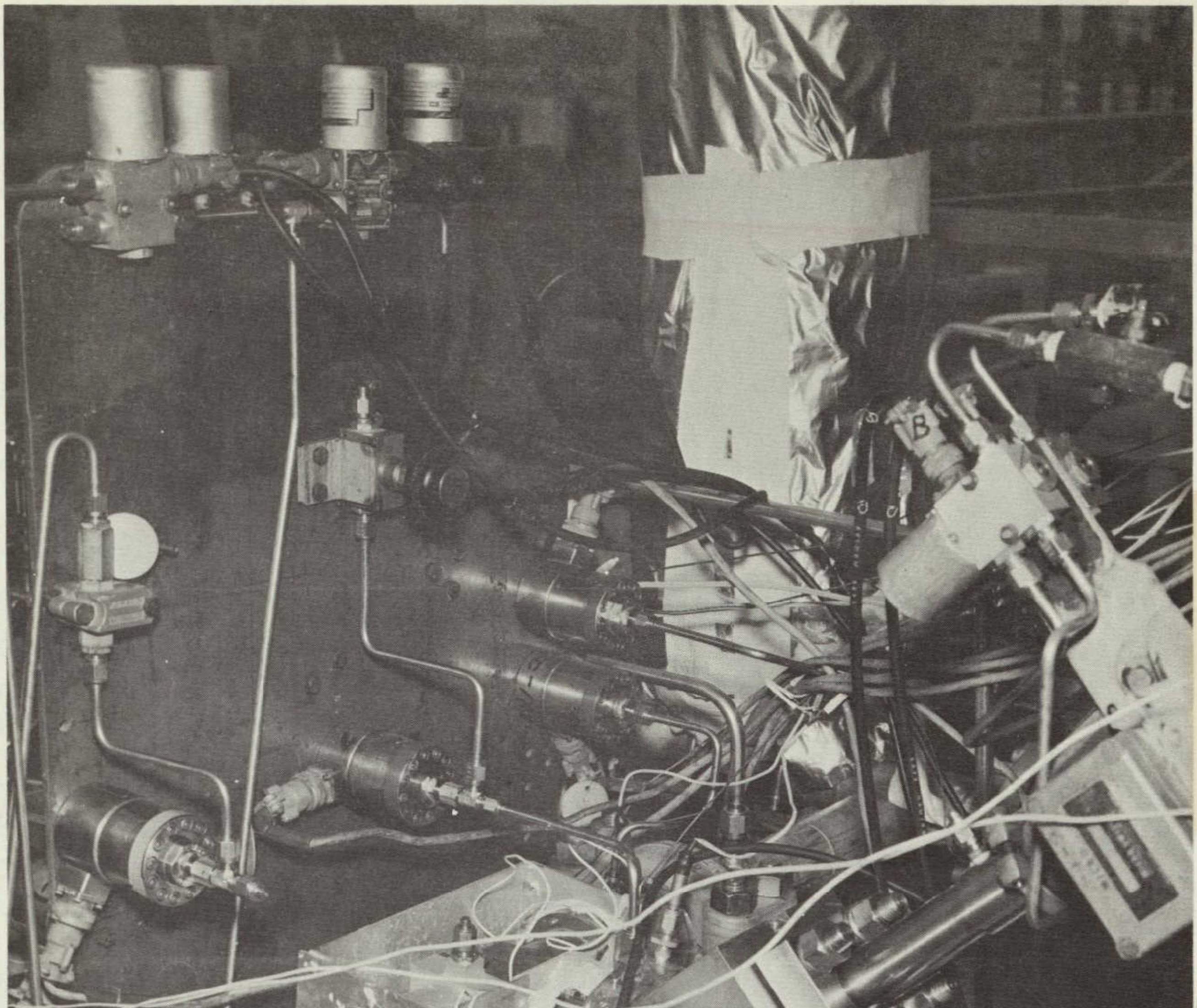


Figure 10. View of LN_2 Container Installed Around SSOV

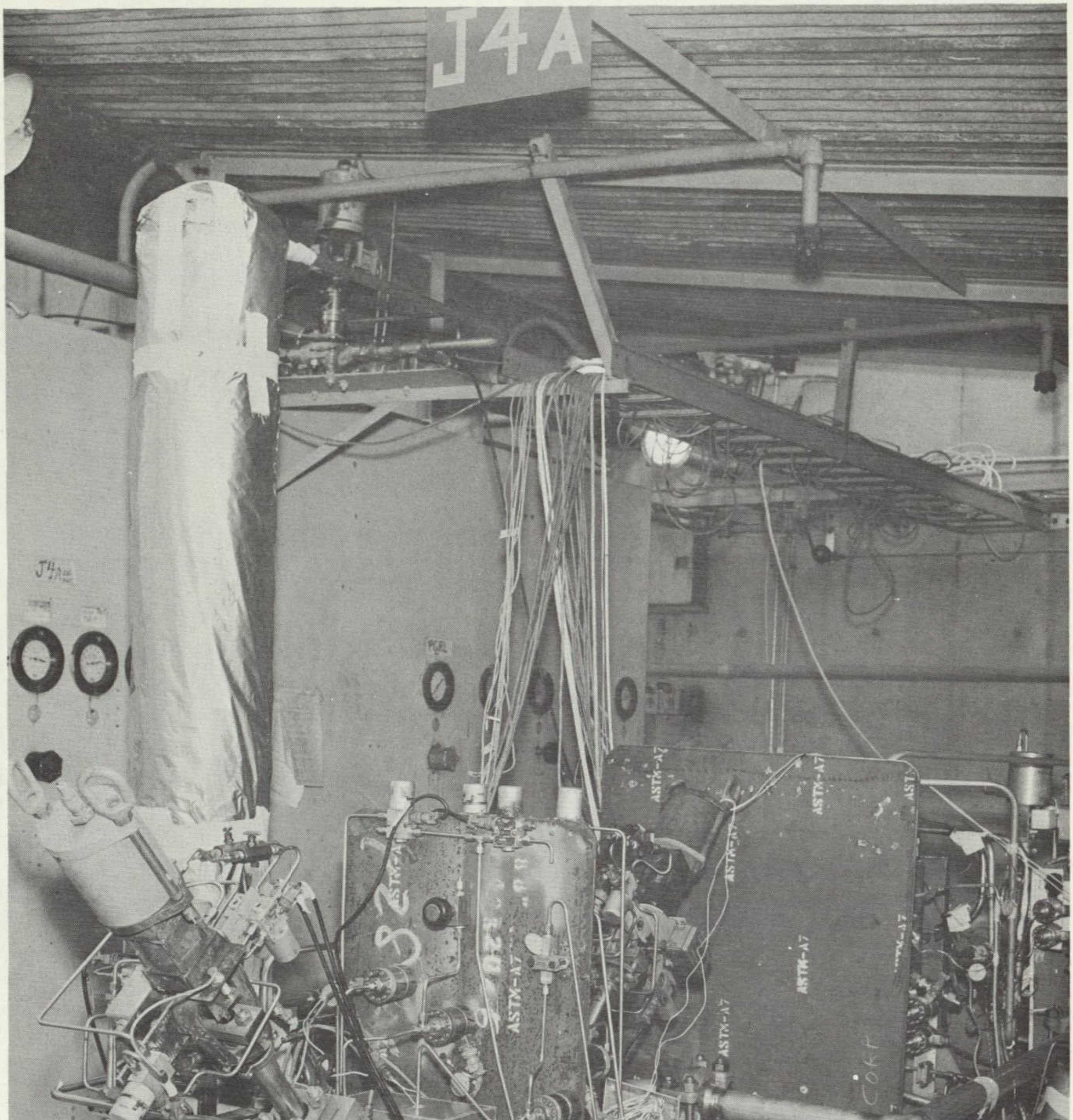


Figure 11. Over-all View of Flow Facility with Return Line in Foreground

2. Operating Cycle and Proof Cycle Tests

SSOV S/N 0000001 (beryllium nickel seal) was subjected to 250 liquid fluorine flow cycles and SSOV S/N 0000002 was subjected to 1006 liquid fluorine flow cycles in accordance with the SSOV Compatibility Test Plan (see Appendix A). The first ten cycles were conducted with an inlet pressure of 25 psig (1.72×10^5 N/m^2, g) and the following 240 cycles were conducted with an inlet pressure of 100 psig (6.89×10^5 N/m^2, g). At this point, the valve with the gold-plated CRES 304L seal showed better leakage results. Therefore SSOV (SN 0000002) was selected for further testing and subjected to 756 flow cycles at a proof inlet pressure of 250 psig (1.72×10^6 N/m^2, g).

