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FINAL REPORT

STUDY FOR CLEANLINESS LEVEL REQUIREMENTS FOR PNEUMATIC AND HYDRAULIC COMPONENTS - SERVICE ARM SYSTEMS, COMPLEX 39

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Contract NAS10-5935

MARTIN MARIETTA CORPORATION

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FINAL REPORT

CLEANLINESS LEVEL REQUIREMENTS FOR PNEUMATIC AND HYDRAULIC COMPONENTS - SERVICE ARM SYSTEMS, COMPLEX 39

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Prepared For

National Aeronautics and Space Administration
J. F. Kennedy Space Center
Kennedy Space Center, Florida

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FOREWORD

This report was prepared by the Martin Marietta Corporation under Contract NAS10-5935 "Cleanliness Level Requirements for Pneumatic and Hydraulic Components - Service Arm System, Complex 39" for the J. F. Kennedy Space Center of the National Aeronautics and Space Administration. The work was administered under the Technical Direction of the Design Engineering Directorate, Mechanical Systems Division, of the J. F. Kennedy Space Center with Mr. James R. McBee acting as project manager.

Notice

Commercial names as used herein are for ease of identification only; their mention does not constitute endorsement by the authors or any government agency.

ABSTRACT

This report describes the effort accomplished, both analytical and experimental, under Contract NAS10-5935 to determine the minimum cleanliness levels required for the pneumatic and hydraulic systems on the Launch Complex 39 Service Arms. The study encompassed an in-depth system review, a critical analysis of components with respect to contamination, a literature/industry search to compile pertinent data and experience, and a test program to demonstrate component functional compliance versus contamination.

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I. INTRODUCTION

The primary purpose of the study conducted under this contract was to determine, by analysis and testing, the minimum levels of cleanliness that would permit the Launch Complex 39 Service Arm Control Systems to meet all functional and reliability requirements.

The cleanliness levels specified for the service arm systems were originally based upon the best judgment of the system designers, and as a result of subsequent launch operations experience all indications were that they were unnecessarily stringent. Considerable expense is involved in cleaning system components to these levels, in addition to other indirect costs associated with logistics, inspection, maintenance, and delays in test operations. It was therefore desirable to reduce these costs if possible.

The objectives of this program were accomplished in four phases: (1) an in-depth review of the system, (2) a critical analysis of components with respect to contamination, (3) a literature/industry search to compile pertinent data and experience, and (4) a test program to demonstrate component compliance versus contamination. This final report describes the work performed in each phase of the program, together with all findings, test data, and conclusions.

The secondary purpose of the study was to derive basic data contributing to the general body of information on part cleanliness requirements. In addition to the data contained in this final report, a separate handbook was prepared as part of the contract requirements. The Contamination Control Handbook for Ground Fluid Systems, Martin Marietta report number MCR-69-485, was prepared as a guideline of contamination control practices for those persons engaged in the design of aerospace ground hydraulic and pneumatic systems.

II. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

At the completion of the study for cleanliness level requirements, the following conclusion was formulated:

1) Cleanliness levels on the service arm systems can be reduced with no degradation in performance. The proposed levels are described in detail in Chapter II, B, 1;
2) The data collected during the study was documented in the form of a contamination control handbook as a guide for future design and operation of hydraulic and pneumatic systems.

The study was conducted in three phases and the conclusion is based upon the results obtained. The primary results of each phase of the study are discussed below.

A thorough evaluation of the system and its components was conducted to determine the system criticality and component sensitivity to contamination. Although many components are critical to the service arm performance, they are relatively insensitive to contamination. Fifteen specific recommendations concerning the service arm system and components are discussed in further detail in Section B, Recommendations.

A contamination test was conducted on 17 service arm components that were determined to be sensitive to contamination. Contamination, in excess of the recommended cleanliness levels, was purposely injected into the system to measure component performance in a highly contaminated system. The test components were procured in a commercial clean condition. All of the components, except one, operated properly throughout all tests with no degradation caused by contamination. The 75M08829 pressure regulator proved to be extremely sensitive to contamination. The cleanliness levels recommended in this study have one reservation; four regulators in the service arm systems must be protected by additional filtration.

The literature search revealed that many systems, similar to the service arm systems, are being successfully operated on less stringent cleanliness levels. Less stringent cleanliness levels should produce substantial cost savings in future procurement and operation of the service arm systems. Cleaning costs for the service arm components range up to 189% of the base component costs. The relaxed cleanliness levels in Section B, 1 are less stringent than the present levels and approach commercial cleanliness levels which should offer a reduction in cleaning costs. More significant savings should be realized in procurement, logistics, quality control, and launch operations.

B. RECOMMENDATIONS

The investigation and analysis of the service arm systems revealed several areas, related to contamination control, that require specific attention. The following recommendations are related to specific problem areas on items that would enhance contamination control on the Saturn V service arm systems.

1. Relaxed Cleanliness Levels

It is recommended that the service arm component and system cleanliness levels be relaxed to the following levels. The present levels specified are also shown for comparison.

a. Hydraulic Systems

1) Component Cleanliness Level

Particle Size (Microns)	0-5	5-15	15-25	25-50	50-100	Over 100
*Quantity per ft^2 of significant surface area	Unlimited	48,000	8,500	1,500	250	50

*Based upon a minimum of 200 milliliters of rinse fluid per square foot of significant surface area.

2) System Cleanliness Level (Level 8 of NAS-1638)

Particle Size (microns)	0-5	5-15	15-25	25-50	50-100	Over 100
Quantity per 100 ml of fluid	Unlimited	64,000	11,400	2,025	360	64

3) Existing Service Arm Criteria for Hydraulic Components (ABMA-SPEC-10425040)

Particle Size (microns)	0-5	25-50	50-100	Over 100	Fibers
Quantity per 100 ml sample	Unlimited	530	60	0	10

b. <u>Pneumatic Systems</u>

1) Component Cleanliness Levels

Particle Size (microns)	0-300	300-500	500-1000	Over 1000
*Quantity per ft^2 of significant surface area	Unlimited†	10	2	None

Fiber Length (microns)	0-750	750-2000	2000-6000	Over 6000
†Quantity per ft^2 of significant surface area	Unlimited†	20	2	None

*Based upon a minimum of 200 milliliters of rinse fluid per square foot of significant surface area.

†Total filterable solids limitation, 0.25 mg/ft^2.

2) System Cleanliness Level

Particle Size (microns)	0-300	300-500	500-1000	Over 1000
Quantity per 100 grams of gas	Unlimited*	10	2	None

Fiber Length (microns)	0-750	750-2000	2000-6000	Over 6000
Quantity per 100 grams of gas	Unlimited*	20	2	None

*Total filterable solids limitation, 0.30 mg/100 grams of gas

3) Existing Service Arm Criteria for Pneumatic Components (MSFC-SPEC-10M01671, Level IV)

Particle Size (microns)	0-50	51-140	141-230	231-320	321-410	411-500	501+
Per ft^2 of significant surface area	No Limit†	40	10	3	2	1	0

Fiber Length (microns)	0-50	51-500	501-1000	1001+
Per ft^2 significant surface area	No Limit†	10	1	0

†Total filterable solids limitation, 1.0 mg/ft^2

2. Filtration for Critical Components

The 75M08829 pressure regulator failed during the contamination tests. This regulator is highly sensitive to contamination due to a very small (0.161 in. diameter) poppet seat. The failure mode is erosion of the main poppet seat, as a result of the high velocities across the small seat area. This failure mode would also apply to all regulators in the service arm systems that have a similar configuration; namely, the small seat area with attendant high velocities. The problem may be solved by eliminating those regulators or by protection by means of filtration. It is recommended that the problem be corrected by filtration. A careful analysis of the service arm systems revealed that the majority of these regulators are adequately protected by 10 micron (nominal) filtration just upstream of the regulators; however, four regulators require additional filtration. It is recommended that 10-micron dual-element filters be placed just upstream of the following components:

Specification	Location
75M08830-2	A5657-4, -5, -6, -7

3. A Closed Hydraulic Reservoir

The hydraulic charging unit (HCU) reservoir is vented to atmosphere, with no adequate means for preventing the entrance of moisture and salt-laden air. Moisture is a significant and contributing factor to problems that were identified with fungus and corrosion in the hydraulic system. It is recommended that the vent to atmosphere be eliminated and that a positive pressure nitrogen system, with relief capability, be incorporated into the HCU reservoir.

4. Further Study to Eliminate Fungus Contamination

A hydraulic sample taken from mobile launcher no. 1 HCU reservoir contained one to two handfuls of a gummy contamination best described as having the appearance of strawberry jam. A biological analysis, conducted in the Martin Marietta Space Biomedical Research Laboratory, concluded that the contamination was fungi. Two other contamination samples, taken on different mobile launchers, indicated the presence of viable organisms in other portions of the hydraulic system. Fungus in a hydraulic system can clog filters, and produce component and system failures.

A review of the literature and industry provided no indication of any effort directed towards the elimination of fungi in HIL-H-5606 hydraulic oil. Further study is recommended in this area of technology to combat fungi formations in hydraulic oil.

5. Hydraulic and Pneumatic System Protection during Inactive Periods

The service arm pneumatic systems are pressurized only during test operations and in the launch countdown. No attempt is made to maintain a positive pressure on the system during the long intervals between launches. The hydraulic system is drained back to the reservoir after each launch.

It is recommended that a small positive pressure be maintained on the service arm pneumatic systems to prevent the entrance of moisture and atmospheric contamination, with its attendant corrosion problems. It is further recommended that a blanket of oil be maintained on the hydraulic system. Elastomers in a hydraulic system will dry out, leak, and deteriorate from age if not blanketed with oil.

6. Filtration for Hydraulic Fluid Fill

The hydraulic oil used to fill or resupply the HCU reservoir is not filtered. Considering the particulate contamination allowable in the MIL-H-5606 oil specification, large quantities of particulate can be introduced into the HCU reservoir.

Filters in the hydraulic system downstream of the reservoir will remove particles larger than 25 microns, and approximately 98% of those particles in the range of 10 to 25 microns. The filters will not remove the small particles which produce silting, component wear, and erosion. It is recommended that the hydraulic oil introduced into the HCU reservoir be filtered to 3 microns absolute.

7. Change to MIL-H-6083 Hydraulic Oil

The service arm hydraulic system uses MIL-H-5606 hydraulic oil. The literature search revealed that industry experience has shown MIL-H-6083 to be superior to MIL-H-5606 hydraulic oil and that it has two distinct advantages: (1) MIL-H-6083 contains a rust preventative as an additive; (2) conglomeration of fine particles will not occur in MIL-H-6083 as they will in MIL-H-5606 hydraulic oil. The properties of MIL-H-6083 are very similar to MIL-H-5606, and no compatibility problems exist. Residual MIL-H-5606 hydraulic oil does not have to be completely drained from a system prior to adding MIL-H-6083 oil.

8. Bubble Point Test on Filters

When performing a component analysis on the filters on the system, it was found that a bubble point test is not conducted on the majority of the filter elements after the final cleaning operation. Our experience has shown that element degradation can occur during the cleaning operation. It is recommended that a bubble point test be performed after final cleaning of the element to verify the integrity of the filter element and its stated filtration level. It is also mandatory to perform a bubble point test after an element has been in service, cleaned, and is being placed back in service.

9. Additional Sampling Procedures

The service arm pneumatic systems are not normally sampled for contamination. To maintain cognizance of the system, it is recommended that the service arm pneumatic systems be sampled at periodic intervals as part of a standard procedure.

There is no procedure or requirement to take contamination samples during the long intervals between launches or during a down-mode operation. It is recommended that procedures be instituted to take samples at three- to six-month intervals.

10. Contractor Equipment Interfaces

If the cleanliness levels on the service arm systems are relaxed, it is necessary to either revise the interface specifications for contractor equipment, or to provide adequate filtration just prior to the interface.

11. Standardization of Component Specifications

A total of eight different cleanliness level specifications are identified on the service arm component specifications. Instances were found where fluid sampling criteria had been specified for component cleanliness levels. Several component specifications applied optional cleanliness levels of widely differing criteria to the same component. This situation is a contributing factor to problems in attaining and maintaining a workable cleanliness program. It is recommended that a single cleanliness specification be referenced on all component specifications, system engineering, and applicable procedures.

12. Quality Control on System Samples

During our investigation of the service arm sampling procedures, there was no evidence of quality control as applied to the results of the contamination samples. No apparent action was taken on numerous system samples that did not meet specification. Once a realistic cleanliness level has been specified for a system, it is necessary to take corrective action if the samples do not meet specification. This action is required to prevent system degradation or subsequent failure. It is recommended that Quality Control monitor the results of the system samples.

13. Atmospheric Protection for Electrical Equipment

Corrosion of component electrical parts is one of the most predominant categories of failure in the service arm systems. The electrical portion of the components is not provided with positive protection against atmospheric moisture and salt. The service arm consoles do not contain an inert gaseous purge, and inspection revealed that the console doors are often left open between launches. The least expensive method of preventing corrosion, caused by atmospheric moisture, is to maintain a dry gaseous positive pressure (0.5-in. water gage) within the service arm consoles. This can be accomplished with dry nitrogen or air, but a compressor-dry air system would probably be more economical than nitrogen.

14. Consolidated NASA Cleanliness Specification

Operational personnel reported that a multitude of cleanliness specifications exists for the different systems on the Saturn V complex. Different specifications also exist for the same system because of different design responsibilities. Most companies in the aerospace industry have consolidated all of their cleaning criteria into one specification to eliminate confusion and reduce total costs. The Saturn V contamination control program would be greatly enhanced if a single consolidated cleanliness specification were prepared for all systems. An extension of this cleanliness specification would also include consolidated criteria for all of the NASA centers.

15. Consolidated Sampling Procedure

The requirement to take a system sample, and the governing criteria for each sample, are specified in each respective operational test procedure. There is no composite correlation of the samples taken on the Saturn V launch stand, and as a result there is no consistent approach to sampling or sampling criteria. A standard sampling procedure should be established to coordinate all of the samples taken on Complex 39. This procedure would combine all sampling information and criteria into one central document and would eliminate confusion among different groups. The procedure should list fluid commodity, sample port location, the procedure used when taking the sample, and the criteria for the sample.

III. SYSTEMS ANALYSIS

A. SERVICE ARM DESCRIPTION

Launch Complex 39 has nine service arms on each launch umbilical tower (LUT). The primary function of the service arms is to provide personnel and astronaut access, fluid commodity loading and unloading, electrical power, environmental control, and checkout of the Saturn V vehicle. After the Saturn V vehicle arrives at the launch pad, the service arms are extended to the vehicle and various checkout functions are performed to ensure the integrity of the systems. Prior to launch, the service umbilicals are connected to the vehicle to perform loading, access, and checkout. After all functions are complete the service arms disconnect all umbilical carriers and couplings from the vehicle, withdraw the umbilical lines, and then retract the arm back to the LUT where the arm is locked into place. Four of the service arms are withdrawn prior to liftoff, and five at or directly after liftoff (Fig. III-1 and Table III-1).

