AD NUMBER

AD822302

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; OCT 1967. Other requests shall be referred to Air Force Rocket Propulsion Lab., Edwards AFB, CA.

AUTHORITY

AFRPL ltr, 27 Oct 1971

Unclassified TR
AFRPL-TR-67-252

STORABILITY DEMONSTRATION PROPELLANT FEED SYSTEMS

A. L. Schuler
R. C. White
D. E. Lawrance

Convair Division of General Dynamics
Technical Report AFRPL-TR-67-252
October 1967

Air Force Rocket Propulsion Laboratory
Research and Technology Division
Air Force Systems Command
Edwards Air Force Base, California

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of AFRPL (RPPR-STINFO), Edwards, California 93523.

NOTICES

When U.S. Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, or in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Qualified requesters may obtain copies of this report from the Defense Documentation Center.

Copies of this report should not be returned to the Research and Technology Division unless return is required by security considerations, contractual obligations, or notice on a specific document.

Unclassified

STORABILITY DEMONSTRATION PROPELLANT FEED SYSTEMS

A. L. Schuler
R. C. White
D. E. Lawrance

FOREWORD

The work documented in this report was accomplished by the Convair division of General Dynamics at San Diego, California, in compliance with United States Air Force Contract No. AF04(611)-11545. It was administered under the direction of the Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, California, with John A. Goodwin, 1st Lt. USAF/RPRP, acting as Project Officer.

This final report describes the tasks accomplished from contract award in May 1966, to contract completion in October 1967.

Convair division performed the contract under the direction of H. E. Wright, Assistant Chief Design Engineer/Mechanical Design, with A. L. Schuler acting as Project Leader, R. C. White as Principal Engineer, M. S. Hersh as Metallurgist Consultant, and D. E. Lawrance as Project Test Engineer. R. E. Bruce acted as Production Engineer, G. R. Bailey was the Quality Assurance Representative, and R. E. Gumtz acted as prime Manufacturing Coordinator. R. B. Amick was Material Administrator and A. M. Smith acted as Buyer for subcontracted components.

This technical report has been reviewed and is approved.

ABSTRACT

This report presents the design, fabrication, testing, and delivery of Storable Prepackaged Propellant Systems (SPPS) for subsequent use in a storability investigation, by the Air Force Rocket Propulsion Laboratory (AFRPL), of a liquid rocket propellant feed system. Each of the twenty-three delivered systems consists of a 15 gallon propellant tank which contains either a Surface Force Orientation (SFO) device, or a Rolling Diaphragm (RD) positive expulsion device, along with one of three different pressurization subsystems. The subsystems include a Liquid Propellant Gas Generator (LPGG), a Solid Propellant Gas Generator (SPGG), or a Stored Gas Device (SGD). The systems were delivered to AFRPL, hermetically sealed, with their respective propellants; Mixed Hydrazine Fuel (MHF-5), Nitrogen Tetroxide (N_2O_4), or Chlorine Pentafluoride (ClF_5); loaded in the propellant tanks.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

SECTION I

INTRODUCTION

Mission requirements for certain Air Force weapon systems of the future will demand high performance vehicles, able to perform flexible duty cycles after five years of operational storage with no maintenance. Air launched missiles and maneuvering re-entry vehicles are examples of such weapon systems. Their requirements are attainable by utilizing liquid rocket propulsion systems which contain advanced storable propellants.

1.1 GENERAL

Presently there is a lack of information about the long term storability of such propellant systems. The Air Force Rocket Propulsion Laboratory (AFRPL) is currently engaged in a project to alleviate this lack of information by demonstrating the storability of advanced liquid propellants in typical missile tanks. Various size tanks of aluminum, steel, and titanium alloys were fabricated by several missile manufacturers, and were filled with propellants by AFRPL prior to storage under extreme environments for several years. This tank storability program was designed to demonstrate the long term compatibility of certain alloys with the tanked propellants, and to improve the capability of industry to produce tanks which have no detectable leakage over long storage periods.

1.2 SCOPE

The AFRPL tank storability program was expanded to include other critical components of the propellant feed system, since the storability of the system can only be demonstrated by integrating these components into a complete model system, subjecting them to the operational environment while filled with propellants and sealed for long time periods, and then performing functional testing. This report documents the design, fabrication, testing, and delivery of twenty-three such model systems.

1.3 TESTING

During the program, demonstration tests were performed on test systems which duplicated the twenty-three delivered systems. These tests demonstrated that the systems would operate as designed. The tests also provided data for comparison with data to be recorded after the systems have been stored.

SECTION II

STORABLE PREPACKAGED PROPELLANT SYSTEM (SPPS)

2.1 DESCRIPTION

Each Storable Prepackaged Propellant System (SPPS) consists of a propellant tank assembly and a pressurization subsystem mounted in a support frame. Figure 1 portrays an SPPS ready for shipment to Air Force Rocket Propulsion Laboratory (AFRPL).

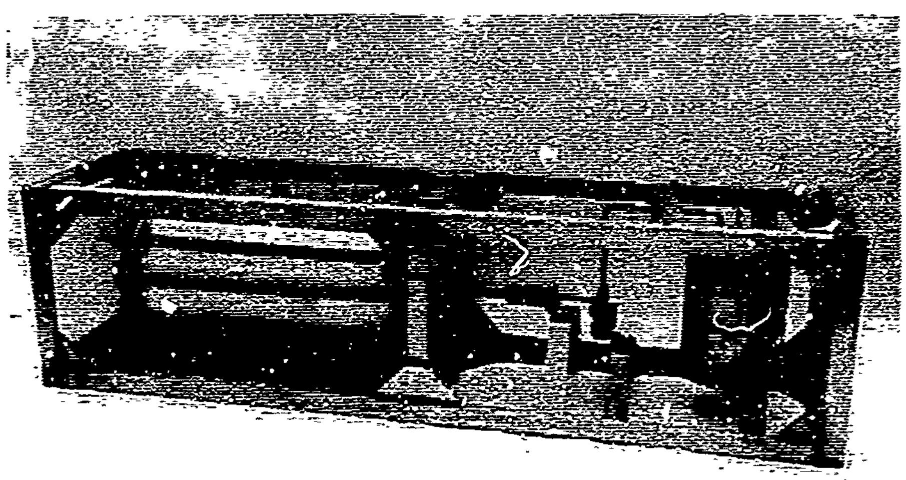

Figure 1. Storable Prepackaged Propellant System Ready for Shipment

The propellant tank is fabricated of 2219 aluminum alloy and has a volume of approximately 15 gallons. It contains either a Surface Force Orientation (SFO) device or a Rolling Diaphragm (RD) for positive expulsion of the propellant. The tanks are loaded by Convair with either Mixed Hydrazine Fuel (MHF-5), Nitrogen Tetroxide (N_2O_4), or Chlorine Pentafluoride (ClF_5), and welded closed such that the propellant is contained within an all metal, welded tank. Metal rupture discs, welded in the tank inlet and outlet, rupture for propellant discharge when pressurized by the pressurization subsystem.

2.2 PRESSURIZATION SUBSYSTEMS

There are three different pressurization subsystems: the Stored Gas Device (SGD), the Liquid Propellant Gas Generator (LPGG), or the Solid Propellant Gas Generator (SPGG). The SGD consists of a gas storage bottle. explosive valve, regulator and a a relief valve. Within the gas storage bottle, 90 percent nitrogen/10 percent helium gas is contained at 3015 psia by the explosive valve. Upon electrical command, the valve opens. The high pressure gas then flows through the regulator into the propellant tank.

The LPGG consists of a gas/hydrazine tank, explosive valve, regulator, decomposition chamber, and a relief valve. Within the gas/hydrazine tank, 68 percent hydrazine, 32 percent water is contained at 2415 or 2815 psia by the explosive valve. Upon electrical command, the valve opens. The high pressure liquid mixture then flows through the regulator and the decomposition chamber into the propellant tank.

The SPGG consists of a relief valve and two identical gas generators which contain solid propellant. Upon electrical signal, one gas generator fires until its propellant is consumed. The hot gas products exhaust into the propellant tank and pressurize it. Upon command, this cycle is repeated for the other gas generator.

A matrix of the twenty-three SPPS delivered to AFRPL is presented in Table I.

2.3 REQUIREMENTS

The primary requirement of a SPPS is zero-maintenance storability. Reliability and functional performance of all system elements must be unimpaired by storage for the time periods and under the conditions specified in Table II. Leakage of propellants cannot be tolerated.

The objective of the program was to demonstrate long term storability of pressurization and propellant tank systems; therefore, optimization of hardware was not essential. It was sufficient that the hardware simulate an operational system and that the materials, fabrication, and quality control duplicate that which would be used for production of large numbers of an operational system. An example is the screen material used in the SFO device. Its micron size is an order of magnitude too large for -1g expulsion. (Aluminum screen, having less than 100 micron absolute value, is beyond current technology at the present time.) The screen material used in the simulated system duplicates the material from which the small micron screen would probably be fabricated. Micron rating changes of the large micron screen (if any); due to storage, vibration, or pressurization subsystem firings; are applicable to an evaluation of whether the smaller micron screen would be suitable for fabrication and long term storage.

TABLE I

STORABLE PREPACKAGED PROPELLANT SYSTEMS DELIVERED TO AFRPL

Part Number	Serial Number	Tank Expulsion Device	Propellant and Weight (lb)		Pressurization Subsystem
SPPS 35-1	023	SFO	MHF-5	117	LPGG
SPPS 35-1	019	SFO	MHF-5	117	LPGG
SPPS 35-3	022	SFO	MHF-5	117	SPGG
SPPS 35-3	017	SFO	MHF-5	117	SPGG
SPPS 35-5	015	SFO	MHF-5	117	SGD
SPPS 35-5	018	SFO	MHF-5	117	SGD
SPPS 35-5	016	SFO	N_2O_4	160.8	SGD
SPPS 35-5	024	SFO	N_2O_4	160.8	SGD
SPPS 35-5	020	SFO	ClF_5	190.2	SGD
SPPS 35-5	021	SFO	ClF_5	190.2	SGD
SPPS 35-801	002	RD	*		LPGG
SPPS 35-801	013	RD	*		LPGG
SPPS 35-801	008	RD	N_2O_4	130	LPGG
SPPS 35-801	004	RD	N_2O_4	130	LPGG
SPPS 35-801	005	RD	MHF-5	94.6	LPGG
SPPS 35-801	006	RD	MHF-5	94.6	LPGG
SPPS 35-803	011	RD	MHF-5	94.6	SPGG
SPPS 35-803	003	RD	MHF-5	94.6	SPGG
SPPS 35-803	014	RD	N_2O_4	130	SPGG
SPPS 35-803	007	RD	N_2O_4	130	SPGG
SPPS 35-803	009	RD	†		SPGG
SPPS 35-805	010	RD	*		SGD
SPPS 35-805	001	RD	MHF-5	94.6	SGD

*Tank was delivered empty to AFRPL

† Tank was passivated with ClF_5 and delivered empty to AFRPL

TABLE II

STORABLE PREPACKAGED PROPELLANT SYSTEM DESIGN PARAMETERS

Minimum Storage Life	5 years
Expulsion Cycle History Liquid Propellant Gas Generator & Solid Propellant Gas Generator Stored Gas Device	a) 7.5 gal @ 700 psi nominal outlet pressure in 40 sec., 11.25 gpm b) 1 minute pause c) complete design expulsion at 700 psi nominal outlet pressure and 11.25 gpm a) 7.5 gal @ 250 psi nominal outlet pressure in 40 sec., 11.25 gpm b) 1 minute pause c) complete design expulsion at 250 psi nominal outlet pressure and 11.25 gpm
Temperature Environment Storage Operation	 -65° F to +165° F Ambient
Atmospheric Environment Storage	 85 percent humidity
Operational Accelerations Longitudinal Transverse	 -1g "
Vibration Accelerations Longitudinal Transverse	 1.4g @ 35 Hz 1.4g @ 35 Hz
Factors of Safety Pressure Vessels Supporting Structure	 Reference MIL-T-5208A: Type I and Type II, Class 2 (Paragraph 1.2), Ultimate Pressure Load (Paragraph 3.10.2.2(a)), Pressure, Proof (Paragraph 6.3.5). 1.50
Tank Configuration Shape L/D Volume Pressurization Line Diameter Expulsion Line Diameter	 Cylindrical w/ellipsoidal heads Approximately 2-1/4 15 gallon ± 3 gallon 1/2 inch nominal 1/2 inch nominal

SECTION III

PROPELLANT TANK

3.1 DESIGN CRITERIA

3.1.1 EXPULSION CYCLE. The propellant tank will expel MHF-5, N_2O_4, or ClF_5 without external leakage when pressurized by either of the three pressurization subsystems. The design criteria used are:

Design limit pressure = 900 psid at material temperature of 300° F

Proof pressure = 1,350 psid at material temperature of 300° F

Burst pressure = 1,800 psid at material temperature of 300° F

Shape - cylindrical with ellipsoidal ends

3.1.2 STORAGE. MHF-5, N_2O_4, or ClF_5 will be stored in the propellant tank at their vapor pressure for five years without maintenance, and no leakage can be tolerated. The storage environment is:

-65 to +165° F

85 percent relative humidity

Periodic vibration in each axis at ±1.4g peak, 35 Hz

There shall be no tank leakage prior to propellant loading. Leakage is detected by pressurizing the tank internally with 90 percent nitrogen, 10 percent helium gas at 125 psid, and placing the tank within a vacuum chamber connected to a mass spectrometer.

Welds shall be radiographically inspected to verify their quality and to provide documented records for comparison after tank storage.

3.2 DESCRIPTION

A cross section of the propellant tank is shown in Figure 2, with dimensions, welds, and materials specified. The tank consists of a cylindrical section electron beam welded to two machined bulkheads which have rupture discs welded or bolted in place.

One-fourth inch diameter 3003 aluminum tubes are welded in the bulkheads for subsequent propellant tank proof pressure, leak check, and propellant filling. These tubes are welded closed prior to delivery.

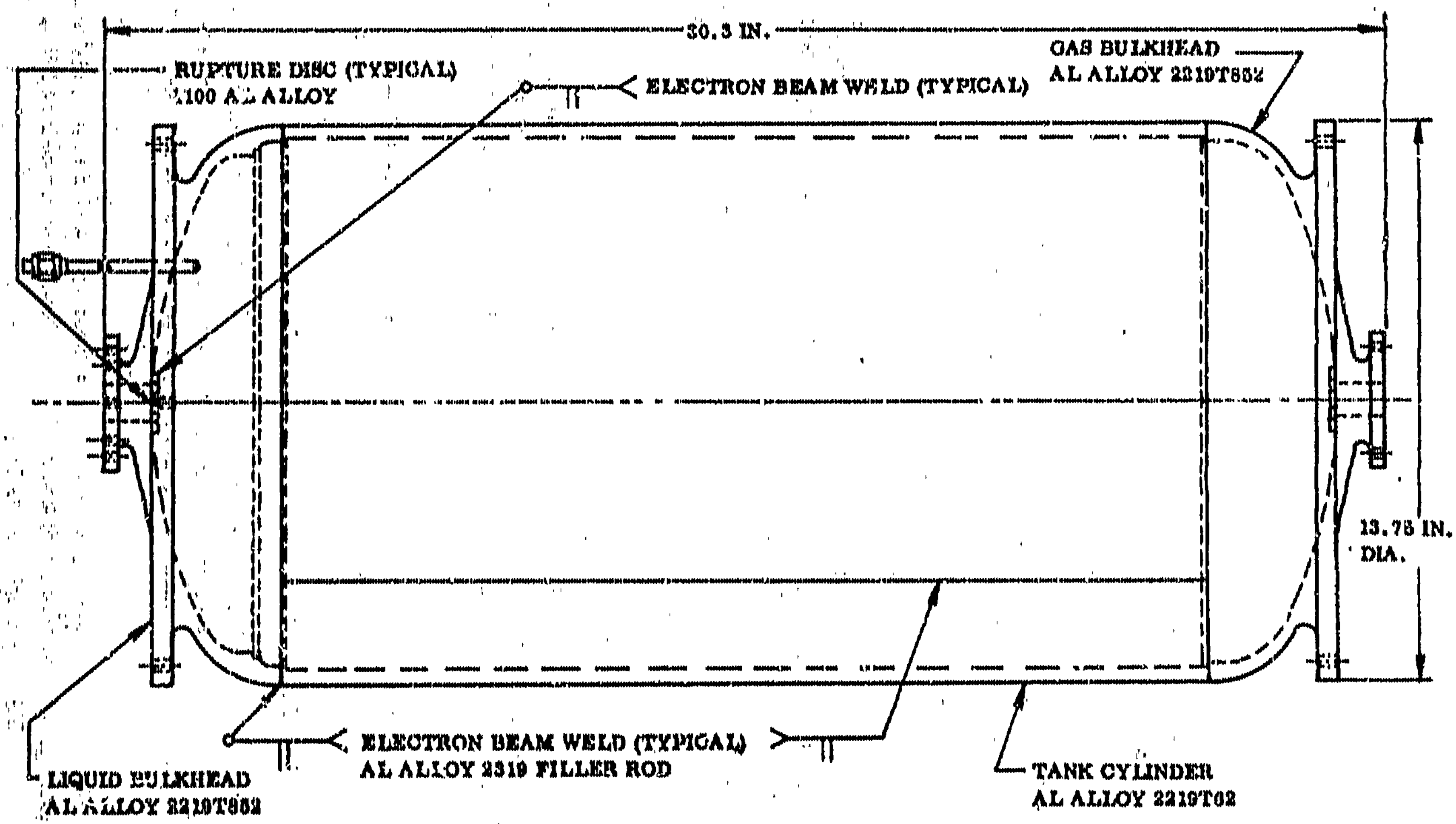

Figure 2. Propellant Tank Cross Section

3.3 MATERIALS

Existing test data on storing ClF_5, N_2O_4, or MHF-5 in candidate high strength stainless steel materials was reviewed. It was recommended that stainless steel not be used in contact with these propellants. Test data from Reference 1 shows that AM 355, 1010 steel, and 347 stainless steel produce excessive outgassing of MHF-5. Test data from Reference 2 shows that AFC-77, 301 stainless steel, AM350, INCO718, and 17-4 PH produce similar results.

A search of References 3 through 6 produced only two materials, 1100-0 and 2014-T6 aluminum alloys, with any significant test data that establishes long term storability with all three propellants. MHF-5 contained in these aluminum alloys has only 2.3 percent of the outgassing experienced when contained in steel vessels. It was therefore recommended that all materials in contact with the propellants during the five year storage period be aluminum alloys. The propellant tank cylinder and bulkheads were fabricated from 2219 aluminum alloy instead of 2014 aluminum alloy because the former is easier to weld and repair, and is less susceptible to weld cracks. Leakage through weld areas had earlier been demonstrated by 2014-T6, during storage with N_2O_4.

Reference 7 contains the stress analysis for the propellant tanks, and all areas analyzed have a positive margin of safety.

Electron beam and gas tungsten arc welding were evaluated to select the better process for welding the propellant tanks. Using Reference 8, it was concluded that electron beam welding offers significant advantages over the gas tungsten arc process because of mechanical and metallurgical properties, weld quality, process reliability, costs, and ease of repair. Electron beam welding was used wherever possible.

3.4 FABRICATION

3.4.1 TANK BULKHEADS. Convair fabricated the propellant tanks. The tank bulkheads were machined from 2219 T852 aluminum alloy billets (see Figure 3). After machining, the rupture disc and the propellant fill tube were welded to the bulkhead. The assembly was subsequently cleaned for liquid oxygen service per Convair specification GDC 0-75002, and packaged for assembly with the positive expulsion device and tank cylinder.

Some difficulty was experienced in welding the 1100-0 aluminum rupture discs into the tank heads. Initially this weld was made by preheating the parts to 300°F and hand fusion welding them together. Most rupture discs would then crack at their minimum thickness area due to the radial stress induced during welding. The tank head was modified, such that the rupture disc was welded to a thin cylindrical protrusion which deflected and absorbed the weld radial stresses. In addition, the welds

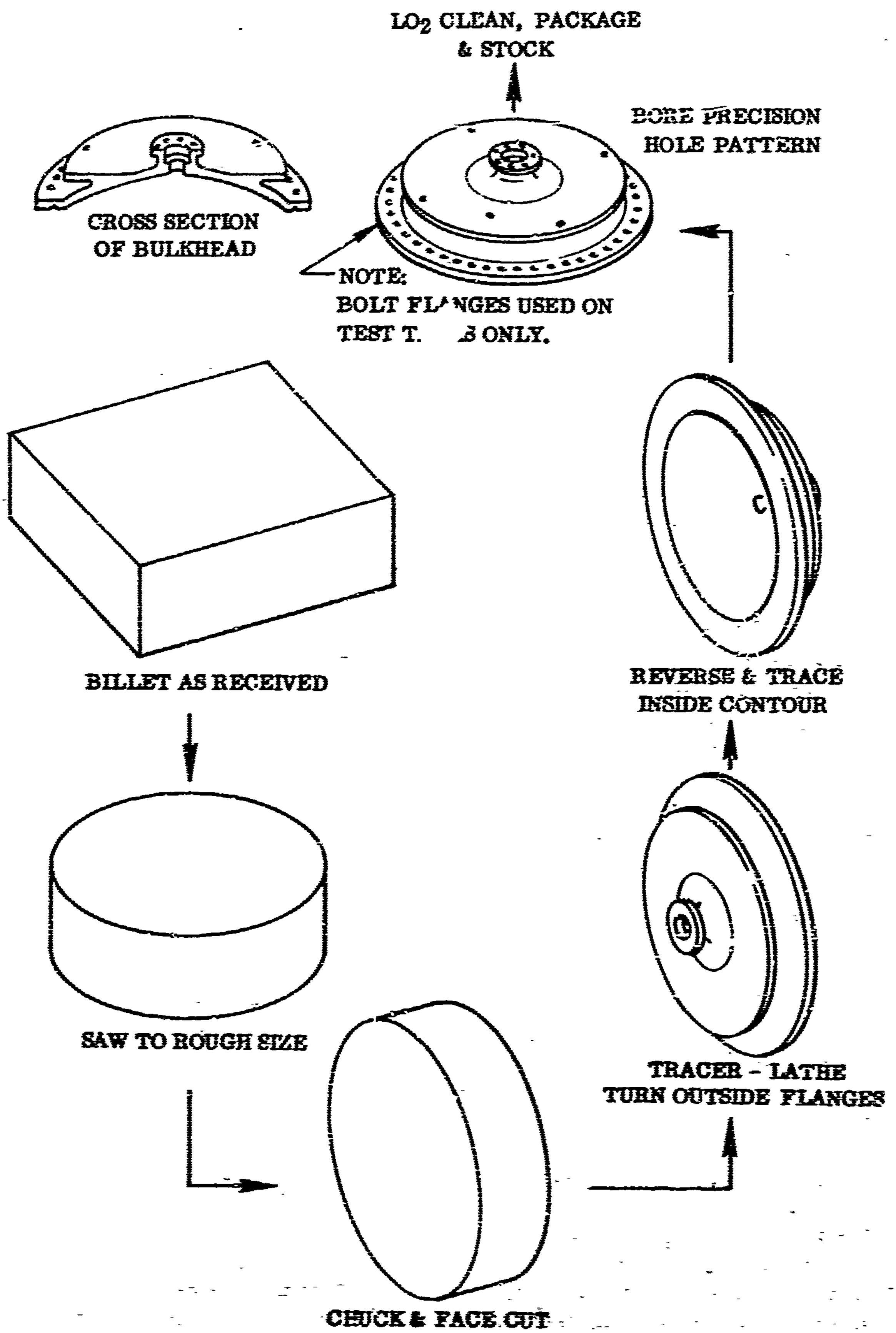

Figure 3. Machining Sequence for Tank Bulkhead

were accomplished on the electron beam welder to minimize the heat input and to accurately control the weld penetration. This method was satisfactory except for the lowest pressure rupture discs used with the SGD pressurization subsystem. These were redesigned and welded into the mechanical seal located at the tank inlet.

3.4.2 TANK CYLINDERS. Convair fabricated the tank cylinders from one-half inch 2219 T-81 plate as outlined in Figure 4. The electron beam welds were performed in two passes using 2319 filler wire for the second pass only. The cylinder was final machined both on the inside and outside diameters for a final wall thickness of three-eighths inch. After this operation it is very difficult to locate these two longitudinal welds; the cylinder appears to be seamless.

A significant variation in film density was found when the radiographs of the tank longitudinal welds were examined. The edges of the electron beam weld appear more dense and the center of the weld appears less dense than the base metal (Reference 9). Radiographs were taken of slices perpendicular to the weld to determine if the grain structure at the edge of the weld was responsible for the variation in film density. The variations in density were found to be real and not artifacts caused by grain structure. The variation of copper content was mapped by using an X-ray spectroscopic miniprobe in areas which radiographed at different densities. It became apparent that the variation in copper content correlated directly with the variation in radiographic film density. The copper content varied from 5.9 percent in the center of the weld, to 6.5 percent at the weld-to-base metal interface, and to 6.25 percent in the base metal. This copper variation is within the 5.8 to 6.8 percent specification allowable. The welds were accepted as satisfactory.

3.5 TANK ASSEMBLY

Either the SFO or the RD positive expulsion device was installed into the tank and the surfaces to be exposed to liquid propellant were cleaned for liquid oxygen service per GDC 0-75002. Surfaces exposed only to the pressurization subsystem gases were cleaned for pneumatic service per GDC 0-75035. The tank heads were installed on the tank cylinder in a clean room. The assembled unit was carried to the electron beam welder where the two cylinder-to-head circumferential welds were made in two passes. The first pass was without filler wire and the second was with aluminum alloy 2319 filler wire. These welds were radiographically inspected for the ten tanks containing an SFO device, but not for the thirteen tanks containing RD devices. It was not possible to obtain any film clarity for tanks containing an RD device due to the substantial thickness of the metal in the background.

After welding, the tanks were pressurized with 1,320 psid, clean gaseous nitrogen to substantiate the design proof pressure. Subsequently, they were installed in a vacuum chamber and pressurized with 125 psia 90 percent nitrogen/10 percent helium gas mixture. No helium leakage from any of the propellant tanks was detected by a helium mass spectrometer connected to the vacuum chamber. The mass spectrometer

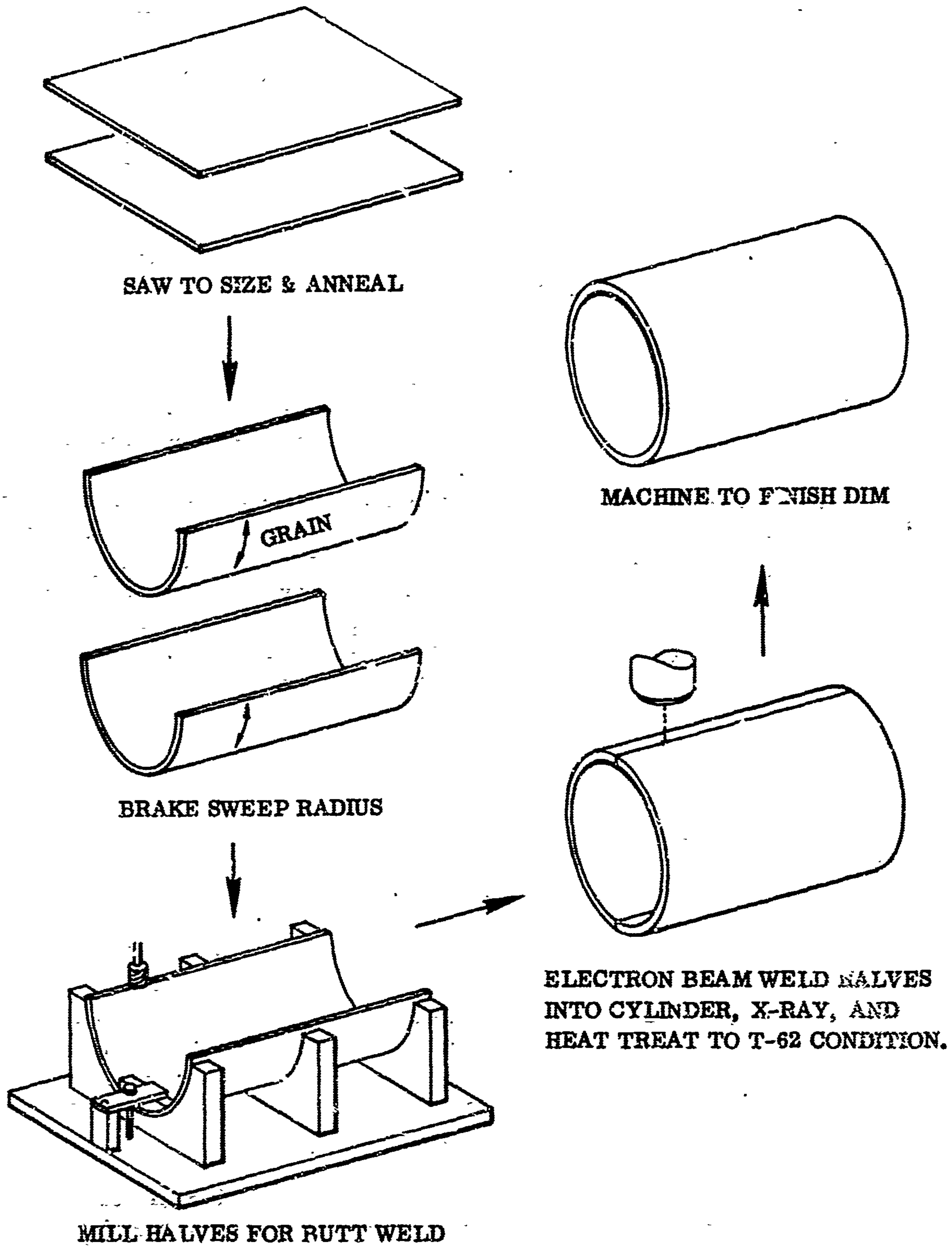

Figure 4. Manufacturing Sequence for Tank Cylinders

sensitivity was 2.6×10^{-10} scc/sec or less. The sensitivity of the vacuum chamber mass spectrometer system was as tabulated in Table III.

TABLE III

PROPELLANT TANK LEAK CHECK

Serial Number	Measured Leakage	Leak Check System Sensitivity (scc/sec)
001	None	4.1×10^{-9}
002	None	4.0×10^{-9}
003	None	4.5×10^{-9}
004	None	2.4×10^{-8}
005	None	8.6×10^{-9}
006	None	4.5×10^{-9}
007	None	6.3×10^{-9}
008	None	8.1×10^{-9}
009	None	7.5×10^{-9}
010	None	7.5×10^{-9}
011	None	3.8×10^{-9}
013	None	9.0×10^{-9}
014	None	8.0×10^{-9}
015	None	9.0×10^{-9}
016	None	9.0×10^{-9}
017	None	3.1×10^{-9}
018	None	3.6×10^{-9}
019	None	5.1×10^{-9}
020	None	3.6×10^{-9}
021	None	1.8×10^{-8}
022	None	5.1×10^{-9}
023	None	4.6×10^{-9}
024	None	1.8×10^{-8}

3.6 TESTS AND RESULTS

Two propellant tanks were fabricated for the demonstration tests. These test tanks simulated the tanks delivered to AFRPL, except the heads were bolted to the cylinders. This permitted economical replacement of expulsion devices during the test program.

Each of the test tanks was pressurized by each of the three pressurization subsystems during the demonstration tests. In addition, each was vibrated at 1.4g and 35 Hz for 60 minutes in the longitudinal axis. The test was repeated for orthogonal transverse axes. The propellant tank met all specifications without any deviations during the entire test program.

SECTION IV

PROPELLANT EXPULSION DEVICES

Every propellant tank contains a propellant expulsion device; either a Surface Force Orientation (SFO) device or a Rolling Diaphragm (RD).

4.1 SURFACE FORCE ORIENTATION DEVICE

4.1.1 CRITERIA. The SFO device must maintain its structural integrity and its absolute micron pore size rating: when stored with either MHF-5, N_2O_4, or ClF_5 for five years; and when exposed to gas products from either of the three pressurization subsystems during propellant expulsion. It does not have to expel propellant in a negative gravity field, due to the present unavailability of fine micron screen.

4.1.2 DESCRIPTION AND FABRICATION. The SFO device consists of a 12.35-inch diameter, 50 x 250 dutch twill weave screen made of 5056 aluminum alloy wire per RR-W-360. The screen is resistance welded to a waffle patterned backup plate made of 2219 T81 aluminum alloy per MIL-A-8920 (see Figure 5). This subassembly is electron beam welded circumferentially to the tank liquid outlet head prior to the head being welded to the tank cylinder (see Figure 6).