During the first flow cycles, it was noted that the initial flow through the valve was being supplied completely from the surge dampener. This caused a delay in flow throughout the system and a corresponding delay in the flow-meter signal. At shutdown, system flow continued until the surge dampener was repressurized to system pressure. This phenomenon had little effect upon the flow results at 25 psig (1.72×10^5 N/m^2, g); however, a pressure spike was noted downstream from the valve poppet during initial valve opening. This spike was caused by the high flow being restricted by the stand valve installed immediately downstream from the SSOV. This close-coupled valve was part of the minimum volume leakage measurement system used to collect and measure SSOV poppet leakage.

During testing at 100 psig (6.89×10^5 N/m^2, g), pressure spikes as high as 181 psig (1.25×10^6 N/m^2, g) were measured at the stand valve inlet flange during SSOV opening. It was apparent that testing at 250 psig (1.72×10^6 N/m^2, g) would be impossible under these conditions without damaging the SSOV bellows. Therefore, with the concurrence of the NASA-LeRC Project Manager, all cycles conducted at 250 psig (1.72×10^6 N/m^2, g) inlet pressure were performed with the pressure balanced across the valve poppet prior to valve opening. System valves were sequenced in a manner that the SSOV was subjected to full flow rate and full pressure shutdown as originally scheduled.

Test cycle results are presented on Tables VI and VII. Leakage data are presented on Tables VIII and IX. Each valve was subjected to approximately 255 purge, functional checkout, instrumentation checkout, and passivation cycles before the first fluorine flow cycle. During these initial cycles, the gold-plated seal seated and the leakage rate of SSOV S/N 0000002 improved to less than the specified leakage rate by the time that the first fluorine flow cycle was accomplished. At the same time, the leakage rate of SSOV S/N 0000001, which incorporated the beryllium nickel seal, deteriorated to an out-of-specification condition before the first fluorine flow cycle. Performance of the beryllium nickel seal did not improve significantly throughout the flow test although the leakage after 250 cycles was only one-half of the leakage measured after the tenth cycle. Gold-plated seal leakage was

TABLE VI. - FLUORINE CYCLE TEST RESULTS - SSOV S/N 0000001 (BERYLLIUM NICKEL SEAL)

Test No. (1334-D01-OV-XXX)		Duration-sec	Tank Pressure-psig	Actuation Pressure-psig	Inlet Temperature °F	Flow lb/sec	Opening Time-MS Orifice-inches	Closing Time-MS Orifice-inches
Pre-test functional		-	25 He	250	ambient	-	230/0.030	270/0.045
Pre-test functional		-	100 He	250	ambient	-	160/0.030	290/0.045
Pre-test functional		-	250 He	250	ambient	-	120/0.030	270/0.045
Pre-test functional		-	250 He	350	ambient	-	85/0.030	270/0.045
Test No.	Cycle No.							
004	1	113	28 LF_2	250	-284	2.59	90/0.030	170/0.045
006	2	20	30 LF_2	250	-280	*	85/0.030	170/0.045
009	4		31 LF_2	250	-283	2.76	105/0.030	185/0.045
	10	160	29 LF_2	250	-290	3.16	102/0.030	180/0.045
011	11		100 LF_2	250	-285	6.14	80/0.033	70/0.065
	49				-285	6.45	75/0.033	72/0.065
	50	160			-285	6.44	75/0.033	74/0.065
012	51				-287	6.27	75/0.033	70/0.065
	52				-287	6.40	77/0.033	70/0.065
	99				-287	6.48	80/0.033	75/0.065
	100	200			-287	6.47	79/0.033	78/0.065
013	101				-286	6.55	72/0.033	76/0.065
	102				-286	6.21	77/0.033	70/0.065
	174				-286	6.33	84/0.033	78/0.065
	175	300			-286	6.35	83/0.033	78/0.065
014	176				-287	6.02	72/0.033	73/0.065
	177				-287	6.16	71/0.033	71/0.065
	249				-287	6.37	79/0.033	78/0.065
	250	300			-287	6.38	83/0.033	78/0.065

*Instrumentation problem - No data

TABLE VI (cont.)

Test No. (1334-D01-OV-XXX)	Cycle No.	Duration sec	Tank Pressure- N/m², g	Actuation Pressure- N/m², g	Inlet Temperature °K	Flow Kg/sec	Opening Time-MS Orifice-Meters	Closing Time-MS Orifice-Meters
Pre-test functional		-	1.72×10^5	1.72×10^6	ambient	-	$230/7.62 \times 10^{-4}$	$270/1.14 \times 10^{-3}$
Pre-test functional		-	6.89×10^5	1.72×10^6	ambient	-	$160/7.62 \times 10^{-4}$	$290/1.14 \times 10^{-3}$
Pre-test functional		-	1.72×10^6	1.72×10^6	ambient	-	$120/7.62 \times 10^{-4}$	$270/1.14 \times 10^{-3}$
Pre-test functional		-	1.72×10^6	2.41×10^6	ambient	-	$85/7.62 \times 10^{-4}$	$270/1.14 \times 10^{-3}$
Test No.	**Cycle No.**							
004	1	113	1.93×10^5	1.72×10^6	97.6	1.13	$90/7.62 \times 10^{-4}$	$170/1.14 \times 10^{-3}$
006	2	20	2.07×10^5		99.8	*	$85/7.62 \times 10^{-4}$	$170/1.14 \times 10^{-3}$
009	4		2.14×10^5		98.1	1.20	$105/7.62 \times 10^{-4}$	$185/1.14 \times 10^{-3}$
	10	160	2.00×10^5		94.3	1.38	$102/7.62 \times 10^{-4}$	$180/1.14 \times 10^{-3}$
011	11		6.89×10^5		97.0	2.68	$80/8.38 \times 10^{-4}$	$70/1.65 \times 10^{-3}$
	49				97.0	2.82	$75/8.38 \times 10^{-4}$	$72/1.65 \times 10^{-3}$
	50	160			97.0	2.81	$75/8.38 \times 10^{-4}$	$74/1.65 \times 10^{-3}$
012	51				95.9	2.74	$75/8.38 \times 10^{-4}$	$70/1.65 \times 10^{-3}$
	52				95.9	2.80	$77/8.38 \times 10^{-4}$	$70/1.65 \times 10^{-3}$
	99				95.9	2.82	$80/8.38 \times 10^{-4}$	$75/1.65 \times 10^{-3}$
	100	200			95.9	2.82	$79/8.38 \times 10^{-4}$	$78/1.65 \times 10^{-3}$
013	101				96.5	2.86	$72/8.38 \times 10^{-4}$	$76/1.65 \times 10^{-3}$
	102				96.5	2.71	$77/8.38 \times 10^{-4}$	$70/1.65 \times 10^{-3}$
	174				96.5	2.76	$84/8.38 \times 10^{-4}$	$78/1.65 \times 10^{-3}$
	175	300			96.5	2.77	$83.8.38 \times 10^{-4}$	$78/1.65 \times 10^{-3}$
014	176				95.9	2.62	$72/8.38 \times 10^{-4}$	$73/1.65 \times 10^{-3}$
	177				95.9	2.69	$71/8.38 \times 10^{-4}$	$71/1.65 \times 10^{-3}$
	249				95.9	2.78	$79/8.38 \times 10^{-4}$	$78/1.65 \times 10^{-3}$
	250	300			95.9	2.78	$83/8.38 \times 10^{-4}$	$78/1.65 \times 10^{-3}$

*Instrumentation problem - No data

TABLE VII. - FLUORINE CYCLE TEST RESULTS - SSOV S/N 0000002 (GOLD-PLATED CRES 304L SEAL)

Test No. (1334-D01-OV-XXX)		Duration sec	Tank Pressure-psig	Actuation Pressure-psig	Inlet Temperature °F	Flow lb/sec	Opening Time-MS Orifice-inches	Closing Time-MS Orifice-inches
Pre-test functional		-	25 He	250	ambient	-	200/0.030	415/0.045
Pre-test functional		-	100 He	250	ambient	-	170/0.030	420/0.045
Pre-test functional		-	250 He	250	ambient	-	120/0.030	420/0.045
Pre-test functional		-	250 He	350	ambient	-	90/0.030	420/0.045
Test No.	Cycle No.							
002	1	122	29 LF_2	250	-284	2.88	90/0.030	200/0.045
005	2	34	26 LF_2	250	-282	*	85/0.030	170/0.045
007	3		31 LF_2	250	-279	2.83	120/0.030	270/0.045
	10	160	28 LF_2	250	-288	3.09	105/0.030	240/0.045
010	11	7	100 LF_2	250	-280	5.74	53/0.033	105/0.060
011	12				-280	4.26	70/0.030	86/0.063
	13				-280	4.40	70/0.030	82/0.063
	49				-280	6.79	75/0.030	87/0.063
	50	156			-280	6.75	75/0.030	86/0.063
012	51				-291	5.83	67/0.030	70/0.067
	52				-291	5.95	63/0.030	70/0.067
	99				-291	6.22	71/0.030	77/0.067
	100	200			-291	6.21	68/0.030	77/0.067
013	101				-286	6.32	67/0.030	72/0.067
	102				-286	6.46	68/0.030	70/0.067
	174				-286	6.61	73/0.030	76/0.067
	175	300			-286	6.64	74/0.030	78/0.067
014	176				-287	6.62	62/0.030	71/0.067
	177				-287	6.67	62/0.030	70/0.067
	249				-287	6.46	73/0.030	75/0.067
	250				-287	6.44	69/0.030	73/0.067

*Instrumentation problem - No data.