Table III-1 Service Arm Retract Times

Arm 1	(S-IC aft)	0 hr 0 min 30 sec
Arm 2	(S-IC forward)	0 hr 0 min 16.2 sec
Arm 3	(S-II aft)	11 hr 30 min 0 sec
Arm 4	(S-II intermediate)	Liftoff
Arm 5	(S-II forward)	Liftoff
Arm 6	(S-IVB aft)	Liftoff
Arm 7	(S-IVB forward)	Liftoff
Arm 8	(service module)	Liftoff
Arm 9	(command module)	0 hr 43 min 0 sec

This study concerns the hydraulic (MIL-H-5606) and pneumatic (nitrogen-helium) control systems that perform the following basic functions on the service arms:

1) Carrier kickoff;
2) Carrier withdraw/reconnect;
3) Coupling kickoff/withdraw;

4) Line tray withdrawal;
5) Service arm extend/retract (automatic);
6) Service arm extend/retract (manual);
7) Latchback mechanism;
8) Water quench system actuation;
9) Platform extend/retract;
10) Environmental chamber operation.

B. DETAILED ANALYSIS

When specifying a cleanliness level for a large and complex system such as the service arms, it is not possible to merely assign a level by association to other systems. This task must first address itself to the function of the system, the criticality assigned to each function of the system, and a review of the backup or redundancy configurations. In addition, the selection of a system cleanliness level depends greatly upon orifice sizes, level and adequacy of filtration, sampling procedures, system sample results, the maintenance provisions used to prevent cleanliness degradation, and finally a careful review of each critical component in the system.

As the initial phase of this contract, a detailed analysis of all service arm fluid systems was performed with the primary objective of identifying those components, both hydraulic and pneumatic, that perform critical system functions. At the initiation of the contract, a decision was made to use the updated configuration of the service arms, effectivity AS-503. Table III-2 lists the basic documentation (and the applicable revisions) that describe the baseline for this study.

During the initial phase of the systems analysis, 47 basic operational functions were identified among the nine service arms. It also became apparent that many of these functions appeared in identical configurations on more than one service arm, including identical component item-find numbers. The logical decision was made, therefore, to consolidate the 47 functions into a set of individual or repetitive systems, resulting in a significant simplification of the analysis task. This activity was subsequently accomplished, with the result that a commonality set of 23 system functions was identified (Table III-3).

Table III-2 Baseline Documentation

Schematic Number	Title	Revision Number
76K02010	Hydraulic Charging Unit	Revision A
76K02011	S-IC Intertank Arm	Revision A
76K02012	S-IC Forward Arm	Revision A
76K02013	S-II Aft Arm	Revision A
76K02014	S-II Intermediate Arm	Revision A
76K02015	S-II Forward Arm	Revision A
76K02016	S-IVB Aft Arm	Revision A
76K02017	S-IVB Forward Arm	Revision A
76K02018	Service Module Arm	Revision A
76K04767	Apollo Access Arm	Revision B
76K03445	Environmental Chamber	New
76K00190	Item Find List, Arm 9	Revision B
75M06518	Item Find List, Arms 1-8	Revision E
76K02001	Service Arm Component Settings	Revision H
Technical Manual No.	**Title**	**Publication Date**
TM439	Pressure Regulators	11 Dec 67
TM440	Solenoid Valves	13 Dec 67
TM441	Cylinders	15 Dec 67
TM442	Pilot Operated Valves	20 Dec 67
TM443	Miscellaneous Components	22 Dec 67
TM500	Hydraulic Charging Unit	30 Jun 67
TM501	S-IC Intertank Arm	15 Jan 68
TM502	S-IC Forward Arm	2 Feb 68
TM503	S-II Aft Arm	3 May 68
TM504	S-II Intermediate Arm	30 Aug 68
TM505	S-II Forward Arm	15 Jul 68
TM506	S-IVB Aft Arm	15 Feb 68
TM507	S-IVB Forward Arm	26 Jul 68
TM508	Service Module Arm	16 Aug 68
TM509	Apollo Access Arm	10 Nov 67

Table III-3 Service Arm Functions

System Description	Arm Usage
Control Console #1	1,2
Control Console #1	4,5,6,7,8
Control Console #1	9
Control Console #2	4,5,6,7,8
Manual Console	3
Water Quench and Latchback	1,2,4,5,6,7,8
Latchback Cylinder	3
Water Quench and Latchback	9
Carrier Reconnect	4
Platform Extend/Retract	5,6,7
Carrier Kickoff	2
Carrier Kickoff	4,5,6,7
Carrier Kickoff	8
Carrier Withdrawal/Reconnect	1
Carrier Withdrawal	4,5,6,7
LEM Withdrawal Cylinder	7
Carrier Kickoff	8
Coupling Kickoff/Withdrawal	4
Tray Withdrawal	2
Tray Withdrawal	6
Tray Withdrawal	7
Environmental Chamber	9
Hydraulic Charging Unit	--

Schematics of the above fluid systems are presented in Figures III-2 through III-23. With all service arm systems now reduced to their basic elements, a detailed study of each isolated system schematic was conducted in conjunction with applicable operational data in order to gain a thorough understanding of the design philosophy and technique. This effort revealed the fact that the set of commonality systems was comprised of nearly 1100 nonduplicating item-find numbers. It was also obvious that many of these were nonfunctional, performed maintenance duties, or were otherwise not critical to a successful launch.

The major effort in the analysis of the service arm systems was an item-by-item examination of each component in each system. For this purpose, charts were prepared for each component showing the item-find number, nomenclature, all possible modes of failure, the system effect of each failure mode, and a classification breakdown of the importance of a failure to the launch. For the purposes of this study, the following failure-effect categories were considered:

1) Loss of life or mission failure;
2) Launch delay of any duration;
3) System malfunction or data loss (used during count-down and launch, but not critical to launch success);
4) Local information loss or maintenance function (not required during countdown and launch);
5) Nonfunctional (no contribution, such as test ports, interface fittings, etc.)

The above effort differed from the usual interpretation of a failure analysis in that, in line with the program objectives, only effects arising from contamination problems were considered. The following ground rules were followed when determining failure modes and establishing failure effects:

1) The worst possible moment of failure in point of time was considered;
2) The functioning of any particular subsystem was considered to be essential, even though a redundant capability exists;
3) Redundancy of components was not considered, since parallel components can be equally susceptible to contamination;
4) Failure by contamination only was considered -- not mechanical, electrical, structural, environmental, or operator error (Example: broken springs, incorrect procedures, etc.);
5) Only one failure was assumed to occur at any given time;
6) Header supplies were assumed to be available at the proper pressures and flowrates at all times;
7) Contractor furnished equipment was not evaluated in the study.

The results of the above categorization were compared to those obtained by The Boeing Company in "Failure Effects Analysis", their document number D5-16494-7. The Boeing analysis was, of course, conducted under different ground rules; in that work, failure due to contamination was not the only failure mode considered, and failures in redundant areas were considered to have no effect. These facts resulted in our analysis showing considerably more Category A and B components than did theirs.

In addition, Martin Marietta made no attempt to differentiate between a launch delay and a launch scrub, as did Boeing. However, for the vast majority of components, our estimation of failure modes and effects was consistently in agreement with that of Boeing.

As a result of this effort, 329 individual item-find numbers out of the original total of approximately 1100 were retained for further consideration; 135 in Category A (loss of life or mission failure) and 194 in Category B (launch delay of any duration). Conversion of this total to a part number arrangement disclosed that 79 different components manufactured by 27 vendors were represented. The categorized list of these 79 components is included in this report as Appendix A. It was from this list of Category A and B components that the final selection was made of the components to be used in the test phase of this program. No further consideration was given to those components classified as Category C, D, and E since these components were not critical to the system operation and generally consisted of hand valves, fittings, and other components that were not critical from a contamination viewpoint. The criteria used for further evaluation of these components is described in Chapter IV, Component Analysis.

In the course of the above system studies, several general areas arose that were felt to be deserving of discussion. These were:

1) Cleanliness specifications;
2) Filtration;
3) General system problems;
4) Sampling procedures;
5) System orifices; and
6) Service arm cylinders.

A discussion of each of these subjects follows.

1. Cleanliness Specifications

During this study it was found that there are a multitude of cleanliness specifications being used to specify fluid, component, and system cleanliness levels on the service arms. Eight different cleanliness specifications have been identified for hydraulic and gaseous nitrogen applications, generated by four different government agencies, and ranging in age from April 1960 to March 1968, a span of eight years. These specifications are listed in Table III-4.

Table III-4 Government Cleanliness Specifications

Specification Number	Fluid	Issuing Agency
1. KSC-C-123	Fluids	NASA Kennedy
2. 10M01621	Pneumatic	NASA Marshall
3. 10425040	Hydraulic	Army Ordinance
4. MSFC-SPEC-164	Pneumatic	NASA Marshall
5. MSFC-PROC-166	Hydraulic	NASA Marshall
6. MSFC-SPEC-234	Nitrogen	NASA Marshall
7. 75M09467	Hydraulic	NASA Marshall
8. MIL-H-5606B	Hydraulic oil	NAV-WEPS

Of this total, the KSC-C-123 and 10M01621 specifications are apparently identical in all respects, but all others specify different criteria levels. Specifications 2, 3, 6 and 8 are referenced in the scope of work for this contract; the other four are not. Instances were found where system fluid sampling criteria had been specified for component cleanliness levels. Several component specifications applied optional cleaning procedures of widely differing criteria to the same component. Detailed criteria for these specifications are contained in Table IV-1.

This situation is a significant and contributing factor to problems in attaining and maintaining a workable cleanliness program. Undoubtedly, several of these eight specifications were prepared for a specific requirement some time ago, then applied intact to the service arm systems whose functional requirements and component configurations may bear little or no resemblance to those for which the specification was originally prepared. Such a large variety of specifications must inevitably lead to confusion by compounding communications problems between those persons who are responsible for actual cleanliness determinations. The use of a single, comprehensive specification is recommended to eliminate confusion and unify the requirements for all aspects of the cleanliness program. Further, this single specification should then be referenced on all component procurement drawings and all system installation drawings and operating or maintenance procedures.

Operational personnel (The Boeing Company) were contacted during the course of this study regarding cleanliness specifications, sampling techniques, contamination control, etc. One significant area of discussion centered around cleanliness specifications. They reported that a multitude of specifications exist for the different systems on Saturn V; and that for the same piece of pipe and commodity, different specifications exist for each system on the tower. This comment would indicate the need for a single consolidated cleanliness specification for all systems on Saturn V. Most companies in the aerospace industry have consolidated all of their cleaning criteria into one specification to eliminate confusion and reduce costs. The optimum solution would be a single consolidated cleanliness specification for all NASA centers. The above recommendation presents a formidable coordination task, but it is not impossible. The net return should result in a significant cost reduction.

It should be noted that a consolidation of cleaning procedures will generally incur an initial cost to engineering and sometimes in procurement. Engineering must be revised to maintain configuration control. Manufacturers will probably request additional price increases in hardware to change their engineering and cleaning processes if the criteria is actually revised. If the criteria is less stringent, a substantial cost savings should be realized. The total impact of the change must be evaluated; but initial costs are generally offset by significant savings in operations, procurement, launch stand operation, and logistics.

2. Filtration

Adequate filtration is one of the best means of maintaining system cleanliness and protecting critical components in the system.

The method of filtration employed on the service arms is shown in Figure III-24. The hydraulic supply in the hydraulic charging unit (HCU) has a 144-micron sump filter that filters all hydraulic fluid used in the service arms. The low pressure pump just downstream of this filter is a gear-type pump and the 144-micron filter is adequate. The vendor for this pump maintains that the pump will operate satisfactorily at Level 9 of NAS 1638 (commercial cleanliness). The high pressure pump inlet, and the pump bypass back to the reservoir, are individually filtered to 10 microns nominal. The hydraulic supply to the service arm consoles is also filtered to 10 microns. The hydraulic return drain to the HCU reservoir is filtered to 10 microns by means of a large depth-type filter. Filters are located within the service arm systems to protect critical components.

Filters for the service arm pneumatic system are located at the console inlets on each level. All pneumatic supplies, with the exception of the 125 psi nitrogen system, are filtered to 10 microns nominal. The 125 psi nitrogen system does not contain any critical components and no additional filtration is recommended. Numerous samples taken in the pneumatic headers to the service arms indicate no particles over 140 microns, with only one to five particles in the range of 50 to 140 microns. Small filters are contained within the pneumatic systems to protect individual components.

The majority of the filters in the system are of the single element in-line type installed in hard piping installations. These filter elements are difficult to maintain and the system will generally receive contamination from the atmosphere unless special protection is provided during checkout. We recommend that dual-element or T-type filters be considered for future design applications.

In our experience, dual element filters have been found to offer several advantages, and the literature reviewed substantiates this position. A typical hydraulic system dual element filter consists of a 15-micron (absolute) primary element backed up by a 3-micron (absolute) secondary element that can effectively control silting contamination. Filters are proportional devices and most manufacturer's define nominal rating as the ability to trap 98% of particles of the rated size or larger. Absolute ratings are generally interpreted at 100%; however, the possibility exists of passing fiber-type contaminants longer in dimension than the absolute rating, but smaller in diameter. With a dual element device, increased turbulence and double filtration effectively increases filtration reliability. Except in extraordinary circumstances, the secondary element need never be changed; the primary element can be readily changed without mechanically disturbing the system or exposing the system to external contaminants. This is the primary advantage of the device. These advantages accrue with little additional expense.

Under circumstances where continuous high flowrates are involved, the dual element-type filter would be more effective when used for critical component protection, with a much coarser filter used off the header supply. However, in the service arm systems, supply flowrates are relatively small and infrequent, and maintenance would probably not be excessive if the device were used off the header as a blanket system protector.

Components that are particularly sensitive to contamination should be protected by filtration just upstream of the component. If the component does not see large quantities of fluid, an integral filter screen (Fig. III-25) contained within the component may be considered. Integral screens should have ample area and sufficient structural backup to prevent loading, ΔP buildup, and subsequent rupture of the screen. Fitting-type screens (Figure III-25) are not recommended. During the contamination tests conducted on this contract, all of the fitting-type screens failed. These screens do not contain sufficient area and often will rupture and proceed down the system, with the possibility of a major contamination failure downstream. Another disadvantage of these screens is that in normal operations they are never maintained or cleaned.

The majority of the filters contained in the service arm systems are manufactured by Fluid Dynamics. A bubble point test for verification of the filtration level is performed after they are manufactured. The filters are then cleaned by another vendor, but are not bubble point tested after cleaning. Our experience has shown that it is necessary to perform a bubble point test after any cleaning operation and prior to usage in order to verify the integrity of the filter and its stated filtration level. Also, it is mandatory to perform a bubble point test after an element has been in service, cleaned, and is being placed back in service. We recommend that the above practices be instituted for the service arm systems.

The HCU reservoir is filled with MIL-H-5606 hydraulic fluid from drums by means of a hand pump. The oil is introduced into the HCU return line downstream of the filter; thus no filtration of the oil is accomplished upon resupply or initial fill of the hydraulic reservoir.

Considering the volume of the reservoir and the particulate contamination allowable in the MIL-H-5606 oil specification, the quantities of particulate that could be introduced into the reservoir in a single fill operation are given in Table III-5.

Table III-5 Potential Reservoir Fill Contamination

Particle Size Range (Microns)	0-5	5-15	15-25	25-50	50-100
Number of Particles	Unlimited	47,200,000	18,900,000	4,720,000	472,000

None of the particles smaller than 10 microns will be removed by the service arm hydraulic system filters. Martin Marietta recommends that all hydraulic oil introduced into the HCU reservoir be filtered to 3 microns.

Contamination tests were conducted on critical service components as the last phase in this contract. The major conclusion reached in these tests was that the 75M08829 pressure regulator is highly sensitive to contamination. The failure mode was erosion of the main poppet stem seat, as a result of the high velocities across the small seat. This conclusion would also apply to all regulators in the service arm systems that have a similar configuration, namely, the small seat area with attendant high velocities.