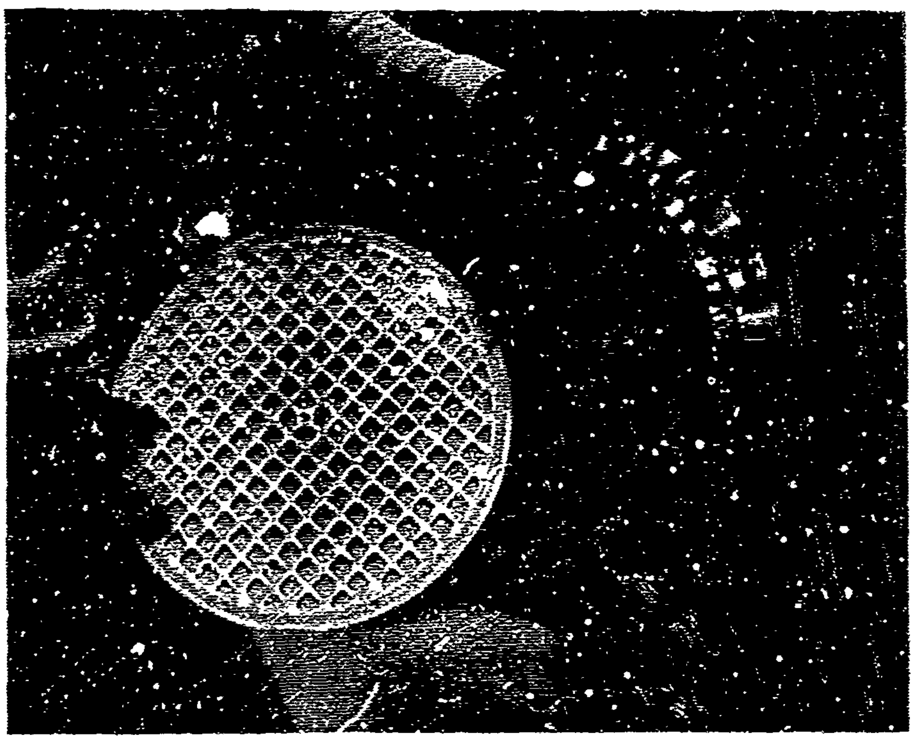

Figure 5. Surface Force Orientation Device Screen, Backup Plate, and Tank Bulkhead

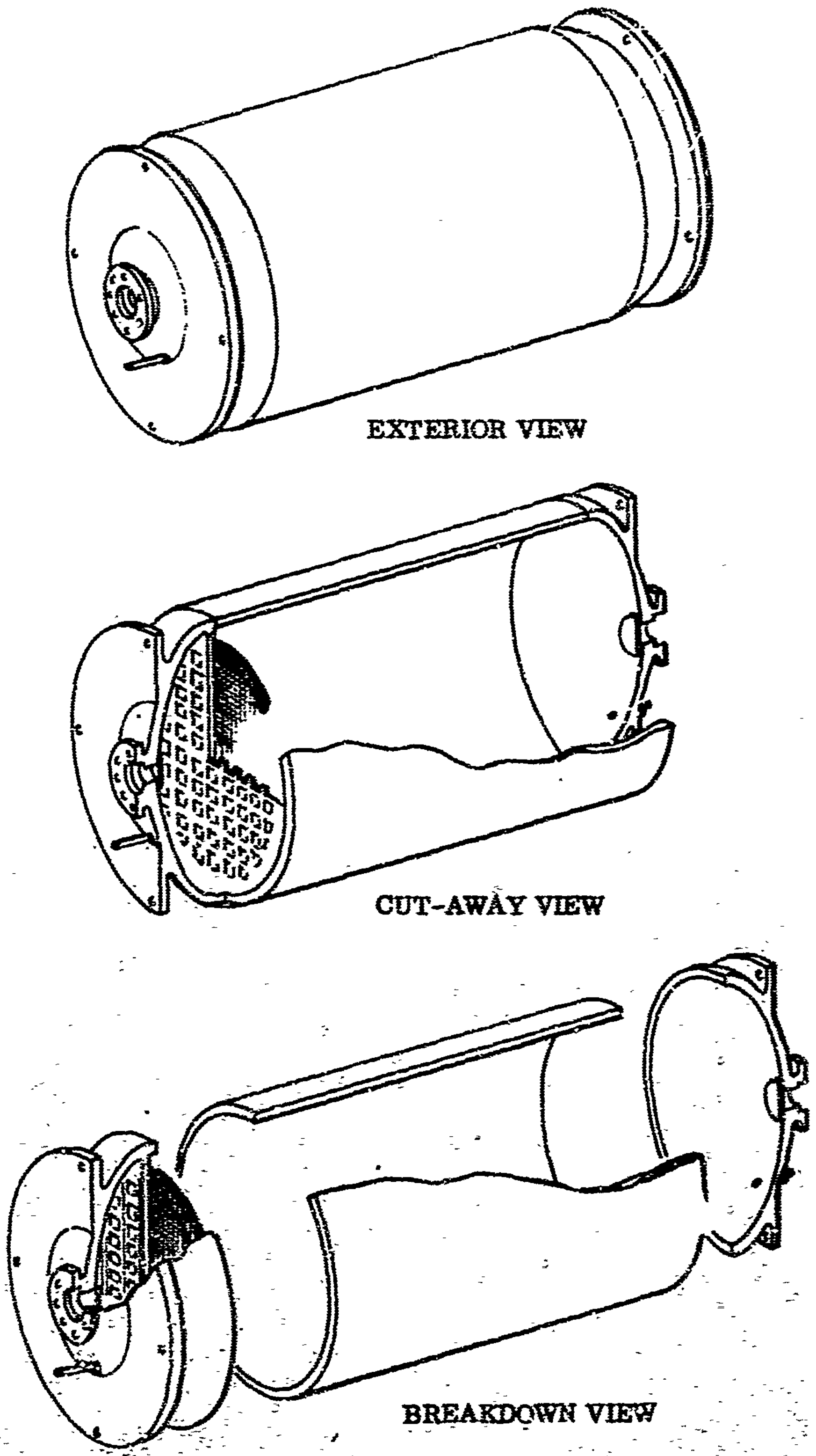

Figure 5. Propellant Tank With Surface Force Orientation Device

The screen and backup plate are cleaned for liquid oxygen service per GDC 0-75002, both prior to and after their subassembly. The subassembly is checked for micron size by submersing the screen one-half inch below the surface of isopropyl alcohol and pressuring the screen's lower surface with gaseous nitrogen. The gas had to pass through the screen first, not through the weld zone, in order for the SFO to be acceptable. All screens passed satisfactorily. They had an absolute micron rating of 100.

4.1.3 TESTS AND RESULTS. MHF-5 was expelled through the SFO device by each of the three pressurization systems during the demonstration tests. There was no deterioration of the screen. The micron rating remained constant. Figure 7 shows the upstream side of the SFO after demonstration Test No. 3, when water was expelled from the propellant tank by the Solid Propellant Gas Generator (SPGG). The deposits shown on the screen are combustion products of the SPGG. Figure 8 pictures the other side of the SFO and shows local areas where the combustion products penetrated the screen. This had no known detrimental effect since the screen micron rating was the same after the test as before.

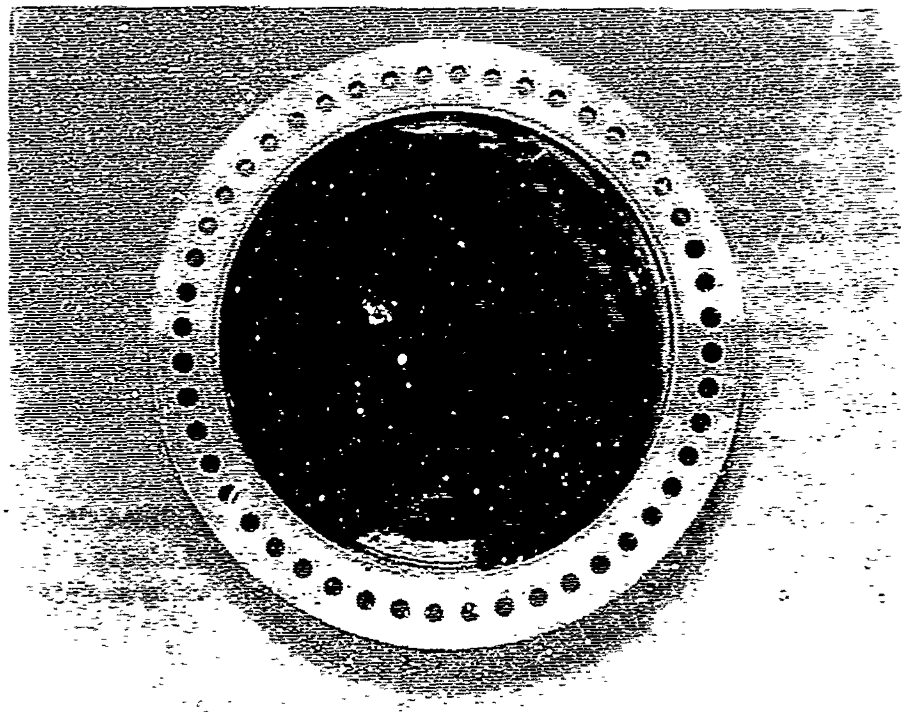

Figure 7. Surface Force Orientation Device After Demonstration Tests (Upstream Side)

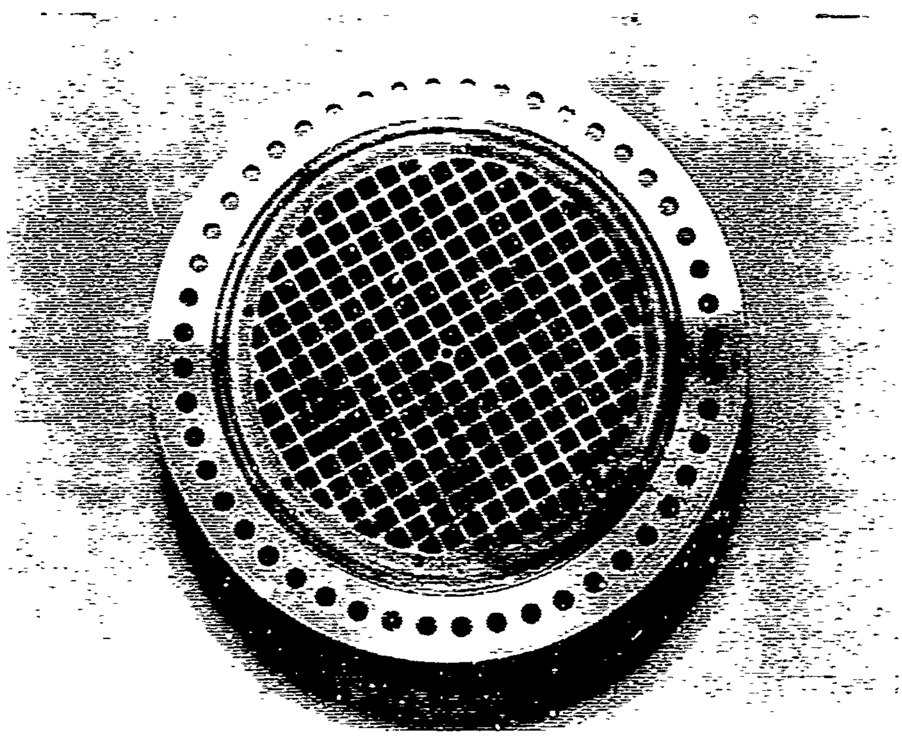

Figure 8. Surface Force Orientation Device After Demonstration Tests (Downstream Side)

4.2 ROLLING DIAPHRAGM (RD)

4.2.1 CRITERIA. The RD must expel either of the three propellants, MHF-5, N_2O_4, or ClF_5, against gravity when pressurized by one of the three pressurization subsystems. The RD must contain either of the propellants for a minimum of five years without leakage. Before, during, and after the expulsion cycle, the RD must maintain its structural integrity and not leak propellant or pressurization gas.

4.2.2 DESCRIPTION. The RD is an all metal, positive expulsion device which contains no dynamic seals. It relies on the yielding of two metal sleeves to provide a continuous barrier between pressurization gas and propellant, while permitting an axial translation of the piston to expel propellant.

A cross section of the RD is included in Figure 9. The tube rolls outside its outer diameter and the shell rolls inside its inner diameter as the pressurization gas forces the piston to translate toward the liquid bulkhead. Figure 9 also shows the RD installed in the propellant tank at the beginning, mid-point, and completion of the expulsion cycle. The silicone rubber between the tube and center post stabilizes the tube and prevents it

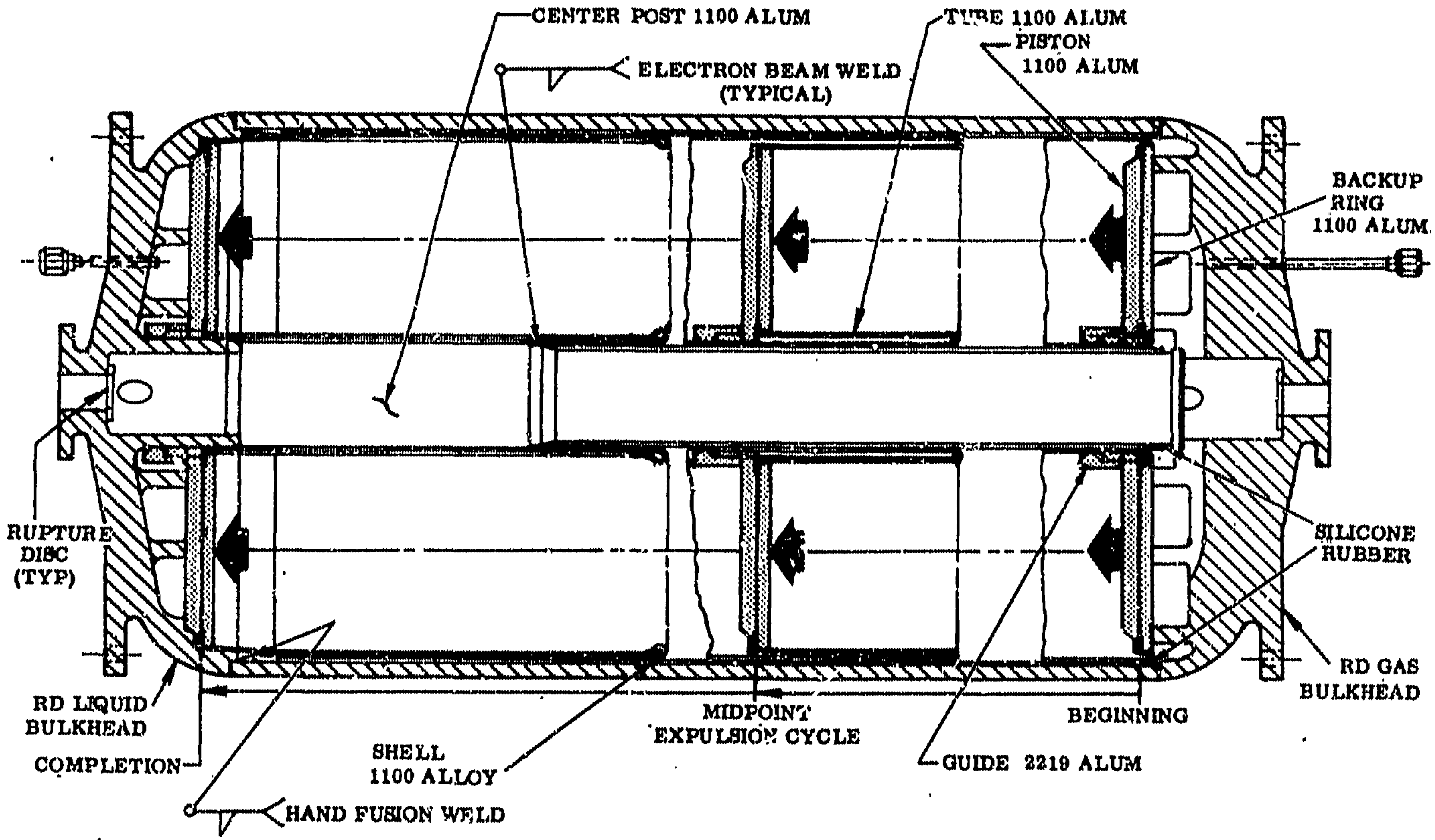

Figure 9. Rolling Diaphragm Installed in Tank (Cross Section)

from buckling longitudinally due to the axial force imposed on it when it is rolled. The silicone rubber between the shell and propellant tank is a seal to prevent pressure from collapsing the shell circumferentially.

The guide on the front of the piston provides a correcting moment to keep the piston normal to the tank centerline and prevent piston cocking with resultant lockup of the RD. The guide is machined from annealed aluminum alloy 2219. The stress analysis for the RD is contained in Reference 7. The tube and shell have a wall thickness of 0.032 inch for ease of manufacture; in theory they could be thinner and work satisfactorily.

4.2.3 FABRICATION. The center post, piston, backup ring, and guide are machined from 1100 aluminum alloy raw stock. The tube is made from 2.5-inch diameter 0.032 wall seamless 1100 aluminum alloy tubing by spinning the roll convolute in one end. The shell (Figure 10) is manufactured from 0.032 thick 1100 aluminum alloy sheet which is rolled into a circular shape and semi-automatic welded without filler wire by the gas-tungsten-arc, direct current, straight polarity (GTA-DCSP) process. A convolute was then spun in the piston end of the shell; the other end was formed outward to fit the propellant tank inside diameter.

Figure 10. Rolling Diaphragm Shell

An anomaly occurred during the production of the shells. Three different lots were manufactured and all were made to the same engineering requirements, but the second lot was not satisfactory. The longitudinal weld in the shell split longitudinally after the piston had bottomed at the end of its stroke.

The manufacturing processes for the different lots were reviewed. Shells from the second lot failed in the longitudinal weld because the weld thickness was less than the base metal. The cause was insufficient welding heat input (Reference 10). The major weld parameters for the first lot were: 16 volts, 45 amps, 8 ipm travel speed, and 160 kilojoules/in./in. heat input. The unsuccessful second lot major weld parameters were: 18 volts, 63 amps, 18 ipm travel speed, and 120 kilojoules/in./in. heat input. The weld parameters for the first lot of shells produced welds that did not fail; the base metal failed first. The welds made in the second lot failed, either in the weld itself, or in the heat-affected zone.

For the shell to operate successfully during propellant expulsion, it is necessary for it to expand circumferentially after the piston has traveled its full stroke. This expansion expels the last propellant contained in the annulus created when the shell rolls on the inside of the inner diameter. The shell material, therefore, has to elongate to this larger diameter, and if the weld elongates before the parent material, the weld will split. This occurs because the length of the weld in the direction of the expansion is only about 0.100 inch, which would require a percentage of elongation greater than 250 percent. If, however, the parent material elongates, it would be required to elongate less than 3 percent because its length in the direction of elongation exceeds 37 inches. Prior to the fabrication of the third lot of shells, special weld specimen tensile tests were performed, using the recommended weld schedule, to be certain that the shell specimen would fail in the parent material first, and not in the weld. The major weld parameters for the third lot of shells were: 11.5 volts, 73 amps, 10 ipm travel speed, and 155 kilojoules/in./in. heat input.

The assembly of the RD is portrayed in Figure 11. The tube and center post were electron beam welded together and were annealed, along with the shell, at 650° F for thirty minutes. After the anneal the piston plate was electron beam welded to the shell and to the tube. The piston backup ring was bonded to the piston to complete the RD assembly (see Figures 12 and 13).

Figure 14 portrays the assembly of the RD into the propellant tank. The RD shell was hand fusion welded to the propellant tank cylinder using aluminum alloy 2319 weld rod. All welds were then leak checked by flooding 100 percent helium on the propellant side of the diaphragm and drawing a vacuum of the pressurization side. A helium mass spectrometer was used to measure helium leakage into the vacuum. If any leakage was detected, the weld was reworked. Table IV contains the mass spectrometer-vacuum sensitivity when the applicable RD had no detectable leakage. The hand fusion weld of the shell to the tank cylinder leaked consistently on all subassemblies checked. Several methods of repair were attempted. The one which worked best was

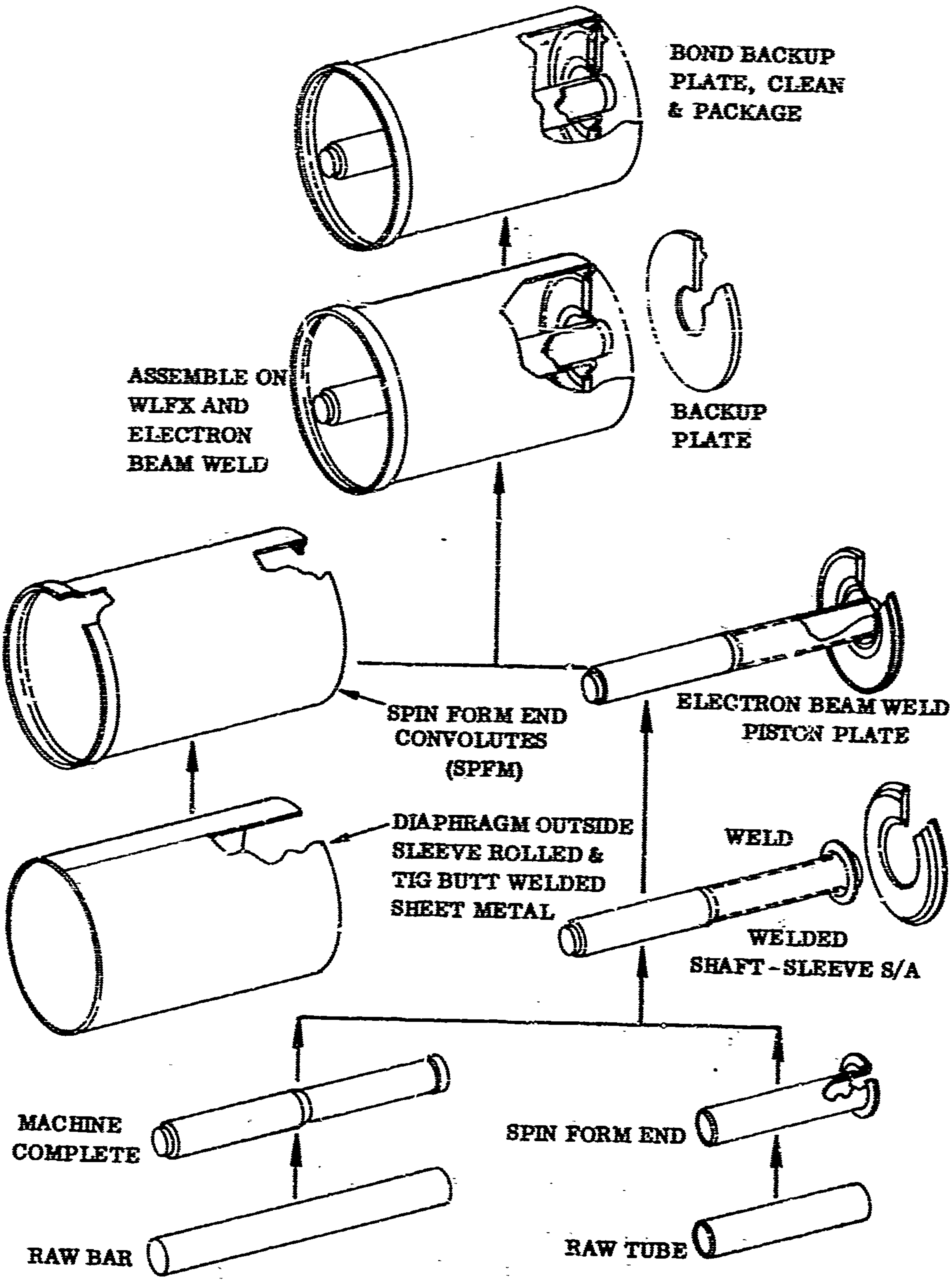

Figure 11. Rolling Diaphragm Assembly Sequence

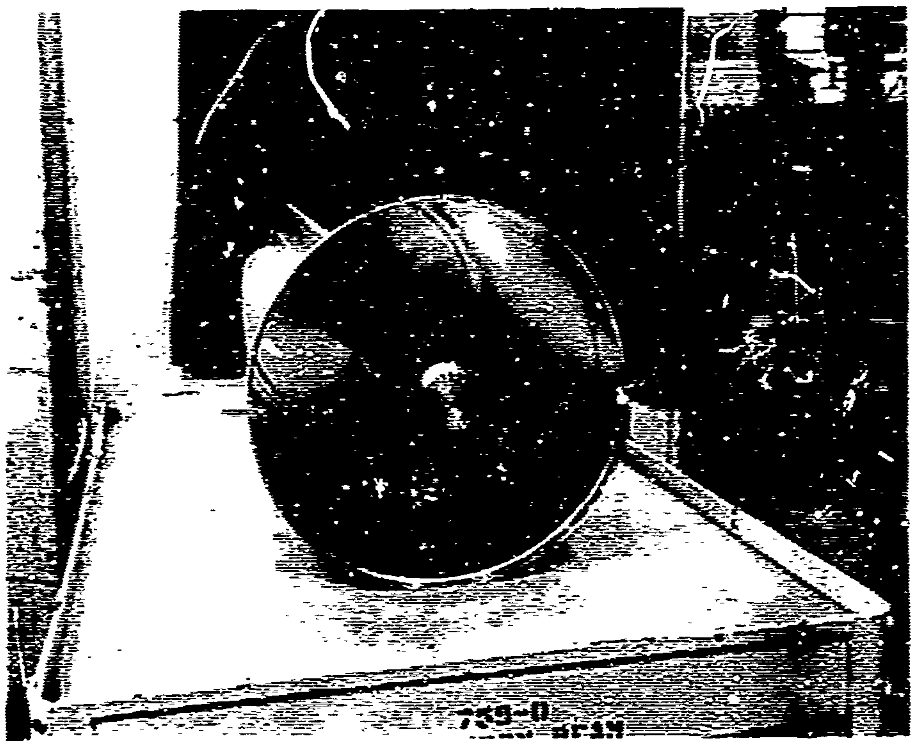

Figure 12. Rolling Diaphragm Piston Assembly and Shell

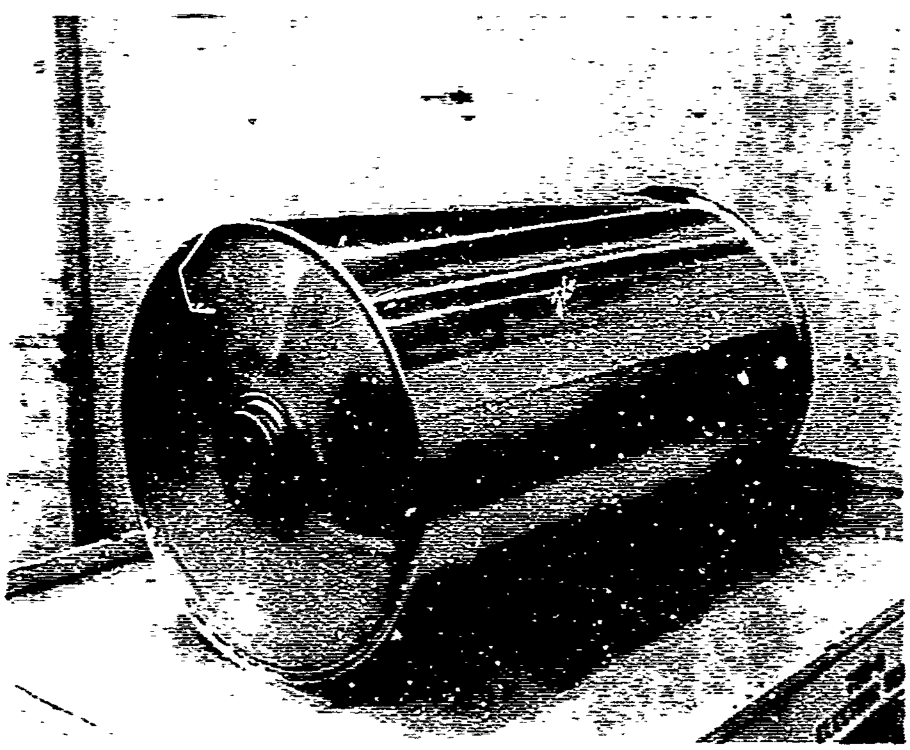

Figure 13. Complete Rolling Diaphragm Assembly

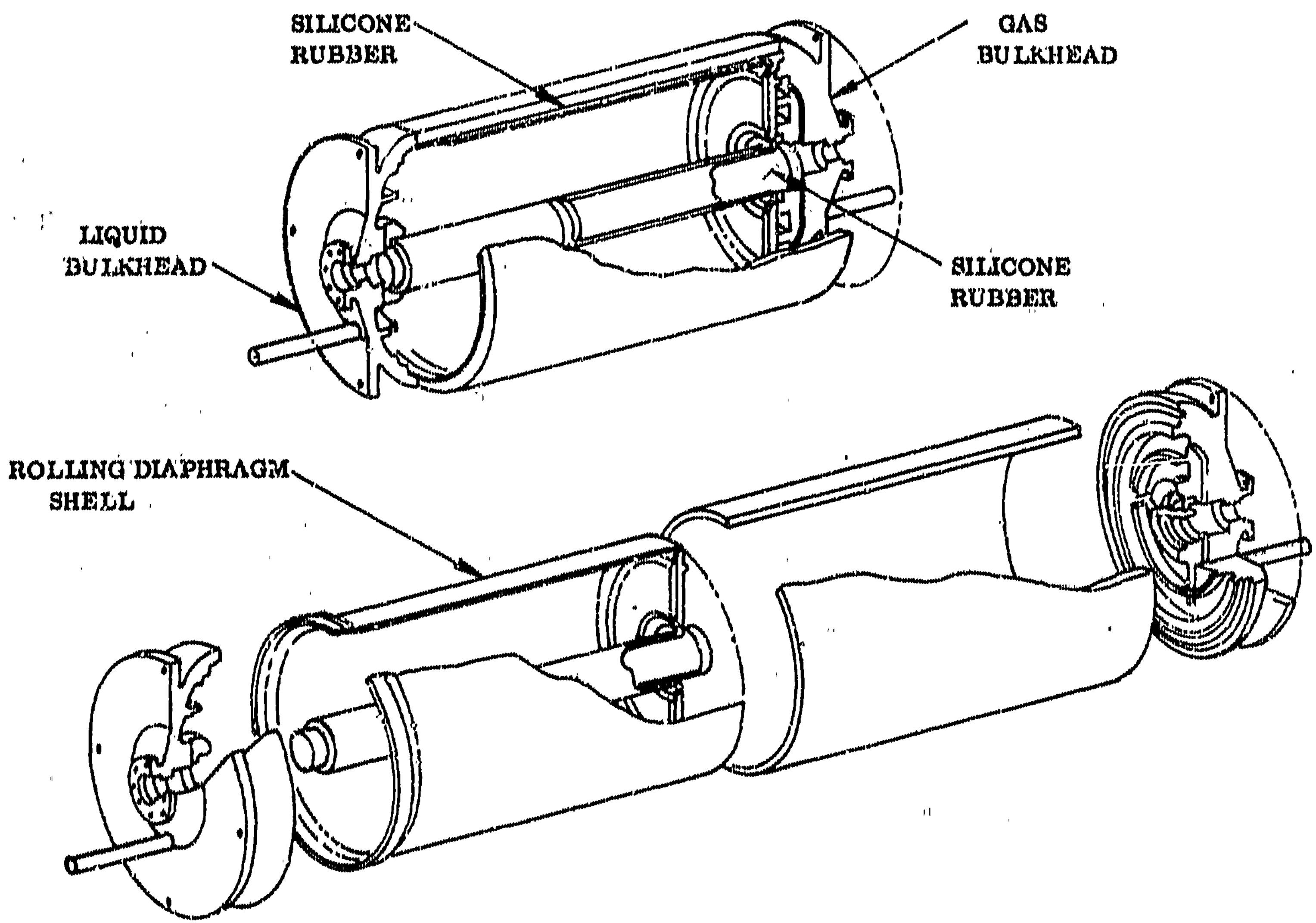

Figure 14. Rolling Diaphragm/Propellant Tank Assembly Sequence

TABLE IV

15 PSID ROLLING DIAPHRAGM LEAK CHECK

Serial Number	Measured Leakage	Leak Check System Sensitivity (scc/sec)
001	None	1.8×10^{-10}
002	None	1.8×10^{-10}
003	None	1.8×10^{-10}
004	None	4.7×10^{-10}
005	None	1.8×10^{-10}
006	None	1.8×10^{-10}
007	None	1.4×10^{-9}
008	None	1.8×10^{-10}
009	None	1.6×10^{-10}
010	None	1.7×10^{-10}
011	None	1.3×10^{-9}
012	None	1.7×10^{-10}
013	None	1.8×10^{-10}
014	None	1.4×10^{-9}

to radiographically inspect the weld to locate the tungsten inclusions, then remove the inclusions and reweld the area using the electron beam welder.

Phalthetic naptha and General Electric Company's 4155 primer were mixed 4:1 by volume. This mixture was poured into the post to tube annuli and into the shell to cylinder annuli. It was then poured c , and the annuli were permitted to dry. The annuli were then pour-filled with General Electric Company's RTV-634.

The tank bulkheads were electron beam welded to the tank cylinder. The propellant side of the RD was proof pressurized with 400 psig gaseous nitrogen, and both sides of the RD were proof pressurized simultaneously with 1320 psig gaseous nitrogen to verify the propellant tank welds.