TABLE VII (cont.)

Test No. (1334-D01-OV-XXX) Test No.	Cycle No.	Duration sec	Tank Pressure-psig	Actuation Pressure-psig	Inlet Temperature °F	Flow lb/sec	Opening Time-MS Orifice-inches	Closing Time-MS Orifice-inches
015	251		250	250	-279	*	102/0.030	152/0.045
	252				-279	14.1	102/0.030	148/0.045
	299				-281	14.4	105/0.030	160/0.045
	300	88			-281	*	105/0.030	160/0.045
016	301	165			-279	11.8	102/0.030	196**/0.045
	302				-279	14.2	109/0.030	137/0.045
	303				-279	14.1	103/0.030	141/0.045
	399				-281	15.5	120/0.030	152/0.045
	400	234			-281	15.6	120/0.030	147/0.045
017	401				-279	14.1	117/0.030	152/0.045
	402				-279	*	115/0.030	150/0.045
	599				-282	15.8	117/0.030	152/0.045
	600	160			-282	15.7	115/0.030	150/0.045
018	601				-279	13.0	110/0.030	144/0.045
	602				-279	13.7	109/0.030	143/0.045
	799				-282	15.0	114/0.030	151/0.045
	800	160			-282	14.8	116/0.030	152/0.045
019	801				-279	12.6	100/0.030	136/0.045
	802				-279	11.9	96/0.030	136/0.045
	999				-282	13.4	110/0.030	157/0.045
	1000				-282	13.5	113/0.030	156/0.045
019	1001				-282	*	110/0.030	60/0.067
	1002				-282	17.6	102/0.030	58/0.067
	1003				-282	16.7	102/0.030	58/0.067
	1004				-282	16.5	103/0.030	58/0.067
	1005				-282	16.4	103/0.030	57/0.067
	1006	164			-282	*	105/0.030	55/0.067

*Instrumentation problem - No data

**Long duration flow test - not a pressure shutdown

TABLE VII (cont.)

Test No. (1334-D01-OV-XXX)	Cycle No.	Duration sec	Tank Pressure-N/m², g	Actuation Pressure-N/m², g	Inlet Temperature °K	Flow Kg/sec	Opening Time-MS Orifice-meters	Closing Time-MS Orifice-meters
Pre-test functional		-	1.72×10^5	1.72×10^6	ambient	-	$200/7.62 \times 10^{-4}$	$415/1.14 \times 10^{-3}$
Pre-test functional		-	6.89×10^5	1.72×10^6	ambient	-	$170/7.62 \times 10^{-4}$	$420/1.14 \times 10^{-3}$
Pre-test functional		-	1.72×10^6	1.72×10^6	ambient	-	$120/7.62 \times 10^{-4}$	$420/1.14 \times 10^{-3}$
Pre-test functional		-	1.72×10^6	2.41×10^6	ambient	-	$90/7.62 \times 10^{-4}$	$420/1.14 \times 10^{-3}$
Test No.	**Cycle No.**							
002	1	122	2.00×10^5	1.72×10^6	97.6	1.31	$90/7.62 \times 10^{-4}$	$200/1.14 \times 10^{-3}$
005	2	34	1.79×10^5		98.7	*	$85/7.62 \times 10^{-4}$	$170/1.14 \times 10^{-3}$
007	3		2.14×10^5		100.4	1.28	$120/7.62 \times 10^{-4}$	$270/1.14 \times 10^{-3}$
	10	160	1.93×10^5		95.4	1.40	$105/7.62 \times 10^{-4}$	$240/1.14 \times 10^{-3}$
010	11	7	6.89×10^5		99.8	2.60	$53/8.37 \times 10^{-4}$	$105/1.52 \times 10^{-3}$
011	12					1.93	$70/7.62 \times 10^{-4}$	$86/1.60 \times 10^{-3}$
	13					1.99	$70/7.62 \times 10^{-4}$	$82/1.60 \times 10^{-3}$
	49					3.08	$75/7.62 \times 10^{-4}$	$87/1.60 \times 10^{-3}$
	50	156				3.06	$75/7.62 \times 10^{-4}$	$86/1.60 \times 10^{-3}$
012	51				93.7	2.64	$67/7.62 \times 10^{-4}$	$70/1.70 \times 10^{-3}$
	52					2.70	$63/7.62 \times 10^{-4}$	$70/1.70 \times 10^{-3}$
	99					2.82	$71/7.62 \times 10^{-4}$	$77/1.70 \times 10^{-3}$
	100	200				2.82	$68/7.62 \times 10^{-4}$	$77/1.70 \times 10^{-3}$
013	101				96.5	2.86	$67/7.62 \times 10^{-4}$	$72/1.70 \times 10^{-3}$
	102					2.93	$68/7.62 \times 10^{-4}$	$70/1.70 \times 10^{-3}$
	174					3.00	$73/7.62 \times 10^{-4}$	$76/1.70 \times 10^{-3}$
	175	300				3.01	$74/7.62 \times 10^{-4}$	$78/1.70 \times 10^{-3}$
014	176				95.9	3.00	$62/7.62 \times 10^{-4}$	$71.1.70 \times 10^{-3}$
	177					3.02	$62/7.62 \times 10^{-4}$	$70/1.70 \times 10^{-3}$
	249					2.93	$73/7.62 \times 10^{-4}$	$75/1.70 \times 10^{-3}$
	250	300				2.92	$69/7.62 \times 10^{-4}$	$73/1.70 \times 10^{-3}$

*Instrumentation problem - No data

TABLE VII (cont.)

Test No.	Cycle No.	Duration sec	Tank Pressure- N/m^2, g	Actuation Pressure- N/m^2, g	Inlet Temperature °K	Flow Kg/sec	Opening Time-MS Orifice-meters	Closing Time-MS Orifice-meters
015	251		1.72×10^{6}	1.72×10^{6}	100.4	*	$102/7.62 \times 10^{-4}$	$152/1.14 \times 10^{-3}$
	252				100.4	6.40	$102/7.62 \times 10^{-4}$	$148/1.14 \times 10^{-3}$
	299				99.3	6.53	$105/7.62 \times 10^{-4}$	$160/1.14 \times 10^{-3}$
	300	88			99.3	*	$105/7.62 \times 10^{-4}$	$160/1.14 \times 10^{-3}$
016	301	165			100.4	5.35	$102/7.62 \times 10^{-4}$	$196**/1.14 \times 10^{-3}$
	302				100.4	6.44	$109/7.62 \times 10^{-4}$	$137/1.14 \times 10^{-3}$
	303				100.4	6.40	$103/7.62 \times 10^{-4}$	$141/1.14 \times 10^{-3}$
	399				99.3	7.03	$120/7.62 \times 10^{-4}$	$152/1.14 \times 10^{-3}$
	400	234			99.3	7.07	$120/7.62 \times 10^{-4}$	$147/1.14 \times 10^{-3}$
017	401				100.4	6.40	$117/7.62 \times 10^{-4}$	$152/1.14 \times 10^{-3}$
	402				100.4	*	$115/7.62 \times 10^{-4}$	$150/1.14 \times 10^{-3}$
	599				98.7	7.16	$117/7.62 \times 10^{-4}$	$152/1.14 \times 10^{-3}$
	600	160			98.7	7.12	$115/7.62 \times 10^{-4}$	$150/1.14 \times 10^{-3}$
018	601				100.4	5.89	$110/7.62 \times 10^{-4}$	$144/1.14 \times 10^{-3}$
	602				100.4	6.21	$109/7.62 \times 10^{-4}$	$143/1.14 \times 10^{-3}$
	799				98.7	6.80	$114/7.62 \times 10^{-4}$	$151/1.14 \times 10^{-3}$
	800	160			98.7	6.66	$116/7.62 \times 10^{-4}$	$152/1.14 \times 10^{-3}$
019	801				100.4	5.71	$100/7.62 \times 10^{-4}$	$136/1.14 \times 10^{-3}$
	802				100.4	5.40	$96/7.62 \times 10^{-4}$	$136/1.14 \times 10^{-3}$
	999				98.7	6.07	$110/7.62 \times 10^{-4}$	$157/1.14 \times 10^{-3}$
	1000				98.7	6.12	$113/7.62 \times 10^{-4}$	$156/1.14 \times 10^{-3}$
019	1001				98.7	*	$110/7.62 \times 10^{-4}$	$60/1.70 \times 10^{-3}$
	1002					7.98	$102/7.62 \times 10^{-4}$	$58/1.70 \times 10^{-3}$
	1003					7.57	$102/7.62 \times 10^{-4}$	$58/1.70 \times 10^{-3}$
	1004					7.48	$103/7.62 \times 10^{-4}$	$58/1.70 \times 10^{-3}$
	1005					7.44	$103/7.62 \times 10^{-4}$	$57/1.70 \times 10^{-3}$
	1006	164				*	$105/7.62 \times 10^{-4}$	$55/1.70 \times 10^{-3}$