To alleviate this condition, these regulators may either be replaced or protected by adequate filtration just upstream of the component. We recommend that the problem be corrected by filtration. A careful analysis of the service arm systems revealed that the majority of these regulators were located in close proximity to the filters at the inlet of the consoles and were the first components downstream of these filters. These regulators will be adequately protected by the 10-micron filters. The following regulators are not protected by adequate filtration.

Specification	Location
75M08830-2	A5657-4, -5, -6, -7

Martin Marietta recommends that 10-micron absolute dual-element filters be installed just prior to the above regulators. This recommendation is made even if the relaxed cleanliness levels, described in this report, are not implemented. The present cleanliness levels of the service arm system (reference Tables III-7 and III-8) are dirty enough to warrant this recommendation.

This study did not include an investigation of the contractor equipment that interfaces with the service arm systems. If the relaxed cleanliness levels described in this report are implemented, the contractor interface specifications should either be revised or adequate filtration should be required in order to protect their equipment.

3. General System Problems

The previous discussion on filtration concerned particulates as a detrimental form of contamination. Another important consideration in hydraulic and pneumatic systems is the elimination of moisture. In the service arm system, the reservoir of the hydraulic charging unit is vented to atmosphere, with no adequate means for preventing the entrance of moisture and salt-laden air. This is felt to be a significant contributing factor to problems that were identified with fungi in the system and corrosion in accumulators and cylinders.

A contaminated hydraulic oil sample was taken from the hydraulic charging unit on mobile launcher No. 1 in January 1969. The sample contained approximately one to two handfuls of a gummy contamination best described as having the appearance of "strawberry jam" of a thick, gummy nature. A chemical analysis was conducted by NASA and the contamination was reported to be a cellulose fiber, but it was not determined whether it was organic or synthetic. There was a small trace of calcium, zinc, and iron.

Since the analysis indicated a fibrous material, the hydraulic system and reservoir mist filter were inspected to determine if any system degradation had produced a "fibrous" material. The inspection did not reveal any degradation or any other contamination in the reservoir vent system or on the hydraulic system filter.

After reviewing the results of the chemical analysis, it appeared that the chemical analysis could be supplemented by a biological analysis, and such an analysis of the contamination was conducted in the Space Biomedical Research Laboratory of Martin Marietta. The analysis concluded that:

> "Microscopic examination of the contaminated hydraulic oil sample revealed the presence of branched filaments (Fig. III-26) characteristic of fungi mycelium. An attempt was made to demonstrate the presence of viable fungi. Standard bacteriological culture media (Sabouraud's dextrose agar, trypticase soy agar and nutrient agar) were inoculated with samples of contaminated oil. After 48 hours incubation at 32°C, typical fungal colonies were evident. Thus, using preliminary data as a basis, it is believed that the oil contaminant is a fungus."

Additional tests were performed on the fungi culture. We were unable to produce a culture in clean MIL-H-5606 hydraulic oil, but were able to produce a culture in plain tap water under the oil. There are four distinct classes of fungi; this particular fungi was isolated to the Fungi-Imperfectii class. Lack of information on structure and presence of fruiting bodies prevented an accurate classification within its individual class without further tests which were beyond the scope of this contract.

Two other contamination samples tenatively indicate the presence of viable organisms in other portions of the hydraulic system - on different mobile launchers. A 0.25-inch clogged hydraulic line was reported on service arm 6, mobile launcher #2 on 12 July 1968. The substance in this line was reported to be a "black gummy mass". Failure analysis conducted by the NASA Materials Analysis Branch reported that the material consisted of stainless steel corrosion products (Fe_2O_3 and Cr_2O_3). The description of a "black gummy mass -- or sludge" related very closely to a viable bio-organism which a biological analysis may have verified. There was no indication, in this sample, of any products resulting from the degradation of elastomers.

A hydraulic oil sample was taken on 26 February 1969 from the hydraulic charging unit reservoir on LUT 2. In addition to particulate contamination found in the sample, it was reported that a "long fiber of pale green jelly" was present in the sample. No biological tests were performed on this sample. If the visual description was accurate, it may also indicate the presence of viable organisms in the hydraulic system.

Viable organisms could have been introduced into the system in a variety of ways; either by atmospheric means, by external means (components, maintenance, etc.), or transported into the system while the hydraulic oil supply was being replenished. All organisms require water to maintain their viable state; others require nitrogen or oxygen in addition to water.

Viable organisms cannot be sterilized by a normal component cleaning procedure. They can be sterilized by either applying heat-steam or by the use of biocides. The applications of heat-steam to the service arm systems is not satisfactory because of the detrimental effects to elastomers and components. Complete elimination of water vapor from the system is a very difficult task and generally can only be accomplished by a vacuum technique.

Viable organisms have caused problems in other systems such as jet fuel tanks, and the problem was solved with biocides. To our knowledge, only one study has been directed towards the use of biocides to control fungi in hydraulic oil. This study was performed in England on a hydraulic oil different than MIL-H-5606. The use of biocides is common knowledge; but its effect on the hydraulic oil, elastomers, and components in the system has not been investigated. Further study is recommended in this area of technology to combat fungi formations in hydraulic oil.

The mass transport of fungi from one part of a system to another can be prevented by the use of filtration techniques. Five-micron nominal (or less) filtration is required; the minimum filtration level in the service arm systems is 10-micron nominal.

It is our recommendation that the vent-to-atmosphere on the hydraulic charging unit reservoir be eliminated. This vent should be replaced with a small positive pressure nitrogen system (with pressure relief capability) to prevent water vapor from entering the hydraulic system. A closed system is recommended to prevent degradation from corrosion and to eliminate conditions conducive to the propagation of viable organisms.

Moisture will enter a hydraulic or pneumatic system by a diffusion process unless a positive pressure is maintained on the system. The service arm systems are pressurized only during test operations and in the launch countdown. No attempt is made to maintain positive pressure on the system during the long interval between launches. It is recommended that a small positive pressure be maintained on the nitrogen system to prevent migration of moisture and particulate into the system through relief ports, calibration fittings, bleed orifices, etc. It is further recommended that the hydraulic system be fully blanketed with hydraulic oil at a small positive pressure to prevent atmospheric contamination and drying out of the seals. Elastomers in a hydraulic system will dry out, leak, and deteriorate from age if not blanketed with oil.

The history of component failures on the service arms indicates that the single largest contamination failure is corrosion of electrical contacts. Most of the electrical components are located in the service arm consoles. The consoles on the service arms are not purged with nitrogen and are not adequately sealed to prevent moisture from entering the consoles. Further, inspection of the service arms revealed that the doors on the consoles are often left open between launches. Again, the least expensive method of preventing corrosion caused by atmospheric moisture is to maintain a positive pressure (0.5-inch water gage) within the service arm consoles. This can be accomplished with dry nitrogen or air. On a system as large as the service arms, a compressor-dry-air system would probably be more economical than the use of nitrogen.

The service arm hydraulic system is essentially a dead-ended system and cannot be thoroughly flushed in the event the system were to become heavily contaminated. On future designs, a flush-through capability should be provided.

The hydraulic oil used in the service arm systems is MIL-H-5606. Our experience has shown that MIL-H-6083 hydraulic oil is superior to MIL-H-5606 and has two distinct advantages: (1) MIL-H-6083 contains a rust preventative as an additive; (2) conglomeration of fine particles will not occur in MIL-H-6083 as they will in MIL-H-5606 hydraulic oil. The properties of MIL-H-6083 are very similar to MIL-H-5606, and no compatibility problems exist. Residual MIL-H-5606 hydraulic oil in a system need not be completely eliminated prior to adding MIL-H-6083. Literature comparing the two is available; no unfavorable accounts were found during our review.

4. Sampling Procedures

Meetings were conducted throughout the course of the contract with those personnel in NASA, Boeing, and Bendix who were directly associated with, or responsible for, sampling procedures, analysis, and contamination control. The following samples are normally taken on the service arm systems:

1) Hydraulic Charging Unit - Two samples are taken at the HCU during validation procedures. These are dynamic samples taken while the system is running. Samples are analysed for acid base, moisture, and particulate. Critiera for moisture are taken from MIL-H-5606B and criteria for particulate are taken from both MIL-H-5606 and 75M09467;

2) Resupply Fluid - Hydraulic fluid received in drums is not sampled for moisture content. Problems have arisen in meeting 75M09467 particulate criteria when sampling the drums. The HCU reservoir is filled from the drums by means of a hand pump that does not meet cleanliness criteria, and fluid is introduced into the HCU return line downstream of the filter;

3) Service Arm Hydraulic System - The hydraulic systems on the service arms are sampled during validation procedures to level II of 75M09467. Samples are taken with pressure on the system at (a) both sides of the arm retract cylinders -- upper and lower hinges; (b) test port of the secondary retract gage; and (c) the hydraulic standby (70 psi) system on the hydraulic side;

4) Pneumatic System - The service arm pneumatic systems are not normally sampled as part of any standard procedure unless "contamination is suspected" or component failures indicate contamination. When samples are taken, level IV of 10M01671 is used for criteria. The pneumatic header is sampled during the validation procedures.

Specification 75M09467 is used as criteria for all service arm hydraulic system samples. This criteria document was not referenced in the contract and was not specified in any of the engineering documentation reviewed during the contract. The cleanliness levels in this document are considerably relaxed as compared to the other existing service arm cleanliness criteria. The specification was orginated at Marshall and was reportedly used on Saturn I. Particulate criteria excerpts from 75M09467 are given in Table III-6.

Table III-6 Particulate Criteria (75M09467)

Usage / Micron Range	I Servo Valves and Close Tolerances	II Actuators and Cylinders	III Accumulators and Reservoirs
10-25	5,360	23,680	42,000
25-50	780	3,640	6,500
50-100	110	555	1,000
100-150 + fibers	11	52	92
150 +	0	0	0

In meeting with the various operational groups concerned with the service arm samples, it was apparent that a group responsible for a particular arm did not know what procedures or criteria were being used for the other arms on the tower. The requirement to take a sample, and the governing criteria for each sample, are only spelled out in each respective operational test procedure. There is no composite correlation of the samples taken on the Saturn V launch stand.

The operational groups were of the opinion that the present cleanliness levels were too stringent. No quality controls were found to exist that specified a "no-go" situation when a system did not meet specification. It was noted that up to three samples were taken on the same system before criteria would be met.

Tables III-7 and III-8 show the results of hydraulic samples taken in the HCU and on the service arms. Figure III-27 depicts these results graphically.

Fifty-six samples from the nitrogen distribution system were reviewed and each sample showed only 1 to 5 particles in the range of 50 to 140 microns, with no particles above that range. An extensive blowdown of the system is performed prior to taking the pneumatic samples in the distribution system.

Table III-7 Service Arm Hydraulic Samples

Samples taken at:	LUT	Arm	Date	Particle Size Range (Micron) 5 to 15	16 to 25	26 to 50	51 to 100	100+	Maximum Size (Microns)
Specification Criteria Used MIL-H-5606, Level II				2,500	1,000	250	25	0	
Bleed Riser #3	2	6	7-9-68	17,098	500	380	85	19	
Valve #5550	↓	↓	↓	110,136	38,688	33,072	73	4	
Deceleration Valve-L	↓	↓	↓	6,634	3,658	1,612	176	76	1100 (fiber)
Deceleration Valve-R	↓	↓	↓	3,307	1,934	1,054	338	412	700 (fiber)
Lower Hinge Rod End	↓	↓	↓	10,220	6,494	239	25	19	200
Bleed Riser #1	↓	↓	↓	275,808	6,739	4,368	151	9	
Bleed Riser #2	↓	↓	↓	3,295	918	144	13	25	200
Upper Hinge Blind End	↓	↓	↓	133,229	42,900	21,060	12,012	73	
Upper Cylinder Rod End	↓	↓	↓	338,208	132,912	36,504	1,089	70	
Lower Cylinder Blind End	↓	↓	↓	10,390	3,879	238	94	107	500

Table III-8 Service Arm Hydraulic Samples

Specification Criteria Used 75M09467			Level	Particle Size Range (Microns) 10 to 25	25 to 50	50 to 100	100 to 150	150+	Maximum Size
			Level (II)	23,680	3,640	555	52	0	--
			Level (III)	42,000	6,500	1,000	92	0	--
Sample taken at:	**LUT**	**Arm**	**Date**						
A5550-6	1	6	2-3-68	TNTC	2,870	98	8	0	
A5414-6	1	6		9,204	476	30	3	0	
A5326-1	1	HCU		13,790	81	2	0	1	240
A5338-1				12,667	82	7	2	0	
A5325-1				12,854	124	6	0	0	
A5326-2				8,923	62	1	0	0	
A5350				14,976	381	25	3	0	
A5325-1				36,504	102	3	0	0	
A5338-2				12,602	140	9	0	0	
A5450	2	2	6-27-68	890	98	1	0	2	400 metal, 420 metal
A5403	2	2	6-27-68	TNTC	466	108	13	2	1,200 (fiber), 210 (particle)
A5415	3	4	12-31-68	TNTC	TNTC	187	13	8	
A5413		4		53,040	10,764	5,304	109	78	
A5550		4		12,792	102	23	5	0	
--		6		11,887	1,123	50	12	0	
--		6		3,058	624	6	2	0	
--		6		7,051	624	24	3	1	

TNTC - To Numerous to Count

Bendix takes samples only when a request is received from the contractor. No conclusion is made by Bendix as to whether the sample meets specification. Hydraulic samples are taken by the open-bottle technique with the volume ranging from 100 to 1000 ml depending upon the contractor's request. Gas samples are taken by the Millipore method with flow volumes of 30 to 130 SCF. A contamination precount is made on both the open bottle and Millipore pad prior to taking a sample. Bendix prefers the open-bottle technique rather than a Millipore bomb because they believe the connection that must be made with the Millipore bomb introduces more contamination. Extensive tests conducted by Martin Marietta on Titan vehicles has proven the reverse; that less external contamination is introduced in using the Millipore bomb, and results are more consistent.

Bendix was questioned as to problems encountered in cleaning components and systems to the KSC-123 specification. They stated that no problems were generally encountered in cleaning components to Level IV of KSC-123, but some problems occurred in cleaning systems to the same level. They also stated that Level I of KSC-123 presented many problems and subsequently required more effort in cleaning, particularly with more complex components.

The sampling procedures used on the service arm systems are believed to be inadequate to ensure an acceptable system cleanliness status throughout all phases of operation. The following procedures are deemed necessary to ensure good practice in this regard:

1) Nitrogen samples should be taken on the service arm systems on a regular basis and as part of a standard procedure;

2) Scheduled hydraulic and pneumatic samples should be taken during the long intervals between launches, or during down-mode;

3) Hydraulic fluid transferred from drums to the HCU reservoir should be filtered prior to entering the HCU;

4) Hydraulic fluid should be received (as validated) as meeting the MIL-H-5606B specification;

5) A standard sampling procedure should be initiated to coordinate all of the samples taken on Complex 39. This procedure would serve to combine all sampling information and criteria into one central document and would eliminate confusion among different groups. The procedure should list fluid commodity, sample port location, the method used for the sampling, and the criteria for the sample;

6) No quality controls were in evidence in the event a sample did not pass criteria. Sample reports should be controlled by quality control and a resolution made if the sample does not meet criteria.