The propellant side of the RD was pressurized with 90 percent nitrogen/10 percent helium gas at 125 psia. The other side was connected to a mass spectrometer vacuum pump system. No leakage was measured per the system sensitivity recorded in Table V, except for Serial Number 003. It had a leak through the RD of 1.7×10^{-3} standard cubic centimeters per second. This tank was filled MHF-5 for delivery to AFRPL.

4.2.4 TESTS AND RESULTS. Table VI lists the ten RD tests performed and any anomalies that occurred during propellant expulsion. Tests 1 and 2 used General Electric Silicone Rubber RTV-511 for the shell-to-cylinder seal. During testing, the shell

TABLE V

125 PSID ROLLING DIAPHRAGM (RD) TANK LEAK CHECK

Serial Number	Leakage	Leak Check System Sensitivity (scc/sec)
002	None	4.0×10^{-9}
003	1.7×10^{-3} scc/sec	
004	None	2.4×10^{-8}
005	None	8.6×10^{-9}
006	None	4.5×10^{-9}
007	None	6.3×10^{-9}
008	None	8.1×10^{-9}
009	None	7.5×10^{-9}
010	None	7.5×10^{-9}
011	None	3.75×10^{-9}
012	None	8.6×10^{-9}
013	None	9.0×10^{-9}
014	None	8.0×10^{-9}
015	None	9.0×10^{-9}
016	None	1.8×10^{-8}
017	None	3.05×10^{-9}
018	None	3.6×10^{-9}
019	None	5.1×10^{-9}
020	None	3.6×10^{-9}
021	None	1.8×10^{-8}
022	None	5.1×10^{-9}
023	None	4.6×10^{-9}
024	None	1.8×10^{-8}

collapsed (Figure 15). Post test examination showed that only 60 percent of the shell-to-cylinder cavity was filled with silicone rubber. Therefore, the shell felt the pressure of the GN_2 on its outer diameter and it collapsed. The assembly for Test 2 was radiographically inspected and it was determined that silicone rubber voids were present. A hypodermic needle was used to fill those that could be reached, but when Test 2 was run, the failure duplicated that in Test 1, for the identical reasons. All future assemblies used RTV-634 which is less viscous. Silicone rubber voids were eliminated. No future shells collapsed.

TABLE VI

ROLLING DIAPHRAGM (RD) TESTS AND ANOMALIES

Test	Pressure Source	Fluid Expelled	Anomalies During Expulsion
1.	Facility GN_2	H_2O	Shell Collapsed
2.	Facility GN_2	H_2O	Shell Collapsed
3.	Facility GN_2	H_2O	Piston Cocked
4.	Facility GN_2	H_2O	Tube Buckled
5.	Facility GN_2	H_2O	Piston Welds Leaked
6.	SGD	MHF-5	Shell Split Longitudinally
7.	SGD	MHF-5	None
8.	LPGG	MHF-5	None
9.	SPGG	MHF-5	None
10.	LPGG	MHF-5	None

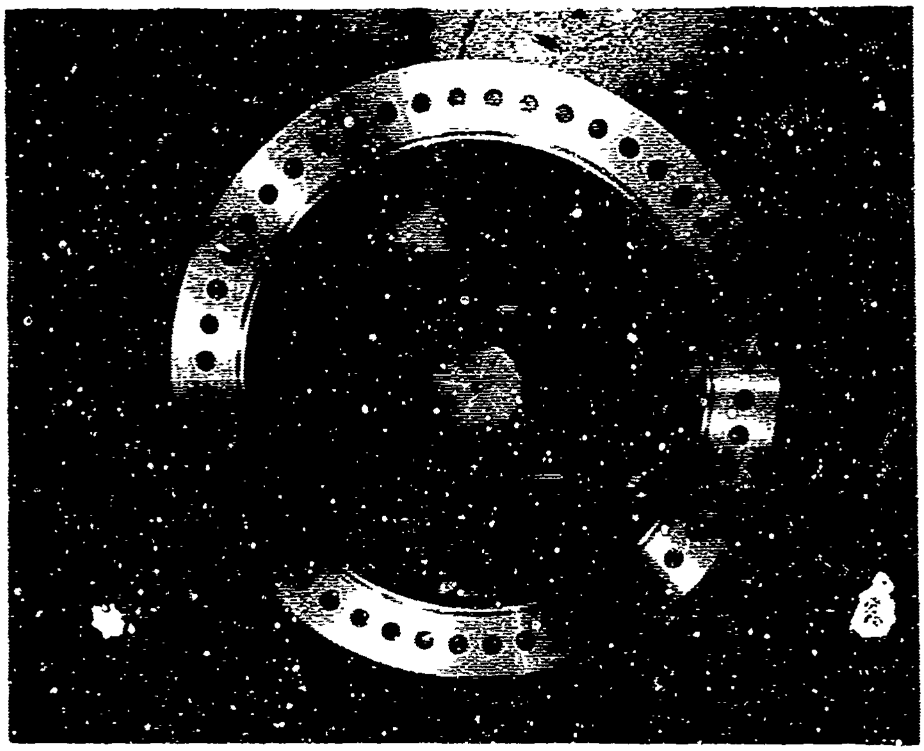

Figure 15. Collapsed Rolling Diaphragm Shell

During Test 3 the piston cocked immediately when the tank was first pressurized. It was wedged on the tube and would not translate. The test tank was disassembled and the piston was made to translate five inches by mechanically pushing on it. The tank was reassembled and then pressurized, and the piston translated for its entire stroke. A piston guide was added to the forward face of the piston for Tests 5 and on. This corrected piston cocking for these tests.

The tube bulked circumferentially during Test 4 (see Figure 16). The tube had only a snug fit to the post to prevent galling during assembly.

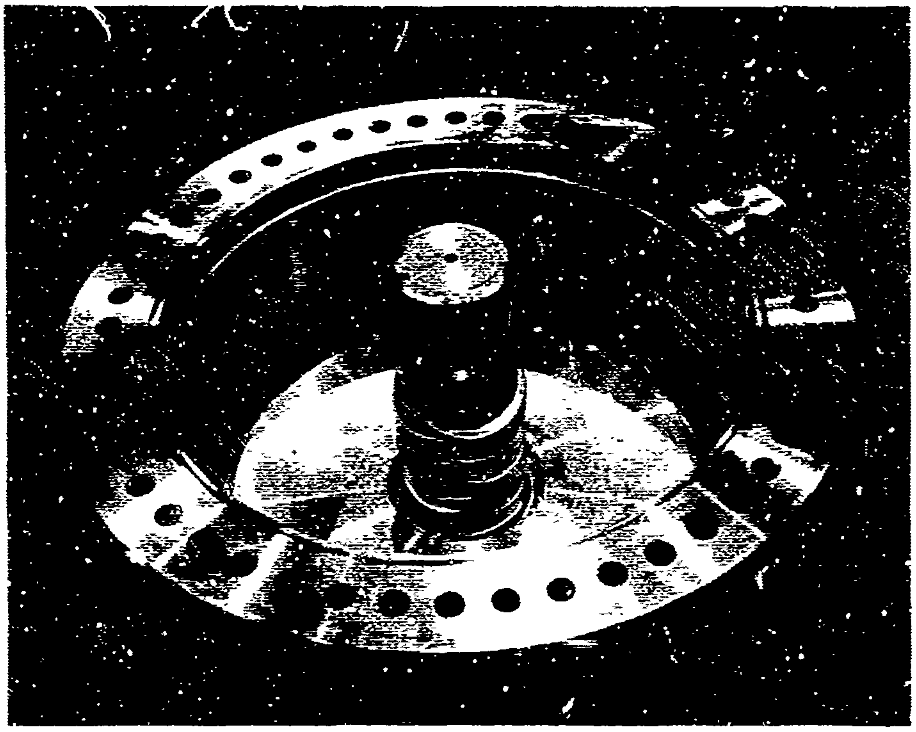

Figure 16. Circumferential Bulking of the Rolling Diaphragm Tube

For subsequent tests the post was machined to a smaller diameter. This created an annulus which was filled with RTV-634 silicone rubber to remove some of the tube roll force through shear. The circumferential bulking did not reoccur.

During Test 5 the RD performed satisfactorily until the piston bottomed in the liquid bulkhead. At that time the piston-to-shell circumferential weld opened when it felt the entire 700 psid. The piston-to-shell and piston-to-tube welds were both changed from hand tungsten gas arc welds to electron beam welds. This method proved satisfactory during subsequent tests.

During Test 6 the RD performed satisfactorily until the piston bottomed in the liquid bulkhead. At that time the shell split longitudinally in the parent material. This was at the end near the piston and liquid bulkhead, where the shell was required to expand circumferentially to the cylinder. A close fitting socket was machined in the liquid bulkhead to minimize this circumferential expansion on subsequent tests.

Tests 7, 8, 9, and 10 were successful. Tests 8 and 9 used shells from the second lot of shells produced. These were supposed to be used for manufacture of the 13 RD propellant tanks requested by AFRPL. After Test 8 the longitudinal weld on the shell split, 17 minutes after completion of expulsion, while still pressurized by the Liquid Propellant Gas Generator (LPGG). After Test 9 the longitudinal weld on the shell split during the post-test helium leak check. Investigation showed that the weld was yielding before the parent material yielded. Therefore, the expansion of the shell into the cylinder at the end of the expulsion required impossible weld elongation properties. A new set of shells was fabricated as described in Section 4.2.3. One shell from that lot was used for Test 10. There were no anomalies during or after that test. Figures 17 and 18 show the assembly after test.

Prior to Test 8 the tank assembly was vibrated in three orthogonal axes for 60 minutes at 1.4g and 35 Hz, and it passed successfully, as determined by the expulsion test. Tests 8, 9 and 10 used the LPGG and SPGG with their hot gas products for pressurization. The only determinable effect on the RD was reduced rolling resistance (ΔP) toward the end of each test.

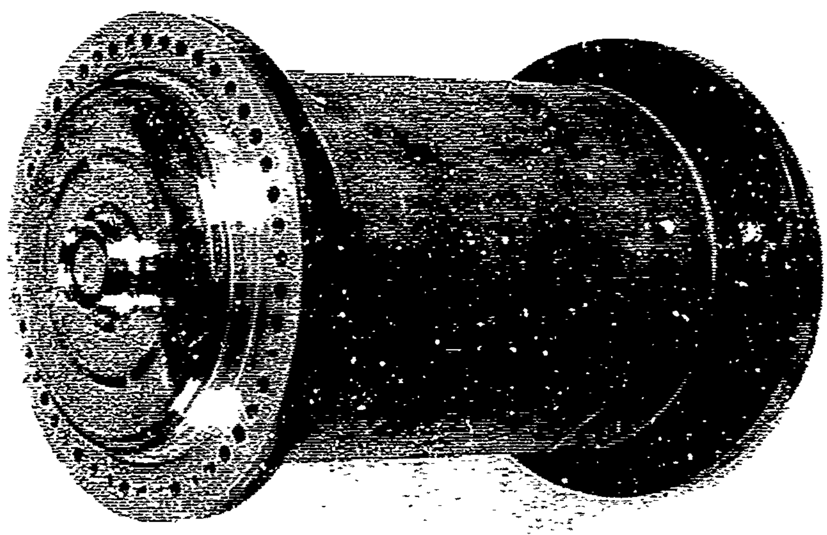

Figure 17. Rolling Diaphragm Assembly After Test 10 (Liquid Bulkhead End)

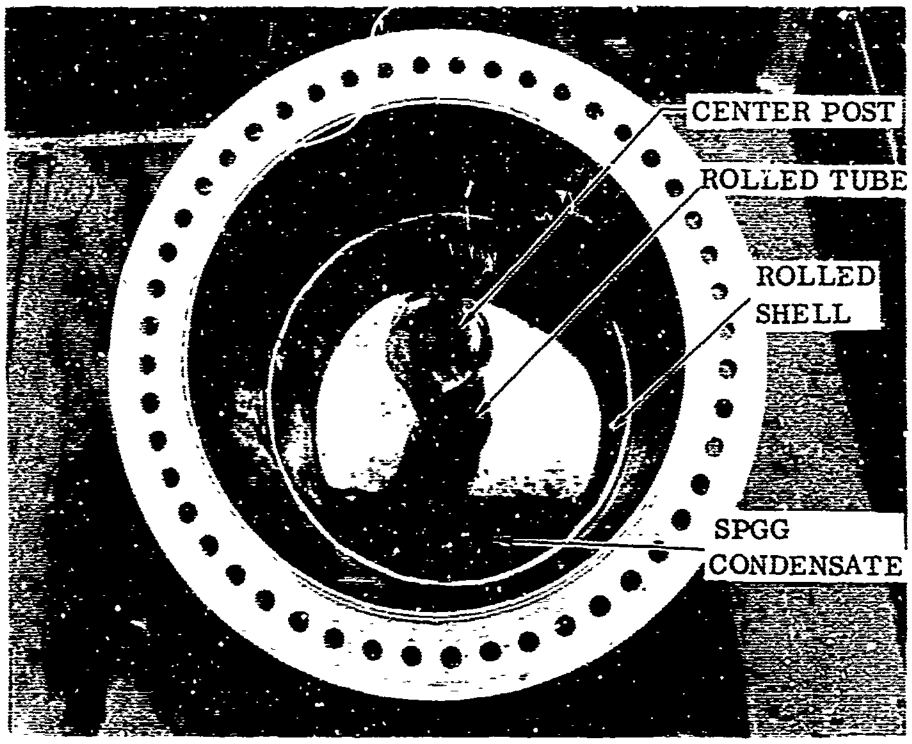

Figure 18. Rolling Diaphragm Assembly After Test 9 (Gas Bulkhead End)

SECTION V

PRESSURIZATION SUBSYSTEMS

Every SPPS contains a pressurization subsystem; either a Liquid Propellant Gas Generator (LPGG), a Solid Propellant Gas Generator (SPGG), or a Stored Gas Device (SGD).

5.1 LIQUID PROPELLANT GAS GENERATOR

5.1.1 DESIGN CRITERIA

Expulsion Cycle. The LPGG, operating in an ambient temperature and pressure environment, was designed to provide pressurization for the following propellant expulsion cycle:

a. Pressurize propellant tank ullage to 700 psig nominal, then expel 7.5 gallons of propellant in 40 seconds at 700 psig nominal pressure. (Note: Initial ullage volume will be 240 to 495 $in.^3$, depending on tank type, propellant, and temperature. Pre-start ullage pressure will be 1 to 455 psia, depending on propellant, storage decomposition, and temperature.)

b. Pause for one minute with propellant outflow stopped by downstream valve.

c. Expel remaining propellant (3 to 6 gallons) at 700 psig nominal pressure and 11.25 gpm.

Storage. The LPGG will be stored for five years in a ready condition with no maintenance and no leakage. Preparation for operation will require only electrical connection to a facility firing circuit, and orificed plumbing to a facility receiver tank. The storage environment is as follows:

-65 to +165°F

85% relative humidity

Periodic vibration in each axis at ±1.4 g peak, 35 Hz.

Maximum use of hermetically sealed, all-metal, all-welded construction will best satisfy these storage requirements.

5.1.2 SUBSYSTEM DESCRIPTION. The LPGG subsystem is shown in Figure 19. It consists of a gas/hydrazine tank, a normally-closed explosive valve, a pressure regulator, a gas generator, a relief valve, and a rupture disc on the relief valve outlet. The propellant tank rupture discs are also shown and discussed here,

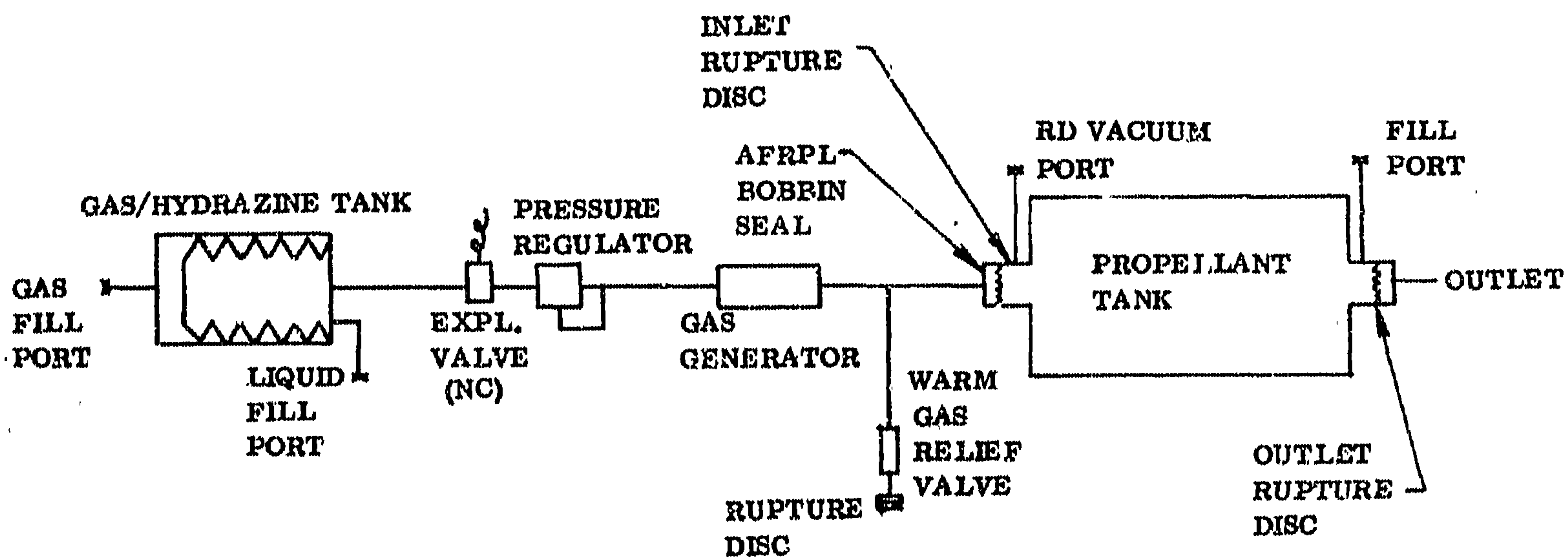

Figure 19. SPPE (Tank/LPGG) Schematic

although not part of the LPGG subsystem, because LPGG operating pressures affect the choice of rupture pressures. Figure 20 shows a system ready for delivery.

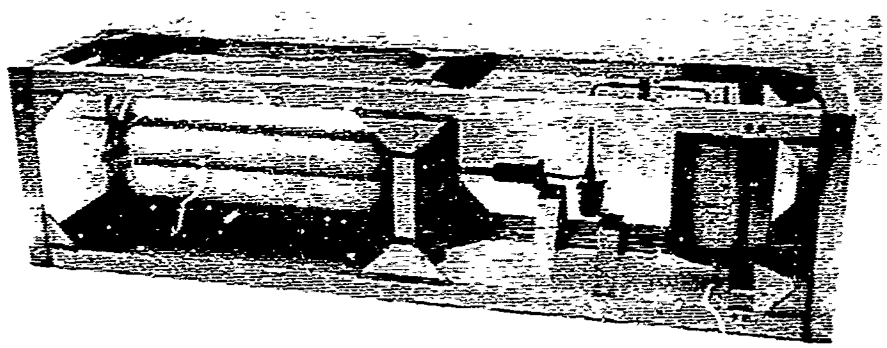

Figure 20. SPPS (SFO/LPGG) Ready for Five Year Storage

The gas/hydrazine tank is a positive expulsion device, using a welded, nested bellows to contain a mixture of 68 per cent hydrazine, 32 per cent water. The volume surrounding the bellows is precharged with 90 per cent GN_2/10 per cent He. The explosive valve initiates hydrazine flow to the pressure regulator, which controls inlet pressure to the gas generator. The gas generator is a catalyst chamber which decomposes the liquid into hydrogen, nitrogen, ammonia, and steam. The gas mixture, at approximately 1150°F, pressurizes the propellant tank to 700 psig to expel the propellant. The relief valve only opens if a system malfunction causes overpressure; then it limits the tank pressure to a safe value. The rupture disc, welded to the relief valve outlet, provides hermetic sealing during storage. The disc ruptures if the relief valve opens, and may rupture during a normal run due to relief valve leakage. The propellant tank is isolated by rupture discs at its inlet and outlet. The inlet disc ruptures when the LPGG outlet exceeds tank pressure by 180 psid, admitting pressurizing gas. The outlet disc ruptures when the tank pressure reaches 400 psid.

The LPGG system has an all-metal, all-welded design of tubing and components. The welds and components are checked with a helium mass spectrometer leak detector at pressures equal to or exceeding their storage pressures. This assures pressure retention in the pressurized portion and it assures hermetic sealing against atmospheric moisture or contamination in the unpressurized portion of the LPGG.

The flanged connection between the LPGG subsystem and the propellant tank subsystem uses an AFRPL bobbin seal (Reference 11) because it connects two dissimilar metals. The LPGG was made of stainless steel because of high gas temperature, and the propellant tank was made from aluminum for propellant compatibility. The bobbin seal was selected because it has demonstrated leakage as low as 2×10^{-8} at 1000 psig in aluminum-to-CRES connections. This leakage rate is equivalent to a 1/2 psi pressure loss per year from one cubic inch of volume.

5.1.3 COMPONENT DESCRIPTIONS

5.1.3.1 Gas/Hydrazine Tank. The gas/hydrazine tank supplied by Metal Bellows Corporation is shown in Figure 21. It is a positive expulsion device, with the pre-mixed water/hydrazine blend contained within a welded metal bellows. The surrounding volume is pre-charged with high pressure gas to provide expulsion force. The liquid blend is 68 per cent hydrazine/32 per cent water, selected to provide a -65°F freezing point. The gas is 90 per cent GN_2/10 per cent He by volume, permitting a mass spectrometer leak check of the fill tube closure weld.

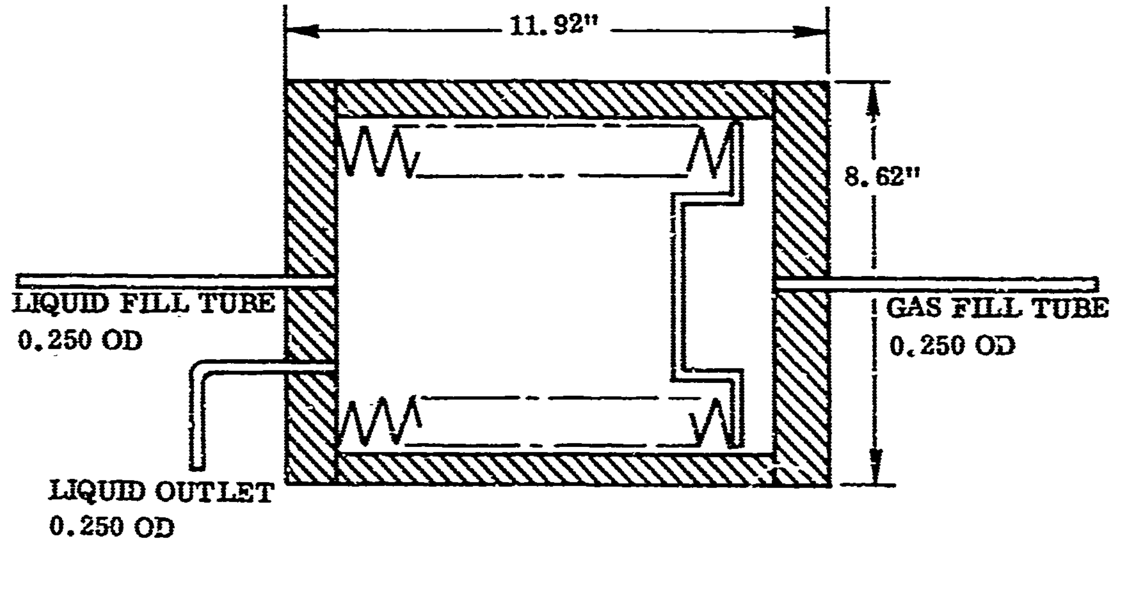

Figure 21. Gas/Hydrazine Tank

The gas/hydrazine tank specifications are summarized in Table VII.

TABLE VII

GAS/HYDRAZINE TANK SPECIFICATIONS

Material	321 and 347 CRES
Volume	
Liquid	192 in.^{3} expellable if bellows completely filled
Gas	130 in.^{3}
Pressure	
Operating	3000 psig at 165° F
Proof	5000 psig
Burst	6600 psig
Temperature	-65 to +165° F
Maximum Leakage	
External	1 x 10^{-8} sccs total when pressurized to 3000 psig with helium
Internal	1 x 10^{-8} sccs helium with 20 psid across bellows
Cleaning	Per Convair division GDC 0-75002
Inspection	Proof pressure, mass spectrometer leak check

To allow for liquid expansion at 165°F, and for possible pressure rise on the liquid side during storage, the unit is not completely filled. The pressures and volumes at ambient temperature for deliverable units are as follows:

Main Tank	Expellable Liquid	Gas Volume	Storage Pressure	Press. at End of Expulsion
SFO	178 in.^{3}	144 in.	2800 psig	1200 psig
RD	150 in.^{3}	172 in.	2400 psig	1200 psig

The gas/hydrazine tank used with the propellant tank containing the SFO is loaded to its maximum capacity consistent with the 165°F storage requirement. Loading for the RD systems is reduced because test results demonstrated lower requirements, and also because off-loading will provide another data point for comparison during the five year storage.

5.1.3.2 Explosive Valve. The explosive valve was supplied by Pyrodyne, Inc. It is a normally closed valve, used to isolate the hydrazine/water mixture from the pressure regulator until propellant expulsion is required. The valve is of stainless construction except for a Viton piston seal and pressure cartridge seal. These are not primary seals during storage because the inlet and outlet tubes have solid ends until sheared by the ram during actuation. The piston seal prevents the pressure cartridge gas from entering the system during actuation, while the cartridge seal prevents escape to the atmosphere of the pressure cartridge gas or system fluid after actuation. The inlet and outlet tubes are 0.25 in. OD. Leakage before actuation is less than 1×10^{-9} sccs (standard cubic centimeters per second) with 200 psig helium after 5000 psig proof pressure.

The valve uses a McCormick Selph pressure cartridge, type M-79 Mod 8, which has a glass-to-metal seal, redundant bridgewires. It mates with a Bendix PCO6E-8-45 connector. Recommended firing current is 5 amps, applied across pins A-D or B-C optionally. Resistance is 0.65 ± 0.1 ohms. This type of valve has previously been furnished by Pyrodyne for Pioneer IV and Agena.

5.1.3.3 Pressure Regulator. The pressure regulator was supplied by Sterer Engineering and Manufacturing Company, and is shown in Figure 22. It is constructed entirely of stainless steel and gold-plated spring steel, and contains no elastomers. Its specifications are as follows:

Operating Fluid:	Hydrazine/water mix
Outlet Pressure:	770 ± 40 psig at 0.2 to 0.8 gpm flow, 850 psig max. at zero flow
External Leakage:	1×10^{-7} sccs at 25 psig, 100 per cent He. Bubble-tight at normal operating pressure
Ports:	0.25 in. OD welded inlet and outlet tubes
Inlet Pressure:	1000 to 3000 psig operating, 4500 psig proof, 7500 psig burst

The regulator is isolated from the high pressure liquid by the explosive valve during storage, and was acceptance tested to verify its proper operation with the slam start imposed by this type of system. It employs a CRES diaphragm between the gas side and the reference spring, using the perimeter of the diaphragm as a gasket between flanges.

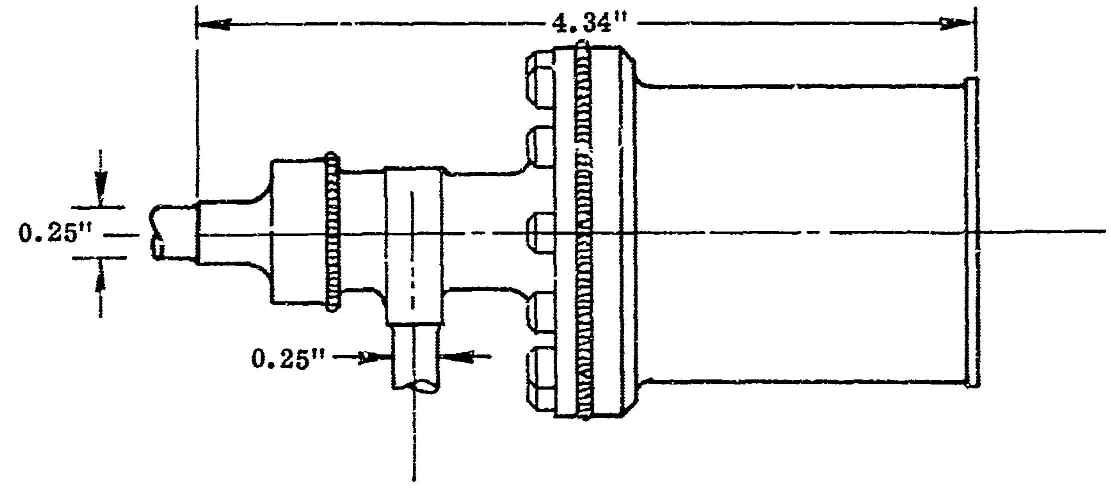

Figure 22. Pressure Regulator

This regulator is a minor modification of units used on Ma[illegible]er and on the MMU (astronaut backpack). Differences are in the reference spring and inlet-outlet configuration.

5.1.3.4 Gas Generator (GG). The GG, shown in Figure 23, is a hydrazine decomposition chamber consisting of a housing, injector, Shell 405 catalyst, outlet orifice, and inlet and outlet ports. It was supplied by Walter Kidde & Co., and is a modification of their 20 lb thrust motor design. It is suitable for use with neat hydrazine or a wide range of binary or ternary blends of hydrazine, water, ammonia, or hydrazine nitrate. Only operation with [illegible] per cent hydrazine/32 per cent water was tested for this program, producing 1150°F discharge gas with the following estimated composition at the nominal .055 lb/sec flowrate (36 per cent ammonia dissociation):

Gas	Mol %	Weight %
N_2	19.2	34.1
H_2	24.2	3.1
NH_3	28.6	30.8
H_2O	28.0	32.0

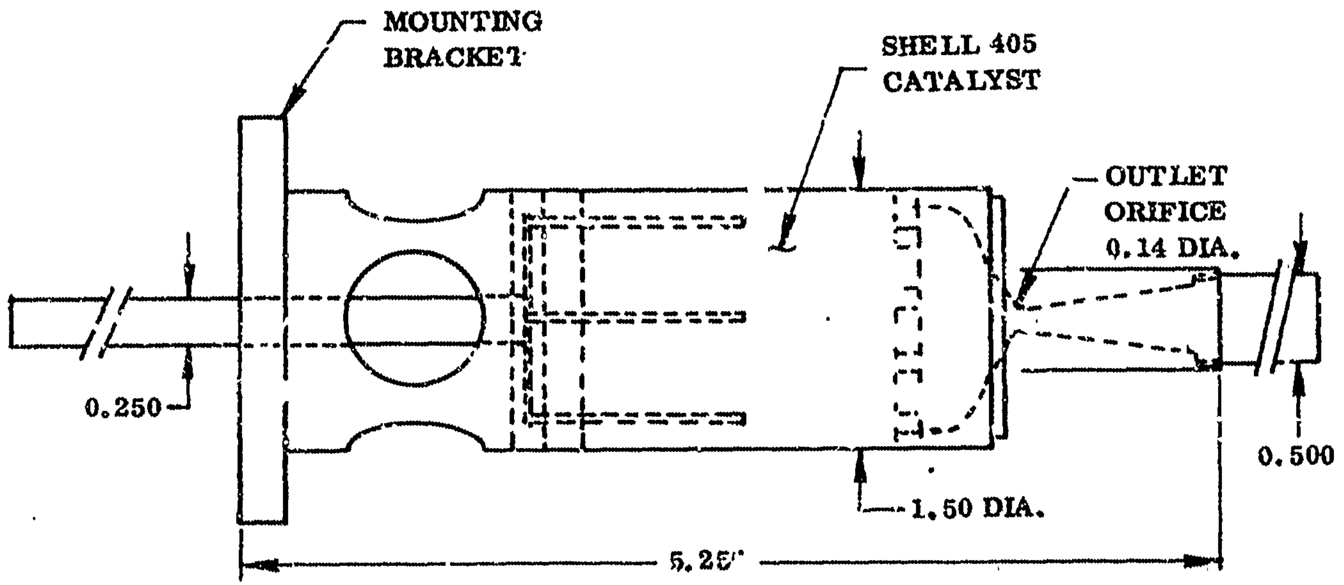

Figure 23. Gas Generator

The gas composition in the propellant tank is different due to condensation of part of the water and ammonia. Composition of the discharge gas also varies with flowrate; higher flows tending to produce more NH_3 and correspondingly less N_2 and H_2.

The GG is of brazed and welded construction, and is made of 300 series CRES except for a pyrolytic graphite heat barrier at the injector and an Inconel catalyst support. The GG performance characteristics are shown in Table VIII.