*Instrumentation problem - No data

**Long duration flow test - not a pressure shutdown

TABLE VIII. - LEAKAGE TEST RESULTS - SSOV S/N 0000001 (BERYLLIUM NICKEL SEAL)

Test	Temperature	Leakage (SCCS) at Test Pressure (psig) 25 (1.72×10^5 N/m^2, g	100 (6.89×10^5 N/m^2, g	250 (1.72×10^6 N/m^2, g
Acceptance test	ambient	9.10×10^{-4}	2.20×10^{-3}	2.66×10^{-3}
Acceptance test	LN_2	-	-	3.40×10^{-3}
Post facility inst.	ambient	1.0×10^{-2}	2.66×10^{-2}	8.66×10^{-2}
Post facility inst.	LN_2	$0^{cc}/5$ min	6.33×10^{-2}	6.60×10^{-1}
Post-passivation	LN_2	1.36×10^{-1}	7.75×10^{-1}	2.63
Post-Cycle 1	LN_2	2.13×10^{-1}	1.28	4.35
Post-Cycle 2	LN_2	6.66×10^{-1}	1.85	4.75
Post-Cycle 10	LN_2	2.26×10^{-1}	1.49	5.00
Post-Cycle 50	ambient	5.67×10^{-2}	2.20×10^{-1}	8.12×10^{-1}
Post-Cycle 100	ambient	3.33×10^{-2}	1.60×10^{-1}	5.95×10^{-1}
Post-Cycle 175	ambient	3.33×10^{-2}	1.53×10^{-1}	5.55×10^{-1}
Post-Cycle 250	LN_2	1.20×10^{-1}	7.52×10^{-1}	2.44
Acceptance test	ambient	1.12×10^{-1}	2.50×10^{-1}	6.83×10^{-1}

Note: Design goal was 2.50×10^{-2} SCCS maximum.

TABLE IX. - LEAKAGE TEST RESULTS - SSOV S/N 0000002 (GOLD-PLATED CRES 304L SEAL)

Test	Temperature	Leakage (SCCS) at Test Pressure (psig) 25 (1.72×10^5 N/m^2, g	100 (6.89×10^5 N/m^2, g	250 (1.72×10^6 N/m^2, g
Acceptance test	ambient	-	5.20×10^{-3}	1.70×10^{-3}
Acceptance test	LN_2	-	-	1.50×10^{-1}
Post facility inst.	ambient	$0^{cc}/5$ min	$0^{cc}/5$ min	5.00×10^{-3}
Post facility inst.	LN_2	$0^{cc}/5$ min	$0^{cc}/5$ min	6.66×10^{-3}
Post-passivation	LN_2	$0^{cc}/5$ min	$0^{cc}/5$ min	4.00×10^{-2}
Post-Cycle 1	LN_2	$0^{cc}/5$ min	$0^{cc}/5$ min	1.33×10^{-2}
Post-Cycle 2	LN_2	$0^{cc}/5$ min	$0^{cc}/5$ min	2.66×10^{-2}
Post-Cycle 10	LN_2	$0^{cc}/5$ min	$0^{cc}/5$ min	5.55×10^{-3}
Post-Cycle 50	ambient	8.33×10^{-4}	1.67×10^{-3}	3.33×10^{-3}
Post-Cycle 100	ambient	$0^{cc}/5$ min	1.67×10^{-3}	2.00×10^{-2}
Post-Cycle 175	ambient	1.67×10^{-3}	3.33×10^{-3}	1.67×10^{-2}
Post-Cycle 250	LN_2	3.33×10^{-3}	3.66×10^{-2}	1.27×10^{-1}
Post-Cycle 300	ambient	8.33×10^{-4}	3.33×10^{-3}	6.67×10^{-3}
Post-Cycle 400	LN_2	$0^{cc}/5$ min	1.66×10^{-2}	3.66×10^{-2}
Post-Cycle 600	LN_2	*	*	*
Post-Cycle 800	ambient	2.50×10^{-3}	2.33×10^{-2}	7.33×10^{-2}
Post-Cycle 1006	LN_2	1.66×10^{-3}	3.66×10^{-2}	1.00×10^{-1}
Acceptance test	ambient	5.33×10^{-3}	2.05×10^{-2}	5.66×10^{-2}
Acceptance test	LN_2	2.08×10^{-2}	1.66×10^{-1}	6.33×10^{-1}

*Invalid results because of a leak in the system.

**Equivalent liquid fluorine leakage = 7.95×10^{-6} PPS (3.61×10^{-6} Kg/sec) LF_2

Note: Design goal was 2.50×10^{-2} SCCS maximum.

within the design goal of 2.50×10^{-2} SCCS at 250 psig (1.72×10^{6} N/m^2, g) helium pressure for 175 liquid fluorine cycles. This leakage increased to 1.00×10^{-1} SCCS after 1006 cycles. Valve pressure drop at rated flow was 3.3 psid (2.27×10^{4} N/m^2).

The test potentiometers attached to the valve actuator pistons and mounted on the actuator end of the valves were used as the primary instrumentation to measure valve travel times. The proximitor probes also were monitored but a comparison of the two probe outputs always gave a longer valve travel time than the potentiometer. During valve travel, the probe from which the washer was moving would signal valve movement within 5 milliseconds from the initial potentiometer signal. However, the probe to which the washer was moving would not signal that valve movement was complete until 75 to 80 milliseconds after the potentiometer signal. This occurred in either the opening or closing direction. After a discussion with the probe supplier, it was determined that the delay was caused by the circuit in the proximitor which drove the probe. Proximitors with shorter delay times were available on special order, but all cycles were conducted with the proximitors on hand.

3. Valve Disassembly and Inspection

The valves were subjected to acceptance leakage tests in the Engineering Laboratories and then disassembled. There was no change in valve stroke or actuator spring load in either assembly. Both actuators and bellows were in good condition.

The spherical surface of the beryllium nickel seal had a cloudy appearance. Seal standoff remained unchanged from that set during assembly. Some of the beryllium nickel material had transferred to the electrolized Inconel 718 seat. A view of the seat is shown on Figure 12.

The gold-plated CRES 304L seal and seat were in good condition although the gold had a dull, cloudy appearance. Seal standoff, however, had changed to 0.00092-in. (2.337×10^{-5} m), a decrease of 48% from the 0.00177-in. (4.496×10^{-5} m) setting made and checked during assembly. The gold plate was in good condition and there was no evidence that it had been distorted by contact with the seat. Figure 13 is a view of the two seals after they were removed from the valves.

The copper Conoseals used to seal the inlet and outlet flanges were in good condition and performed with zero leakage through the test.