5. System Orifices

Orifices are one of the more important factors to be considered in the analysis of cleanliness levels for fluid systems. An analysis was performed on all of the orifices in the service arm systems as part of this study. Table III-9 presents a compilation of all of the orifices, both hydraulic and pneumatic, that exist as individual find numbers in the service arm systems. The table presents each orifice diameter in inches, and the equivalent micron size.

Table III-9 Service Arm Orifice Size Tabulation

Item-Find Number	Specification Number	Service Commodity	Diameter (in.)	Diameter (microns)
A-5469	75M04165	Hydraulic	0.020	508
A-29601	75M04165-2	Pneumatic	0.030	762
A-5872	75M21479-7	Pneumatic	0.1406	3,570
A-5873	75M21479-7	Pneumatic	0.1406	3,570
A-5738	75M50184-1	Hydraulic	0.114	2,895
A-5644	75M50184-6	Hydraulic	0.030	762
A-5648	75M51695-2	Hydraulic	0.030	762
A-34762	76K00189-1	Pneumatic	0.077	1,955
A-34765	76K00189-1	Pneumatic	0.077	1,955
A-34815	76K00189-1	Pneumatic	0.077	1,955
A-35730	76K00189-2	Hydraulic	0.043	1,092
A-35731	76K00189-2	Hydraulic	0.043	1,092
A-34951	76K03578-1	Pneumatic	0.047	1,193
A-34971	76K03578-9	Pneumatic	0.093	2,360
A-34989	76K03578-12	Pneumatic	0.040	1,016
A-5594	---	Hydrualic	0.450	11,430
A-5865	---	Pneumatic	0.030	762
A-5973	---	Pneumatic	0.030	762

The smallest diameter in the service arm system is 0.020 inches, or 508 microns. This orifice was included in the contamination tests (see Chapter VII) and the orifice did not clog even though particles up to 1000+ microns and fibers (up to 2000+ microns) were injected into the test system.

Our conclusions, backed up by test, are that the orifices in the service arm systems are not too small; even with the new cleanliness level recommended by this study.

At this juncture it should be recognized that factors other than the absolute orifice diameter must be considered when evaluating the possibility of orifice clogging. Some of these factors are:

1) Particle shape. If all particles were of a hard spherical shape, the orifice diameter would be the limiting factor. This, however, is practically never the case; and since current measuring practice gages the longest particle dimension, the probability is quite high that a given particle would pass through an orifice even though its longest dimension is greater than the orifice diameter. In low velocity hydraulic systems, fibers will form a mat, thus acting as a screen that traps smaller particles resulting in a clogged orifice. However, this circumstance should be minimized by the application of adequate filtration techniques;

2) Particle composition. Ordinarily, typical contamination is composed of both hard (metallic) and soft (organic) materials. Depending on the fluid velocity within the system, softer particles larger than the orifice diameter will be extruded through an orifice. Harder particles will not pass through an equivalent orifice size;

3) Particle Density. In gaseous systems, high-density particles tend to settle out in traps inherent in the system, due to large density ratios between the particle and the gas. Fibrous-type contamination would more likely be entrained in the fluid stream. In hydraulic systems where the fluid density is more nearly the same as that of the particulate, much less settling can be expected and entrainment should be considered to be predominant.

When design requirements dictate the use of orifices that are within the size range covered by cleanliness requirements, a method that should receive consideration is the use of series orifices. This technique involves placing two or more larger orifices in series to achieve the same flow-limiting effect as would be obtained from one very small orifice. Low-flow hydraulic systems are felt to be most deserving of this approach; pneumatic systems with attendant high fluid velocities are much less prone to buildup or nesting of particulate contaminates.

6. Service Arm Cylinders

The major service arm component problems associated with contamination that were identified to us by NASA involved cylinders and accumulators. These problems were not a direct result of particulate, but rather resulted from internal corrosion products and deteriorated seals. The causes of such difficulties were:

1) Inadequate removal of cleaning solvents;

2) Lack of blanket pressurization;

3) Improper lubrication during reassembly;

4) Seal damage during assembly.

Making the assumption that these factors are controlled, the critical failure mode for cylinders and accumulators is a piston sticking due to massive amounts of particulate contamination.

The cylinder force analysis (Table III-10) was conducted to determine the probability of a piston becoming stuck in one position due to contamination. Using the appropriate inlet pressures, calculations were conducted to determine the hypothetical thickness of material that could be sheared. The numbers tabulated in the "Shear Capacity" column of Table III-10 reflect a circumferential band of metallic material, having a shear strength of 100,000 psi, that could be sheared by the forces available on the piston. This analysis is theoretical, and only presents a relative gage in evaluating the forces present in each cylinder since the shear strength of contamination is a variable and has not been determined with any degree of accuracy. As can be seen from the tabulation, significant thicknesses would represent such massive amounts of contamination that this failure mode is considered to be an extremely remote possibility. This analysis only considers the forces necessary for a piston to become stuck on one position, and does not relate to the shearing of seals due to contamination.

Table III-10 Service Arm Cylinder Force Analysis (Category A and B Cylinders)

Nomenclature	Item-Find Number	Specification Number	Service Commodity	Piston End Pressure (psi)	Rod End Pressure (psi)	Piston End Force (lb)	Rod End Force (lb)	Shear Capacity (in)
Cable Retract	A-5583	75M08231	nitrogen, hydraulic	3000	--	115,300	--	0.0524
Upper and Lower Hinge	A-5497 A-5492	75M09362	hydraulic	3000	3000	150,900 21,200	121,800 15,900	0.0484 0.0169
Carrier Withdraw	A-5702	75M06506	hydraulic	3000	3000	21,200	15,900	0.0169
LH_2, LOX Withdraw	A-6018 A-6007	75M09014	nitrogen, helium	--	1400	--	8,520	0.0091
Line Tray Handling	A-5811 A-5894	75M07998 75M07725	nitrogen nitrogen	1300 875	1300 875	12,500 2,750	10,900 2,058	0.0099 0.0038

Note: The minimum shear capacity, 0.0038 inches, is equivalent to 96.5 microns

The maximum shear capacity, 0.0524 inches, is equivalent to 1330 microns. These capacities represent a continuous band of contamination around the cylinder bore, of the thickness indicated.

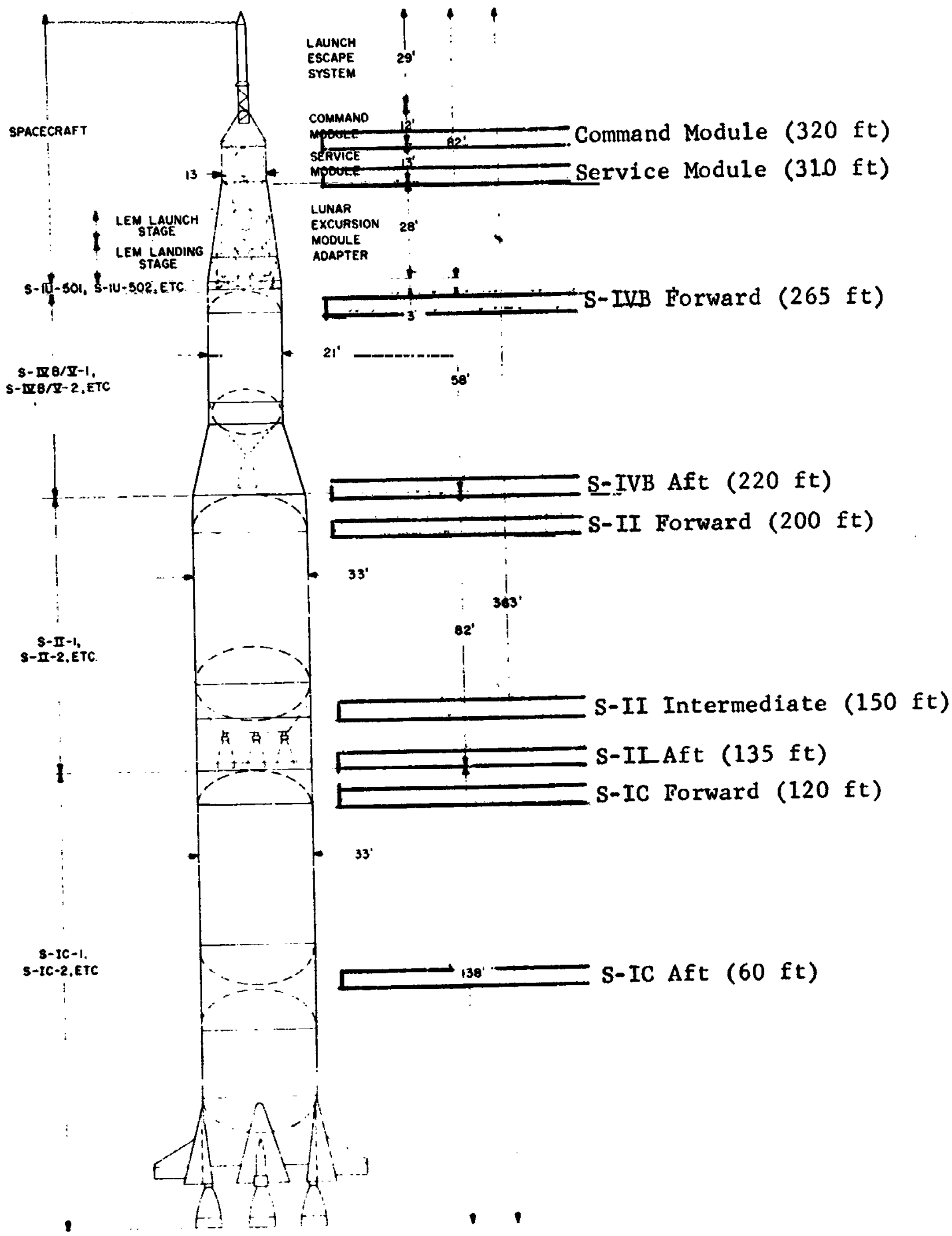

Figure III-1 Saturn V Service Arms

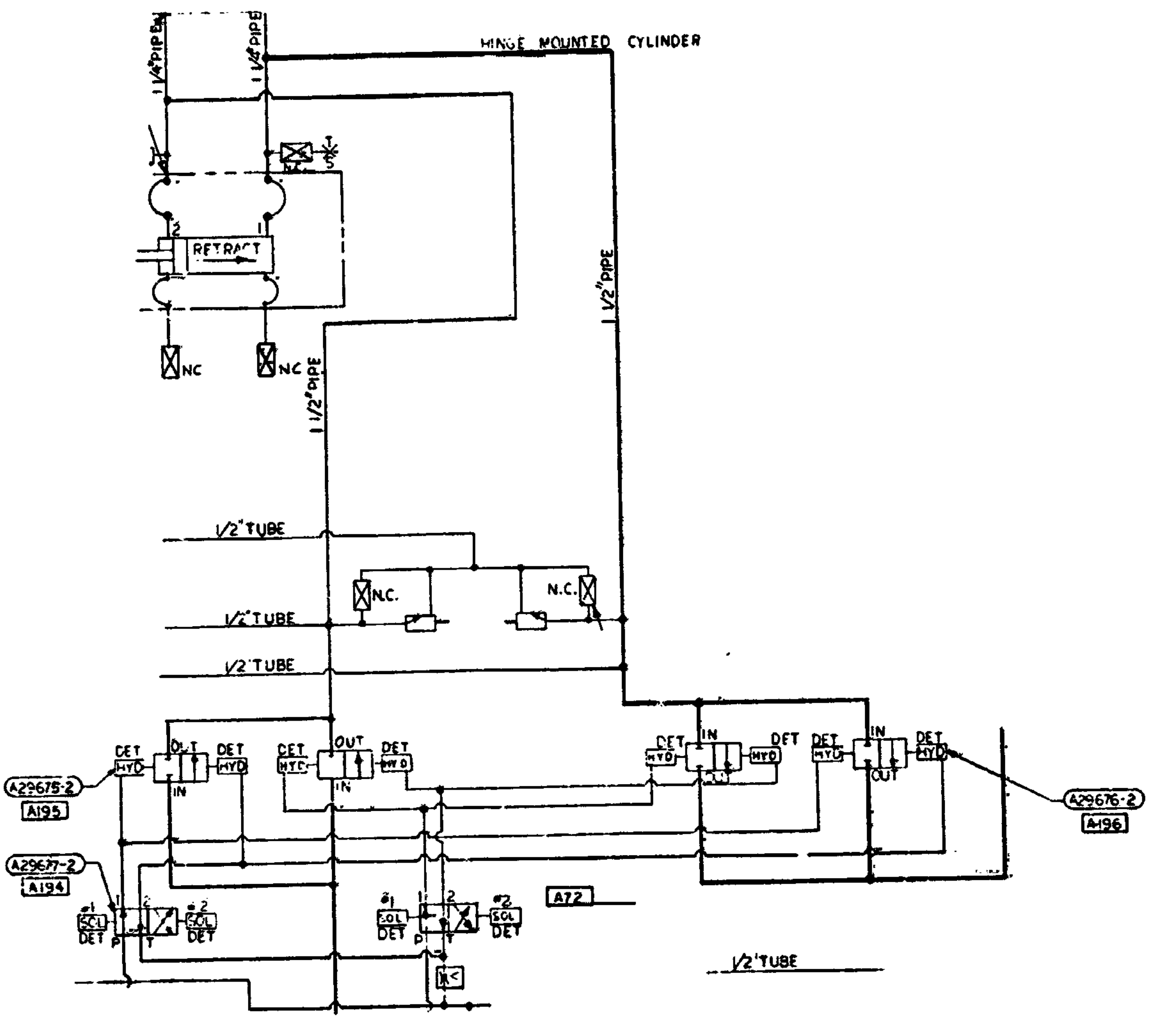

Figure III-2 Service Arm Function, Extend/Retract, Control Console #1, Arms 1, 2

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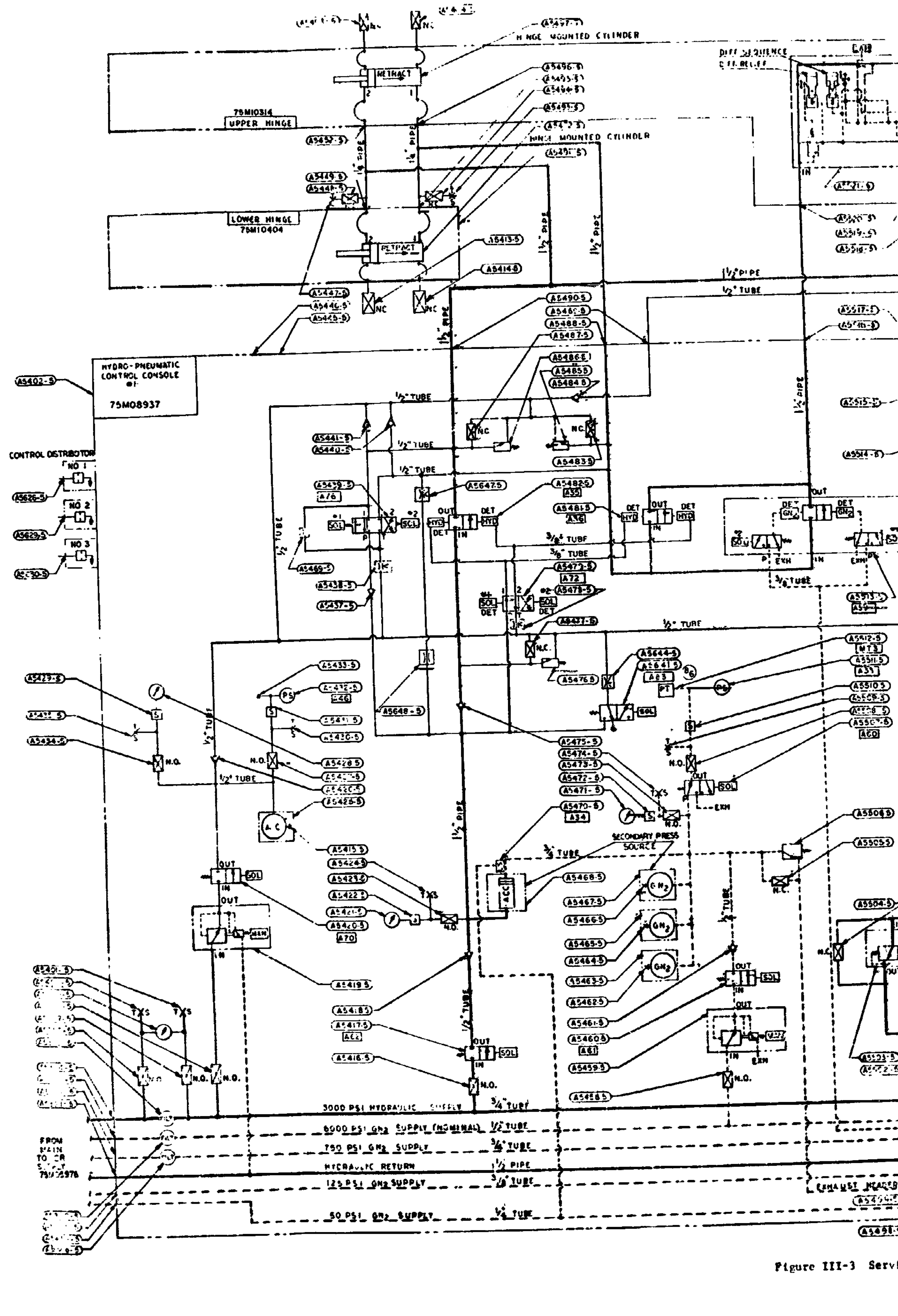