TABLE VIII

GAS GENERATOR PERFORMANCE

Nominal Flowrate	0.055 lb/sec
Pressure Drop at Nominal Flowrate	63 psid nominal
Maximum Flowrate (choked Flow in Outlet Nozzle)	0.096 lb/sec nominal with 755 psig inlet
Proof Pressure	1840 psig (equiv. to 1320 psig at operating temperature)
Burst Pressure	3300 psig inlet pressure with 1200 psig or less downstream, internal pressure determined by ΔP characteristics
External Leakage	1×10^{-8} sccs at 15 psig, 90 percent GN_2 10 percent He

Vendor development tests included a simulation of the system duty cycle, which verified stable operation at any flowrate from zero to maximum.

5.1.3.5 Warm Gas Relief Valve. The relief valve is shown in Figure 24, and was supplied by Pyronetics, Inc. The valve protects the propellant tank from overpressure in case of regulator malfunction. It is made of stainless steel except for an Inconel poppet and seat, and is welded closed after assembly and adjustment. Its characteristics are given in Table IX.

The first cracking may occur above 1000 psig because the relief outlet is sealed by a 50 psig rupture disc, which can shift the cracking pressure up that amount. After the rupture disc bursts, the relief valve will operate to the specifications tabulated below. The relief valve will not crack if the rest of the LPGG system is functioning normally. The rupture disc may burst during a normal run, however, due to internal leakage past the relief valve poppet, but internal leakage

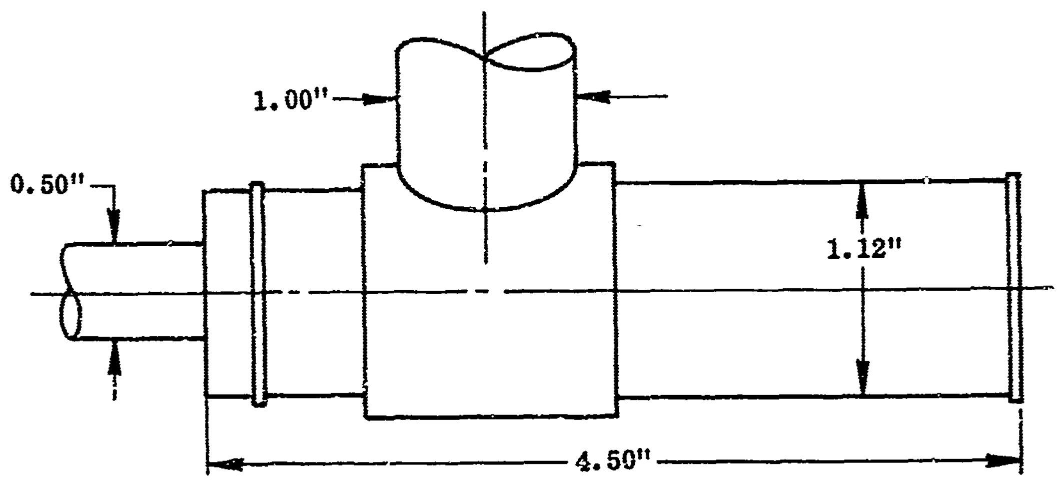

Figure 24. Warm Gas Relief Valve

during the 130 second operating time, at the specified maximum of 0.001 lb/sec., amounts to only 2 per cent of the total system gas generating capacity.

TABLE IX

WARM GAS RELIEF VALVE CHARACTERISTICS

Cracking Pressure	1000 psig nominal
Full Flow	20 lb/min minimum
Full Flow Pressure	1200 psig maximum
Reseat Pressure	930 psig minimum
Ports	0.50 in. welded inlet 1.00 in. welded outlet
Internal Leakage	0.001 lb/sec maximum
External Leakage	1 x 10^{-5} sccs at 25 psia, 90 per cent GN_2/10 per cent He

The warm gas relief valve is the same as the relief valves used in the other two types of pressurization systems under this contract, except for different cracking pressures and material changes for temperature compatibility. This is a new design, but very similar to a hot gas relief valve that Pyronetics makes for Shillelagh.

5.1.3.6 Rupture Disc -- Relief Valve Outlet. The relief valve outlet is sealed by a 50 ± 7 psig rupture disc supplied by Del Manufacturing Co. (see Figure 25).

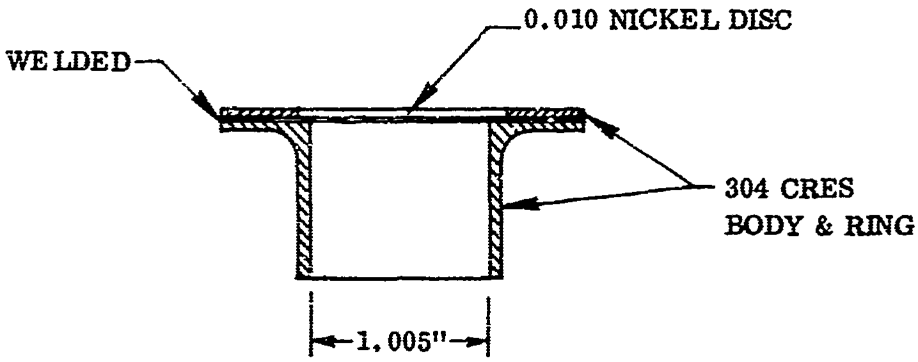

Figure 25. Rupture Disc Relief Valve Outlet

The rupture disc is welded to the relief valve outlet, and it protects the internal valve parts from atmosphere while hermetically sealing the system against leakage past the relief valve poppet during storage. The disc is nickel, giving better reproducibility and greater thickness than a CRES disc. Although it may show visible corrosion during storage, the corrosion is self-limited and will not change the rupture pressure.

5.1.3.7 Propellant Tank Rupture Discs. The aluminum propellant tank is sealed with aluminum rupture discs, manufactured by Del Manufacturing Co., welded to the tank inlet and outlet. The inlet disc ruptures at a differential pressure from the pressurization side of 180 ± 18 psi, assuring the rupturing of the disc by the LPGG in spite of any pressure rise that might occur in the propellant tank during storage. The rupture disc is supported against rupture in the reverse direction, and can withstand at least 500 psi differential pressure from the propellant side. The rupture discs are fabricated from 1100 aluminum alloy.

The outlet rupture disc is designed to rupture at 400 ± 40 psi differential pressure. The 440 psig rupture disc upper limit is equal to 1/4 of the propellant tank burst pressure, and was considered a desirable maximum for long term propellant storage.

5.1.4 SYSTEM FABRICATION. Components were purchased with integral welded inlet and outlet tubes. The tubes were pre-bent and cut to specific dimensions, cleaned, and helium mass spectrometer leak checked by the vendor before delivery. Fabrication at Convair required butting the components together and joining them with weld sleeves. The LPGG subsystem was installed in the frame with support brackets, and was bolted to the propellant tank inlet flange using coatings and adhesive where required for corrosion protection and vibration resistance. The liquid pressure regulator and the catalyst chamber were vacuum baked for one-half hour at 150° F before welding into the system. This eliminated any residual moisture not purged out after vendor wet tests.

The pressure cartridge was installed in the explosive valve. A shorting plug was installed and the cartridge was then potted with RTV-60 silicone rubber to retain the shorting plug and prevent corrosion. Pre-treatment with WD-40 was used to assure clean removal of the silicone rubber when the system is prepared for operation after storage. Figure 26 shows an explosive valve after potting.

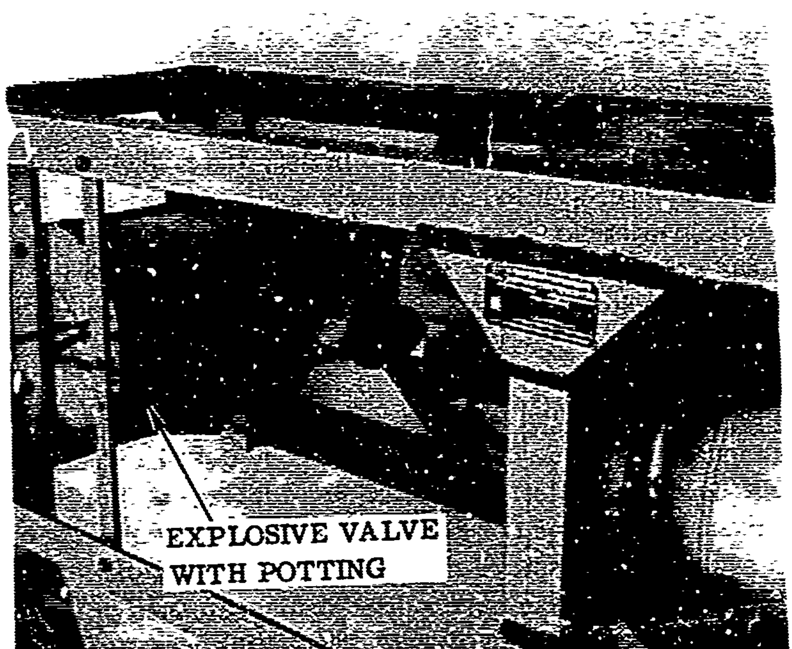

Figure 26. Explosive Valve Potting

5.1.5 TESTS AND RESULTS. Expulsion and vibration tests of the LPGG subsystem were made to provide evidence that the system will perform in compliance with the contract requirements. The test results also provide a baseline for future comparison when the delivered systems are tested after storage.

Four expulsion tests were performed with the LPGG, two utilizing the SFO tank and two with the RD tank. Vibration at 35 cps and 1.4 g was performed for one hour in each of three axes while the LPGG was connected to the RD tank. Either the SFO or the RD tank was loaded with MHF-5, while the LPGG bellows tank was loaded with 68 per cent N_2H_4/32 per cent H_2O for all tests. The test results were generally satisfactory except for a regulator failure requiring a minor component design change. When used with the SFO tank, the LPGG exhibited wider variations in tank pressure and higher gas requirements than anticipated. This was attributed to apparent dissolving of the ammonia from the pressurizing gas into the MHF-5 along with high heat transfer. Both are aggravated by absence of an inlet diffuser. Results of the expulsion tests are shown in Figures 27 through 30, and further discussion of the tests and results is given in the following paragraphs.

5.1.5.1 First Expulsion Test (SFO In Propellant Tank). Test results and data are shown in Figure 27. MHF-5 was loaded while the test specimen was on a platform scale. Scale accuracy was approximately ±1/2 pound, and tare weight variations were estimated at ±1/2 pound . Further error was probably introduced on this occasion by the effects of wind and rain on the test specimen and on balance weights.

Weighing would not have provided acceptable accuracy for loading of the hydrazine/water blend, so a rod was inserted in the gas-side tube during filling to measure the bellows position. The bellows was filled to within one inch of the fully extended position, providing 6 pounds of expellable hydrazine/water if the tank was to conform to the specification minimum. Actual expellable volume of the test article was not measured directly, but was calculated from blueprint dimensions and from measurement of actual bellows stroke. This was found to be 262 in^3, or 10 in^3 above specification minimum. The calculated amount expellable for this test was 6.36 pounds, plus a calculated 0.9 pound residual.

The test was initiated by a manual switch which supplied 5 amps to one of the bridgewires in the pressure cartridge of the explosive valve. Regulator outlet pressure jumped to a normal value without overshoot, but dropped 65 psi in the next two seconds and did not fully recover for ten seconds. This was initially attributed to two-phase flow due to entrained pressure cartridge gas, since post-test inspection revealed that the explosive valve piston seal was not effective. However, the disturbance duration was rather long for the small amount of gas available, and it is more likely that this anomaly was caused by partial deflection of the regulator pin which failed during the third test.

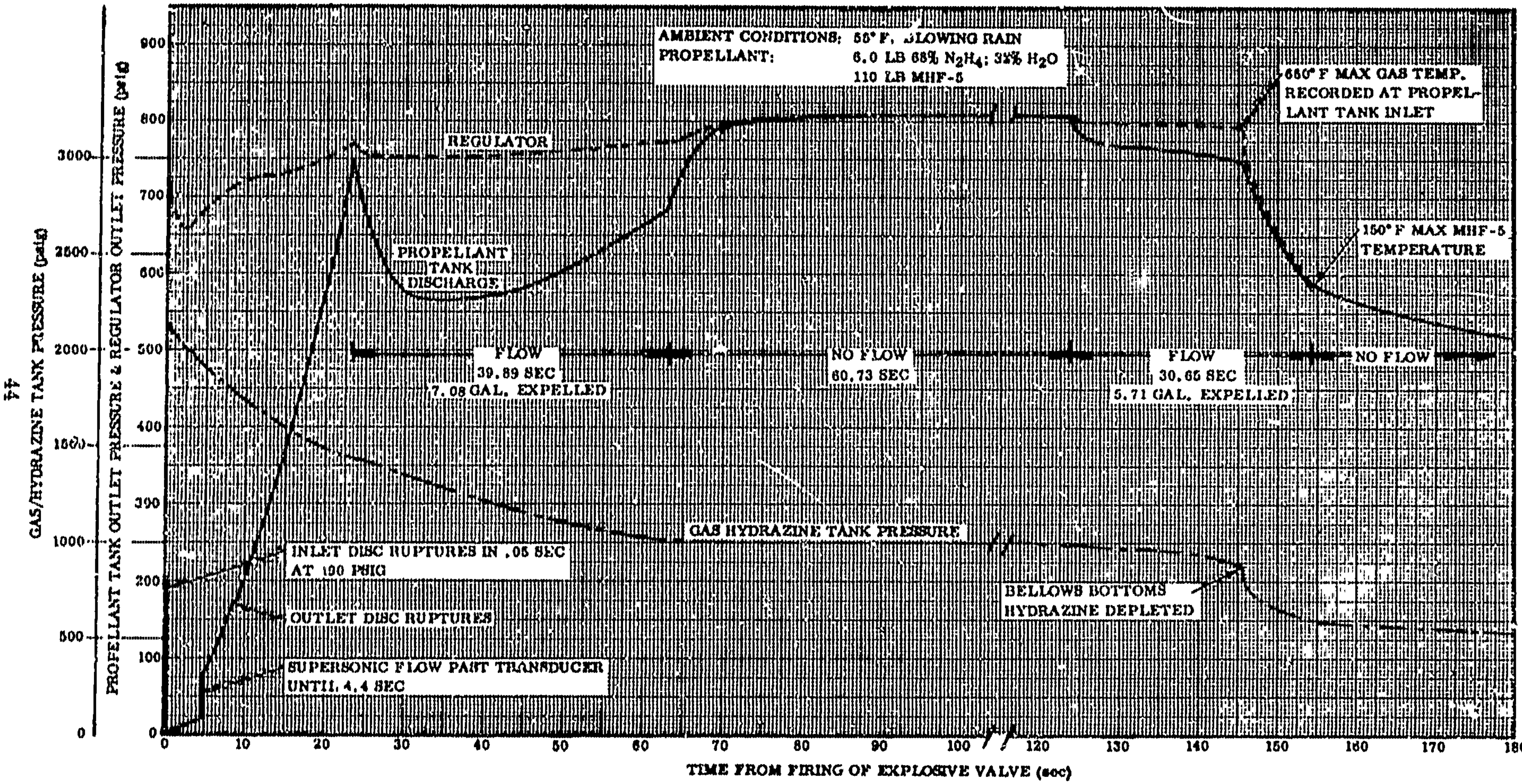

Figure 27. Liquid Propellant Gas Generator Test 1 With SFO In Propellant Tank

The inlet rupture disc opened within the 180 ± psid limit, but the outlet disc ruptured below its 400 ± 40 psid specification. This was attributed to weld stresses which had partially weakened the disc. This anomaly was later resolved by providing a small machined lip to which the disc could be welded. This reduced the heat input required for welding and thereby minimized thermal effects.

Gas requirements were much higher than predicted, as evidenced by: a) Time to reach 707 psig was 22.4 sec instead of the 6 sec predicted, b) Hydrazine supply was depleted before the end of the test, while a surplus of 15 to 20 per cent had been predicted, and c) Tank pressure dropped 140 psi below the desired value during the first part of expulsion, indicating that the gas generator flowrate was not sufficient to meet the demand. The gas generator output reached a calculated value of 0.085 lb/sec at a point 33 sec after firing of the explosive valve. The predicted value was about 0.048 lb/sec. Multiplying 0.085 by the ratio of desired/actual absolute tank pressure indicated that an output of 0.105 lb/sec would have been required to maintain proper pressure. This was more than twice the predicted requirement. Heat transfer was probably high because there is no inlet diffuser and the incoming gas penetrates several inches below the propellant surface during the first part of a run. But the LPGG test results cannot be explained by heat transfer and condensation alone, even if it is assumed that the gas is cooled to propellant temperature and that the condensations of water and ammonia instantaneously go to equilibrium values for that temperature. The data indicates that essentially 100 per cent of the water and ammonia "disappear" in the first 35 seconds of a run. The ammonia, because it has a vapor pressure of 129 psia at 70° F, cannot all be condensing, so it was concluded that the uncondensed ammonia dissolved in the propellant. This conclusion was supported by the observed erratic behavior of the liquid level gage on the facility receiver tank toward the end of the run, which was probably caused by agitation from two-phase flow entering the receiver. The pressure trace recorded upstream of the discharge orifice was smooth, which indicated that the flow was still all liquid at that point, so the ammonia was apparently flashing out of solution in the low pressure region downstream of the orifice. This phenomenon could be disastrous to a rocket engine, where gas bubbles forming in fuel injector passages would throttle the flow and cause an oxidizer rich condition.

Post-test inspection of the explosive valve showed that the Teflon lip seal on the piston was not effective and had allowed cartridge gases to leak into the hydrazine/water stream after actuation. Although this caused no apparent ill effect, it was considered undesirable and all remaining valves were reworked to replace the seal with a Viton O-ring. All reworked valves functioned properly and retained the cartridge gases.

5.1.5.2 Second Expulsion Test (SFO In Propellant Tank). Test results for this test are shown in Figure 28. The test was identical to the first expulstion test except that the amount of hydrazine/water loaded was increased by 1/2 pound. The 6.5 pound

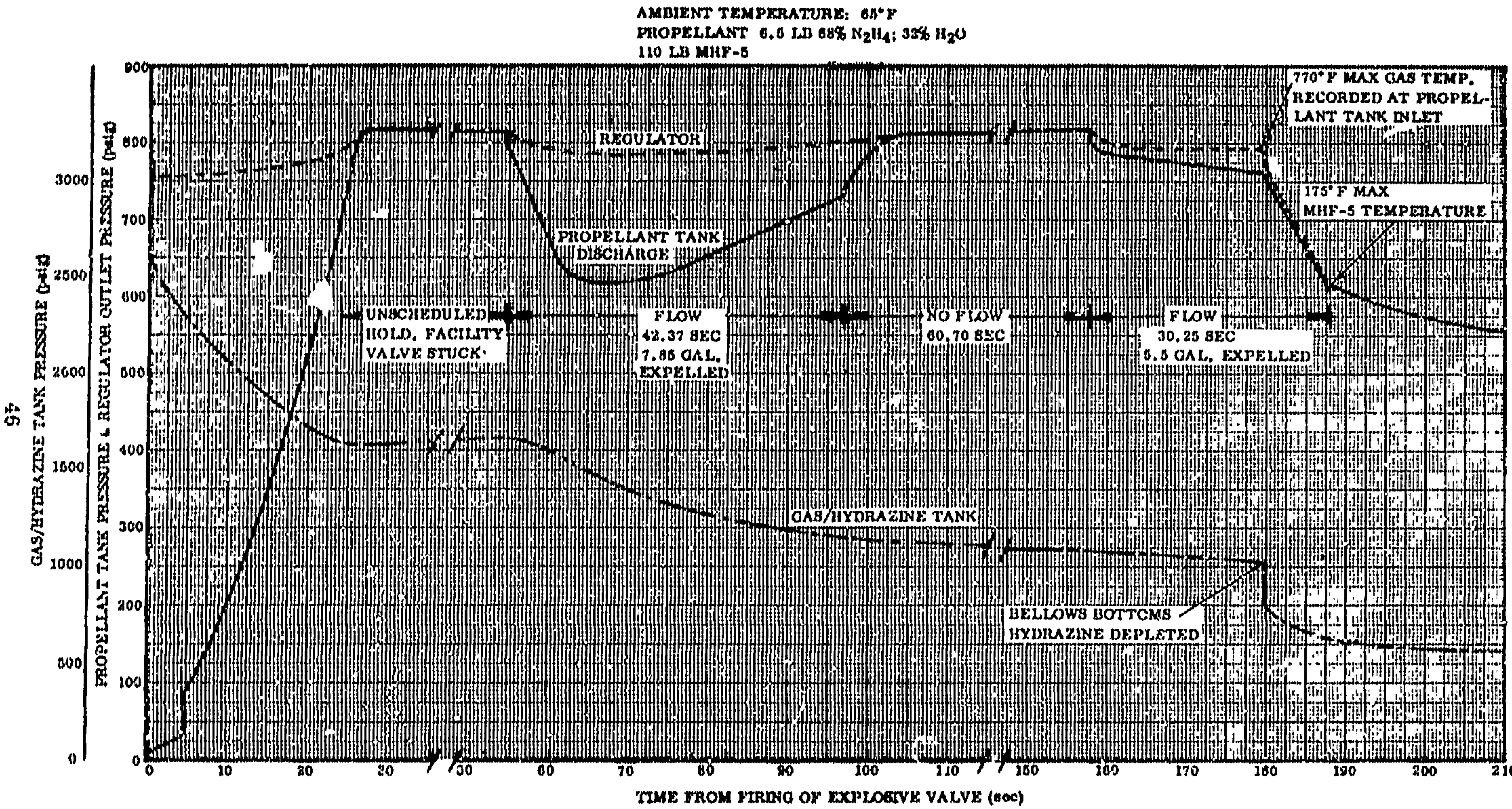

Figure 28. Liquid Propellant Gas Generator Test 2 With SFO In Propellant Tank

nominal loading used in this test (bellows filled to within 1/2 inch of full extension) represents the maximum loading for deliverable systems, allowing for liquid expansion at 165° F.

Regulator outlet pressure showed a brief spike to 1300 psig when the explosive valve was fired, but it immediately returned to normal. The facility valve controlling propellant flow from the SFO tank failed to open on command at 700 psig tank pressure. Pressure leveled off at 817 psig (regulator lockup) during the 30 seconds required for corrective action. The test then proceeded with essentially the same results as the first test. Hydrazine/water depletion occurred as in the first test, the extra loading having been offset by the extra 30 second hold.

5.1.5.3 Third Expulsion Test (RD In Propellant Tank). Prior to this test the LPGG system was vibrated in a loaded condition at 1.4 g and 35 Hz for 60 seconds in three orthogonal axes. The results were satisfactory, with no resonance or amplification found. The first attempt to perform a post-vibration expulsion test resulted in failure of the pressure regulator. The explosive valve operated properly but no pressure was recorded downstream of the pressure regulator. The test was terminated and the gas/hydrazine tank was vented and drained. Upon removal and disassembly of the regulator, the cause was found to be failure of the pin which transmits the force from the spring and piston to the ball. The pin which failed is shown in Figure 29.

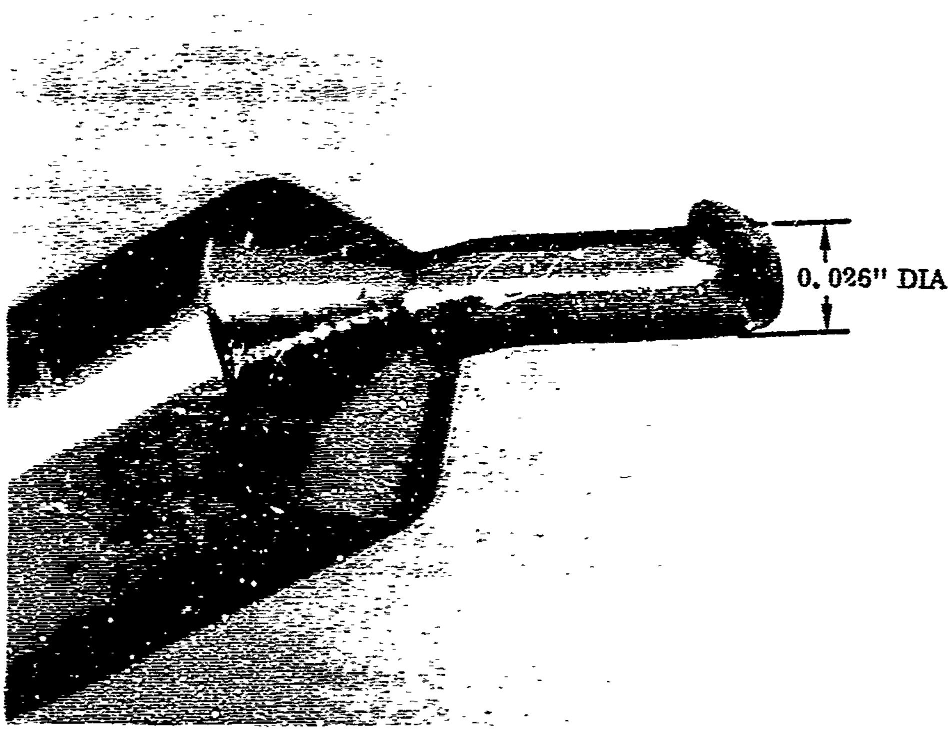

Figure 29. Regulator Pin After Failure

When downstream pressure is low the pin pushes a ball off the seat, increasing flow through the regulator. High downstream pressure acts on the spring and piston to retract the pin, allowing the ball to return to the seat and stop flow. In the prestart condition, when the ball is lifted off the seat, the incoming fluid applies a shock load to the ball at the time the explosive valve opens. This load was transmitted to the pin, which bent and slid off to the side of the ball, letting the ball move to the seat and prevent flow. The regulator had been subjected to several previous slam starts with no apparent harm, but was not disassembled for inspection between tests. It is possible that previous starts had created a slight deformation of the pin, causing it to contact the ball slightly off center, and the resulting side load in the third test caused failure.

A new pin was made, with the diameter of the failed region increased from 0.026 to 0.036 inch. This increases compressive strength by a factor of approximately 1.9, bending strength by 2.6, and buckling strength by 3.7.

The test regulator was reassembled and tested with GN_2 because it was still welded to the catalyst chamber and a water flow test might have harmed the catalyst. Regulation was satisfactory but leakage at lockup was 0.2 scfm GN_2. The pin which failed had scratched the seat. This was considered acceptable. Repair of the seat would have required cutting welds on the regulator and system, and rewelding and retest after repair, which would have postponed the expulsion test.

The third expulsion test was performed successfully, as shown in Figure 30. Leakage past the scratched regulator seat was greater than predicted, however, and tank pressure was limited by intermittently opening a facility vent valve. The warm gas relief valve would have opened automatically at approximately 1050 psig if pressure had been allowed to continue rising. This pressure would have gone off the scale of the existing instrumentation.

The rupture disc on the relief valve outlet was bulged but not ruptured by this test, showing that valve leakage was very low.

Pressure regulation and hydrazine/water usage corresponded closely to predicted values in this test with the RD tank, confirming the conclusion that deviations with the SFO tank were caused by the combination of exposed liquid surface and no inlet diffuser.

5.1.5.4 Fourth Expulsion Test (RD In Propellant Tank). Another LPGG expulsion test was performed as a final proofing of the RD tank design. LPGG liquid loading and charge pressure were those selected for the deliverable RD systems. Test results are shown in Figure 31. The regulator seat was repaired before this test, eliminating the pressure rise encountered in the previous test.

All test results were satisfactory, and the hydrazine/water supply was more than adequate. When the system was vented after the test, sufficient hydrazine/water remained for 15 additional seconds of gas generation.

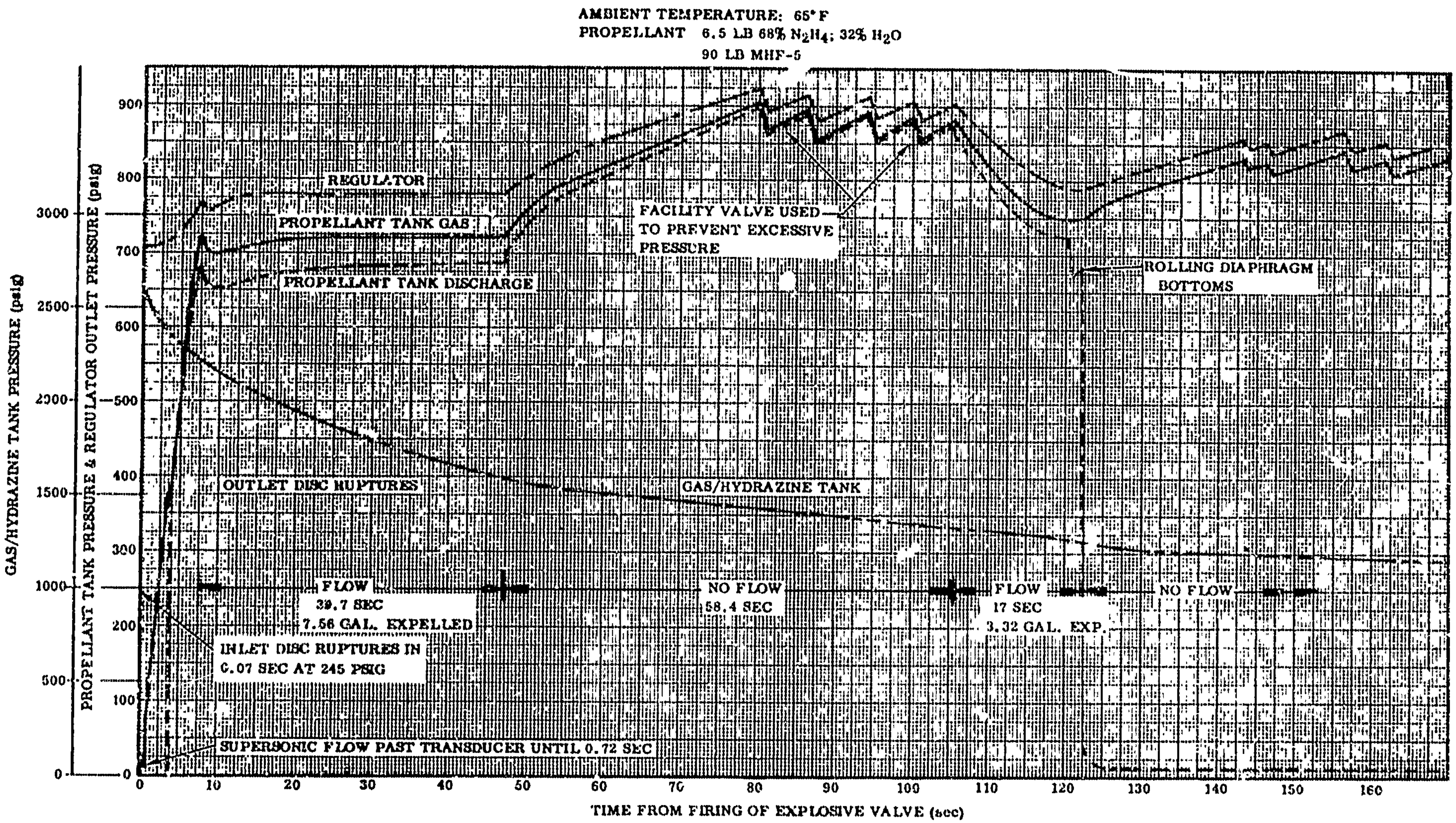

Figure 30. Liquid Propellant Gas Generator Test 3 With RD In Propellant Tank

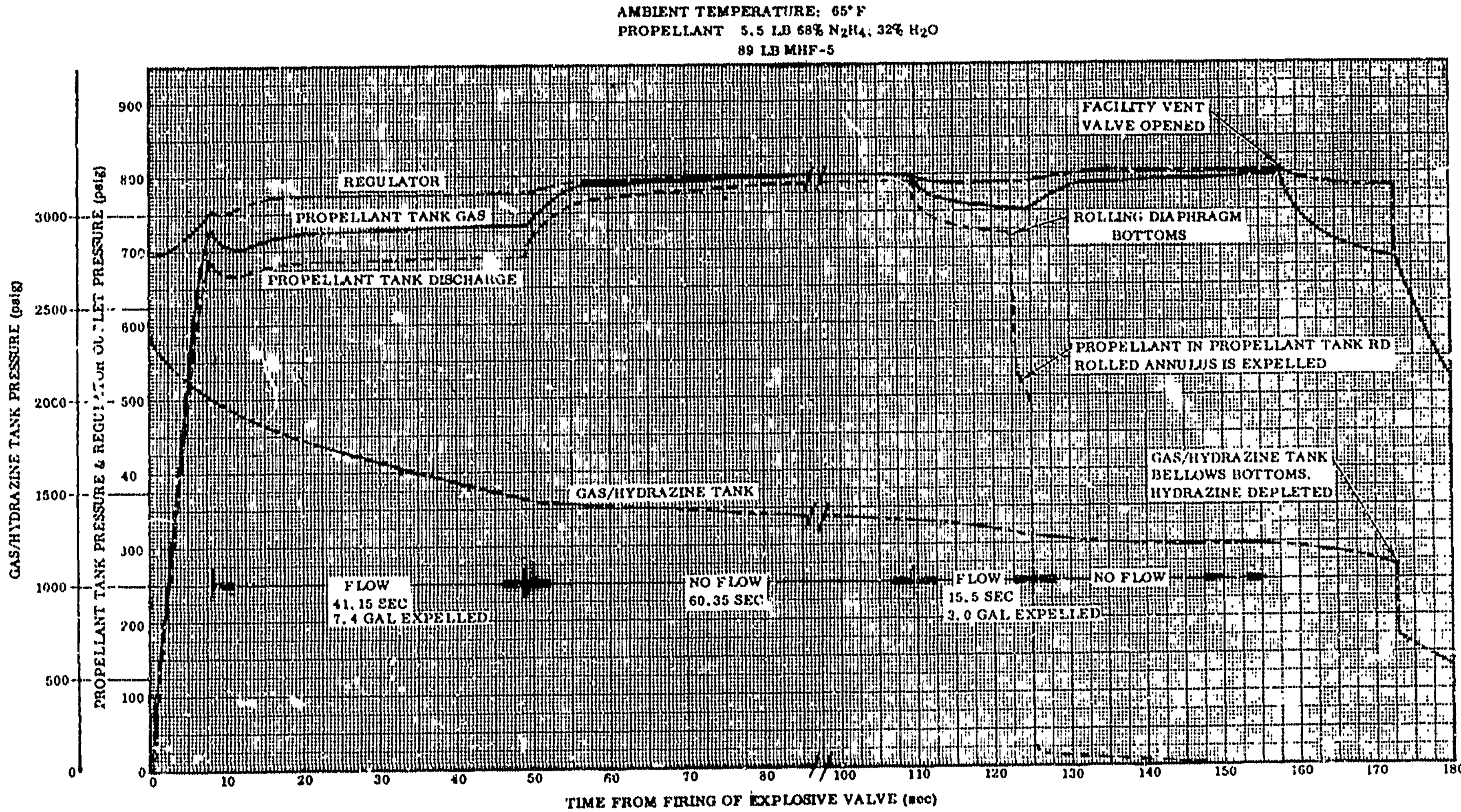

Figure 31. Liquid Propellant Gas Generator Test 4 With RD In Propellant Tank

5.2 SOLID PROPELLANT GAS GENERATOR (SPGG)

5.2.1 DESIGN CRITERIA. The SPGG subsystem was designed, tested, and fabricated to the same criteria as described in Section 5.1 for the LPGG.