IV. DISCUSSION OF RESULTS

All of the liquid flow cycles were performed successfully without any problem or damage to the two space storable oxidizer valves. The materials selected for the valves also performed satisfactorily during passivation and the fluorine flow tests without any evidence of fluorine reaction. Even the

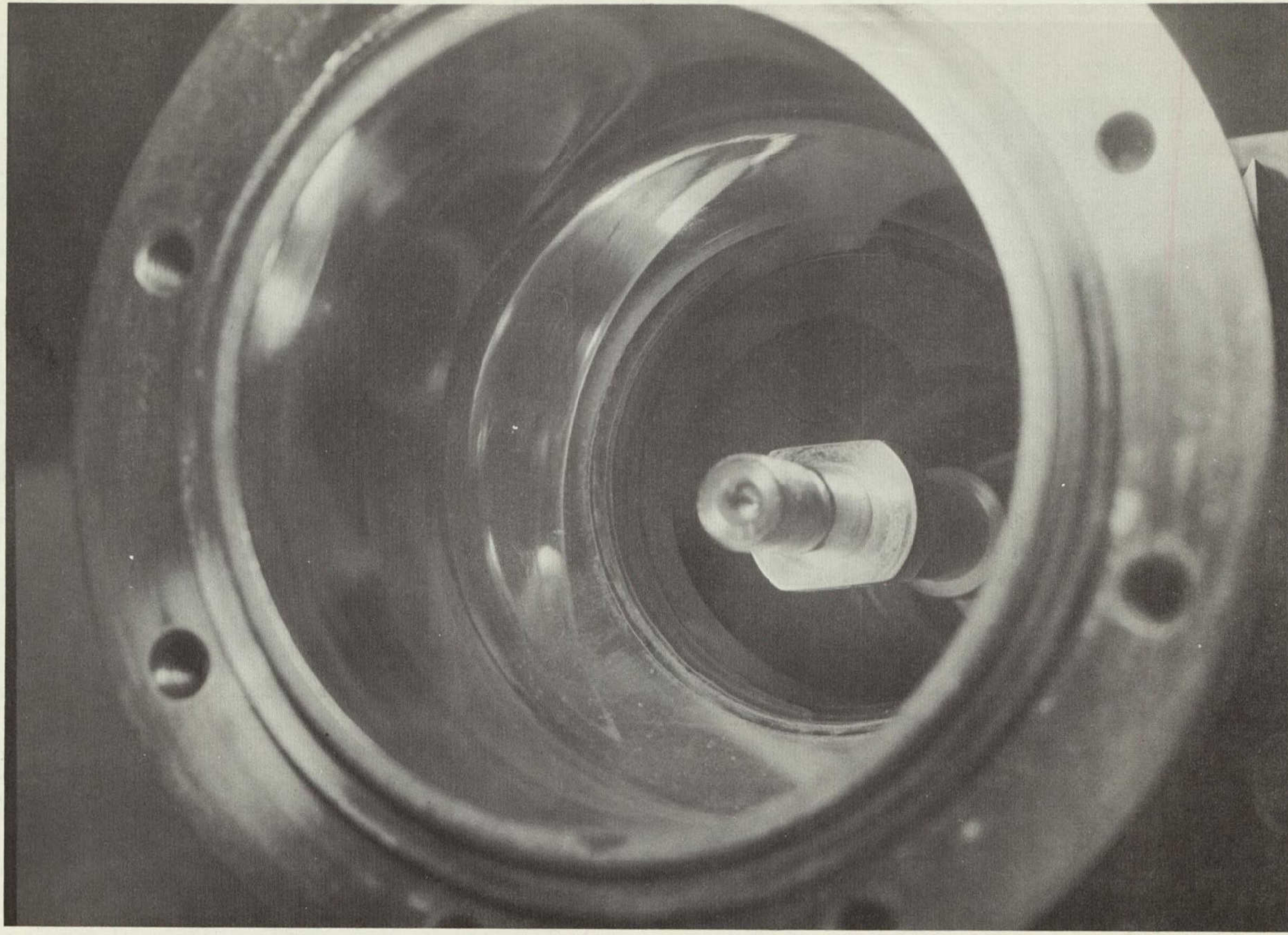


Figure 12. View of the Electrolized Inconel 718 Seat from SSOV S/N 0000001 after Fluorine Exposure

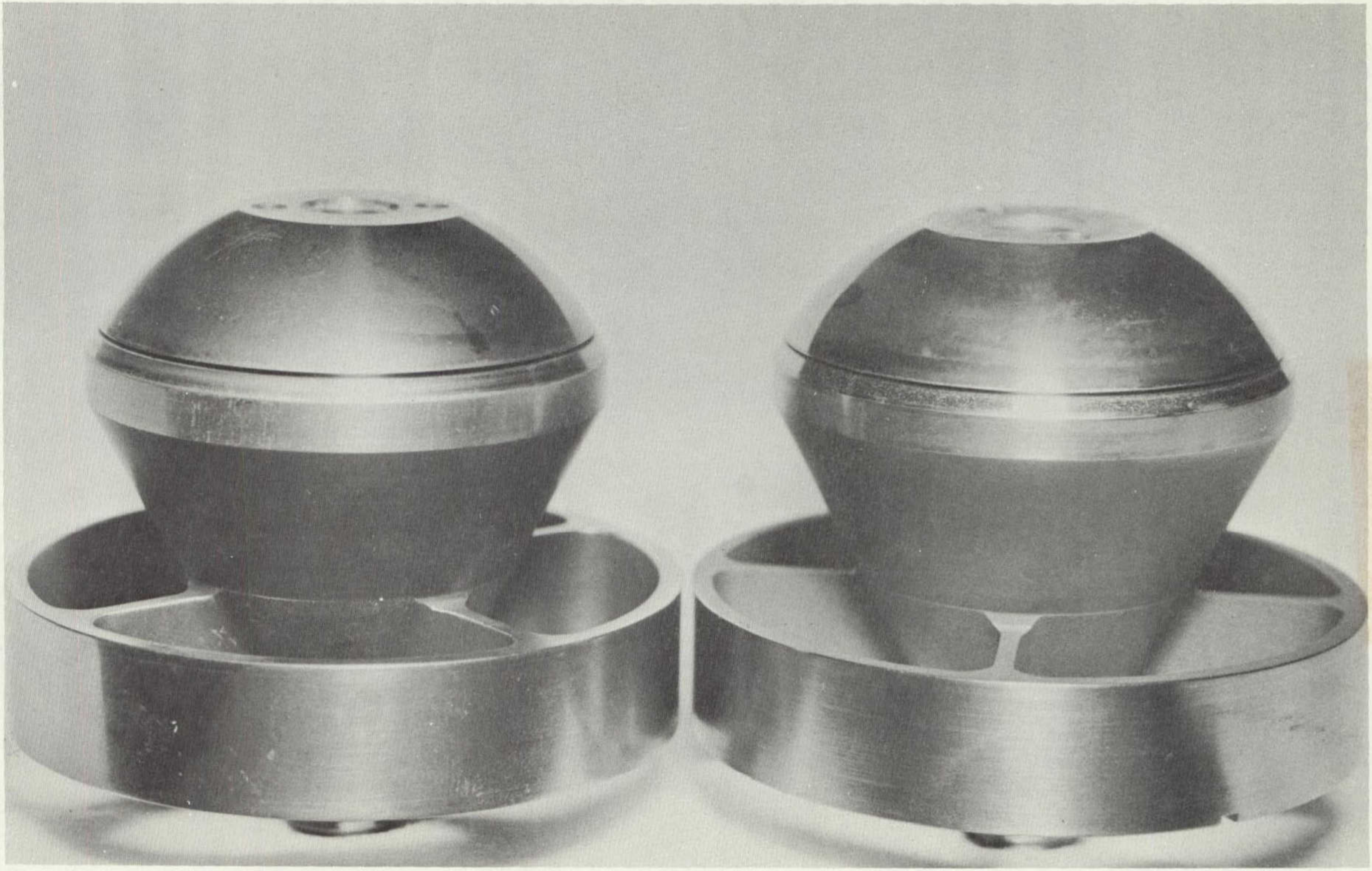


Figure 13. View of the Metal Seals after Fluorine Exposure

threads and the locking strips, which are normally considered vulnerable when exposed in the flow stream, displayed no damage. This performance verified that the proper valve material was selected, the space storable oxidizer valves were properly cleaned and assembled, and that the flow system was assembled and maintained in a scrupulously clean condition.

The valve pressure drop of 3.3 psid (2.27×10^4 N/m^2) at design flow rate was well within the design goal of 5.0 psid (3.45×10^4 N/m^2). Valve actuation times were easily controlled by orificing the actuator helium supply and vent lines. The valve bellows, actuators, and the proximitor probes performed satisfactorily throughout the program. They were in good condition when inspected during the post-test valve disassembly operation.

The transfer of beryllium nickel material to the valve seat definitely caused the leakage measured for the beryllium nickel seal. This phenomenon had occurred once before with another beryllium nickel seal in an SSOV. It is believed that diffusion bonding occurs between the beryllium nickel seal and the seat. This is caused by localized deformation of the high points in the sealing surface where the yield strength of the beryllium nickel is exceeded. Microscopic bits of material then are pulled from the seal surface when the valve is actuated. This occurred after the newly assembled and acceptance tested valve remained inactive in the closed position for a period of two weeks in both instances.