Figure III-3 Servic

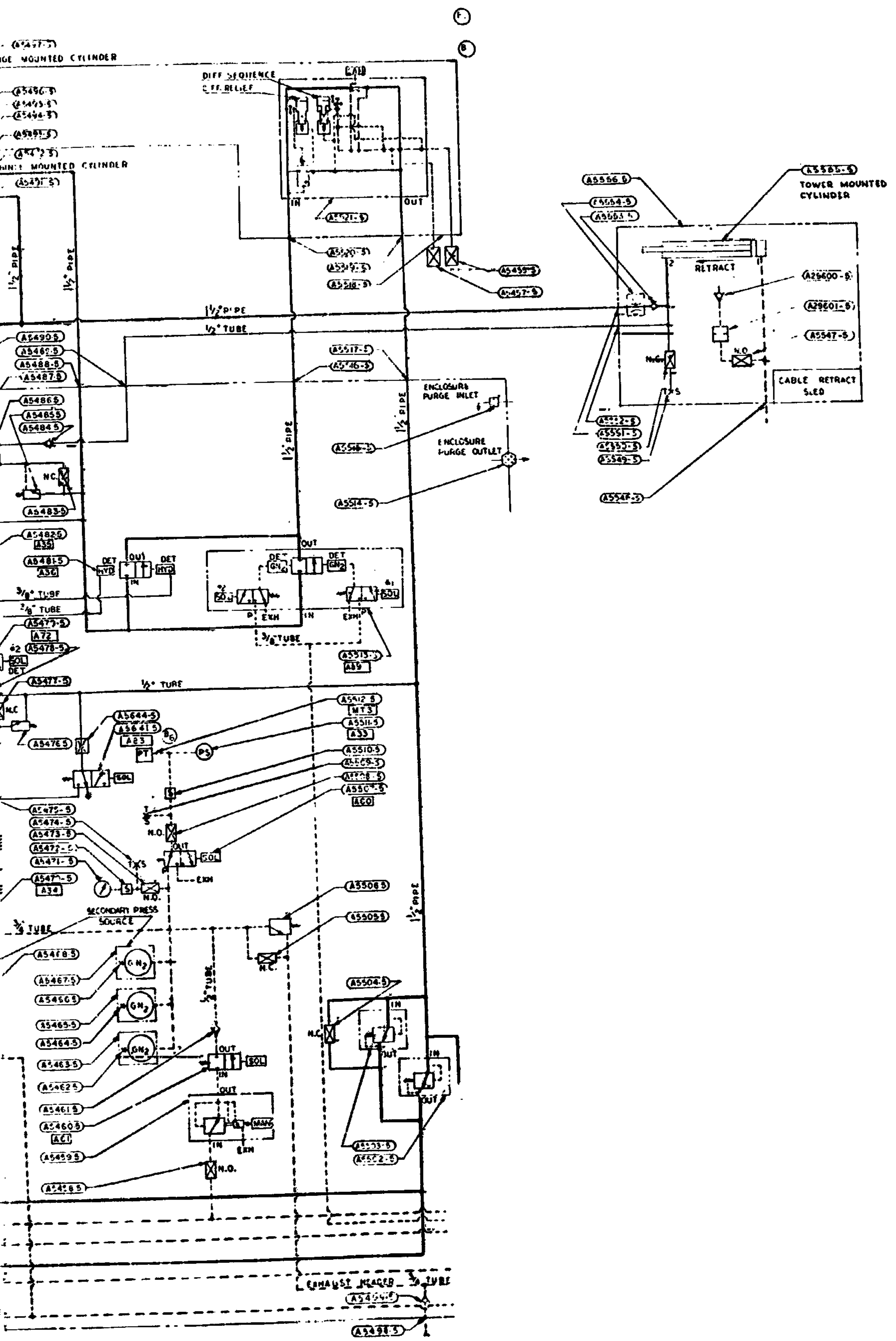
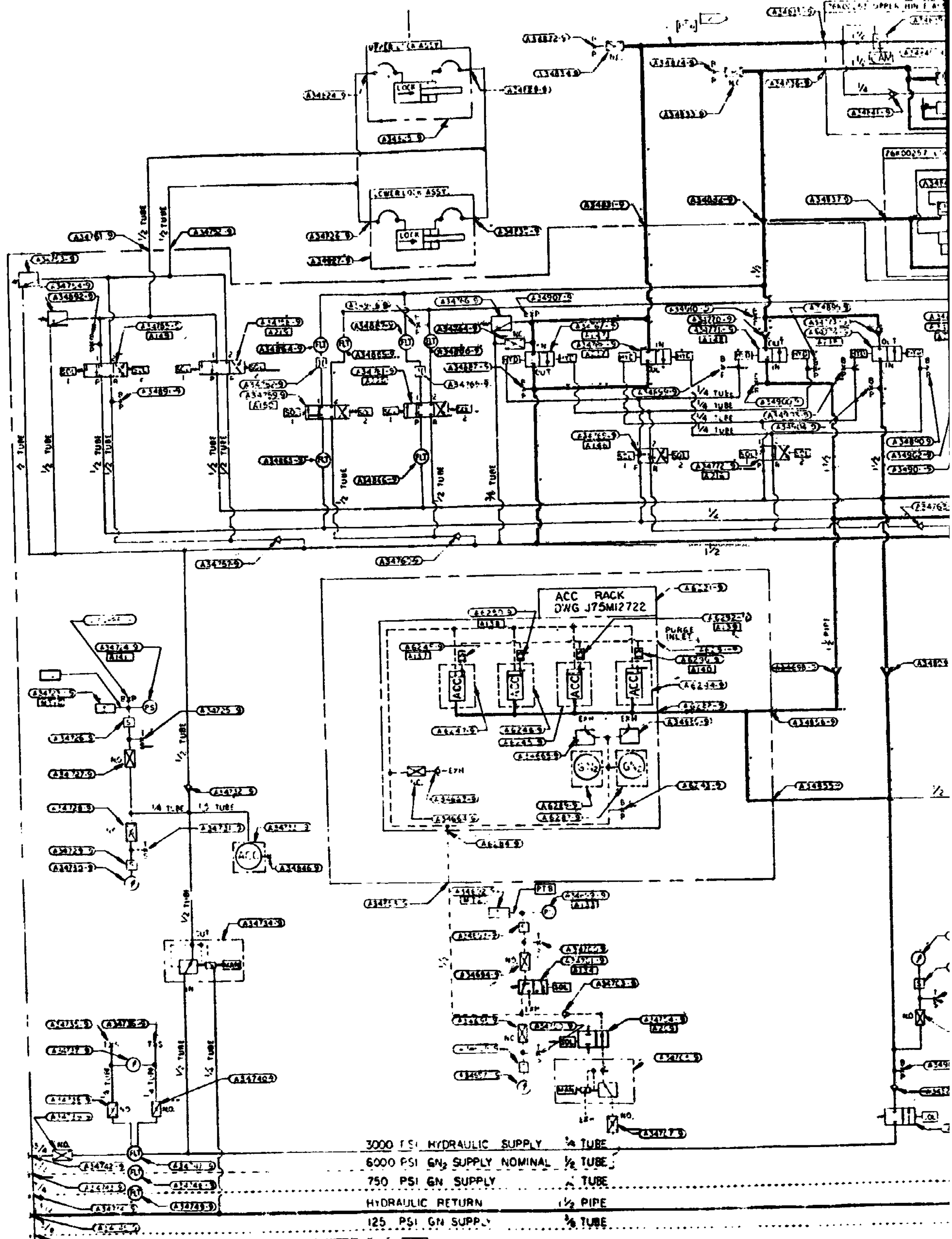


Figure III-3 Service Arm Function, Hydro-pneumatic, Arm Extend/Retract, Arms 4, 5, 6, 7, 8



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FOLDOUT FRAME 1

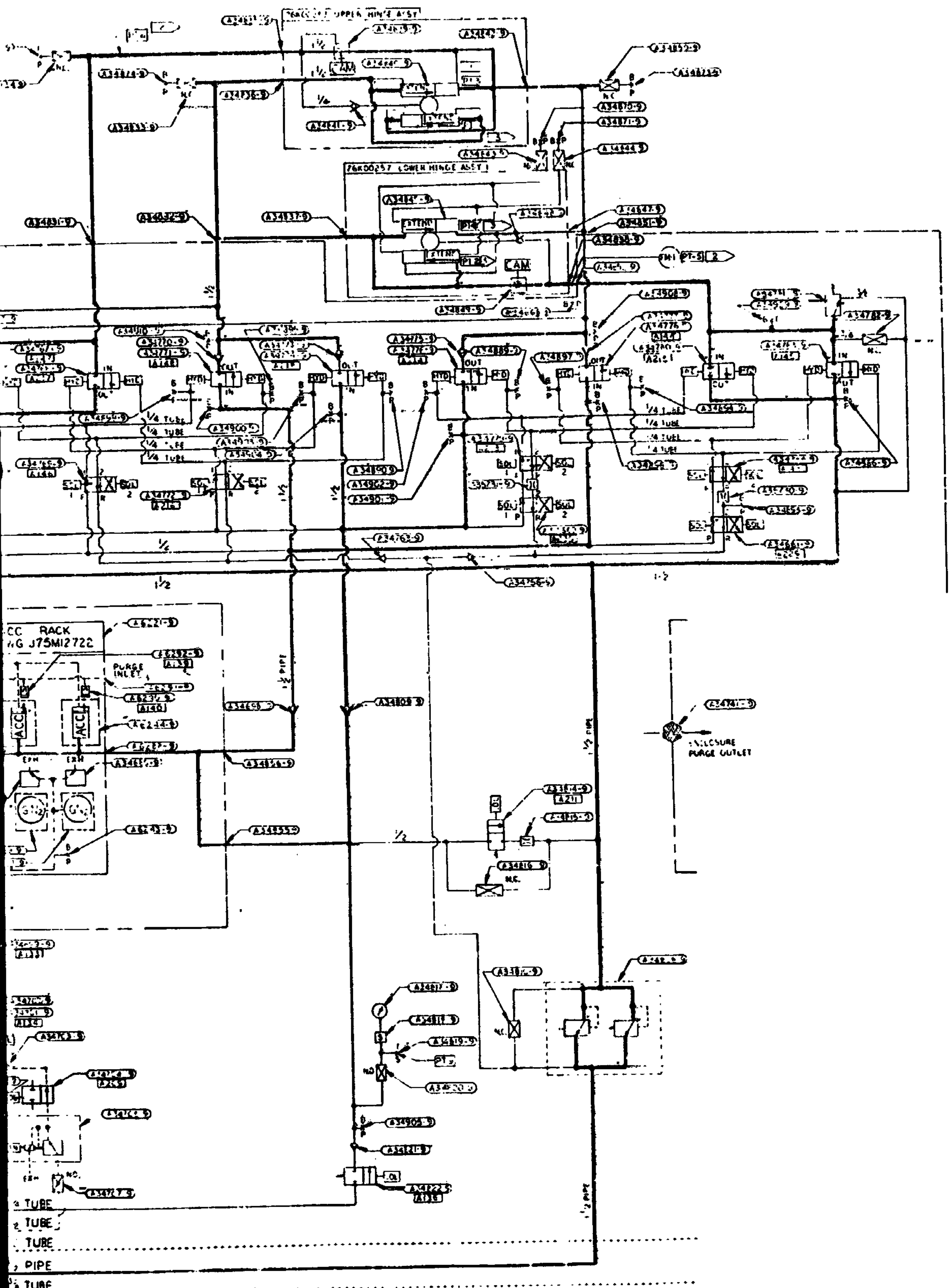


Figure III-4 Service Arm Function, Control Console #1, Arm 9 Only

FOLDOUT FRAME 2

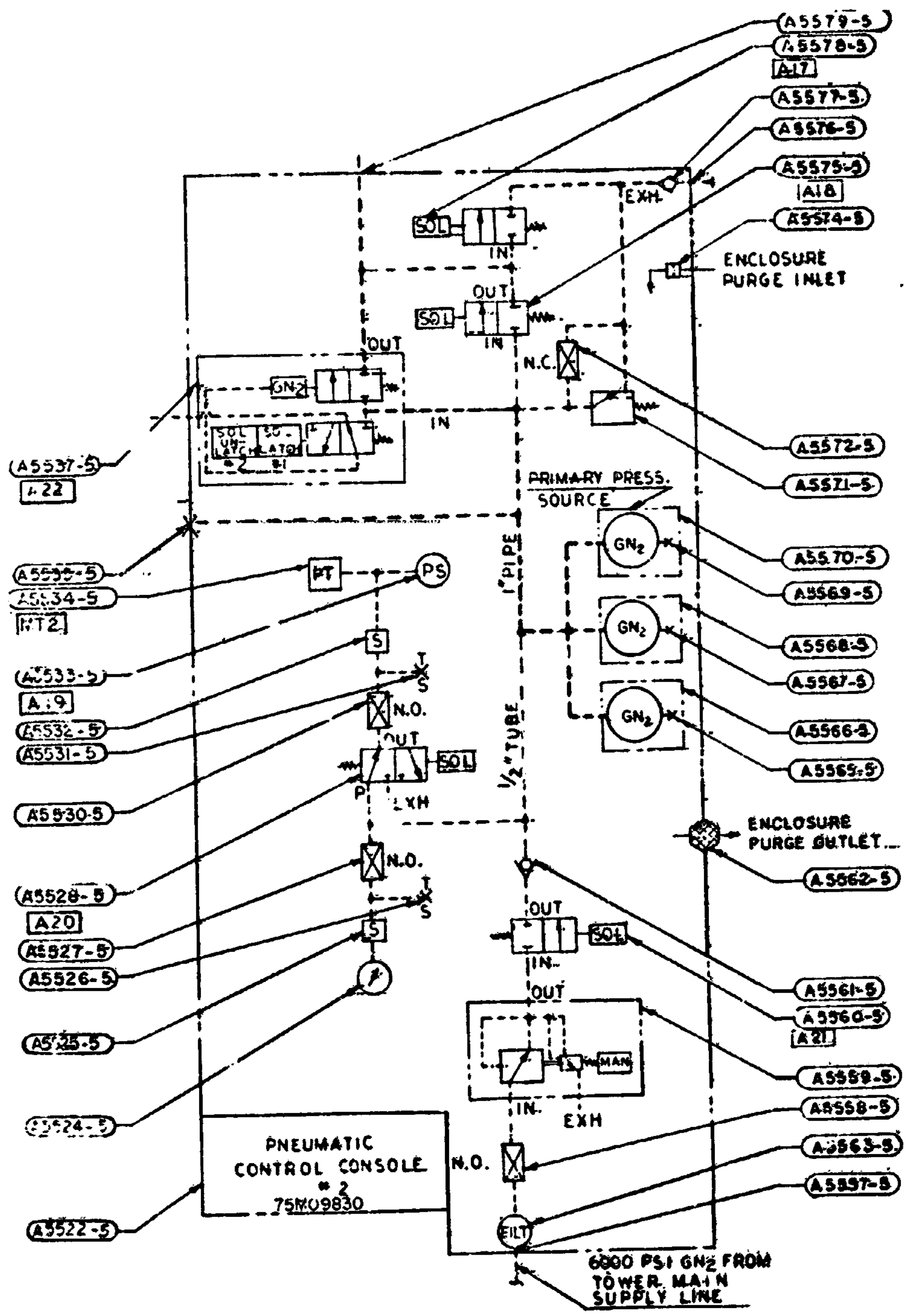


Figure III-5 Service Arm Function, Cable Retract, Control Console #2, Arms 4, 5, 6, 7, 8