5.2.2 SYSTEM DESCRIPTION. The SPGG subsystem is shown in Figure 32. It consists of an SPGG assembly, a pressure regulating relief valve, and a rupture disc on the relief valve outlet.

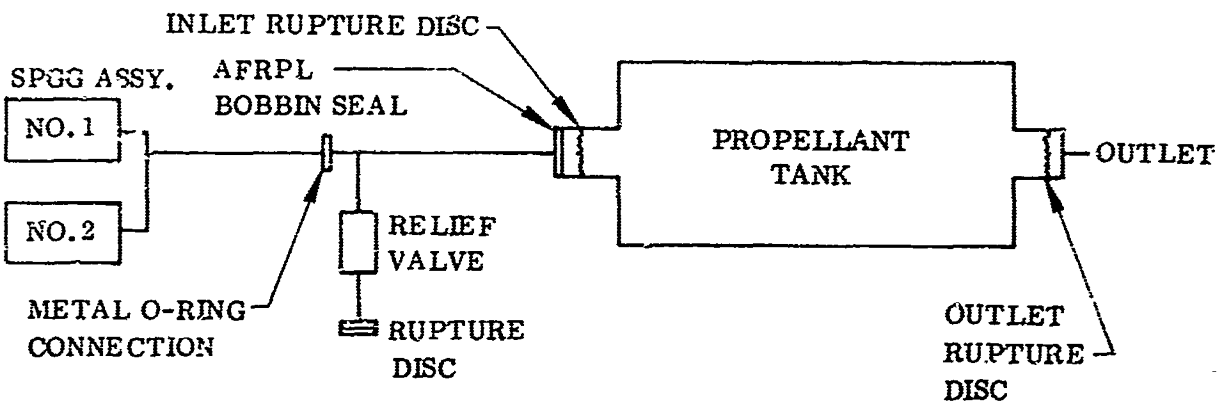

Figure 32. SPPS (Tank/SPGG) Schematic

Figure 33 shows a system ready for storage.

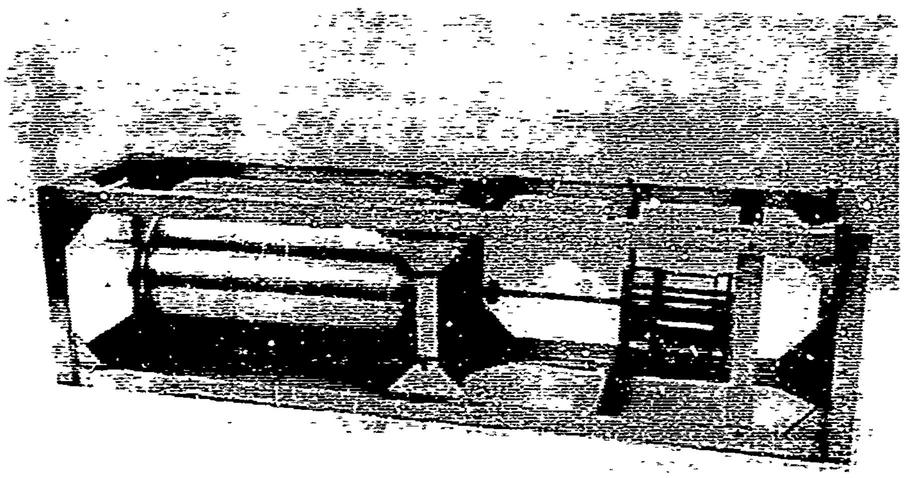

Figure 33. SPPS (SFO/SPGG) Ready for Five Year Storage

The propellant tank rupture discs are also shown and discussed here, although not part of the SPGG subsystem, because SPGG operating pressure affects the choice of rupture pressures.

The SPGG assembly consists of two identical gas generators connected to a common m[illegible] a single outlet. The second gas generator is fired approximately one [illegible] after burnout of the first gas generator. The gas output is greater than required, and the surplus is vented by the relief valve to maintain the desired nominal tank pressure of 700 psig.

The use of a relief valve to regulate the pressure simplified the development of the SPGG system because it eliminated the necessity to develop a gas generator with a flowrate precisely matched to propellant tank demands. Instead, the gas generator is oversized and the surplus flow is vented by the relief valve. This also eliminated the large number of test firings that would be required to tailor the gas generator. A relief valve is also required to be representative of operational systems which must operate at -65 to 165°F. Solid propellant burn rates and burn times vary considerably with change in temperature. An operational gas generator sized to give adequate flow at -65°F would have excessive output at 165°F, requiring a relief valve to protect the propellant tank from overpressure.

The propellant tank is isolated by rupture discs at its inlet and outlet. The inlet disc ruptures and admits pressurizing gas when the SPGG pressure exceeds tank pressure by 180 $\pm$ 18 psid. The outlet disc ruptures when tank pressure reaches 400 $\pm$ 40 psig. Thereafter, propellant flow is controlled by a downstream facility valve.

The SPGG system is designed for five year zero-maintenance storage at 85 per cent humidity, at from -65 to 165°F. The components and tubing, except as noted below, were all metal and welded together to provide hermetic sealing for storage. The connection designs below have been verified by existing gas generators which have been stored successfully for five years.

a. SPGG-to-Propellant Tank: A flanged connection using an AFRPL bobbin seal as described in Reference 11. This seal isolates the inside of the SPGG discharge tubing and relief valve from atmosphere during storage, and prevents external leakage of hot gas during operation.

b. SPGG-to-Relief Valve: Flanged connection using an Inconel O-ring with silver plating. It performs the same function as the AFRPL bobbin seal.

c. Manifold-to-Gas Generator: Each of the two gas generators is sealed to the manifold with a CRES O-ring, protected from hot gas with zinc chromate putty. Ambient and hot gas sealing with metal O-rings is established practice on the Sidewinder gas generator, which has five year storability.

d. Manifold-to-Propellant: The propellant chamber is isolated from downstream by a burst disc, retained in a metal-to-metal crush connection. This isolates the propellant during storage, improves ignition, and protects the Number 2 gas generator from ignition by Number 1 gas generator discharge. There is no external leakage path from this connection.

e. Propellant-to-Atmosphere: The aft closure is sealed by a silicone rubber O-ring. It is identical to that used for Terrier, which has five year storability. This O-ring is exposed to pressure, and to gas of moderate temperature, during operation, as in Terrier. The igniter is sealed by a copper crush washer, similar to Sidewinder gas generator igniter installation.

The relief valve is all-metal and all-welded. Its relief port is hermetically sealed during storage with a welded burst disc to protect internal parts.

5.2.3 COMPONENT DESCRIPTIONS

5.2.3.1 Solid Propellant Gas Generator (SPGG) Assembly. The SPGG assembly was supplied by Amoco Chemical Corp., and is illustrated in Figure 34. It consists of two identical gas generators connected to a common manifold which has a single outlet. Each gas generator has the characteristics given in Table X.

The propellant charge is end-burning and restricted on its outside diameter and on one end. The initial grain surface is grooved to provide greater surface during ignition. This results in rapid pressurization of free volume and in compensation for heat losses. The grain is the same as in the Advanced Terrier and was made with the same tooling. The restrictor material, CAP, is also the same as was used in Advanced Terrier production at Amoco. The grain is supported by flexible rayon felt to prevent excessive thermal stresses in the propellant during temperature cycling, and is supported axially by bonding to the end plate. The case is insulated with phenolic-filled asbestos. The exhaust gases pass through a filter adapted from Sidewinder which complies with NOTS XS-186. The gases then pass through a discharge orifice where sonic flow occurs, making the discharge rate independent of downstream pressure. The igniter is a McCormick Selph M-75 cartridge with a secondary basket loading of 3 U.S. Flare boron-potassium nitrate 2L ignition pellets (3.2 gm) and 5 Amoco JT-1 propellant pellets (3.0 gm). The cartridge has

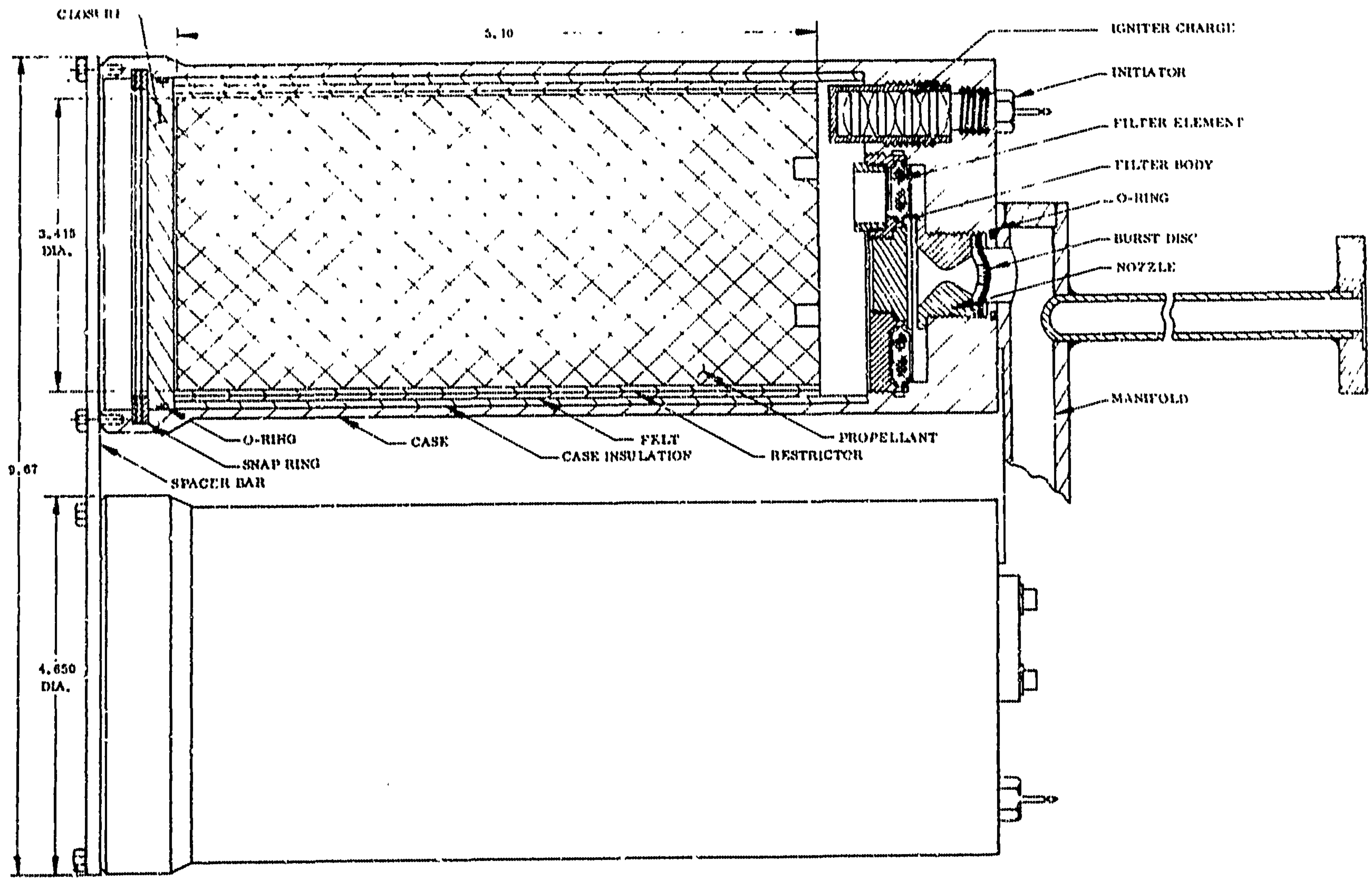

Figure 34. Solid Propellant Gas Generator Assembly

TABLE X

GAS GENERATOR CHARACTERISTICS

Propellant	LFT-3
Propellant Weight	2.54 lb plus 0.18 lb restrictor
Discharge Rate	0.05 lb/sec at 70°F
	0.0485 lb/sec at 50°F
	0.052 lb/sec at 90°F
	0.053 lb/sec at 100°F
	±13% instantaneous
	±5% average
Operating Time	49 sec at 70°
	50.5 sec at 50°F
	47.5 sec at 90°F
	46.5 sec at 100°F
	±8.7% tolerance
Chamber Pressure	1480 psia when preconditioned at 70°F
Grain Diameter	3.415 in
Grain Length	5.10 in
Case Material	CRES
Storage Temperature	-65 to +165°F
Firing Temperature	+40 to +100°F

The characteristics of Amoco LFT-3 propellant are as follows:

Type	Ammonium nitrate, thermoplastic binder	
Flame Temperature	1800°F	
Gas Molecular Wt	20.1	
Specific Heat Ratio	1.28	
Specific Heat at 1800°F	0.446 Btu/lb°F	
C*	3,650 ft/sec	
Grain Density	0.056 lb/in.^{3}	
Burn Rate at 70°F & 1000 psia	0.079 in./sec	
Pressure Exponent, n	0.50	
Temperature Coeff., K	0.25%/°F	
Const. Press. Temp. Coeff., p	0.12%/°F	
Gas Cleanliness	2.48 gm. solids/kg gas	
Gas Composition	Mol %	Wt. %
CO	23.0	32.0
CO_2	10.3	22.6
H_2	28.6	2.9
H_2O	21.2	19.0
N_2	16.9	23.5

parallel redundant bridgewires and the recommended firing current is 5 amps, applied pin-to-case. Resistance is 1.0 ± 0.2 ohms. The gas generator cases, manifold, and discharge tube are made of stainless steel. The complete assembly weighs approximately 35 pounds.

Although the unit is storable at -65 to +165°F, its operation temperature limits are +40° to +100°F. These limits were selected as representing a reasonable ambient range. The narrow range was used to minimize development cost, since a large number of firings would be required to develop and verify an igniter which gave reliable ignition at -65°F but didn't produce overpressure at 165°F. Amoco verified the storage and operating range by cycling units to -65 and +165°F, and by firings at 45 to 90°F.

5.2.3.2 Pressure Regulating Relief Valve. The relief valve is shown in Figure 35 and was supplied by Pyronetics, Inc.

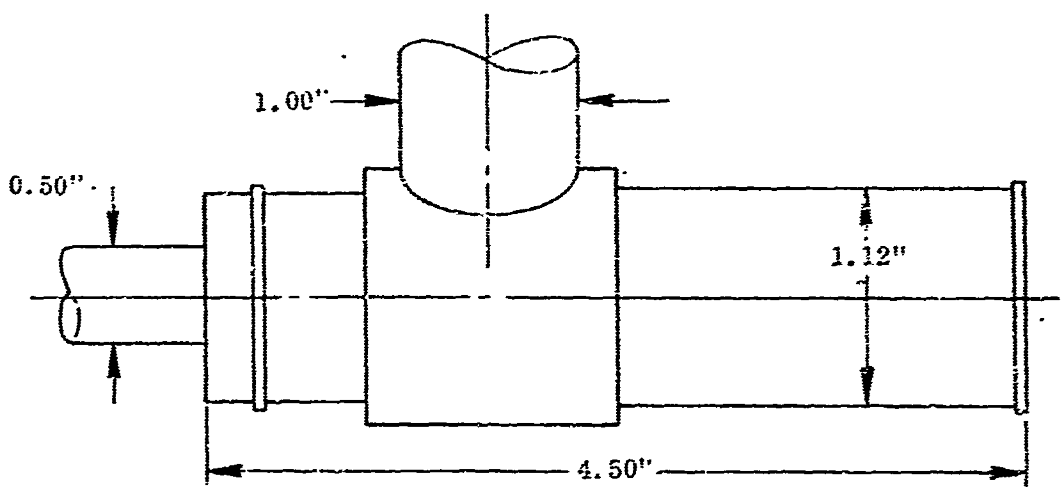

Figure 35. Pressure Regulating Relief Valve

This valve regulates propellant tank pressure by venting surplus SPGG output. It is also a safety relief valve with a flow capacity four times as large as normal SPGG output. The housing is stainless steel, welded closed after assembly and adjustment. The poppet and seat are made of molybdenum TZM alloy to withstand gas temperature and erosion. The reference spring is made of Inconel, with insulators and coatings for further heat protection. The specified valve characteristics are as follows:

Normal relief flow	Up to .06 lb/sec at 707 ± 35 psig
Emergency flow	0.20 lb/sec at 1000 psig max.
Reseat pressure	650 psig minimum
External leakage (max)	1 x 10^{-9} sccs at 25 psia, 90 per cent N_2/10 per cent He
Internal leakage	0.001 lb/sec maximum
Ports	0.50 in. welded inlet 1.00 in. welded outlet

Cracking pressure is unspecified to avoid overdefining the parameters, since pressure regulation at normal flow is of greater concern.

This relief valve is the same as those used in the other two types of pressurization systems under this contract, except for pressure settings and material upgrading for high temperature.

5.2.3.3 Rupture Disc - Relief Valve Outlet. The relief valve outlet is sealed by a 50 ± 7 psig rupture disc, identical to the one used with the other pressurization systems, and described in Section 5.1.3.6. Although the disc may show visible corrosion during storage, the corrosion is self limiting and will not change the rupture pressure.

5.2.3.4 Propellant Tank Rupture Discs. The aluminum propellant tank is sealed with aluminum rupture discs identical to those used with the LPGG, described in Section 5.1.3.7.

5.2.4 SYSTEM FABRICATION. During the SPGG system assembly, the relief valve, relief valve rupture disc, and inlet fitting were first welded into a subassembly. The SPGG was received from the vendor with solid propellant already loaded and leak checked. The preassembled subassembly and the SPGG, with their applicable brackets, were bolted into the frame with the SPGG outlet flange connected to the propellant tank inlet. The two SPGG igniters, complete with shorting spring, were installed. The external surfaces of igniters and shorting springs were then sprayed with WD-40, wiped dry, and potted with GE RTV-60 silicone rubber

The potting prevents corrosion and assures retention of the shorting spring, while the slight residual of WD-40 limits the adhesion and allows clean removal when preparing for the expulsion test.

5.2.5 TESTS AND RESULTS. Three expulsion tests were performed with the SPGG: two using the SFO tank and one with the RD tank. The fluid expelled was water in the first test with the SFO tank, and MHF-5 in the remaining tests. The solid propellant grain operated satisfactorily, but a tendency toward slant burning in the latter half of operation produced a slightly progressive output, and also produced operating durations on the low side of the tolerance band. High heat transfer and gas solubility in the SFO tank resulted in pressure rise times of 10 to 11 seconds longer than predicted, and a corresponding SPGG burnout before the end of the first expulsion cycle. Although further development would be justified for an actual rocket feed system, the SPGG system is entirely satisfactory for the storability demonstration purpose of this contract. The pressure regulating relief valve worked well during the first half of each test, but exhibited a tendency to stick after the one minute pause, apparently due to deposits. Design changes reduced this tendency but did not eliminate it. The system would still be safe if the relief valve stuck completely during the second expulsion, since extrapolation of test results indicated the maximum tank pressure before SPGG burnout would only reach 1000 psig, while tank proof pressure is 1320 psig.

Test results are shown in Figures 36 through 38, and discussed further in the following paragraphs.

5.2.5.1 First Expulsion Test (SFO in Propellant Tank). Results and data are shown in Figure 36. Water was expelled from the SFO tank in the first test to verify the system before introducing the added hazard of MHF-5. The Number 1 SPGG was ignited and the inlet rupture disc opened slightly above specification due to the high strain rate. The outlet rupture disc opened below specification due to partial yielding from welding (later cured by the revised weld method). Pressure build-up took twice as long as predicted, indicating very high heat transfer and possibly some of the CO_2 in the gas going into solution in the water. Knowing the pressure, volume, and nominal SPGG output, and assuming condensation of all the water vapor in the gas, the calculated ullage gas temperature was 90 to 95°F at 15 seconds after ignition and 150 to 155°F at 32 seconds. An extremely high degree of mixing with the liquid would be required to produce temperatures this low when the inlet gas is approximately 1600°F, suggesting loss of some gas into solution as a contributing factor.

The facility valve controlling water outflow was opened when tank pressure reached 670 psig. The gas requirement was so high that the SPGG could not produce the desired 700 psig, even though the relief had not opened yet and all gas was going to the tank. The relief valve opened later and went through a 50 psi blowdown before reseating, largely due to the overpressure caused before opening by the relief valve rupture disc. SPGG duration was two to three seconds shorter than nominal, and pressure build-up had taken longer than expected, so SPGG

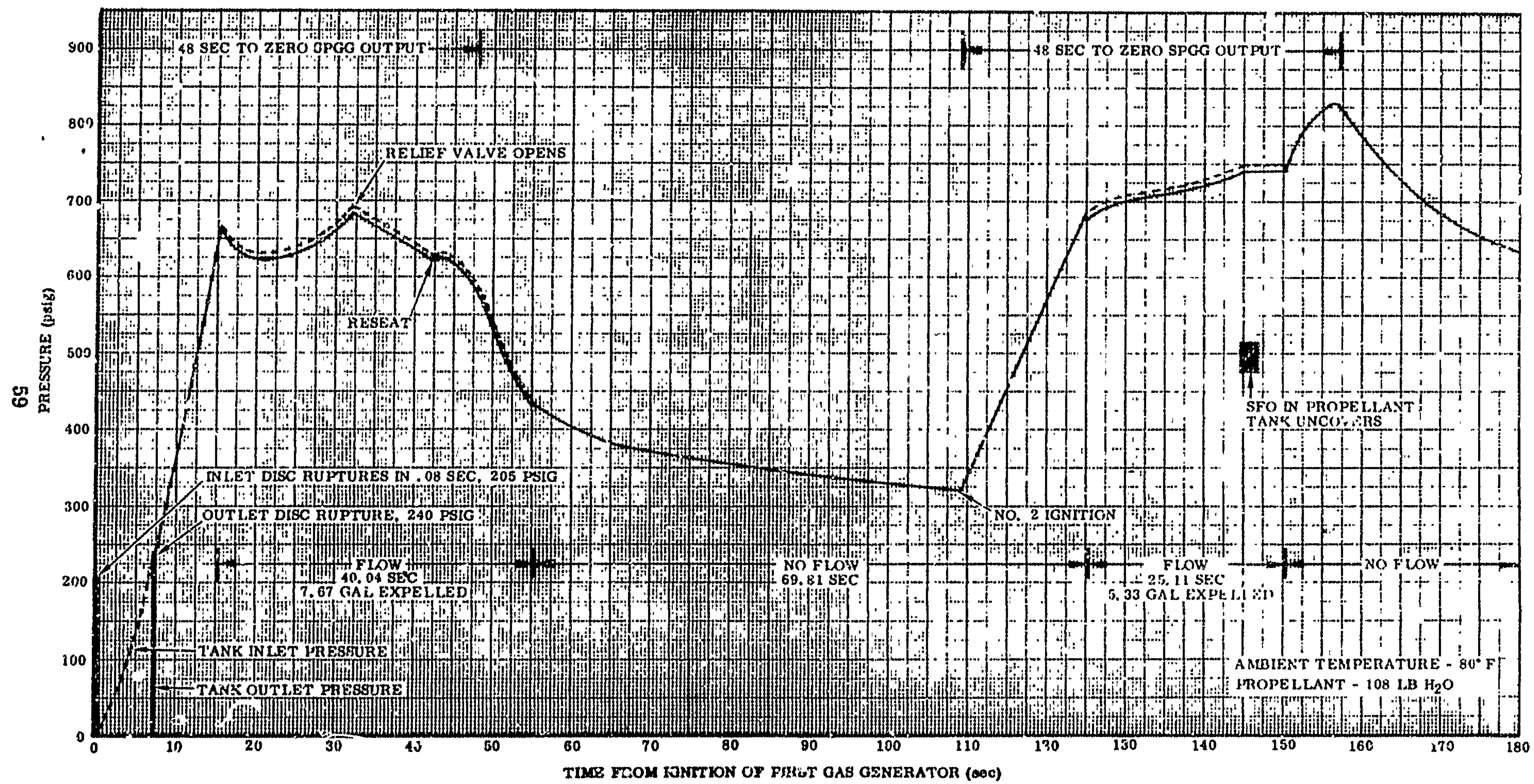

Figure 36. Solid Propellant Gas Generator Test 1 With SFO In Propellant Tank

burnout occurred before the end of the 40 second expulsion cycle. After the pause, the Number 2 SPGG was ignited and the second expulsion cycle was successfully performed. However, data indicated that the relief valve was stuck shut.

After the test the relief valve was checked with GN_2. Pressure was raised to 850 psig without obtaining cracking, although cracking should have occurred at 660 to 670 psig. Rather than go to a higher pressure to find the cracking point, the valve was disassembled to preserve any evidence of the cause for sticking. No obvious explanation was found. Soot deposits on the poppet were soft and oily and did not cause resistance to movement. The spring showed no evidence of dirty gas or heat.

Deposits on the seat were fairly heavy and may have bonded the poppet to the seat, although they gave no indication of adhesiveness when examined at ambient temperature. Appreciable drag could be felt from the piston ring on the poppet which was used to prevent hot gas leakage into the spring cavity. This drag would reduce the sensitivity of regulation by the valve and contribute to any sticking tendency. It was decided to delete this ring on the remaining valves, since the sealed spring cavity will effectively prevent leakage without the ring. A re-check of the thermal analysis showed some possibility of differential expansion causing the poppet to bind under transient conditions, so the clearance was increased approximately 0.003.

The SPGG was disassembled after the test. Appearance was normal, but there was some evidence of slant burning which gives progressive output.

5.2.5.2 Second Exp[illegible] Test (SFO In Propellant Tank). Results of the second test are shown in Figure [illegible] MHF-5 was successfully expelled, but high gas requirements again kept the pressure below 700 psig. Pressure build-up was approximately 12 percent slower than it had been with water on the first test. Lower SPGG output, due to lower ambient temperature, can only account for half of this difference, so it appears that heat transfer and/or solubility of gas is greater with MHF-5. Flow was not initiated on this test until the relief valve rupture disc was heard to open. The long pressure build-up time again resulted in SPGG burnout before the 40 second expulsion was complete. A new relief valve was used, incorporating the changes from the first test, and it gave smooth response.

The outlet pressure transducer, which gives a sharp transient indication of the start and stop of liquid outflow, failed to operate during the second test. The sequence of events at the start of the second outflow could not be determined with certainty from the inlet pressure transducer alone. Relief valve operation was satisfactory, but a slight tendency to stick was evident from discrete slope changes in the pressure trace.

5.2.5.3 Third Expulsion Test (RD In Propellant Tank). MHF-5 was expelled from the RD tank in the third test, with the results shown in Figure 38. This was the only inverted test in the test program. It was performed with the SPGG on the bottom and propellant expelled upward as shown in Figure 39.

Pressure decay of the SPGG during the one minute pause would cause reverse rolling of the RD if any gas was on the propellant side. Inverted firing expels any gas at the

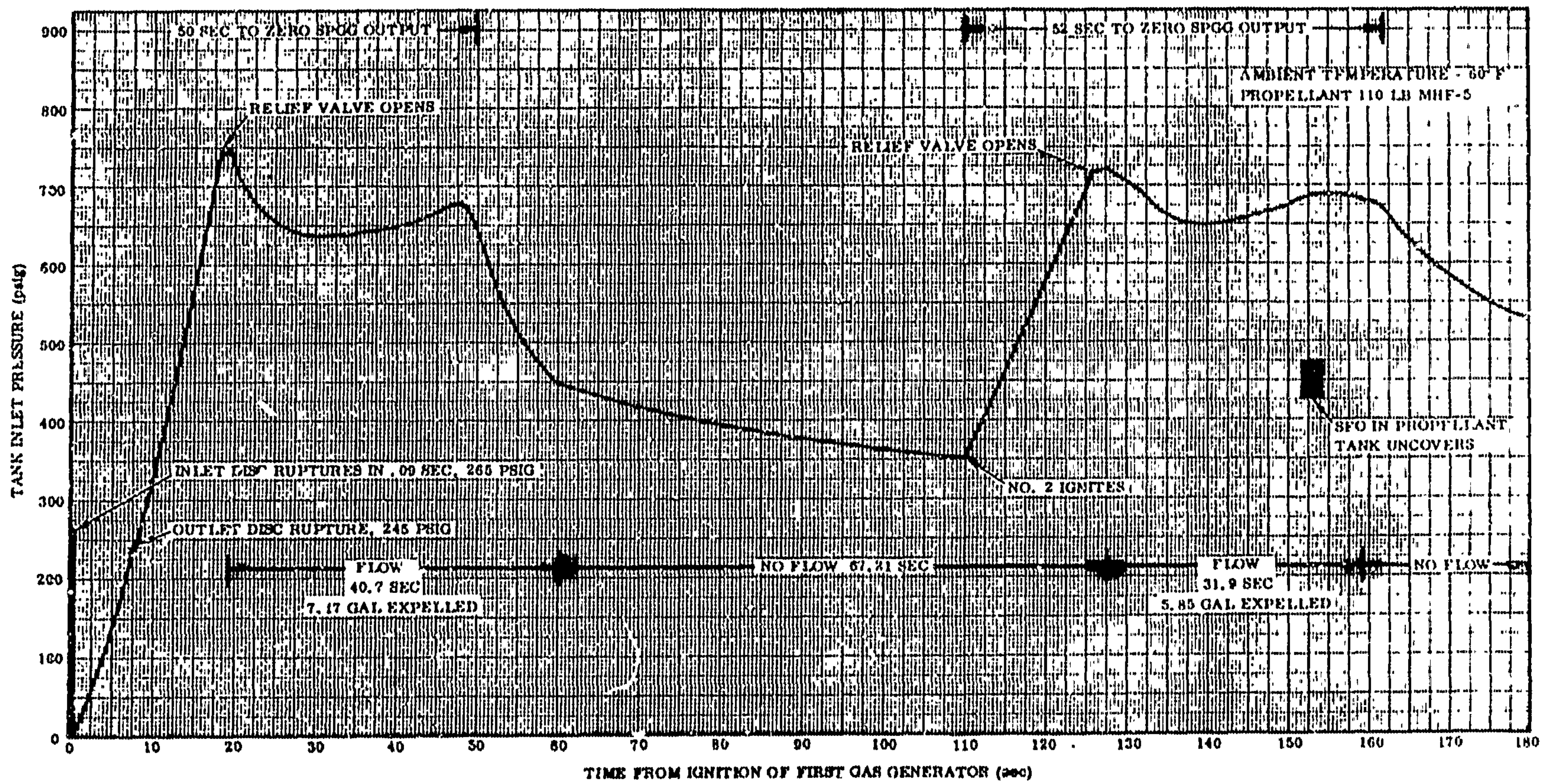

Figure 37. Solid Propellant Gas Generator Test 2 With RD In Propellant Tank

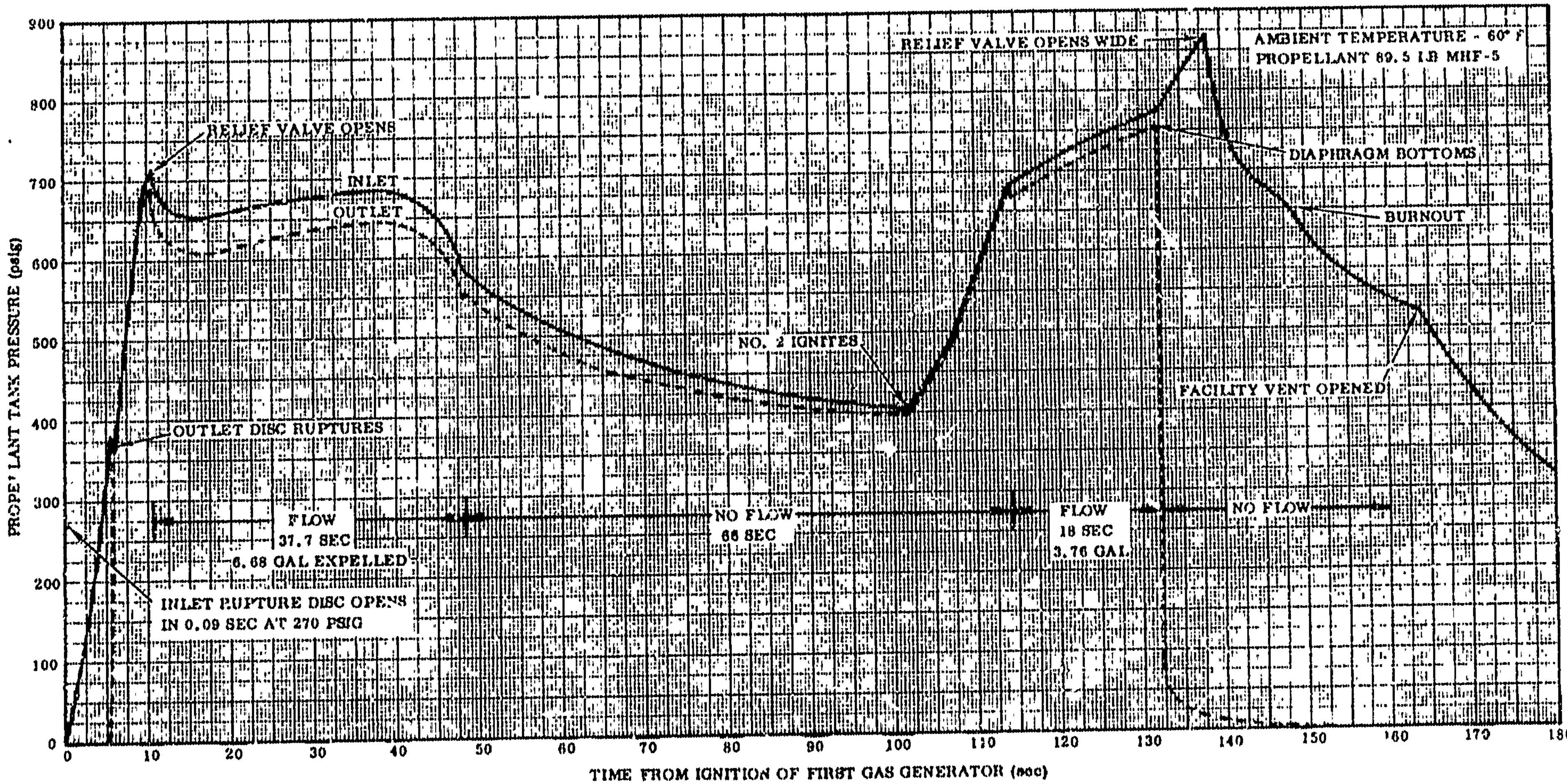

Figure 38. Solid Propellant Gas Generator Test 3 With RD In Propellant Tank

start of expulsion, assuring all-liquid during the pause. This potential problem should not be overlooked whenever an operational system combines a nonreversible rolling diaphragm with a pressurization system or cycle which has decaying pressure during no-flow periods.