A beryllium nickel seal was successfully used in a bipropellant valve[6] designed for use with oxygen difluoride (OF_2) and diborane (B_2H_6) without material transfer. Spherical poppet seals, smaller but similar to the one used in the SSOV, were installed in 20-degree conical seats. The seat material and plating were the same as that used in the SSOV. This valve has a higher seal loading than the SSOV but there was no material transfer even after inactive periods in excess of three weeks. The difference in performance between the two seals could result from the different seat angles. Additional analysis and testing are required to completely evaluate the material transfer problem and the use of unplated beryllium nickel as an SSOV seal material.

Sealing of the SSOV main shutoff seal is dependent upon the seal load against the seat. This load is controlled by the adjustment of the seal standoff setting made between the seal and stop as previously discussed. Both the beryllium nickel seal and the CRES 304L seal were subjected to a thermal stabilization cycle during manufacture to prevent changes in this setting resulting from material changes during use. The seals were rough machined, then subjected to ten thermal cycles from room temperature to -320°F (77.6°K), and back to room temperature prior to finish machining. This process was intended to remove all internal stresses in the material so that the material would be stable after machining and would not be affected by cryogenic cycling in the valve.

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(6) Bipropellant Shutoff Valve, Aerojet Liquid Rocket Company Interim Report 7-733-1I, Contract NAS 7-733, 15 December 1970.

Apparently the beryllium nickel material was stabilized by the thermal cycling while the CRES 304L was not. A more effective, but more hazardous, thermal stabilization of the low 300 series stainless steels would be to utilize a liquid hydrogen soak at -423°F (20.4°K). It can be postulated that some phase transformation occurred in the CRES 304L (i.e., austenite changing to martensite) when the material was subjected to cryogenic temperatures during test, or that there was creep in the CRES 304L material when the seal was under load.

V. CONCLUSIONS

The CRES 304L material does not appear to have the stability required for this type of metal seal. The loss of seal standoff because of a change in material detracted from an otherwise excellent valve performance. Also, the transfer of the beryllium nickel material to the valve seat was an unexpected anomaly. The beryllium nickel seal performed satisfactorily in all other respects and there was no change in seal standoff. The gold plate on the CRES 304L seal prevented galling throughout the 1006 test cycles and was in good condition at the end of testing.

It can be concluded that a gold-plated beryllium nickel seal would give excellent service in a fluorine valve. The beryllium nickel would maintain the set standoff adjustment and the gold plate would prevent transfer of the beryllium nickel material. Both materials were proven to be compatible with fluorine for long exposure periods. The materials are readily available and no manufacturing problems are anticipated.

VI. RECOMMENDATIONS

It is recommended that a gold-plated beryllium nickel seal be evaluated in one of the test valves. The hardware is available and the beryllium nickel seals can be repolished and plated at nominal cost. The procedures and techniques for assembly and testing are developed and refined as a result of the program completed. This assures an effective follow-on program at minimal costs and time. The recommended evaluation would complement the SSOV program and would provide necessary data regarding fluorine technology.

Additional analysis and testing are required to ascertain why the beryllium nickel seal material transferred to the valve seat. This material performed satisfactorily in all other respects and its compatibility in a fluorine environment was demonstrated. It is recommended that a material evaluation be performed to ascertain the reason for the phenomenon which will allow extended use of this relatively new material.

APPENDIX A

COMPATIBILITY TEST PLAN

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17 September 1970

Revision 1

COMPATABILITY TEST PLAN

SPACE STORABLE OXIDIZER VALVE PROGRAM

CONTRACT: NAS 3-12035

TITLE:

FLUORINE COMPATABILITY TESTING
OF THE SPACE STORABLE OXIDIZER
VALVE

Prepared for

NASA Lewis Research Center
Cleveland, Ohio

by

Liquid Rocket Division
Aerojet-General Corporation
Sacramento, California

Approved By: O D Goodman
O D Goodman
Program Manager

Prepared by: R. L. Crosier
R L Crosier
Project Engineer

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Revisions

Number	Pages	Date
1	Enclosures (1) and (2)	9-17-70

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TABLE OF CONTENTS

PAGE

FIGURES

Enclosures:

TABLES

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I. NAME AND FUNCTION OF COMPONENT

The component to be tested is the Space Storable Oxidizer Valve (SSOV), P/N 1157220, designed and fabricated under NASA Contract No. NAS 3-12035. The function of the component is to provide an on-off oxidizer flow control for use on rocket engines using LF_2, LO_2 and FLOX as an oxidizer. Figure 14 shows a cross sectional view of the valve, and Figure 15 the test setup schematic.

II. PURPOSE OF TESTS

The purpose of this test program is to demonstrate that the Aerojet-General designed SSOV will function properly in a gaseous and liquid fluorine environment. Compatability of materials with fluorine, cycle endurance, and the capability of the main shut-off seal to satisfy the low leakage criteria specified in the governing contract will be demonstrated. Two valves will be tested; one valve will utilize a gold-plated CRES 304L shut-off seal and the second valve will use a beryllium nickel seal. The two configurations will be P/N 1157220-9 and P/N 1157220-19, respectively.

III. REQUIREMENTS

A. DOCUMENTATION

1. The part number, serial number, and description of the valve assembly tested will be listed with the test data.

2. An accurate chronological history of all significant events that occur during testing will be maintained for the test. This record will contain the test title, date, time, number, and validity, a brief description and explanation of each discrepancy, and any other documentation or information pertinent to the test.