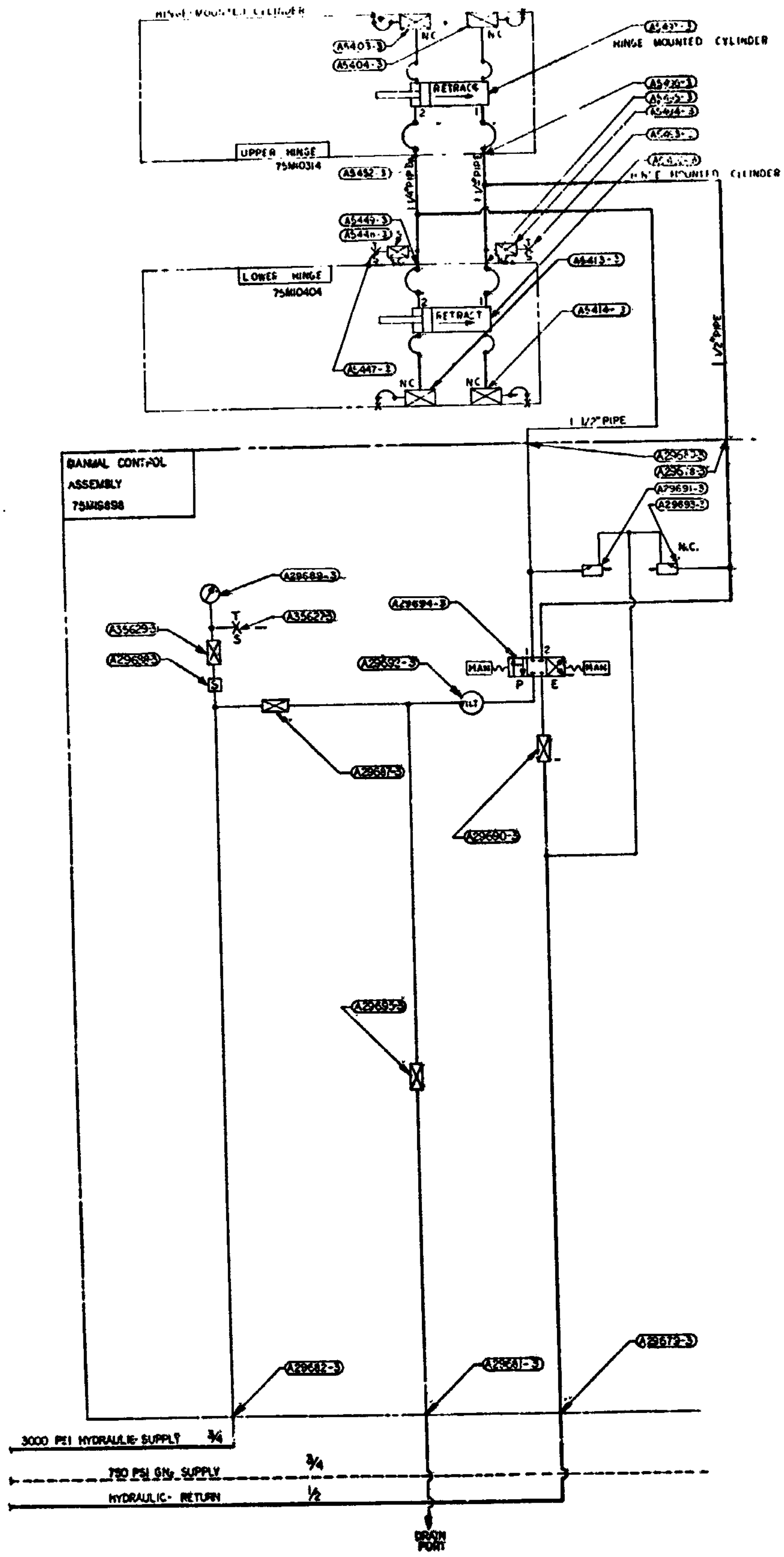


Figure III-6 Service Arm Function, Extend/Retract, Manual Console, Arm 3 Only

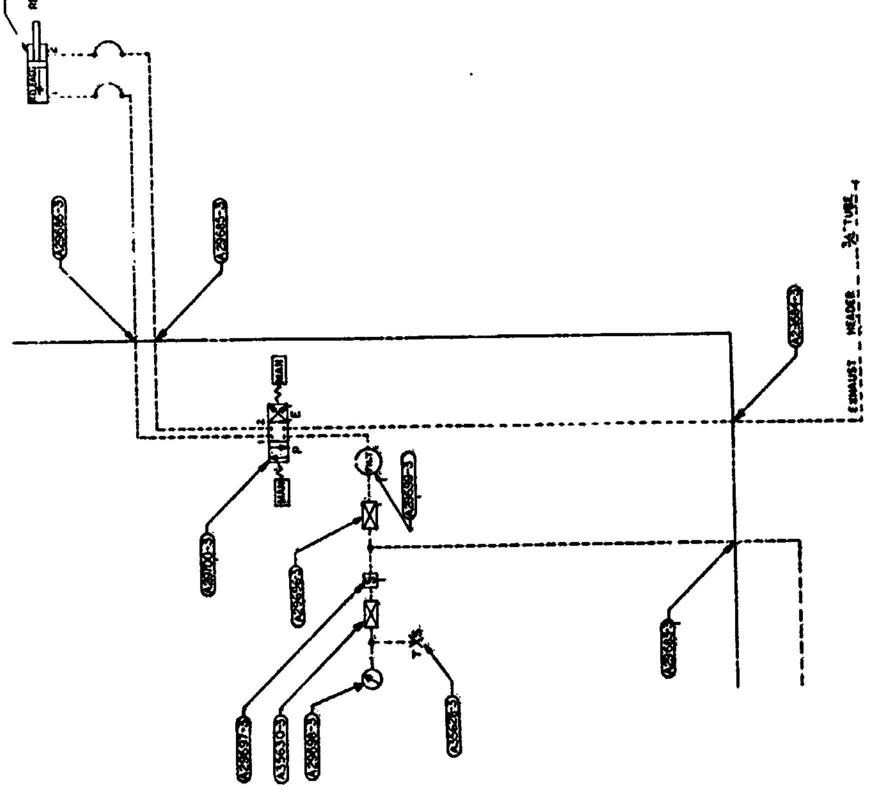


Figure III-7 Service Arm Function, Latchback Cylinder, Arm 3 Only

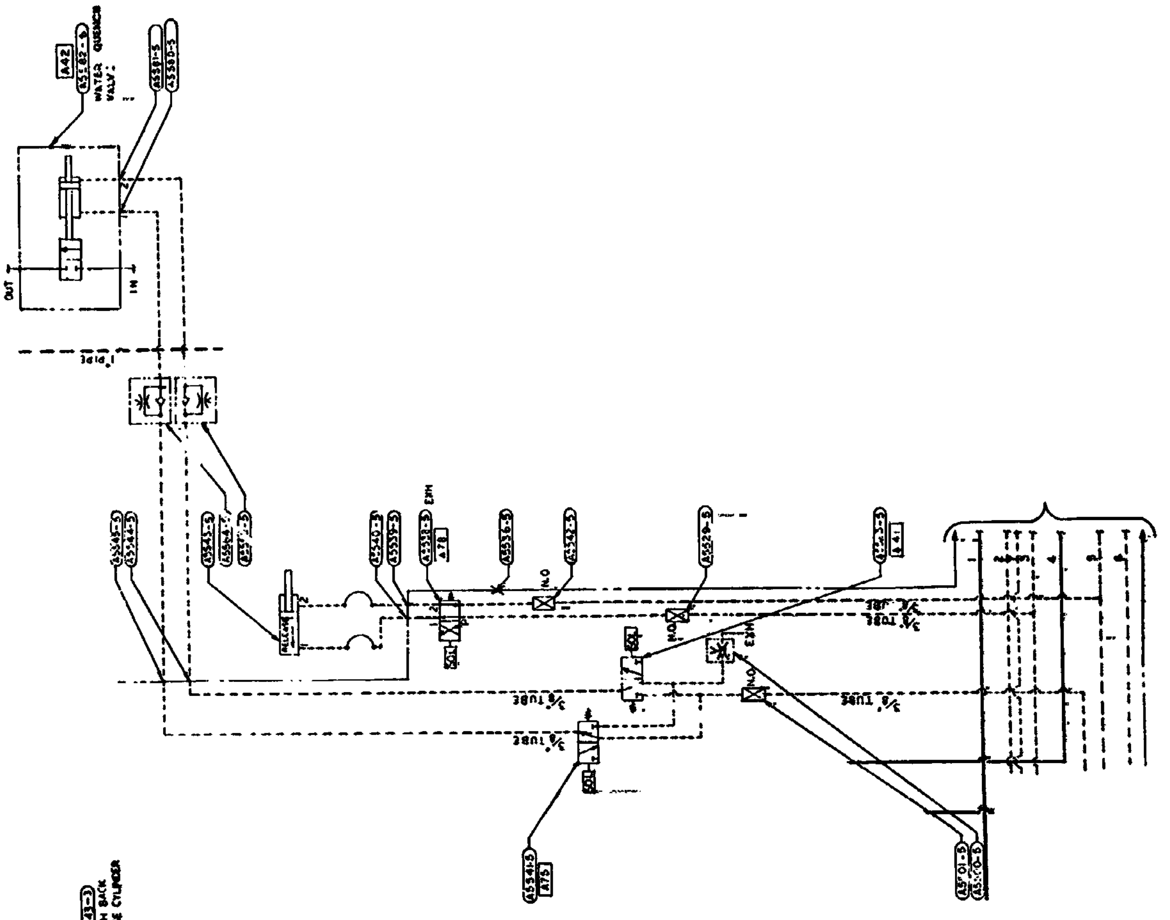


Figure III-8 Service Arm Function, Water Quench Valve and Latchback Cylinder, Arms 1, 2, 3, 4, 5, 6, 7, 8

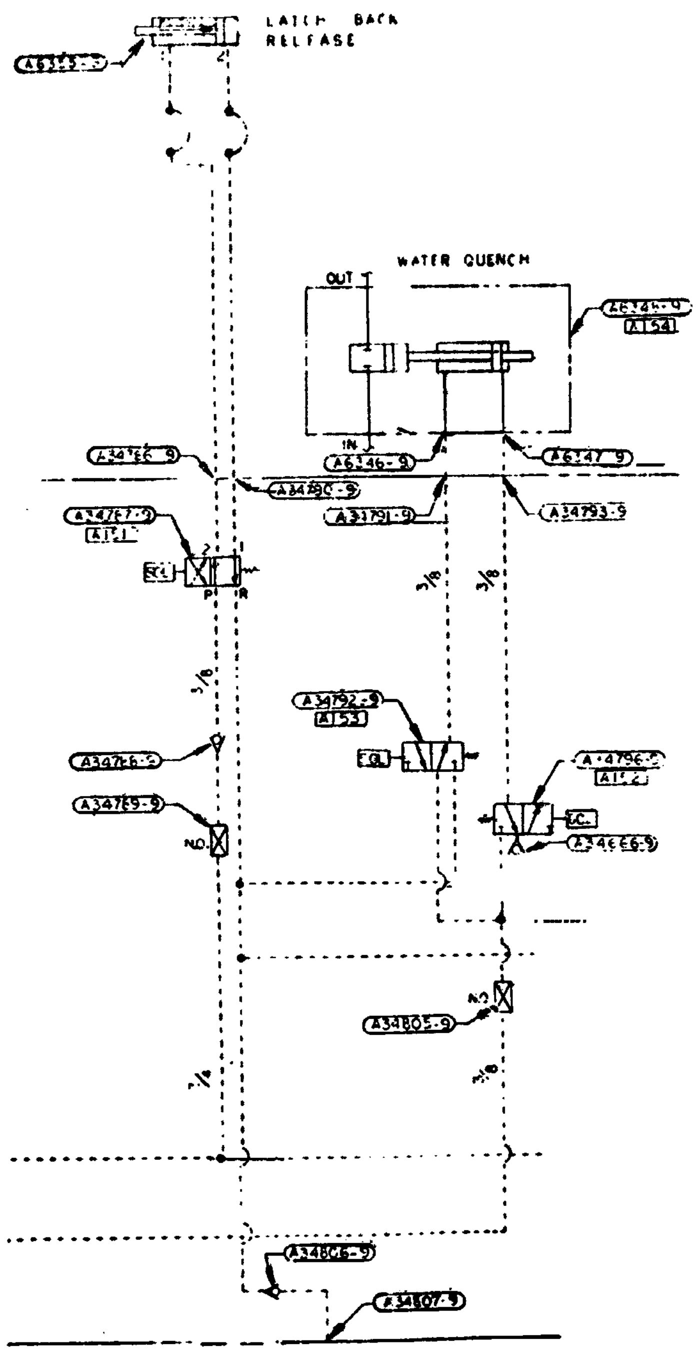


Figure III-9 Service Arm Function, Latchback Cylinder and Water Quench Valve, Arm 9 Only