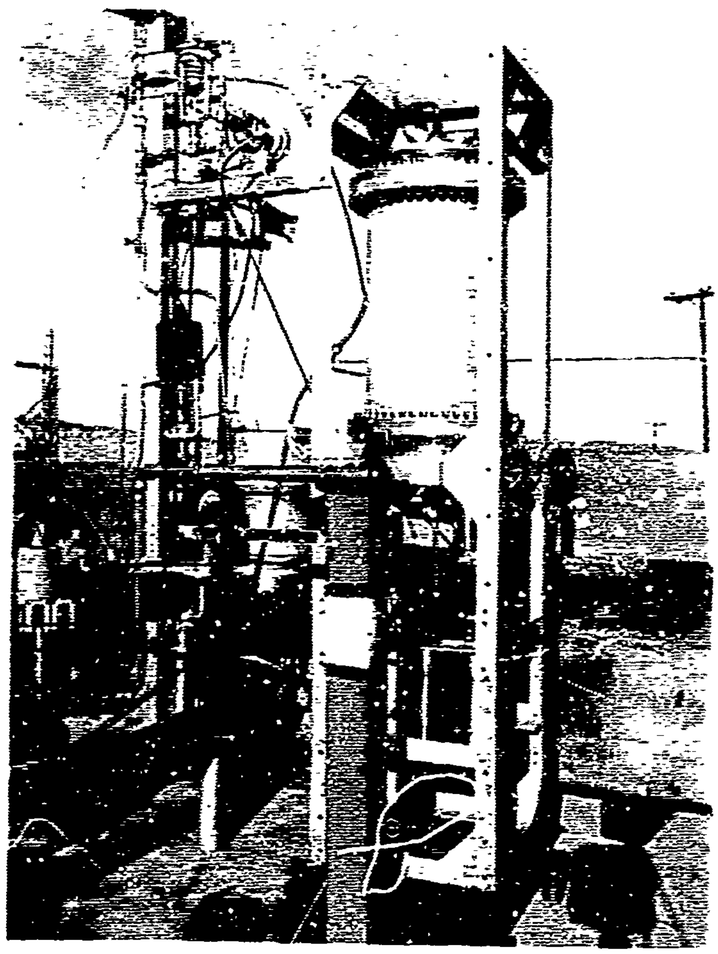

Figure 39. Inverted Solid Propellant Gas Generator Test Setup

The inlet rupture disc opened at 270 psig. The outlet disc incorporated the improved weld method (welded to a narrow lip, providing flexibility and permitting reduced heat input), and it ruptured within specification. Even with the elimination of the exposed liquid surface, pressure build-up took longer than the originally predicted eight seconds. SPGG duration was about three seconds less than nominal, and burnout occurred before the end of expulsion. Relief valve operation was smooth during the first outflow, and pressure variations were less than with the SFO tank. During the second outflow, the relief valve remained closed until the SPGG pressure reached 865 psig. This was higher than expected but was acceptable as the propellant tank operating pressure is 880 psig. Post test examination demonstrated that the valve required 820 psig for the first venting when tested with GN_2. Thereafter it would crack at 600 psig, and not reseat tight until pressure dropped below 100 psig, indicating sticking and seat deposits.

5.3 STORED GAS DEVICE (SGD)

5.3.1 CRITERIA. The SGD system was designed, tested, and fabricated to the same criteria as described in Section 5.1.1 for the LPGG, except that the SGD nominal expulsion pressure is 250 psig rather than 700 psig.

5.3.2 SYSTEM DESCRIPTION. The SGD subsystem consists of a gas storage bottle, a normally-closed explosive valve, a pressure regulator, a relief valve, and a rupture disc on the relief valve outlet. The propellant tank rupture discs are also shown and discussed here, although not part of the SGD subsystem, because SGD operating pressures affect the choice of burst disc operating pressures. The working fluid is 90 percent GN_2/10 percent He for maximum storability with minor weight penalty. This fluid also permits mass spectrometer leak detection. Figure 40 shows an assembled SPPS with a SGD configuration ready for testing, and the SPPS system is shown schematically in Figure 41.

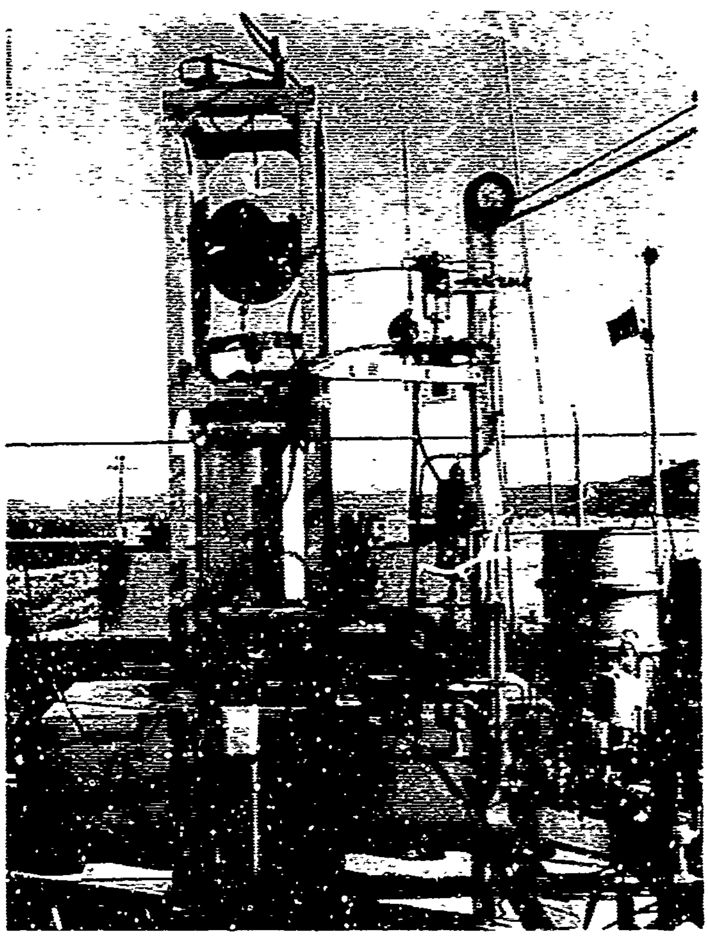

Figure 40. Stored Gas Device Ready for Testing

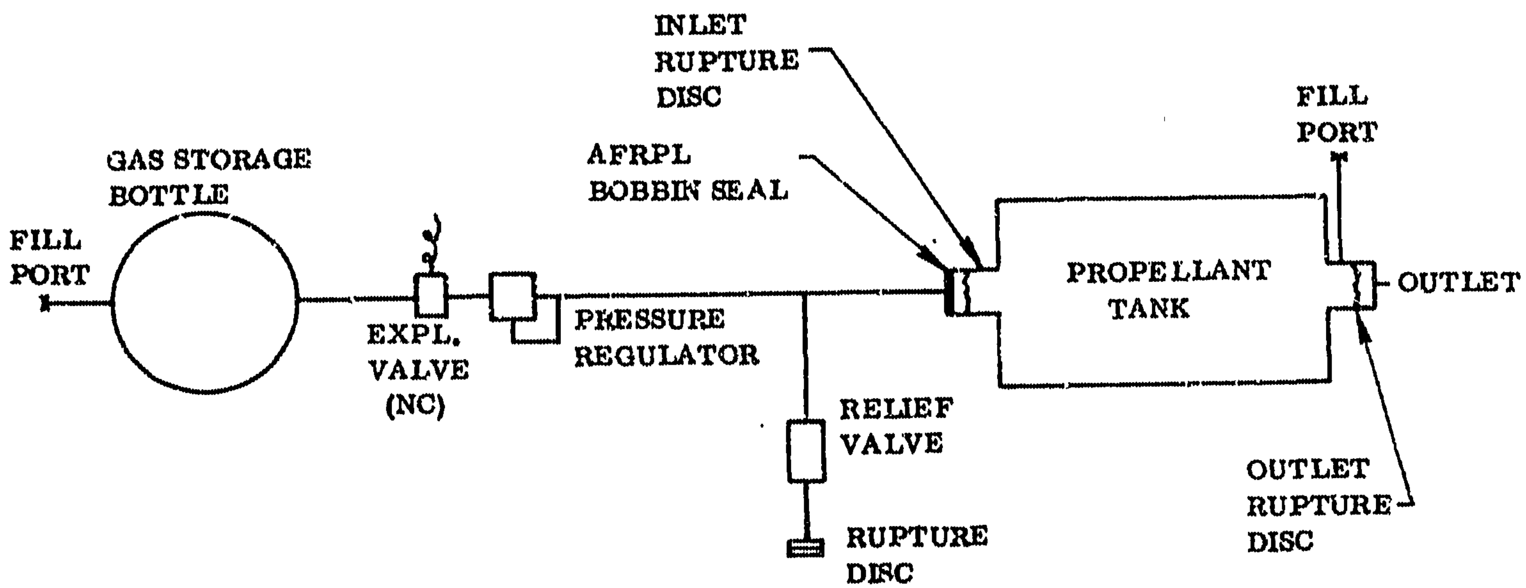

Figure 41. SPPS (Tank/SGD) Schematic

The SGD subsystem is a conventional design except for provisions to provide five year storage in a pre-charged condition with zero maintenance. These provisions are accomplished by all-metal, all-welded design of tubing and components, except for a crush seal on the pressure regulator diaphragm which is not pressurized during storage. The welds and components are checked with a helium mass spectrometer leak detector at pressures equal to or exceeding storage pressures. This assures pressure retention in the pressurized portion, and hermetic sealing against atmospheric moisture or contamination in the unpressurized portion of the system.

The only non-welded connection is a flanged connection between the SGD subsystem and the propellant tank subsystem, using an AFRPL Bobbin seal as described in Section 5.1.2. This was required because of the dissimilar metals; the propellant tank is aluminum while the SGD subsystem is stainless steel.

5.3.3 COMPONENT DESCRIPTIONS

5.3.3.1 Gas Storage Bottle. The gas storage bottle was supplied by Capital Westward, Inc., and is illustrated in Figure 42. It has two 0.25 OD outlet and fill tubes diametrically opposite to each other, and mounting bosses integral with the tubes.

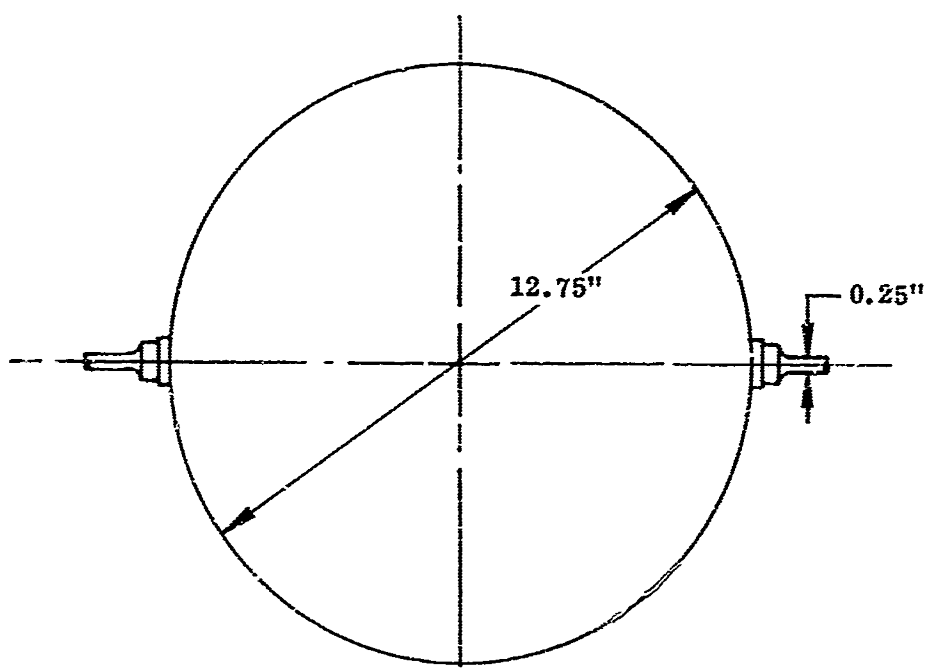

Figure 42. Gas Storage Bottle

Its characteristics are given in Table XI.

TABLE XI

GAS STORAGE BOTTLE CHARACTERISTICS

Material	304 CRES
Outside Diameter	12.75 in.
Wall Thickness	0.75 in.
Outlets (2)	0.25 in. OD
Mounting Bosses	0.40 in. OD
Operating Pressure	3000 psig
Proof Pressure	5000 psig
Burst Pressure	6660 psig
Volume	740 in^3
Max. Total Leakage	1×10^{-8} sccs at 3000 psig, 90 percent GN_2/10 percent He
Inspection	Weld X-ray, proof pressure, mass spectrometer leak check at 3000 psig
Cleanliness	Pneumatic clean per Convair spec. GDC 0-75035
Weight	100 lb

The actual burst pressure of the gas storage bottle should exceed 15,000 psig, because the wall thickness is greater than required. The volume is also larger than required, since calculations indicate that 620 in^3 would be adequate for the system. The size and thickness were determined by existing dies and could not be changed without new tooling. This storage bottle was selected because it greatly reduced program cost as compared to a new design tailored for this application. This bottle adequately accomplishes the intent of the program.

5.3.3.2 Explosive Valve. This component is identical to the one used in the LPGG subsystem described in Section 5.1.3.2.

5.3 3.3 Pressure Regulator. The pressure regulator was supplied by Sterer Engineering and Manufacturing Company, and is shown in Figure 43.

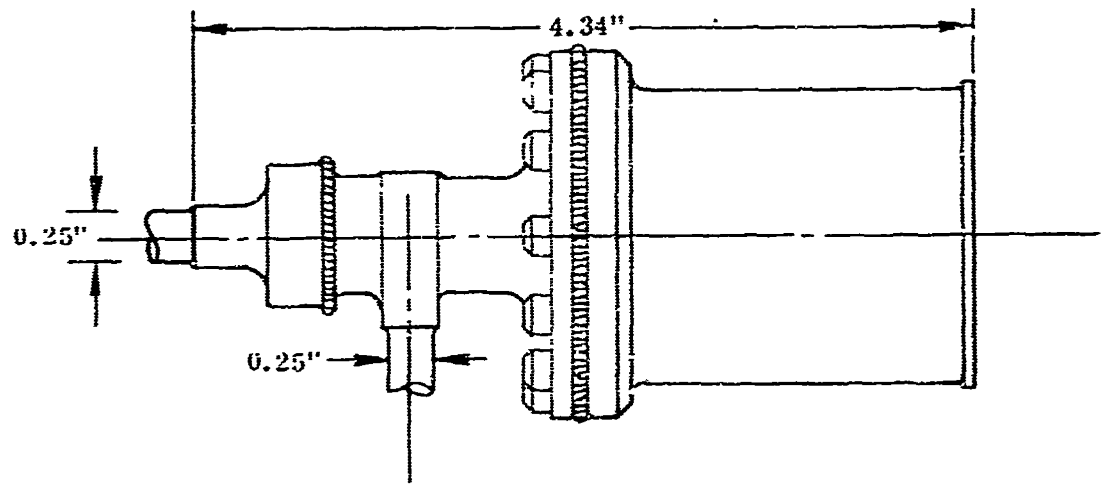

Figure 43. Pressure Regulator

It is constructed entirely of stainless steel and contains no elastomers. Its characteristics are given in Table XII.

TABLE XII

PRESSURE REGULATOR CHARACTERISTICS

Operating Fluid	GN_2, or 90 per cent GN_2/10 per cent He
Outlet Pressure	257 ± 15 psig at 2.5 lb/min flow; 300 psig max. at zero flow and 1200 psig inlet
External Leakage	1×10^{-7} sccs at 25 psig, 100 per cent He. Bubble-tight at normal operating pressures.
Ports	0.25 in OD welded inlet and outlet tubes
Inlet Pressure	500 to 3000 psig operating, 4500 psig proof, 7500 psig burst

The pressure regulator is isolated from the high pressure bottle by the explosive valve during storage. Each regulator was acceptance tested to verify its proper operation with the slam start required by this type of system. It is almost identical to the LPGG regulator, but uses a larger sensing piston and diaphragm to obtain the lower pressure.

5.3.3.4 Nitrogen Relief Valve. The relief valve is shown in Figure 44, and was supplied by Pyronetics, Inc.

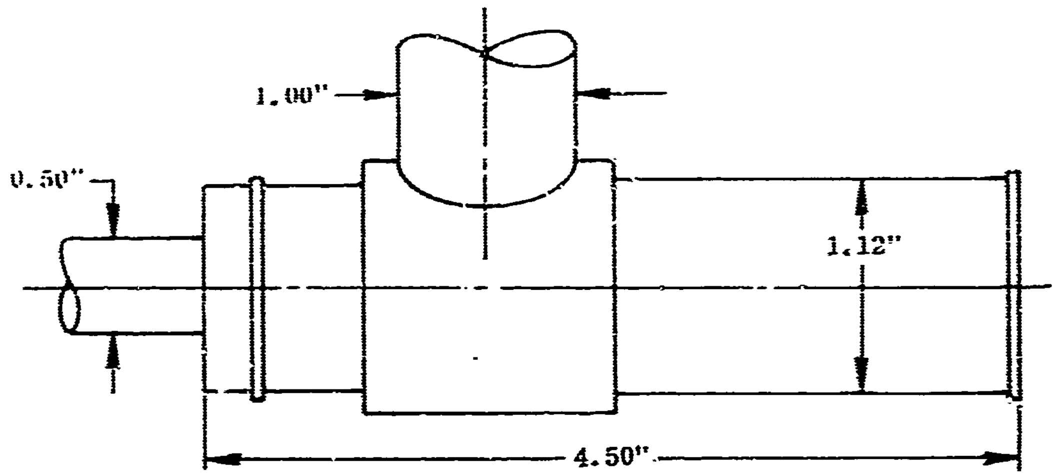

Figure 44. Warm Gas Relief Valve

It protects the propellant tank from overpressure in case of regulator malfunction. It is entirely of stainless steel construction, welded closed after assembly and adjustment. Its specifications are given in Table XIII.

TABLE XIII

NITROGEN RELIEF VALVE SPECIFICATIONS

Cracking Pressure	350 psig nominal
Full Flow	20 lb/min minimum
Full Flow Pressure	420 psig maximum
Reseat Pressure	320 psig minimum
External Leakage (Max.)	1 x 10^{-9} sccs at 25 psia, 90 per cent GN_2/10 per cent He
Ports	0.50 in. welded inlet 1.00 in. welded outlet
Internal Leakage	0.001 lb/sec maximum

The nitrogen relief valve is the same as the relief valves used in the other two types of pressurization subsystems under this contract, except for the different cracking pressures and material upgrading for higher temperatures in the other relief valves.

5.3.3.5 Rupture Disc -- Relief Valve Outlet. The relief valve outlet is sealed by a 50 $\pm$ 7 psig rupture disc, identical to the one used in the LPGG subsystem.

5.3.3.6 Propellant Tank Rupture Discs. The aluminum propellant tank is sealed with aluminum rupture discs. These are welded to the tank outlet and welded into the bobbin seal at the tank inlet. The inlet disc will rupture at a differential pressure of 90 $\pm$ 10 psi from the pressurization side. The rupture value was set low enough to assure the rupturing of the disc by the SGD, in spite of any pressure rise that might occur in the propellant tank during storage. The inlet rupture disc is supported against rupture in the reverse direction, and can withstand approximately 800 psi differential pressure from the propellant side without leakage or rupture. The outlet disc ruptures at 180 $\pm$ 18 psig.

5.3.4 SYSTEM FABRICATION. The SGD subsystem components were purchased with integral welded inlet and outlet tubes. These tubes were pre-bent and cut to specific dimensions, cleaned, and helium mass spectrometer leak checked by the vendor before delivery. Convair assembled the system by welding the component tubes together, installing the SGD subsystem in the frame, and connecting the SGD to the propellant tank inlet. Coatings and adhesive were used where required for corrosion protection or vibration resistance.

5.3.5 TESTS AND RESULTS. Three expulsion tests and one vibration test were made with the SGD. Two of the expulsion tests were with the RD tank, while the vibration test and other expulsion test were with the SFO tank.

The pressure regulator failed wide open during the first expulsion test, which provided an unscheduled test of the relief valve. It satisfactorily limited the tank pressure. A minor design change eliminated the regulator problem, and all other results of the SGD tests were satisfactory. Test results are shown in Figures 45 through 47, and further discussion is given in the following paragraphs.

5.3.5.1 First Expulsion Test (RD in Propellant Tank). The explosive valve operated satisfactorily. No inlet rupture disc was used in this test. The outlet disc ruptured within specification. Initial operation appeared satisfactory, but oscillations appeared on the pressure trace during part of the pressure build-up. These were indications of regulator instability. The regulator then operated normally until 6.3 seconds, when oscillations again appeared and the regulator failed wide open. Tank pressure was automatically kept below 340 psig with intermittent venting by the SGD system relief valve, as shown in Figure 45.

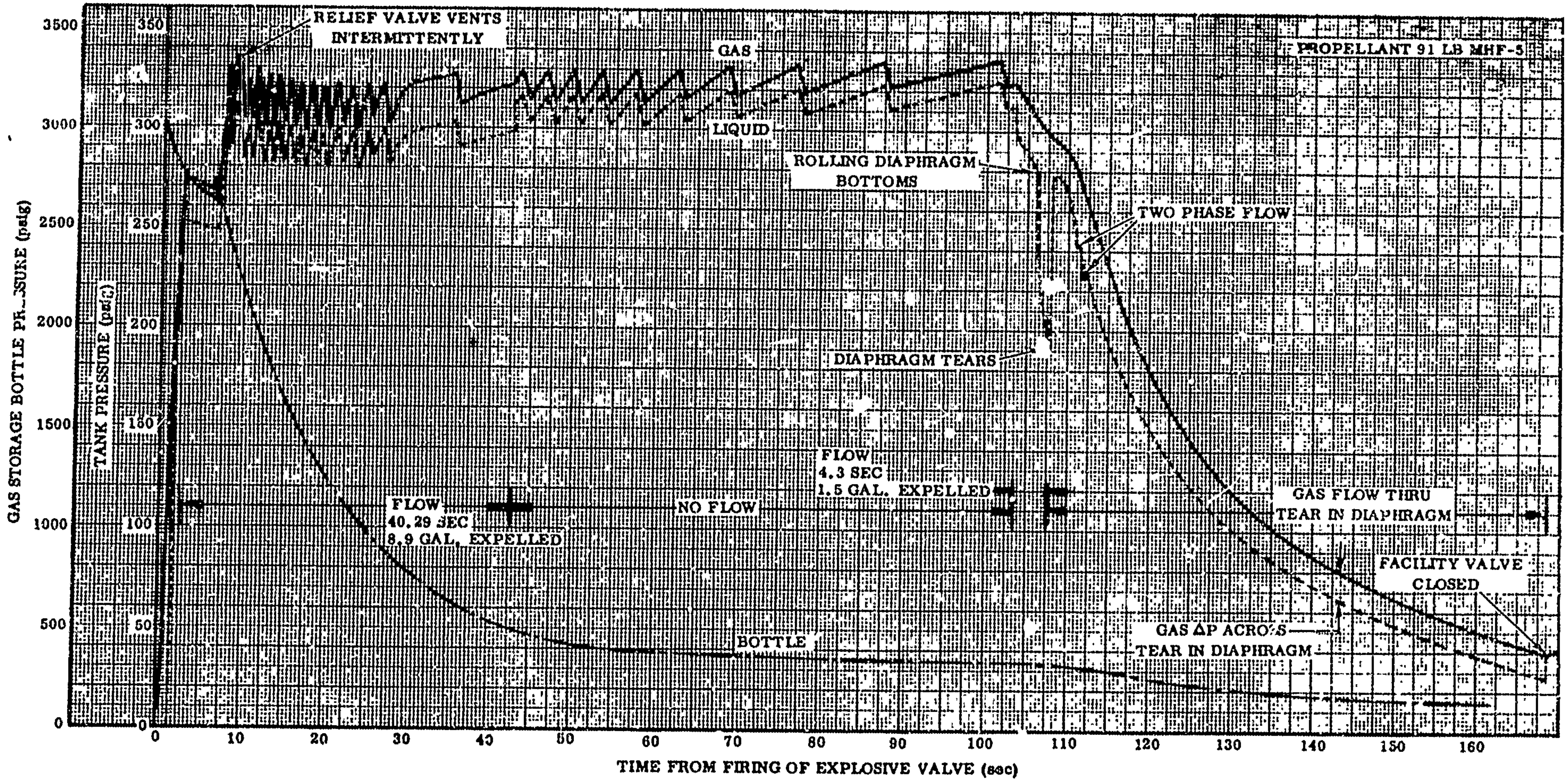

Figure 45. Stored Gas Device Test 1 with RD in Propellant Tank

Gas supply pressure was below 340 psig by the start of the second expulsion, and no further venting occurred.

Post-test disassembly of the regulator disclosed a break in the 0.001 diaphragm which isolates the ambient pressure housing of the reference spring and piston from the downstream pressure region of the regulator. This diaphragm is backed-up by the piston, and it transmits piston movement to the poppet to control regulator opening as the piston and spring respond to downstream pressure. The hole in the diaphragm admitted gas to the spring cavity faster than it could escape through the small ambient vent hole. The resultant pressure build-up forced the piston to the full-open position.

The regulator was reassembled with a new diaphragm and bench tested. It was found that instability could be induced by high flow demand on the regulator, evidenced by a loud screeching vibration as the piston apparently oscillated. After only a few seconds of accumulated unstable operation, the regulator was again disassembled and the new diaphragm found to be broken.

The problem was solved by eliminating the two sensing passages in the poppet support, leaving only the clearance around the poppet to transmit downstream reference pressure to the diaphragm and piston. This provided a dashpot effect and blocked exposure to turbulent flow passing the seat. The regulator was reassembled with a new diaphragm and bench tested with 20 cycles of slam start and high regulated flow. No instability occurred and no effect on response, regulation, or lock-up could be detected. The diaphragm was in perfect condition upon disassembly.

5.3.5.2 Second Expulsion Test (SFO in Propellant Tank). In this test, the SGD was vibrated with a propellant tank containing a SFO device. The vibration tests were completed satisfactorily, with no resonance or amplification after a support bracket was installed to support the explosive valve. Without disassembly or detanking after the vibration test, an expulsion test was made. Results were satisfactory, as shown in Figure 46. The facility orifice used resulted in a higher expulsion rate than nominal, providing a successful proofing of the new SFO screen weld method and verifying that high regulator demand would not repeat the regulator failure of the first test. Inlet and outlet rupture discs opened within specification. The test was continued to propellant depletion, with the outlet pressure transducer showing oscillations as gas bubbles appeared. The eight to twelve psi differential between the SGD gas pressure and the propellant pressure recorded downstream of the propellant tank outlet is due to the tank outlet pressure drop and to the conversion of part of the total pressure to velocity. The transducers recorded static pressure only.

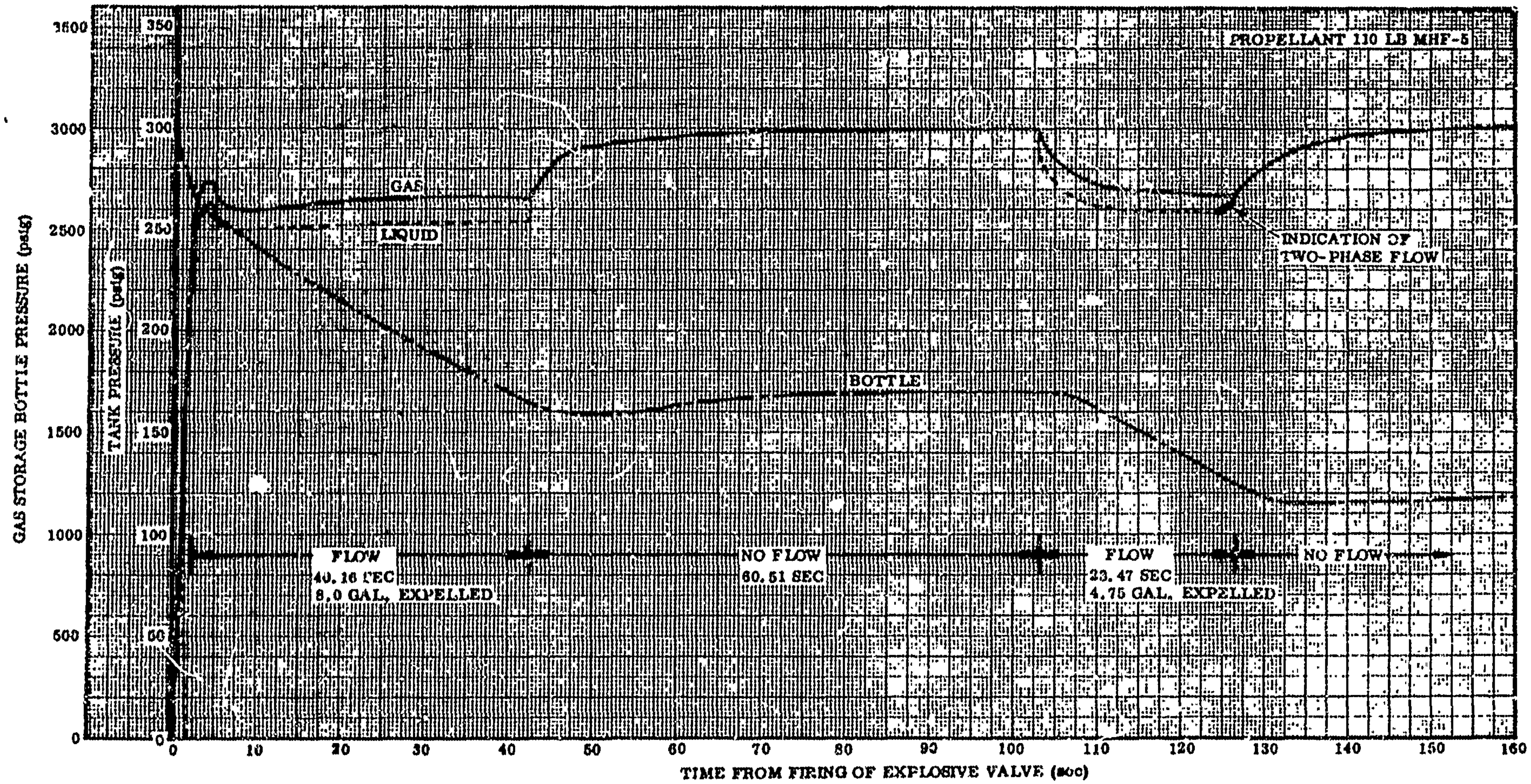

Figure 46. Stored Gas Device Test 2 with SFO in Propellant Tank

5.3.5.3 Third Expulsion Test (RD in Propellant Tank). Results were satisfactory and are shown in Figure 47. The expulsion rate was above nominal because the orifice size was based on a higher assumed differential pressure across the rolling diaphragm. Tests at 700 psig had indicated a 45 to 50 psid differential, but the differential is lower at lower operating pressures.