3. All original data records (such as oscillograph paper and

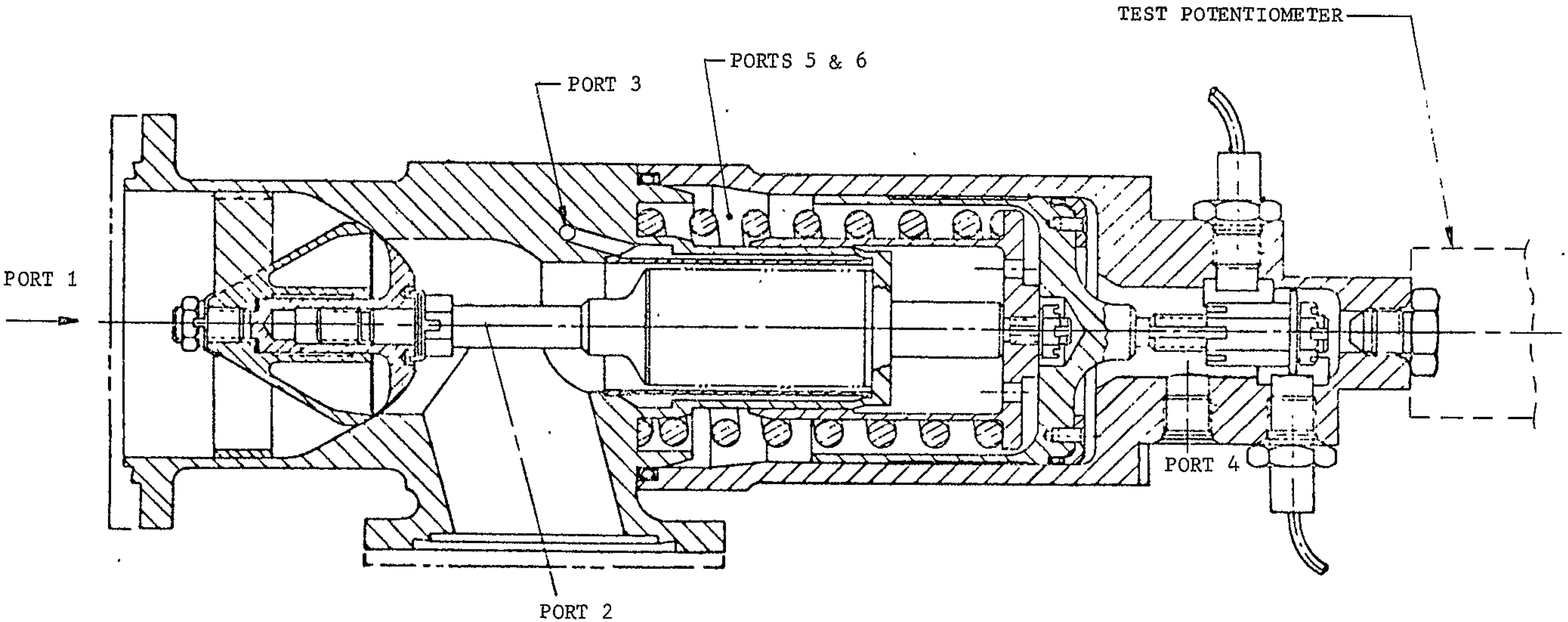

Figure 14. Cross Sectional View of Space Storable Oxidizer Valve

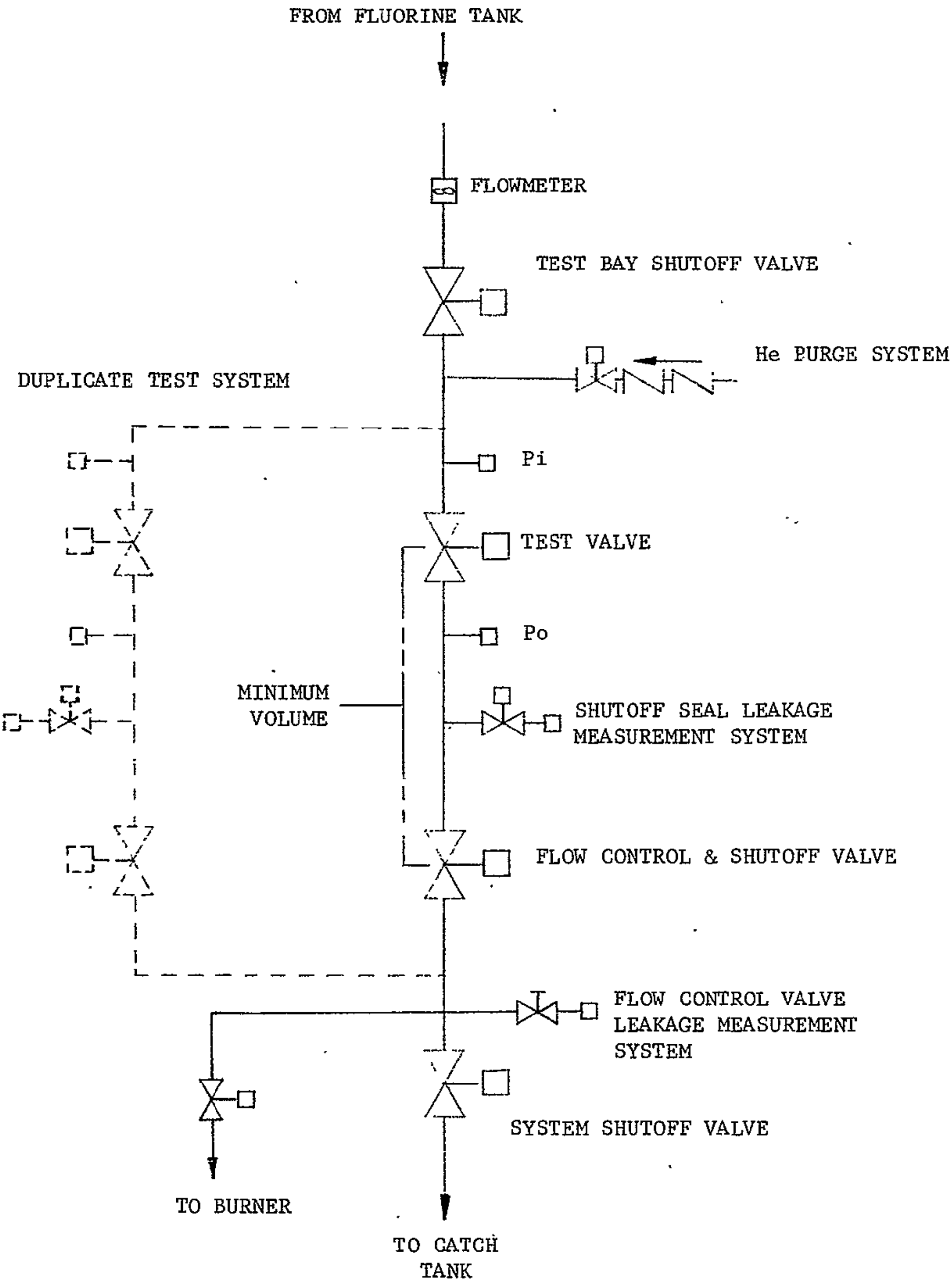

Figure 15. Test Setup Schematic

strip charts) will be labeled to fully identify the test and all recorded parameters.

4. A record of cumulative total valve cycles and cumulative valve exposure time to fluorine will be maintained for each test.

5. Still black and white photographs will be taken of the test setup and of any significant hardware failure or damage incurred during the performance of the tests.

6. Check lists will be prepared and utilized to ensure that each testing sequence is performed in conformance with the requirements of this document. The completion of each step will be verified by the initials or stamp of the individual performing the task.

7. A Test Request form will be issued by the project engineer to initiate test facility preparation and testing. Test Request Supplements will be issued for each test change or investigation conducted on an SSOV assembly or component.

8. Additional records and forms may be inaugurated as the need arises; however, the need and format of these records must be approved by the cognizant project engineer prior to their use.

B. INSTRUMENTATION

1. The calibration of equipment and instrumentation specified herein will be in accordance with the requirements of Specification MIL-C-45662, Calibration System Requirements, and the AGC Sacramento Liquid Rocket Plant Measurement Standards Instructions Manual.

2. Instrumentation for this test series will be as specified in Table X. Any additional instrumentation required for performance of the tests is left to the discretion of the test facility personnel.

TABLE X

TEST INSTRUMENTATION

Parameter	Transducer	Recorder	Range	Response
Inlet Pressure	Strain Gage	Strip Chart or Oscillograph	0-500 psig	0-500 cps
Outlet Pressure	"	"	"	0-100 cps
Spring Cavity Pressure	"	"	0-100 psig	"
Actuation Inlet Pressure	"	"	0-1000 psig	"
Closed Proximitor Output Voltage	Direct	"	0-30 Vdc	0-500 cps
Open Proximitor Output Voltage	"	"	"	"
Potentiometer	"	"	0-5 Vdc	"
Pilot Valve Current	"	"	0-2 amps	"
Propellant Inlet Temperature	Thermocouple	"	+100 to -320°F	0-5 cps
Valve Outlet Flange Temperature	"	"	"	"
Temperature Near Open Proximitor	"	"	"	"
Propellant Flow	Flowmeter	"	0-15 lb/sec	-
Fire Switch	Direct	"	0-30 Vdc	0-100 cps
Shutoff Seal Leak Pressure	Strain Gage	"	0-5 or 0-10 psig	"
Bellows Leak Pressure	"	"	"	"

Total steady state measurement accuracy (3σ) will be $\pm$ 2%.

III,B, (continued)

3. Instrumentation locations and connections will be as required to obtain optimum measurement accuracy and to minimize errors due to such factors as lead wire impedance and sensing line pressure drop.

4. As a minimum, the following parameters will be measured:

(a)	Valve inlet pressure	Pi
(b)	Valve outlet pressure	Po
(c)	Propellant flow rate	FMo
(d)	Spring cavity pressure	Psc
(e)	Actuation inlet pressure	Pa
(f)	Closed proximitor output voltage	Vcp
(g)	Open proximitor output voltage	Vop
(h)	Linear potentiometer	LOV
(i)	Pilot valve current	Ipv
(j)	Fire switch	FS
(k)	Propellant inlet temperature	Ti
(l)	Valve outlet flange temperature	Tof
(m)	Temperature near open proximitor	Top

C. TEST FACILITIES

1. Actuation fluid and leak test fluid will be Bureau of Mines Grade A gaseous helium with a maximum dew point of $-70^{o}F$.

2. Oxidizer will be liquid fluorine with the following analysis by weight: 98.7% LF_2 minimum, 0.3% maximum HF and CH_4, and 1.0% maximum O_2, N_2, and other inerts.

3. All actuation test fluids will be filtered through 10 micron nominal, 25 micron absolute, filters immediately before entering the valve.

4. Service ports that are vented to atmosphere during testing (valve ports 5 and/or 6) will be protected by a vent check valve.

5. The internal surfaces of the valve and test system will be maintained clean to Level D or E of Specification AGC-46350 throughout all testing specified herein.

D. ACCEPTABLE CRITERIA

1. The valve opening and closing times as measured from the potentiometer trace shall be 50 to 75 milliseconds.

2. Leakage from the propellant cavity to the actuation cavity (across the bellows) shall not exceed 1×10^{-6} SCCS helium.