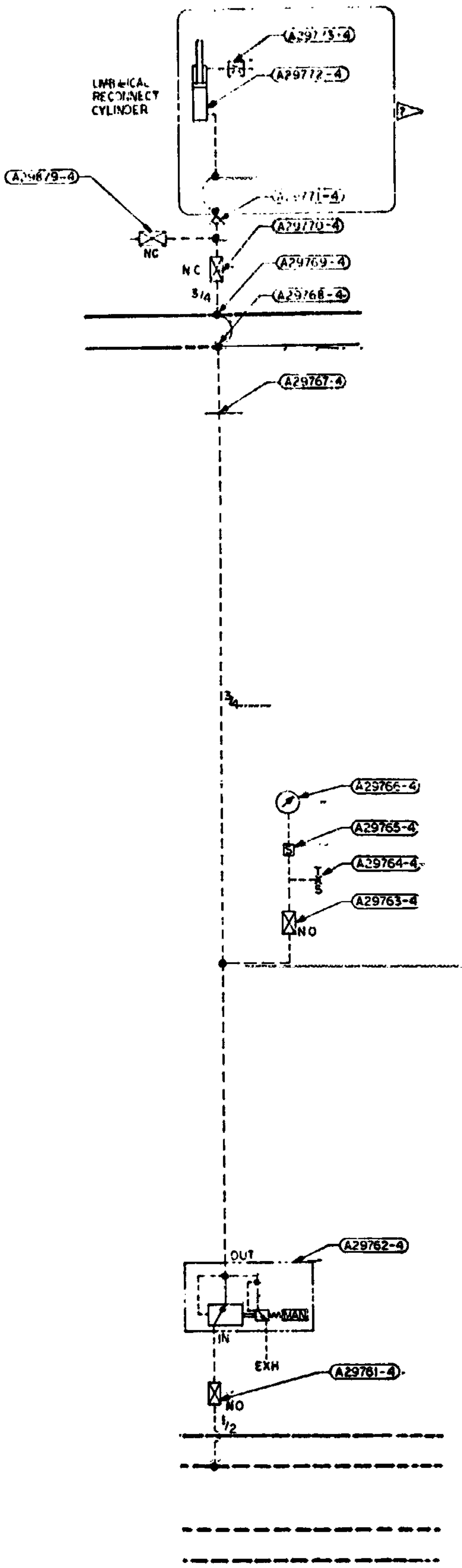


Figure III-10 Service Arm Function, Umbilical Reconnect Cylinder, Arm 4 Only

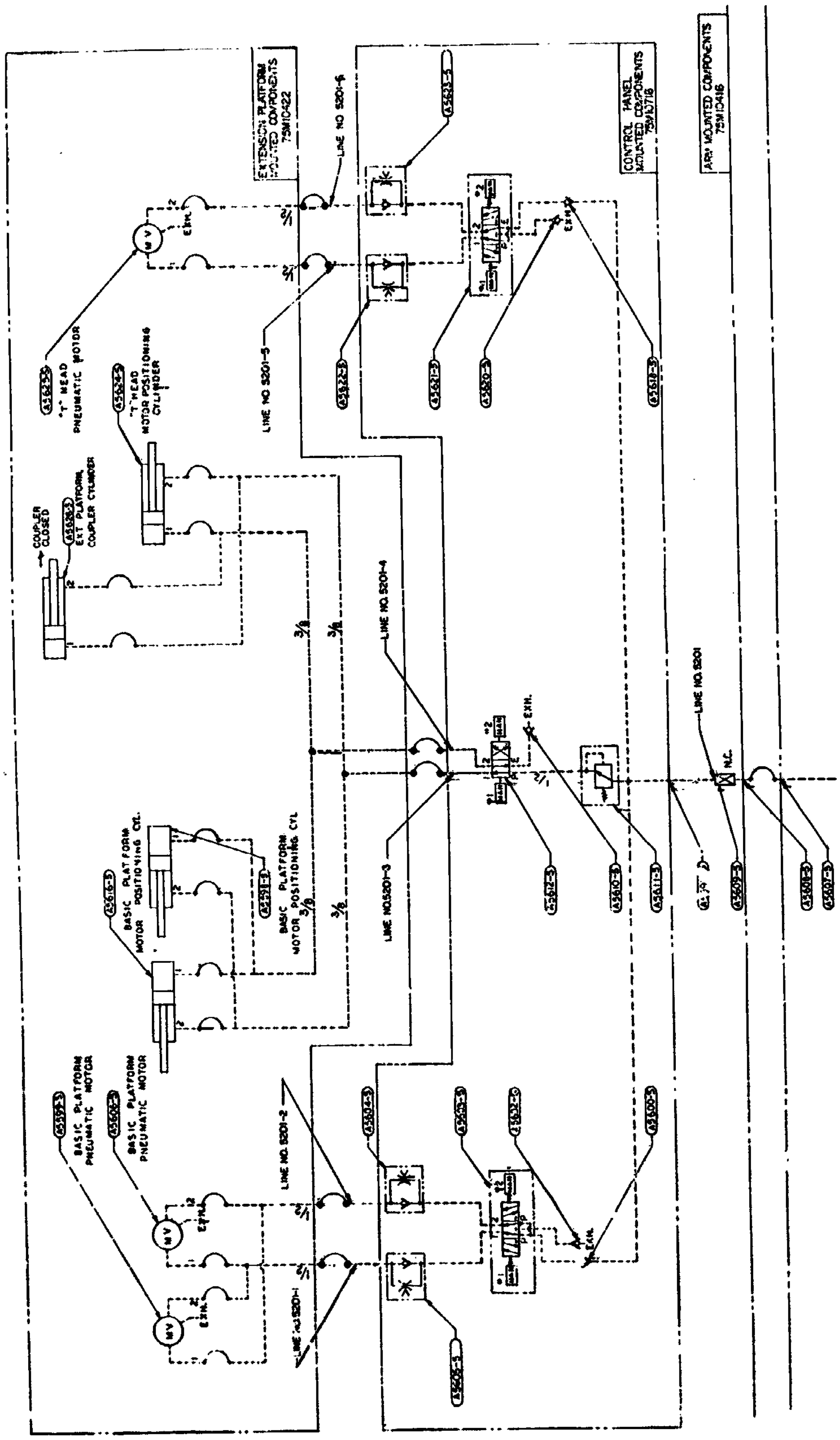


Figure III-11 Service Arm Function, Platform Extend/Retract, Arms 5, 6, 7

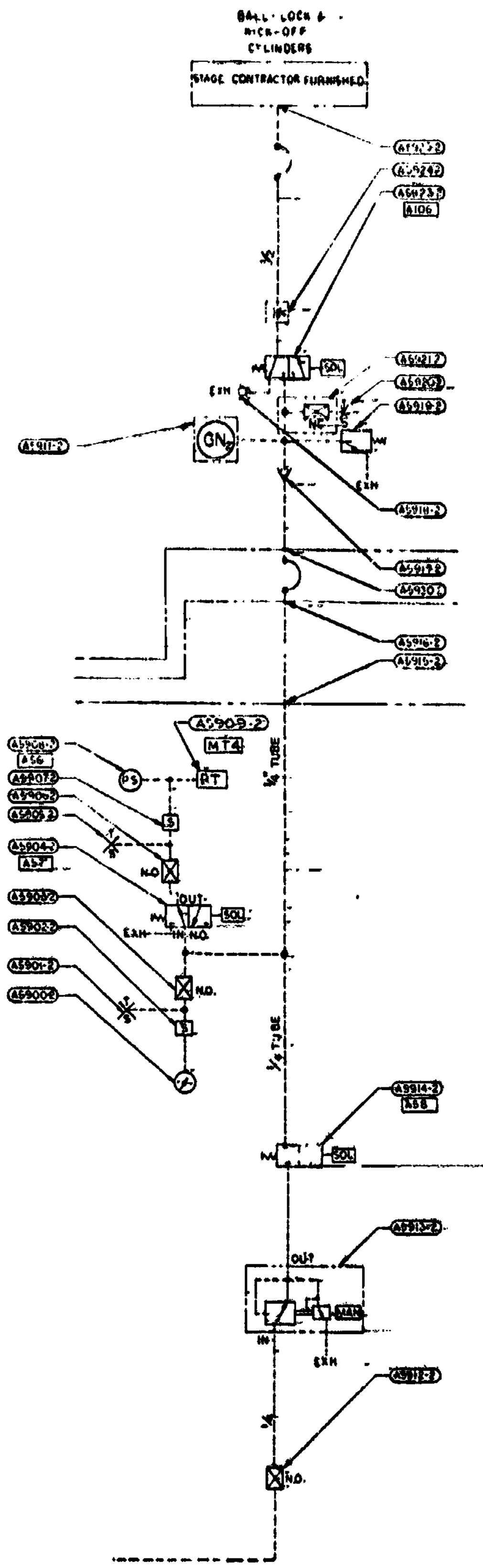


Figure III-12 Service Arm Function, Carrier Kickoff, Arm 2 Only

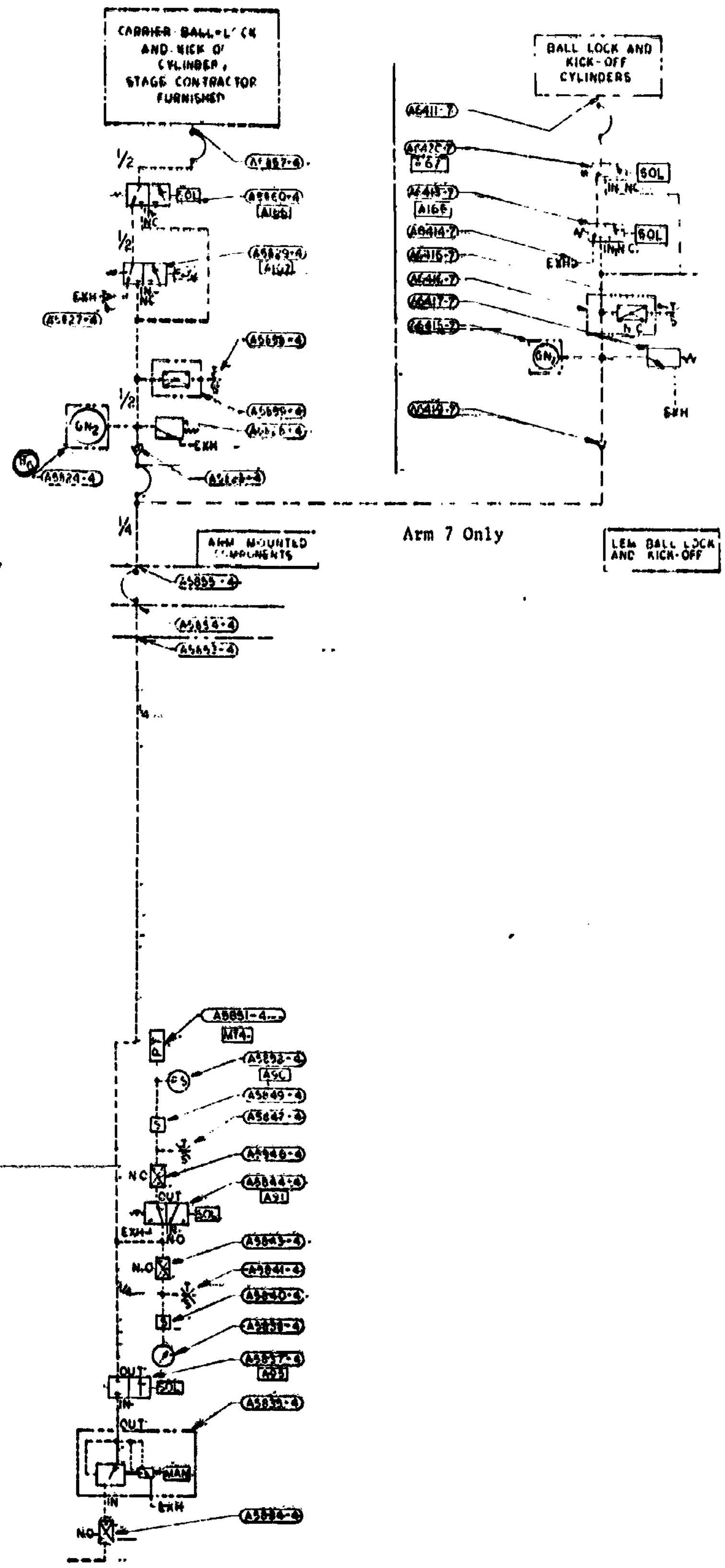


Figure III-13 Service Arm Function, Carrier Kickoff, Arms 4, 5, 6, 7

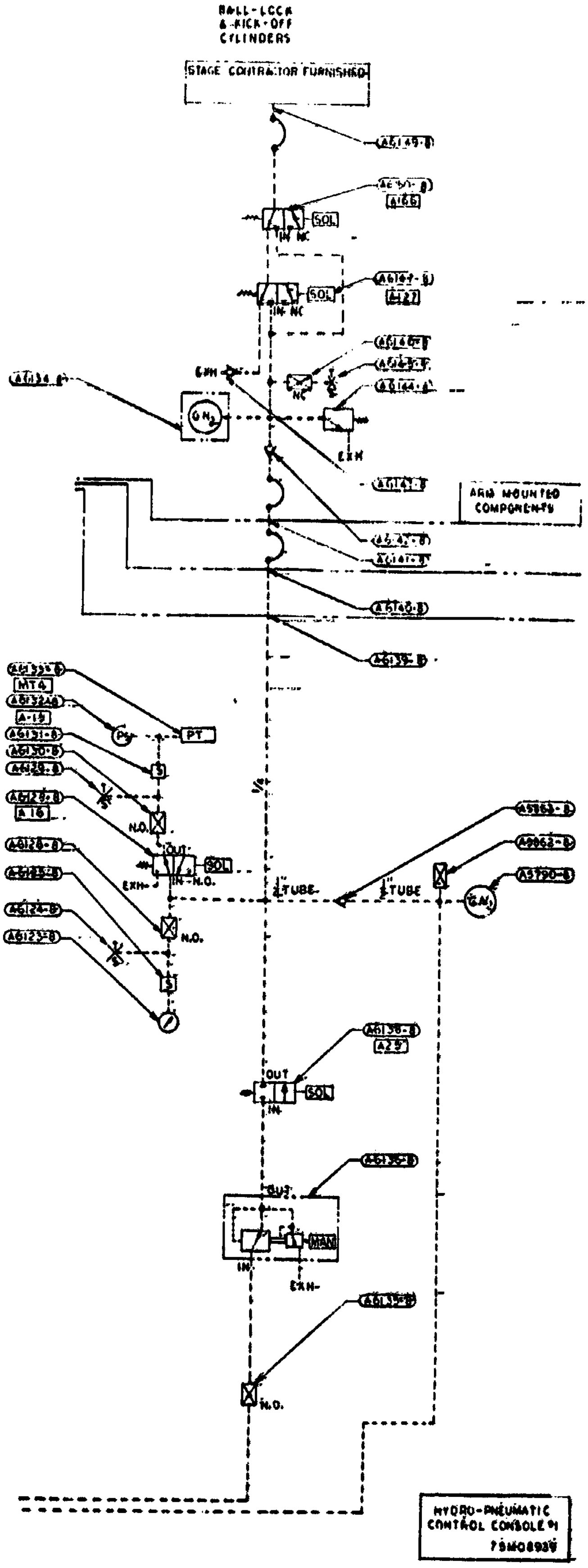


Figure III-14 Service Arm Function, Carrier Kickoff, Arm 8 Only