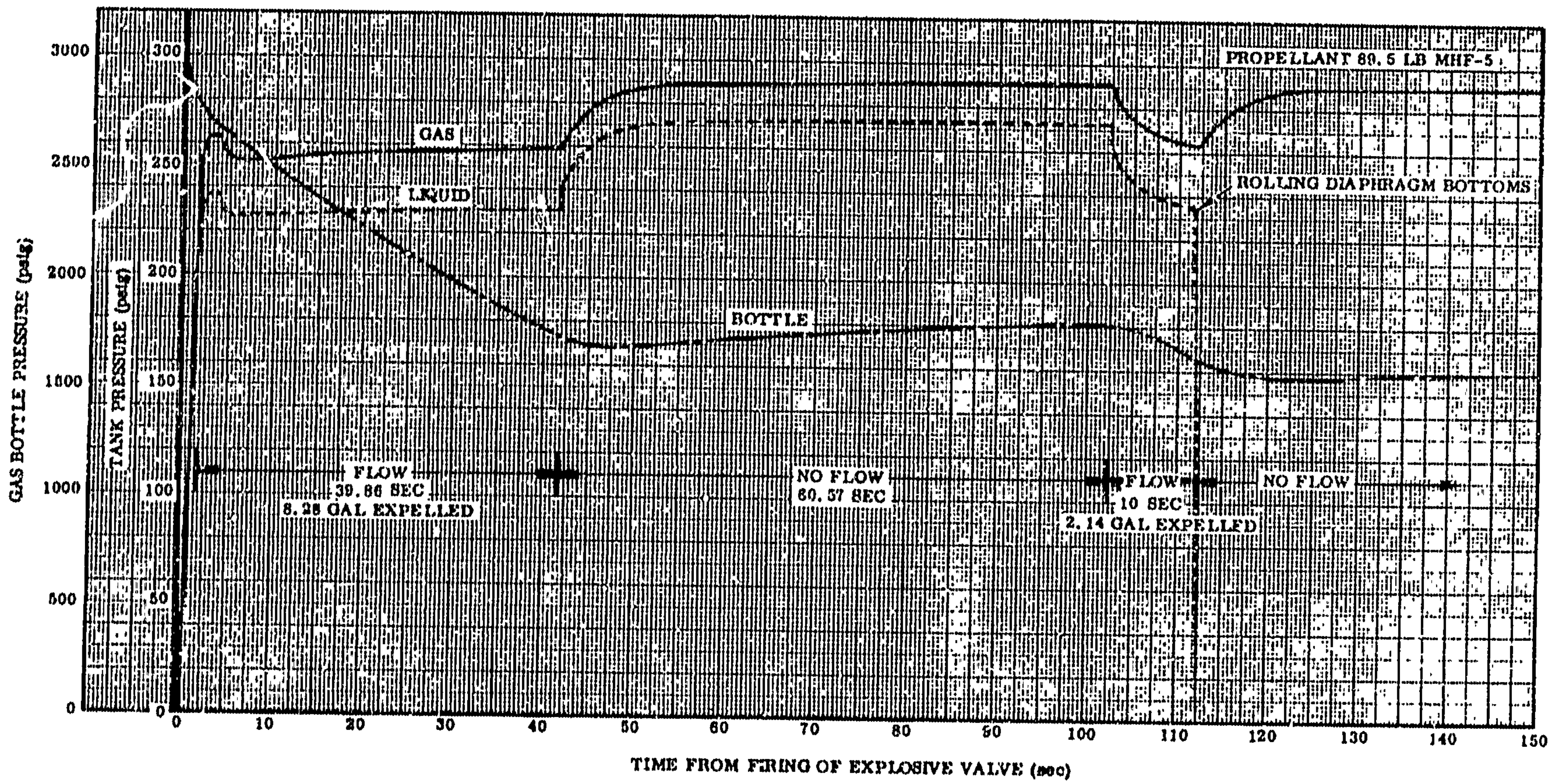

Figure 47. Stored Gas Device Test 3 With RD In Propellant Tank

SECTION VI

DEMONSTRATION TESTS

6.1 OBJECTIVES

The objectives of the demonstration test program were to demonstrate that the propellant tank, expulsion devices (SFO and RD), and pressurization subsystems (LPGG, SPGG, and SGD) operate to the contracted criteria; and to provide test data for comparison with post storage test data.

6.2 TEST PROGRAM

The test program was divided into three parts: RD development tests, SPPS expulsion tests, and SPPS vibration tests. The first tests developed the RD from a concept into hardware, while the latter two tests substantiated the SPPS operation as a system. The components had previously been tested individually by their respective manufacturer.

6.2.1 ROLLING DIAPHRAGM DEVELOPMENT TESTS. For these tests a facility pressurization system was used to simulate the operation of the SPPS pressurization subsystems. Water simulated the propellant. Figure 48 contains the test schematic, and Figures 49 and 50 are photographs of the test setup used for the RD development tests. Five RD development tests were performed in the following sequence:

a. The propellant tank was leak checked, prior to testing, by pressurizing the liquid side of the tank with GHe. Leakage through the diaphragm to the gas side was measured by the water displacement method. The liquid side was vented. Both sides of the diaphragm were evacuated and the weight of the assembly was recorded. The required weight of water was aspirated into the tank and the tank outlet valve was closed.

b. The tank inlet valve was opened and the tank was pressurized. The expulsion profile was accomplished by opening the outlet valve and allowing the water to be expelled into the catch tank, at the required rate, through a flow restricting orifice. Flow was terminated when the diaphragm bottomed out.

c. Flow rate, tank inlet pressure, tank outlet pressure, and the RD differential pressure were measured and recorded. The weight of the assembly was recorded again.

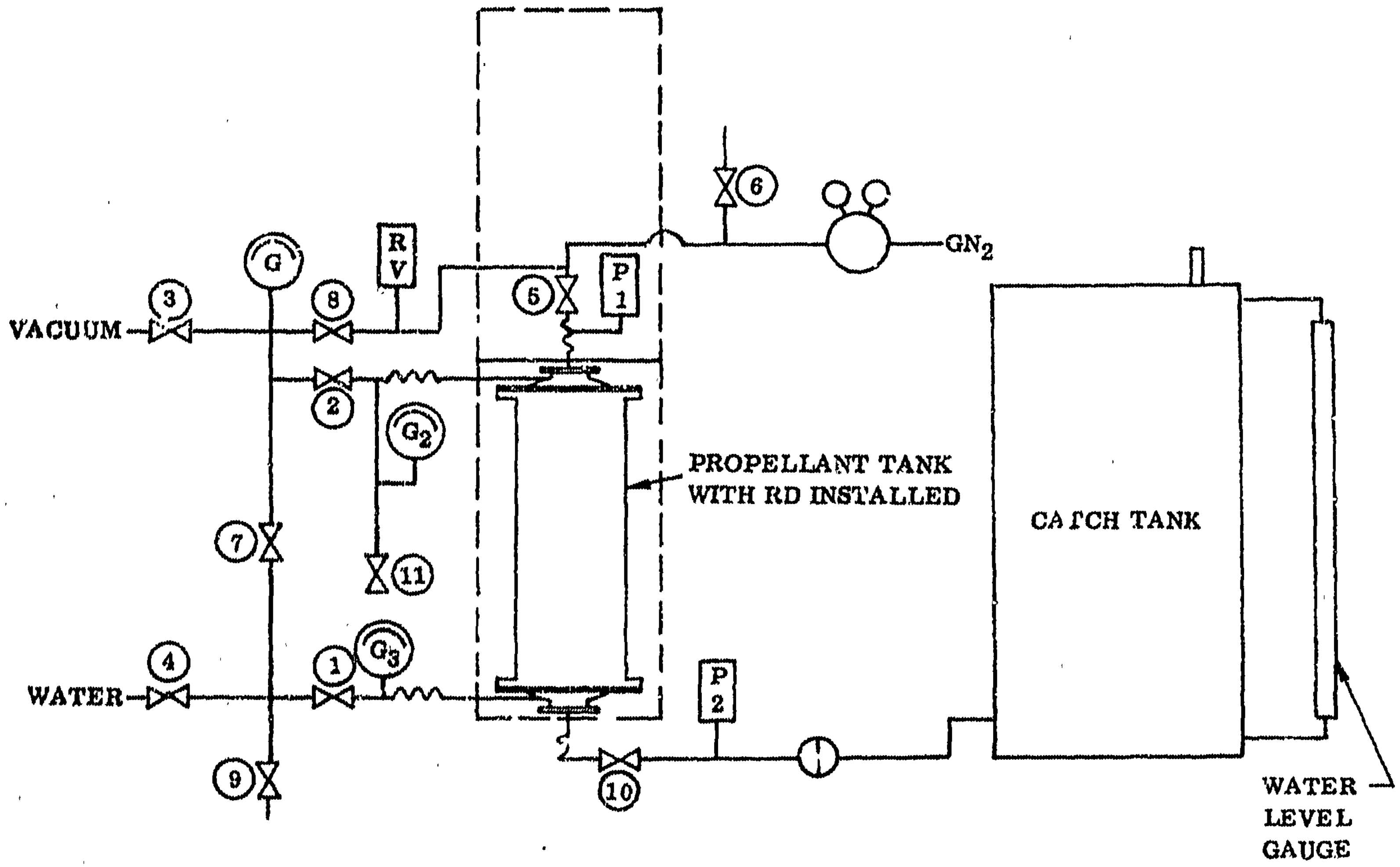

Figure 48. Test Schematic for Rolling Diaphragm Development Tests

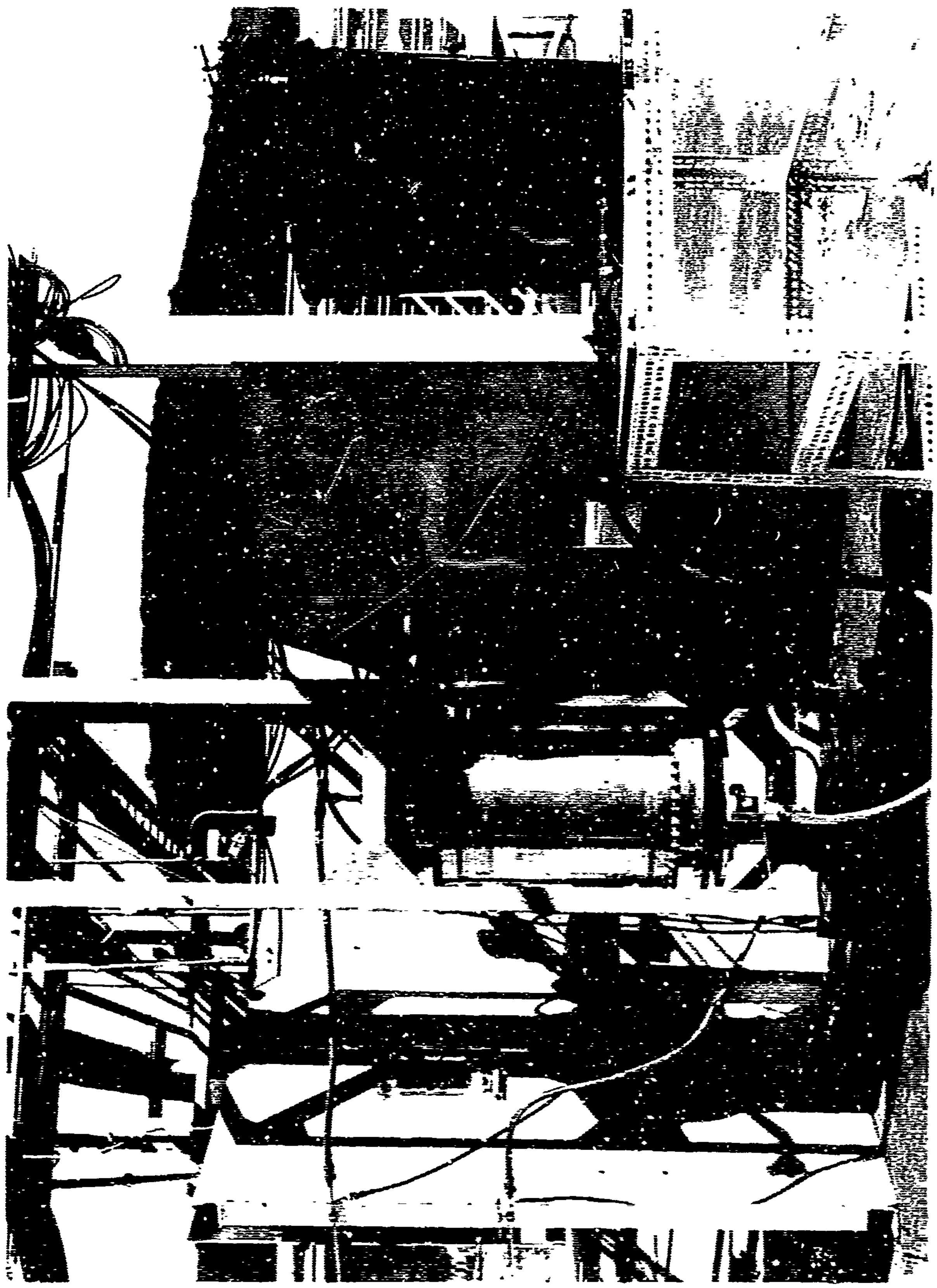

Figure 49. Test Setup for Rolling Diaphragm Development Tests

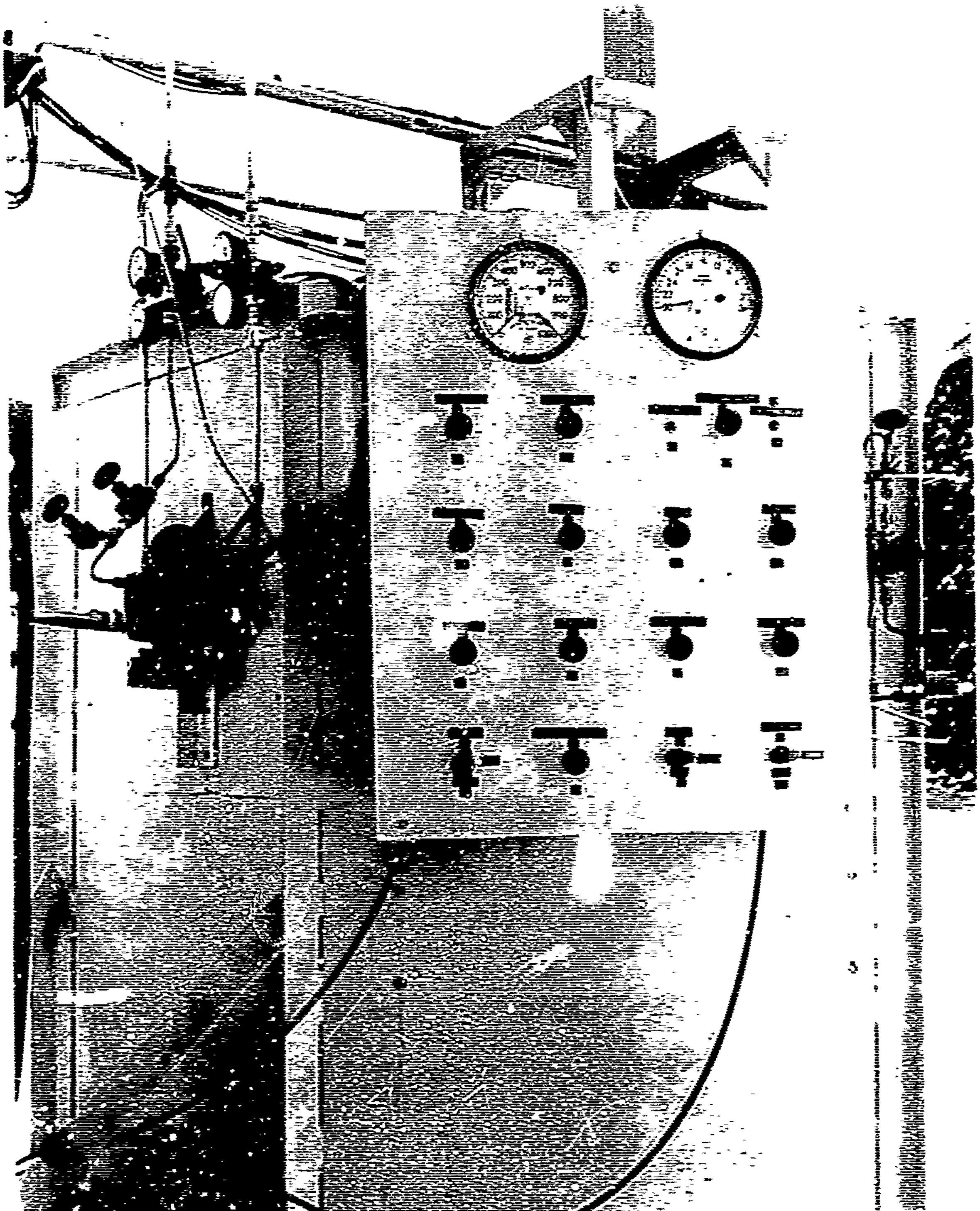

Figure 50. Control Panel for Rolling Diaphragm Development Tests

6.2.2 STORABLE PREPACKAGED PROPELLANT SYSTEM EXPULSION TESTS. This part of the test program contained one expulsion test of each SPPS configuration specified in Table XIV. MHF-5 was used as the fluid expelled from the propellant tank except in test number 1 where water was used. A test schematic is shown in Figures 51 and 52; equipment lists in Tables XV and XVI; and test setups in Figures 53 thru 55. A typical test cycle is hereafter presented.

TABLE XIV

STORABLE PREPACKAGED PROPELLANT SYSTEM EXPULSION TESTS

TEST NO.	PRESSURIZATION SUBSYSTEM	PROPELLANT TANK EXPULSION DEVICE
1	SPGG	SFO
2	SPGG	SFO
3	LPGG	SFO
4	LPGG	SFO
5	SGD	RD
6	SGD	SFO
7	SGD	RD
8	LPGG	RD
9	SPGG	RD
10	LPGG	RD

If an RD was used in the propellant tank, it was leak checked prior to testing by pressurizing the propellant side with gaseous helium. The leakage, if any, was measured on the pressurization subsystem side of the RD. The weight of the SPPS was recorded and the appropriate weight of water or MHF-5 was aspirated into the propellant tank.

After weighing, the pressurization subsystem was loaded. If the LPGG was used, the 68 per cent hydrazine/32 per cent water mix was loaded, then the gas side of the gas/hydrazine tank was charged with 90 per cent GN_2/10 per cent He to 2600 psig. If the SGD was used, the stored gas bottle was charged to 3000 psig with 90 per cent GN_2/10 per cent He. In each instance, the electrical connections were made which initiate the explosive valve or solid propellant igniters.

The explosive valve was then fired in the LPGG or in the SGD pressurization subsystem. If a SPGG subsystem was being tested, the SPGG assembly squib was fired. When Station P_2 recorded the proper tank pressure for the pressurization subsystem utilized, outlet valve 5 was opened for 40 seconds, closed for 60 seconds, and re-opened until propellant depletion. With a SPGG subsystem, the second squib was fired before re-opening valve 5.

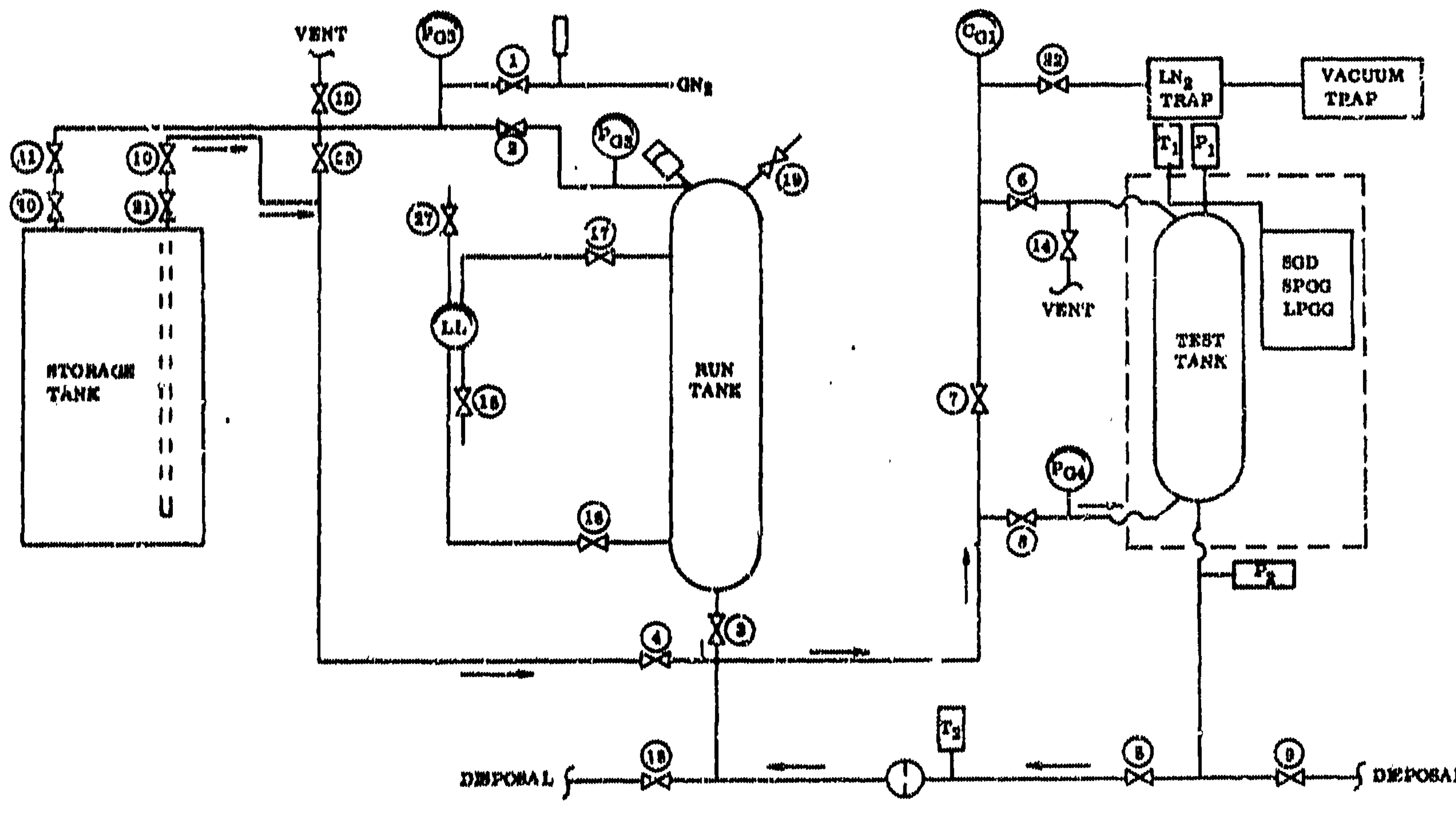

Figure 51. Test Schematic for Storable Prepackaged Propellant System Expulsion Tests

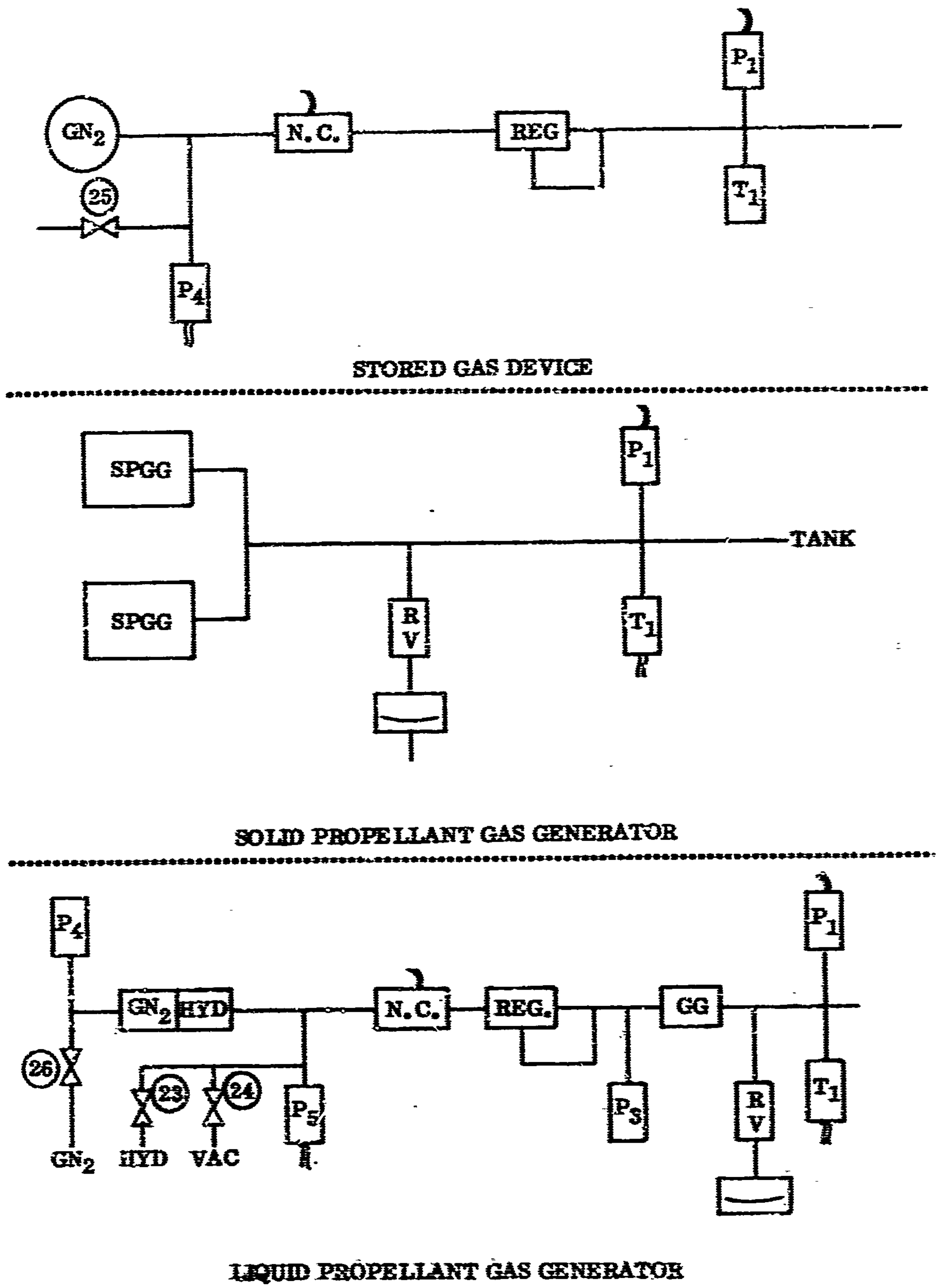

Figure 52. Pressurization Subsystem Test Schematic

TABLE XV

TEST SYSTEM EQUIPMENT

SCHEMATIC	PART NAME	MFG.	VENDOR P/N	TEST ITEM PURPOSE
P_1	Pressure Transducer	Kistler	614A/644	Test Tank Inlet Pressure
P_2	Pressure Transducer	Statham	PG285TC	Test Tank Outlet Pressure
P_3	Pressure Transducer	Statham	PG285TC	LPGG Regulator Outlet Pressure
P_4	Pressure Transducer	Statham	PA226TC-1M	LPGG and SGD GN_2 Pressure
P_5	Pressure Transducer	Statham	PG285TC	LPGG Hydrazine Tank Outlet Press.
T_1	Thermocouple	Autocontrol	252VCI	Test Tank Inlet Temperature
T_2	Thermocouple	Autocontrol	252VJI	Test Tank Outlet Temperature
GG	Compound Gage	Supergauge	1931T	Test Tank Pressure/Vacuum
PG_2	Pressure Gage	Supergauge	1831T	Storage Tank Pressure
PG_3	Pressure Gage	Supergauge	1831T	Run Tank Pressure
PG_4	Pressure Gage	Supergauge	1831T	Test Tank Outlet Pressure

TABLE XVI

TEST SYSTEM VALVES

SCHEMATIC VALVE NO.	VALVE NAME	VALVE SIZE	VALVE TYPE	MFG.	VENDOR P/N
1	GN_2 Supply	1/4"	Remote	Hoke	4251X9
2	GN_2 Run Tank Pressure	1/4"	Manual	Hoke	4251G4Y
3	Run Tank Inlet	1"	Remote	Annin	Model 1620
4	Propellant Bypass	1/2"	Remote	Annin	Model 1620
5	Test Tank Outlet	1"	Remote	Annin	Model 1620
6	Test Tank Top Fill	1/4"	Remote	Hoke	4251X9
7	Vacuum Gage Shutoff	1/2"	Remote	Hoke	4312X1
8	Test Tank Bottom Fill	1/2"	Remote	Hoke	4312X1
9	Test Tank Disposal	1/2"	Remote	Annin	Model 1620
10	Storage Tank Drain	1/2"	Remote	Hoke	4312X1
11	Storage Tank Pressure	1/4"	Remote	Hoke	4251X9
12	Supply-Run Tank Vent	1/4"	Remote	Hoke	4251X9
13	Gaseous Bypass	1/4"	Remote	Hoke	4251X9
14	Test Tank Top Vent	1/4"	Remote	Hoke	4251X9
15	LL (Gas) Run Tank (Drain)	1/4"	Manual	Hoke	4251G4Y
16	LL (Liquid) Run Tank (Shutoff)	1/4"	Manual	Hoke	4251G4Y
17	LL (Gas) Run Tank (Shutoff)	1/4"	Manual	Hoke	4251G4Y
18	Run Tank Disposal	1/2"	Remote	Annin	Model 1620
19	Run Tank Top Vent	1/2"	Remote	Annin	Model 1620
20	Storage Tank Inlet	1/4"	Manual	Hoke	4251G4Y
21	Storage Tank Outlet	1/2"	Remote	Hoke	4312X1
22	Vacuum Shutoff	1/4"	Manual	Hoke	4251G4Y
23	Hydrazine Fill (LPGG)	1/4"	Manual	Hoke	4251G4Y
24	Hydrazine Vac. (LPGG)	1/4"	Manual	Hoke	4251G4Y
25	GN_2 Fill (SGD)	1/4"	Manual	Grove	310S
26	GN_2 Fill (LPGG)	1/4"	Manual	Grove	310S
27	LL (Liq) Run Tank (Drain	1/4"	Manual	Hoke	4251G4Y