3. Leakage across the poppet seal shall not exceed 2.5×10^{-2} SCCS helium.

4. If the acceptable criteria is exceeded, the cognizant project engineer will be notified before additional tests are conducted.

IV. TEST PROCEDURES

A. PRE-TEST OPERATIONS

1. The valve assembly will be visually inspected for shipping damage and port covers when it is received for test.

IV,A, (continued)

2. It will be verified that the valve has passed an acceptance test and a cleanliness verification test in accordance with Specification AGC-46966 within three weeks prior to receipt of valve for test.

3. Prior to installation of the valve into the passivation system, the system will be cleaned, leak checked, and passivated with gaseous fluorine, as required, in accordance with standard test facility procedures.

B. PASSIVATION PROCEDURE

1. The valve will be installed in the passivation and flow facility by personnel wearing clean standard plastic disposable gloves to maintain the cleanliness level.

2. With the valve in the open position and port 2 capped or closed off downstream, the valve cavity will be purged with helium and then evacuated to 22 to 29 in. Hg. through ports 1 and 3.

3. Gaseous fluorine will be slowly introduced into the evacuated valve cavity through ports 1 and 3 until the system pressure reaches 5 to 10 psig. This pressure will be maintained for 15 minutes minimum. During this period, the valve will be cycled closed and open five times. The system pressure and temperature will be monitored for any indication of excessive reaction throughout the passivation period.

4. The valve will be re-evacuated, then backfilled with gaseous fluorine to a pressure of 80 to 100 psig. This pressure will be maintained for 30 minutes minimum. The valve will be cycled closed and

2 A—

open four times during this period.

5. The system pressure will be increased to 240 to 260 psig by the addition of gaseous fluorine or gaseous helium. This pressure will be maintained for two hours minimum. During this period, the valve will be cycled closed and open two times.

6. The system will be vented to zero psig, then purged with gaseous helium for two minutes minimum. The valve will be cycled closed.

7. The passivation procedure will be repeated whenever a line is broken and/or a valve is replaced.

C. PRE-TEST FUNCTIONAL AND LEAKAGE TESTS

1. With the valve immersed in LN_2, Tof at $-300^{\circ}F$ maximum, and the inlet port unpressurized, the outlet port will be checked for leakage. This test will determine the tare leakage of the test system and will be conducted immediately prior to all leakage tests. The test duration will be 15 minutes minimum. Tare leakage will be subtracted from the test leakage to determine the true leakage of the poppet seal during subsequent leakage tests.

2. With the valve still immersed in LN_2 and Tof at $-300^{\circ}F$ maximum, the valve inlet port will be pressurized with gaseous helium to 25^{+5}_{-0} psig. The valve will be cycled open and closed one time. Opening and closing times shall be in accordance with III.D. for all functional and endurance cycles.

3. With the 25^{+5}_{-0} psig helium pressure and $-300^{\circ}F$ maximum temperature maintained and the leakage detection system isolation valve open, a leak test will be conducted across the main shutoff seal for 15 minutes

minimum. All leakages will be recorded and shall not exceed the leakage rates specified in III.D. If leakage is found to be greater than the acceptable limit, the cognizant project engineer will be notified before additional tests are conducted.

4. The helium pressure at the valve inlet will be increased to 100^{+10}_{-0} psig, then the valve will be cycled open and closed.

5. The leakage test of IV.C.3 will be repeated except the inlet pressure will be 100^{+10}_{-0} psig.

6. The helium pressure at the valve inlet will be increased to 250^{+25}_{-0} psig, then the valve will be cycled open and closed.

7. The leakage test of IV.C.3 will be repeated except the inlet pressure will be 250^{+25}_{-0} psig.

8. With Tof maintained at -300°F maximum and ports 2 and 3 at zero psig pressure, port 5 will be checked for a pressure increase or decrease over a 15 minute test period. This test will determine the tare pressure change in the valve spring cavity and will be conducted immediately prior to each bellows leak test. The spring cavity pressure will be adjusted by the tare pressure change to determine the true pressure increase during the bellows leak test. This test may be conducted during the 250 psig shutoff seal leakage test.

9. With Tof maintained at -300°F maximum and ports 1,2, and 3 pressurized to 250^{+25}_{-0} psig, port 5 will be checked for a pressure increase over a 15 minute test period. No pressure increase will be allowed.

IV, (continued)

D. LIFE CYCLE TESTING AT INLET PRESSURES OF 25 AND 100 PSIG

NOTE: Two valves will be subjected to the following tests:

1. The valve will be subjected to liquid fluorine flow tests at the test conditions specified in Enclosure (1). The system will be bled and cooled prior to testing to ensure liquid flow. During flow testing, the actuator potentiometer trace and spring cavity pressure reading will be visually monitored for any indication of malfunction.

2. During flow testing, the main shutoff seal and bellows will be leak tested at the intervals shown in Enclosure (1). Leakage tests will be conducted with gaseous helium with the valve immersed in LN_2 and with Tof at -300°F maximum. Leakage tests will be conducted in accordance with the pre-test leakage tests, IV.C.1,3,5,7,8, and 9. All valve leakage will be recorded.

3. A valve cycle will consist of the following:

a. The valve will be cycled open by energizing the system pilot valve.

b. The valve will be held in the full open position until stabilized flow has been obtained.

c. The valve will be cycled closed by deenergizing the system pilot valve.

d. Valve actuation times shall be in accordance with III.D.

E. LIFE CYCLE TESTING AT INLET PRESSURE OF 250 PSIG

NOTE: The "better valve" from the preceeding test series will

IV, E, (continued)

be subjected to the following tests:

1. This series of tests will be identical to the preceeding test series (IV.D) except the valve inlet pressure will be 250 psig and leakage checks will be conducted at intervals in accordance with Enclosure (2). The valve cycle specified in IV.D.3 will be utilized for this test series.

F. POST-TEST FUNCTIONAL AND LEAKAGE TESTS

1. A post-test functional test, and post-test leakage tests of the main shutoff seal and bellows, will be conducted at room ambient temperature in accordance with Specification AGC-46966.

Space Storable Oxidizer Valve Test Parameters for Tests Conducted at Inlet Pressures of 25 and 100 psig

Each of two valves will be subjected to 250 LF_2 endurance cycles; the first of ten cycles will be conducted with an inlet pressure of 25 psig, the remaining 240 cycles will be conducted with an inlet pressure of 100 psig.

Parameter	First 10 Cycles	Last 240 Cycles
Test Fluid	LF_2	LF_2
Inlet Pressure (psig)	$25 {}^{+5}_{-0}$	$100 {}^{+10}_{-0}$
Flow Rate (lb/sec)	$9 {}^{+1.0}_{-0.5}$	$12 {}^{+1.0}_{-0.5}$
Maximum Pressure Drop at Rated Flow (psid)	5	5
Actuation Fluid	GH_e	GH_e
Actuation Pressure (psig)	500 ± 15	500 ± 15
Pilot Valve Voltage (Vdc)	28 ± 2	28 ± 2
Proximitor Voltage (Vdc)	-28 ± 0.1	-28 ± 0.1
Potentiometer Voltage (Vdc)	5 ± 0.1	5 ± 0.1
Leakage Tests at (No. Cycles)	1,2,10	50,100,175,250
Exposure Flow Time, Min (Sec)	30*	570*

*Exposure Flow Time at Leakage Tests, Min.(Sec)	Cycles	Exposure Time
	1	3
	2	6
	10	30
	50	140
	100	275
	175	435
	250	600

Space Storable Oxidizer Valve Test Parameters for Tests Conducted at Inlet Pressure of 250 psig

The "better valve" from the preceeding test series, Enclosure (1), will be subjected to 750 LF_2 endurance cycles at an inlet pressure of 250 psig.

Parameter	750 Cycles
Test Fluid	LF_2
Inlet Pressure (psig)	$250\ ^{+25}_{-0}$
Flow Rate (lb/sec)	$12\ ^{+1.0}_{-0.5}$
Maximum Pressure Drop at Rated Flow (psid)	5
Actuation Fluid	GH_e
Actuation Pressure (psig)	500 ± 15
Pilot Valve Voltage (Vdc)	28 ± 2
Proximitor Voltage (Vdc)	-28 ± 0.1
Potentiometer Voltage (Vdc)	5 ± 0.1
Leakage Tests at (No. Cycles)	300, 400, 600, 800, 1000
Exposure Flow Time, Min. (sec)	600*

*Exposure Flow Time at Leakage Tests, Min (Sec)	Cycles	Exposure Time
	250 (ref)	600 (ref)
	300	640
	400	7[illegible]0
	600	880
	800	10[illegible]0
	1000	1200

APPENDIX B

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