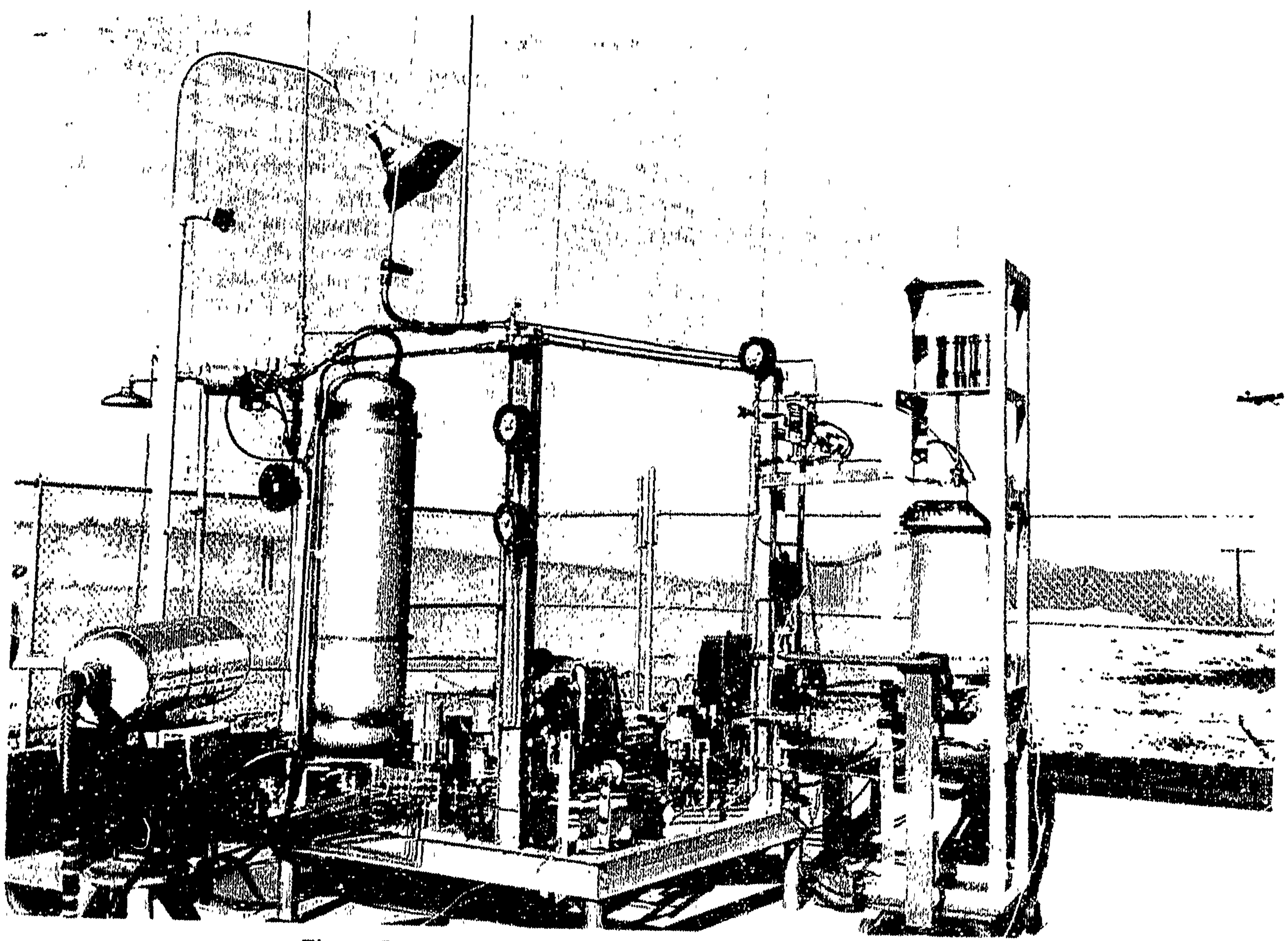

Figure 53. Test Setup for SPPS Expulsion Test (SFO/SPGG)

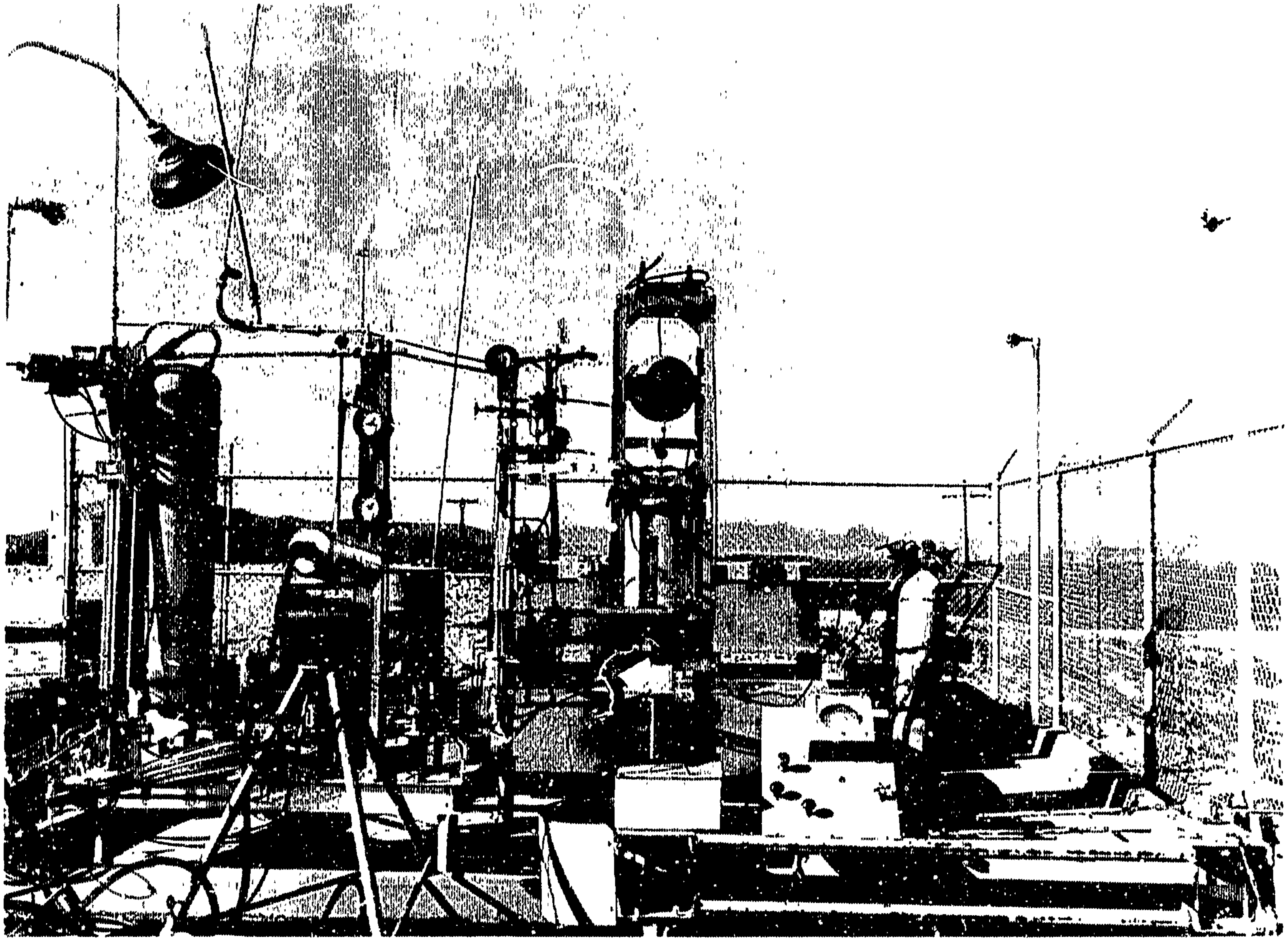

Figure 54. Test Setup for SPPS Expulsion Test (RD/SGD)

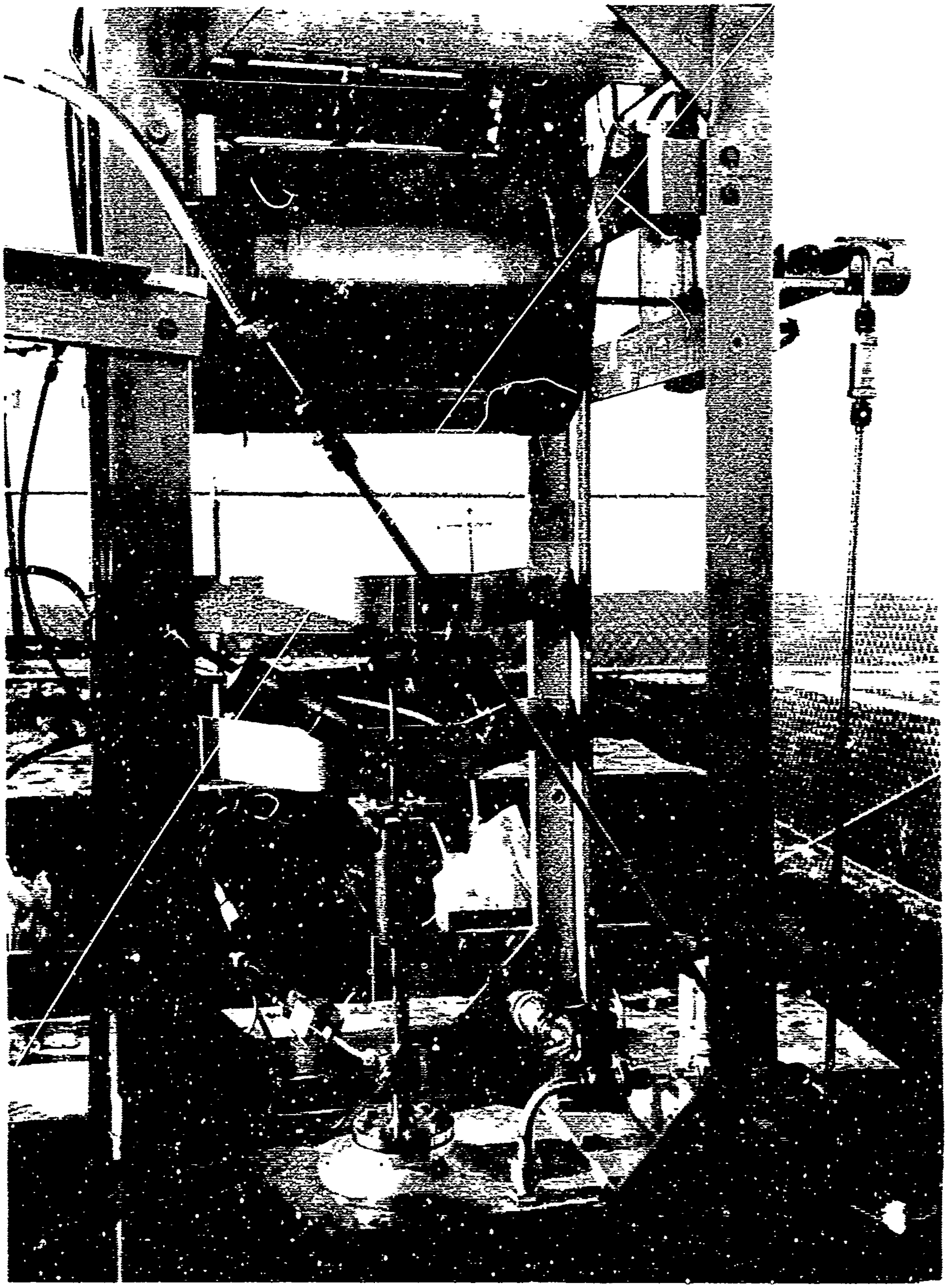

Figure 55. Instrumentation for Expulsion Tests

The propellant flow rate was measured by the liquid level indicator on the run tank. Pressures and temperatures were measured as shown in Figures 51 and 52.

6.2.3 STORABLE PREPACKAGED PROPELLANT SYSTEM VIBRATION TESTS. Two SPPS's were vibrated. One consisted of a propellant tank containing an SFO expulsion device and a SGD pressurization subsystem; the other consisted of a propellant tank containing an RD expulsion device and an LPGG pressurization subsystem.

The SPPS propellant tank was loaded with MHF-5 and the other appropriate propellant was loaded into the pressurization subsystem. Accelerometers measured acceleration in the input direction. They were located, as applicable, at the input, regulator, propellant tank inlet, propellant tank outlet, explosive valve or gas generator, and at the gas storage bottle or gas/hydrazine mix tank. These measurements were recorded on a Sandborn recorder.

The SPPS was subjected to 1 g RMS at 35 Hz for 60 minutes in each of its orthogonal axes. Figures 56 and 57 provide schematics of the test setup. Figures 58 and 59 are photographs of the same setup.

After vibration, each SPPS performed an expulsion test as described previously. Neither SPPS experienced any anomalies as a result of these vibration tests.

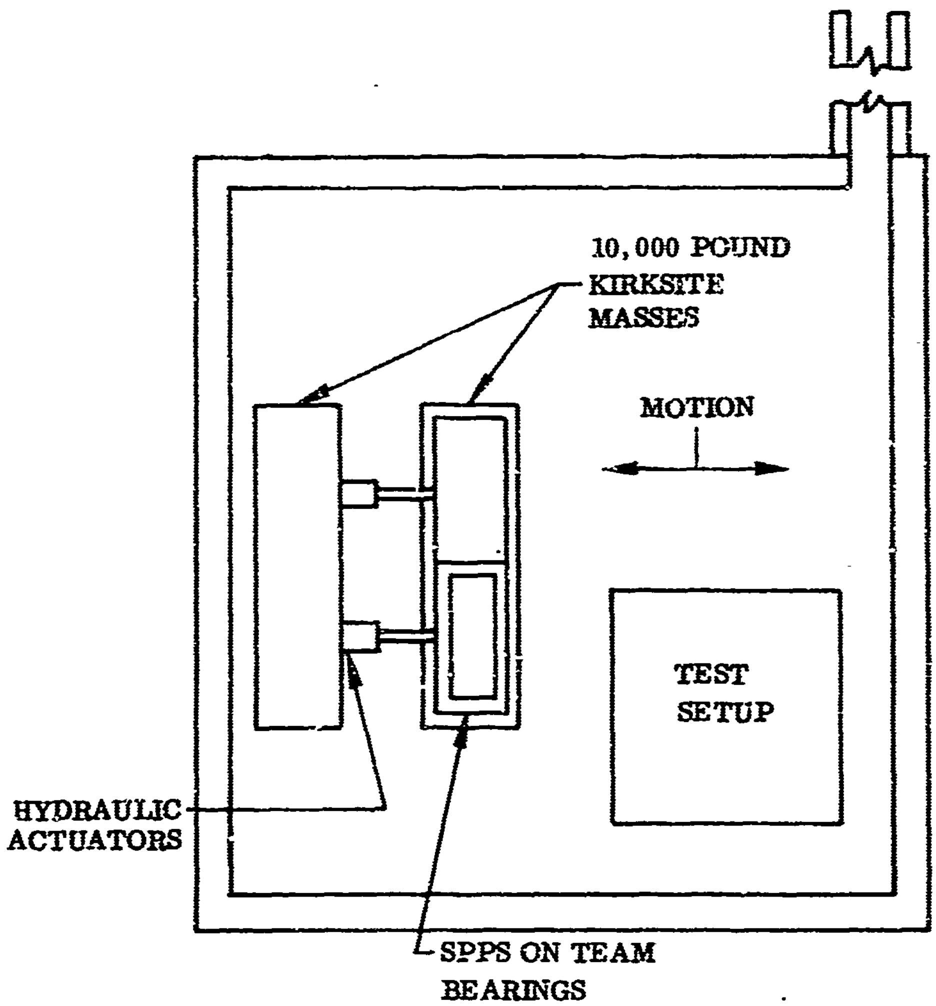

Figure 56. Vibration Test Setup (X and Y Axes)

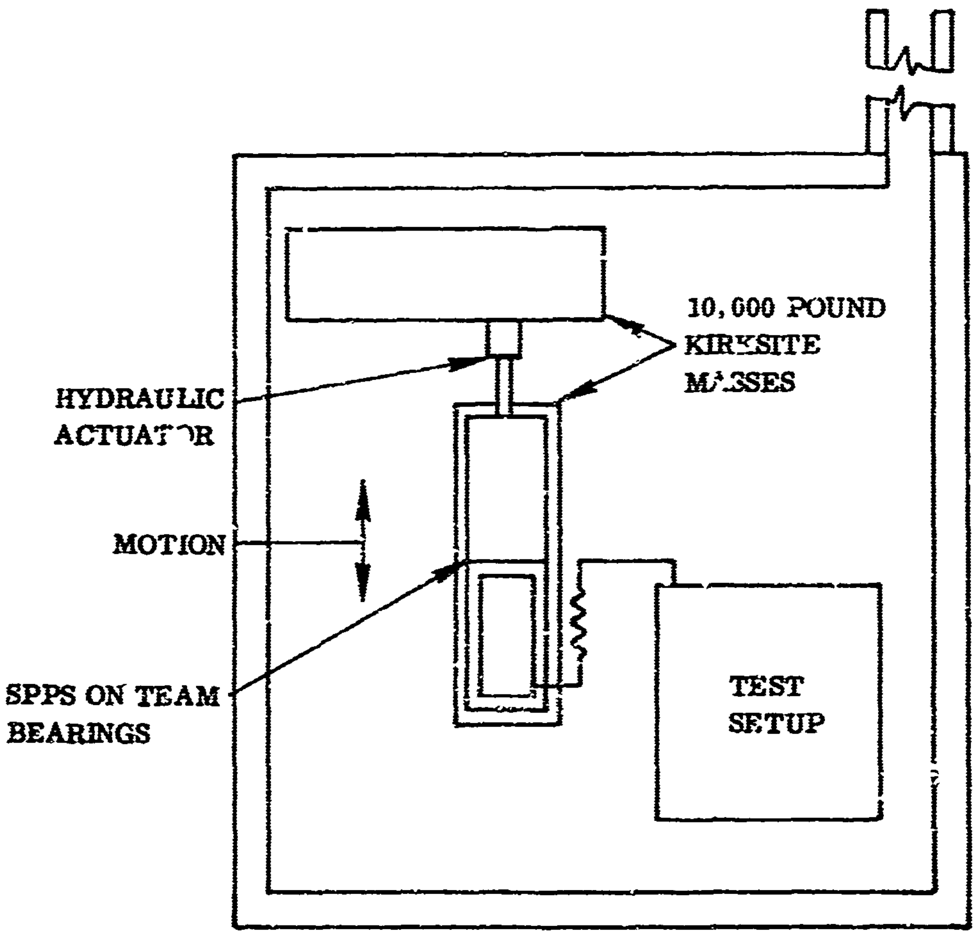

Figure 57. Vibration Test Setup (Z Axis)

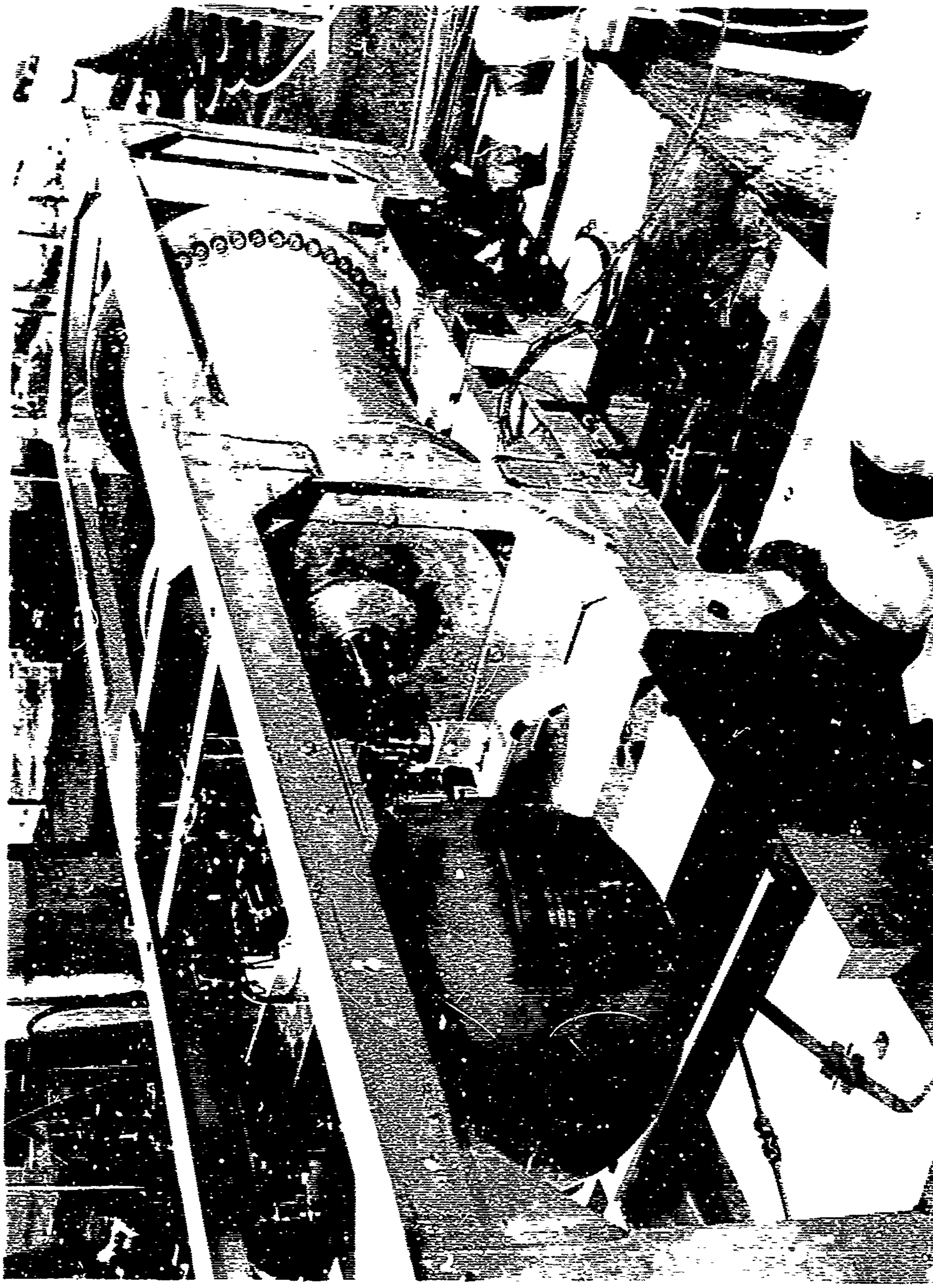

Figure 58. Test Setup for SPPS Vibration Test (SFO/SGD)

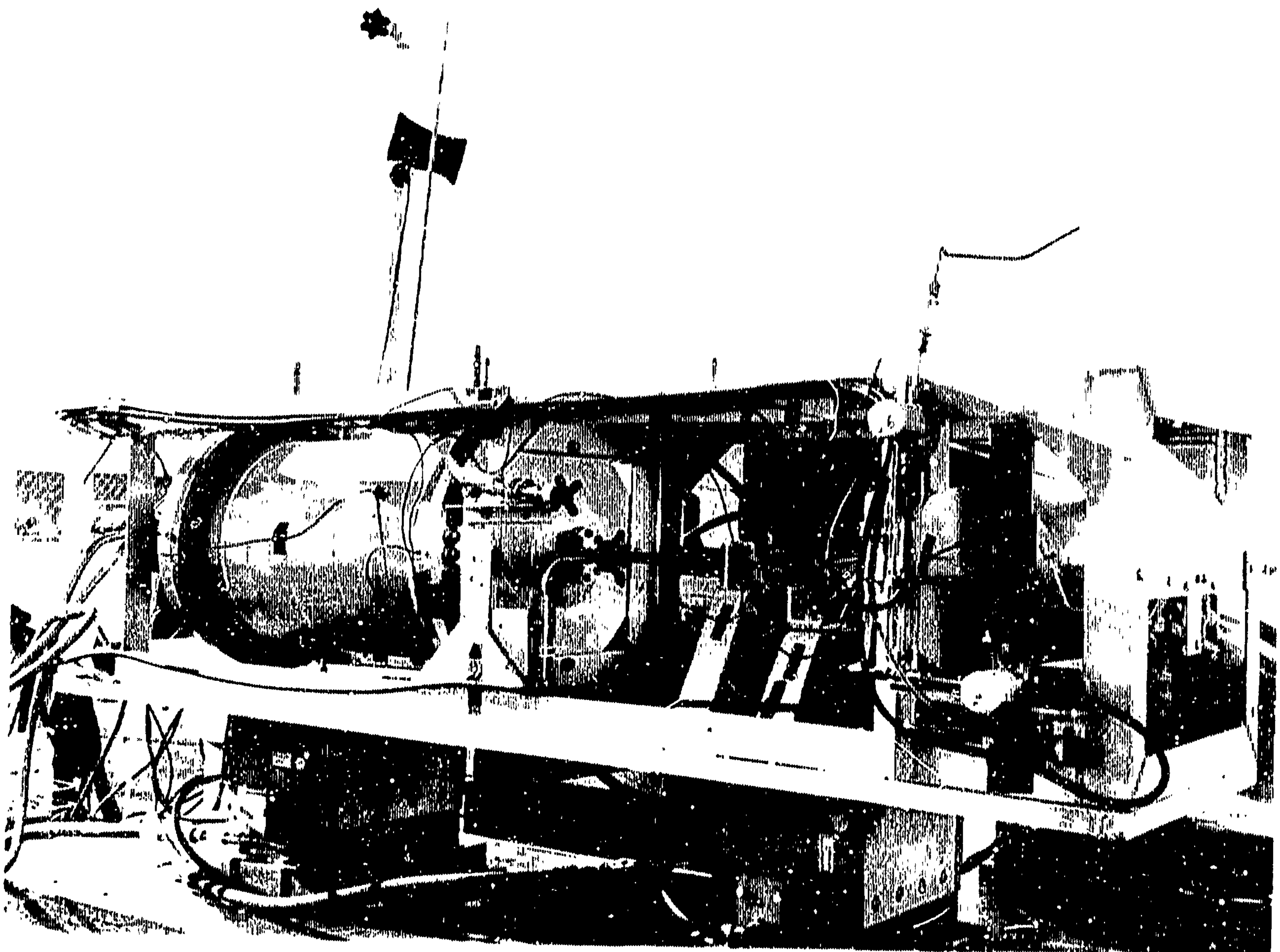

Figure 59. Test Setup for SPPS Vibration Test (RD/LPGG)

SECTION VII

STORABLE PREPACKAGED PROPELLANT SYSTEM PROPELLANT LOADING

Table I in Section II presented the final configuration of each SPPS when it was delivered to AFRPL. It also listed the quantity of propellant contained in each system. The propellant tanks were weight loaded by placing them on a scale during the fill operation. In each instance the propellant tank, and the facility lines which connected it to the propellant container, were vacuum dried prior to loading. MHF-5 and N_2O_4 were vacuum loaded by drawing a vacuum in the propellant tank and then opening the propellant container valve. The ClF_5 propellant tanks were passivated with ClF_5 gas at 40 psig for two hours prior to loading ClF_5 liquid. This gas was aspirated from the propellant tank before ClF_5 was loaded by temperature transfer. The SPPS propellant tank was cooled by liquid nitrogen boiloff.

After loading the propellant through the one-quarter inch, 3003 aluminum alloy tank fill tube, the tube was welded closed. For the weld, an 1100 aluminum alloy plug with a tapered end was inserted into the tube. A heliarc spotwelder was positioned vertically above the tapered plug tip and the spotwelder was actuated remotely to fuse the plug and the tube. Tube clamps were positioned between the propellant tank and the weld to isolate the propellant from the weld during welding. These clamps were removed after the weld was complete.

The pressurization subsystems were welded closed after loading. The weld method used duplicated that of the propellant tanks, except for weld schedule differences required because the tube and plug were stainless steel in the subsystem instead of aluminum. After welding the high pressure gas tubes the weld was checked by a helium mass spectrometer. No leakage was noted from any of the welds.

The liquid side of the gas/hydrazine tank in the LPGG was evacuated to remove moisture and atmosphere. The premixed hydrazine/water mixture was then admitted into the evacuated bellows to accomplish filling. Fill level was determined by a rod inserted into the gas fill tube to measure the bellows position. System weight and supply drum weight were also recorded to confirm the quantity of propellant loaded.

SECTION VIII

PROPELLANT TANK RUPTURE

On 10 July 1967 an SPFS was being packaged for delivery to AFRPL. The system consisted of a RD tank loaded with 154 pounds of ClF_5, and an SPGG pressurization subsystem. The ClF_5 had been loaded into the tank twenty days previously and the tank had always been maintained in a vertical position. On 10 July the tank was laid in a horizontal position to package for shipment. Within 10 seconds after obtaining a horizontal attitude, a reactant noise came from inside the tank. Ninety minutes later the tank ruptured.

Post rupture examination showed that the weld between the liquid bulkhead and the tank cylinder had parted due to high internal tank pressure. The ClF_5 had leaked through the RD or one of its weld joints and had combined with the silicone rubber to evolve gas. The RD shell-to-tank cylinder weld was the most probable leak path. Figure 60 is a photograph of the tank cylinder and RD after the rupture. Note the areas where silicone rubber is missing due to combination with ClF_5.

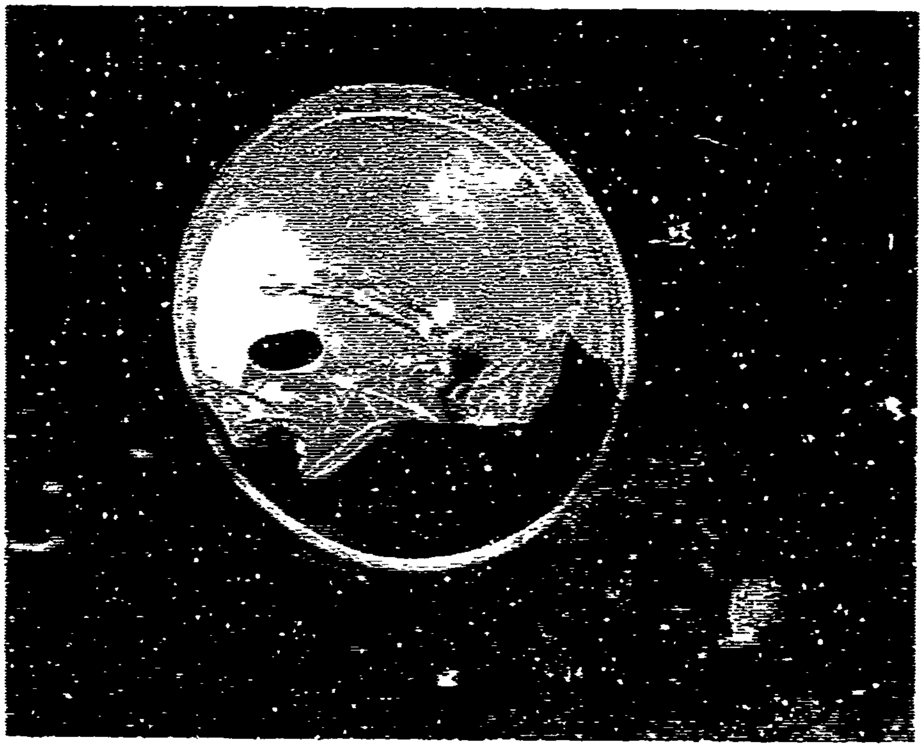

Figure 60. Rolling Diaphragm and Tank Cylinder after Rupture

The helium leak check records were reviewed to determine if the RD was leak-tight prior to filling. There was no leakage recorded during any of the leak checks. The mass spectrometer sensitivity for the 14.7 psid 100 per cent helium leak check of the RD was 1.7×10^{-10} scc/sec. The mass spectrometer system sensitivity for the 125 psid 90 per cent GN_2/10 per cent He leak check across the RD after the tank was welded closed was 8.6×10^{-9} scc/sec.

After leak check, the propellant tank had been vacuum dried for two hours, passivated for one hour with 40 psig ClF_5 and passivated for twenty hours with 8 psig ClF_5. The tank was filled with ClF_5 while the propellant tank was in a vertical position. It remained in this orientation for twenty days with ClF_5 in the tank. The suspected weld was only exposed to ullage gas because during these twenty days, the liquid level was below this weld.

Figure 61 is a photograph of the outside of the RD 1100 aluminum shell.

Figure 61. Rolling Diaphragm Shell After Rupture

This is the side the silicone rubber and propellant tank cylinder is on. Note the corrosion of the metal. This probably occurred during the twenty days storage when the ullage gas leaked or corroded through the weld and eventually developed a fairly large leak path. When the tank was laid horizontally, liquid ClF_5 leaked through the developed leak path and combined with the silicone rubber to increase the tank internal pressure. The tank ruptured as a result.

SECTION IX

REFERENCES

1. NOTS in-house memo from J. L. Carter, Code 4581 to Code 4582, Reg. 4581-022 of 17 March 1966.

2. RMD 5074-Q-1 Thiokol Advanced Packaged Liquid Propellants, Research Contract NOW-65-0575C.

3. Compatibility of Materials with Rocket Propellants and Oxidizers, Defense Metals Information Center, Battelle Memorial Institute, Columbus, Ohio.

4. The Handling and Storage of Liquid Propellants, January 1963, Office of the Director of Defense Research and Engineering, Washington 25, D.C.

5. AFRPL-TR-65-46, Vol. III, Part 2, "Air Launch Propulsion System Study Contract No. AF04(611)-10217," prepared by RMD Division of Thiokol.

6. Titan II Storable Propellant Handbook, AF4(694)-72, AFBSD-TR-62-2.

7. Storable Prepackaged Propellant System Stress Analysis, GDC DDG66-011, Convair Division of General Dynamics Corporation, San Diego, California.

8. Selection of the Welding Process for the Storable Pre-Packaged Propellant Systems Tanks, ZZL-66-026, Convair Division of General Dynamics Corporation, San Diego, California.

9. Variation in Radiograph Film Density of Electron Beam Longitudinal Welds in 2219 Aluminum SPPS Tanks, M-202, Convair Division of General Dynamics Corporation, San Diego, California.

10. Welding the 0.032 Inch, 1100 Aluminum, SPSS Tank Rolling Diaphragm, ZZL-67-011, Convair Division of General Dynamics Corporation, San Diego, California.

11. Development of AFRPL Threaded Fittings for Rocket Fluid Systems, AFRPL-TR-65-162, prepared under Contract No. AF04(611)-9578 by Battelle Memorial Institute, Columbus, Ohio.