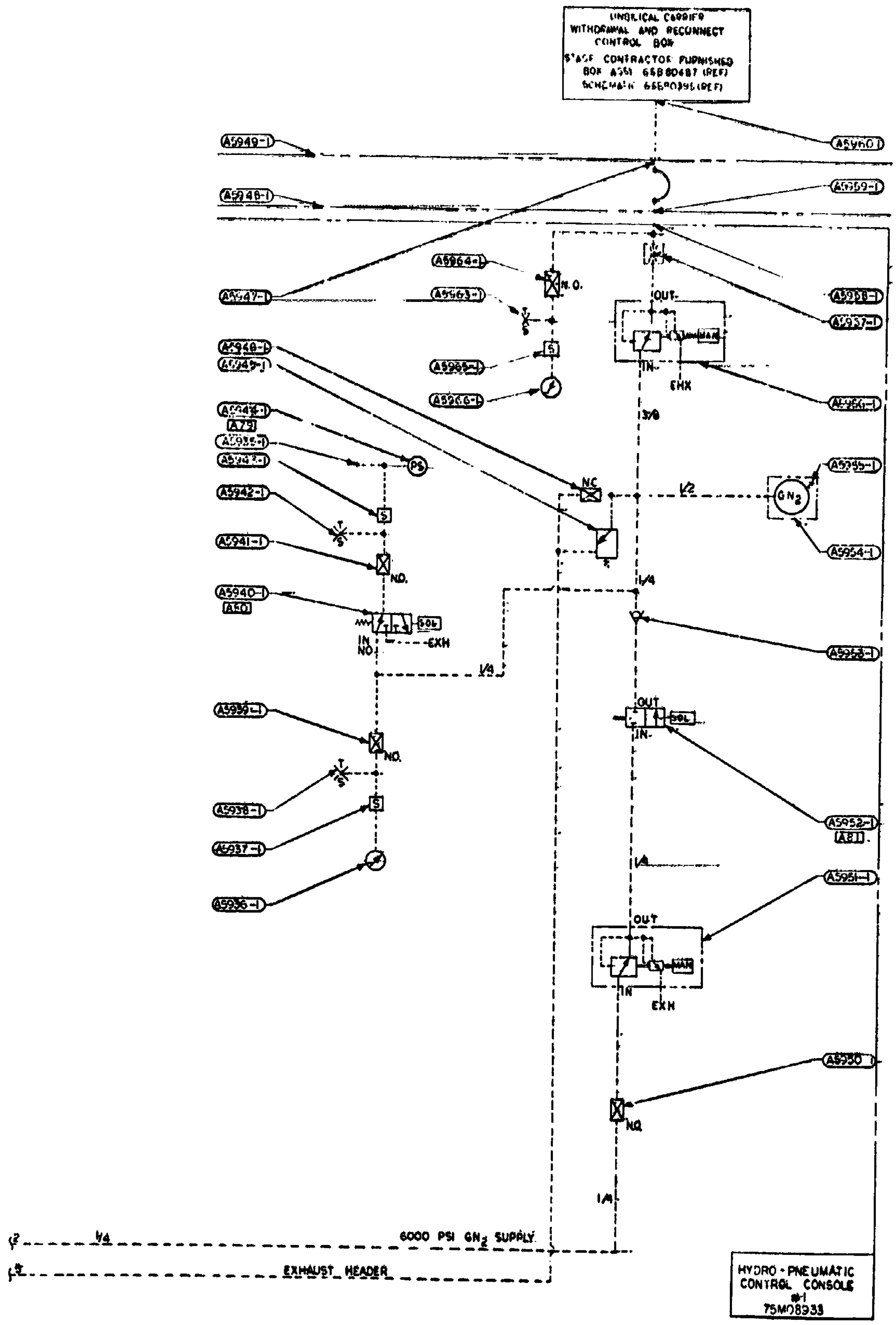


Figure III-15 Service Arm Function, Carrier Withdrawal/Reconnect, Arm 1 Only

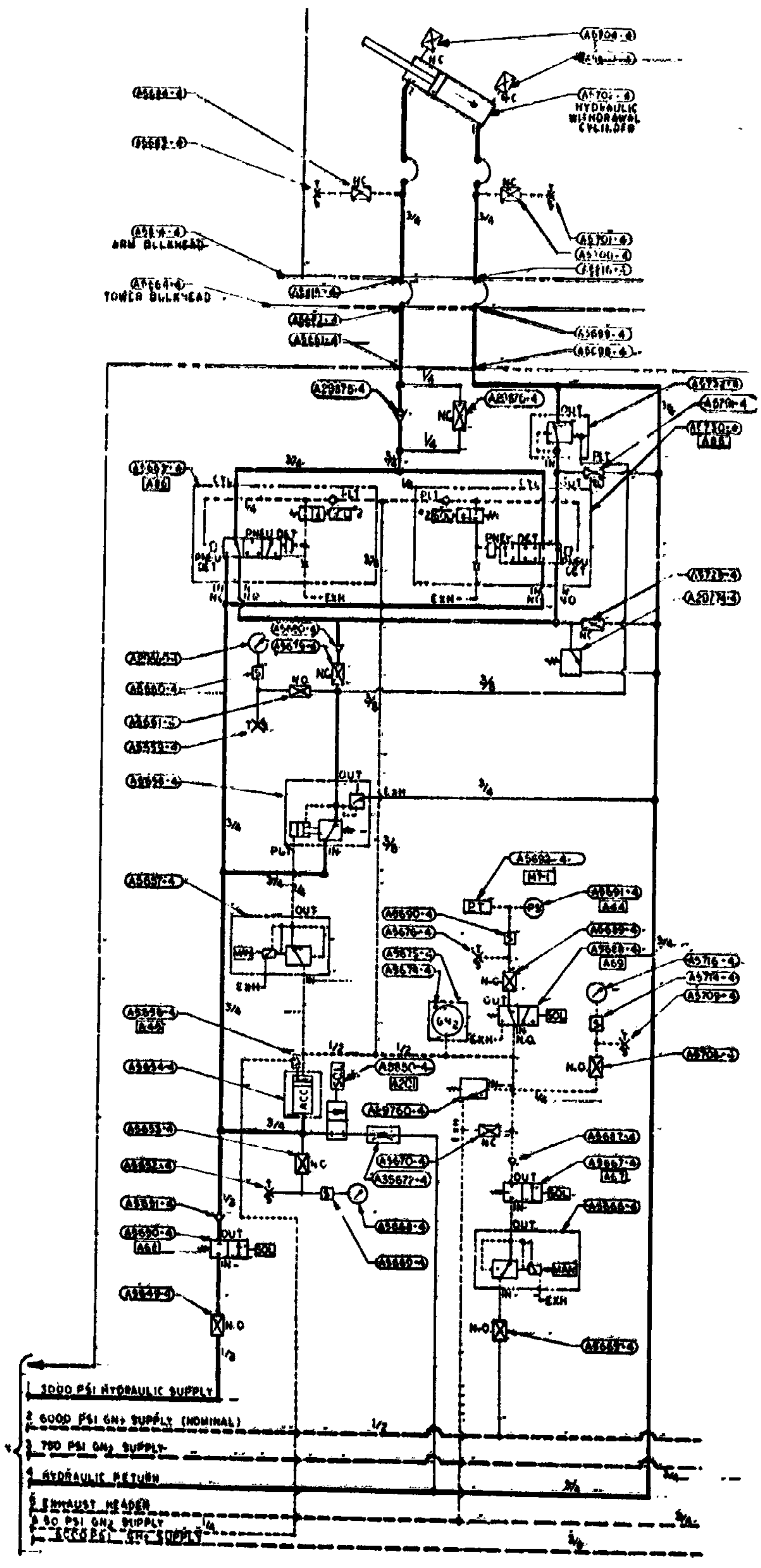


Figure III-16 Service Arm Function, Hydraulic Carrier Withdrawal Cylinder, Arms 4, 5, 6, 7

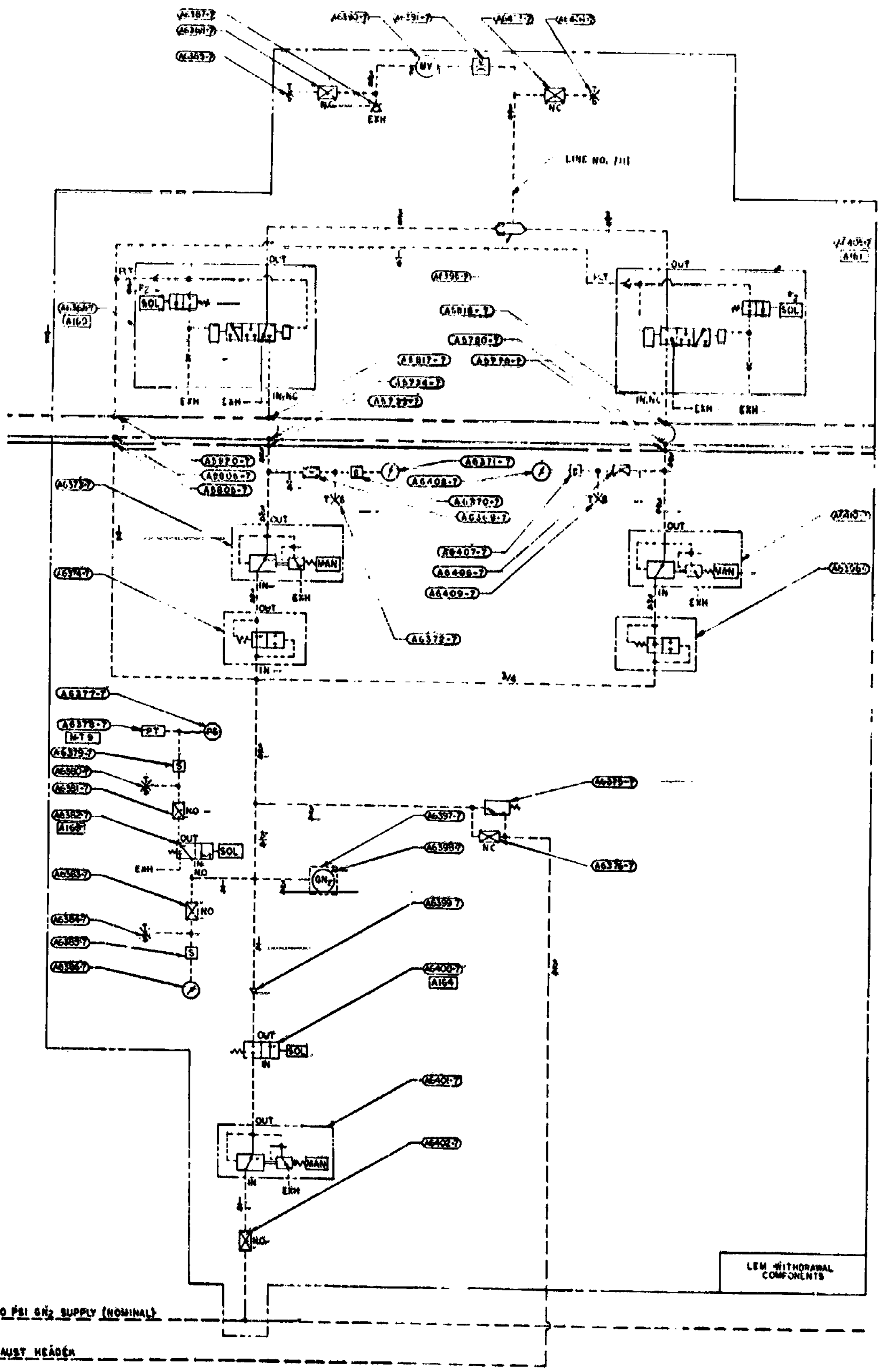


Figure III-17 Service Arm Function, LEM Withdrawal Cylinder, Arm 7 Only

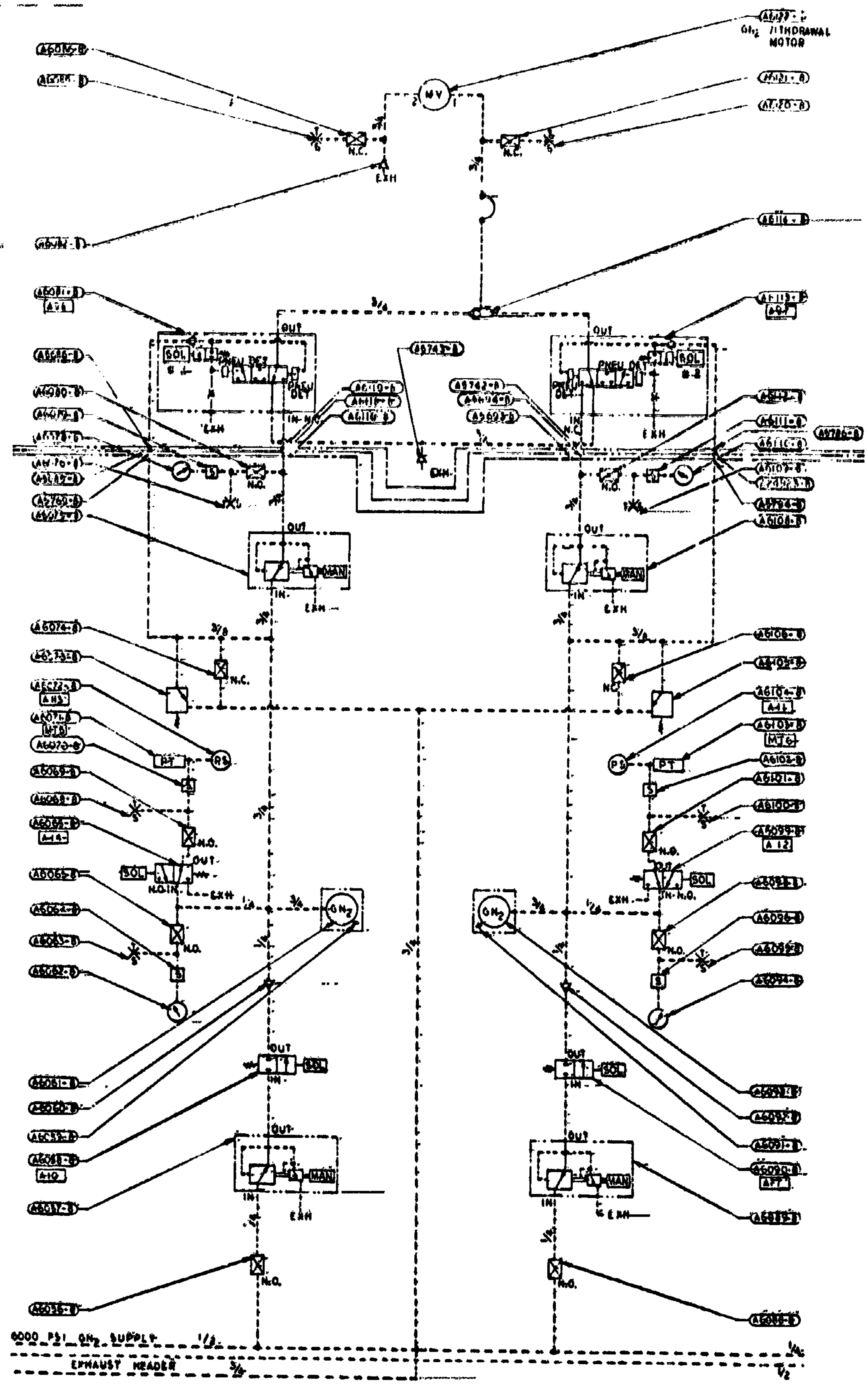


Figure III-18 Service Arm Function, Service Module Carrier Withdrawal, Carrier Kickoff, Arm 8 Only

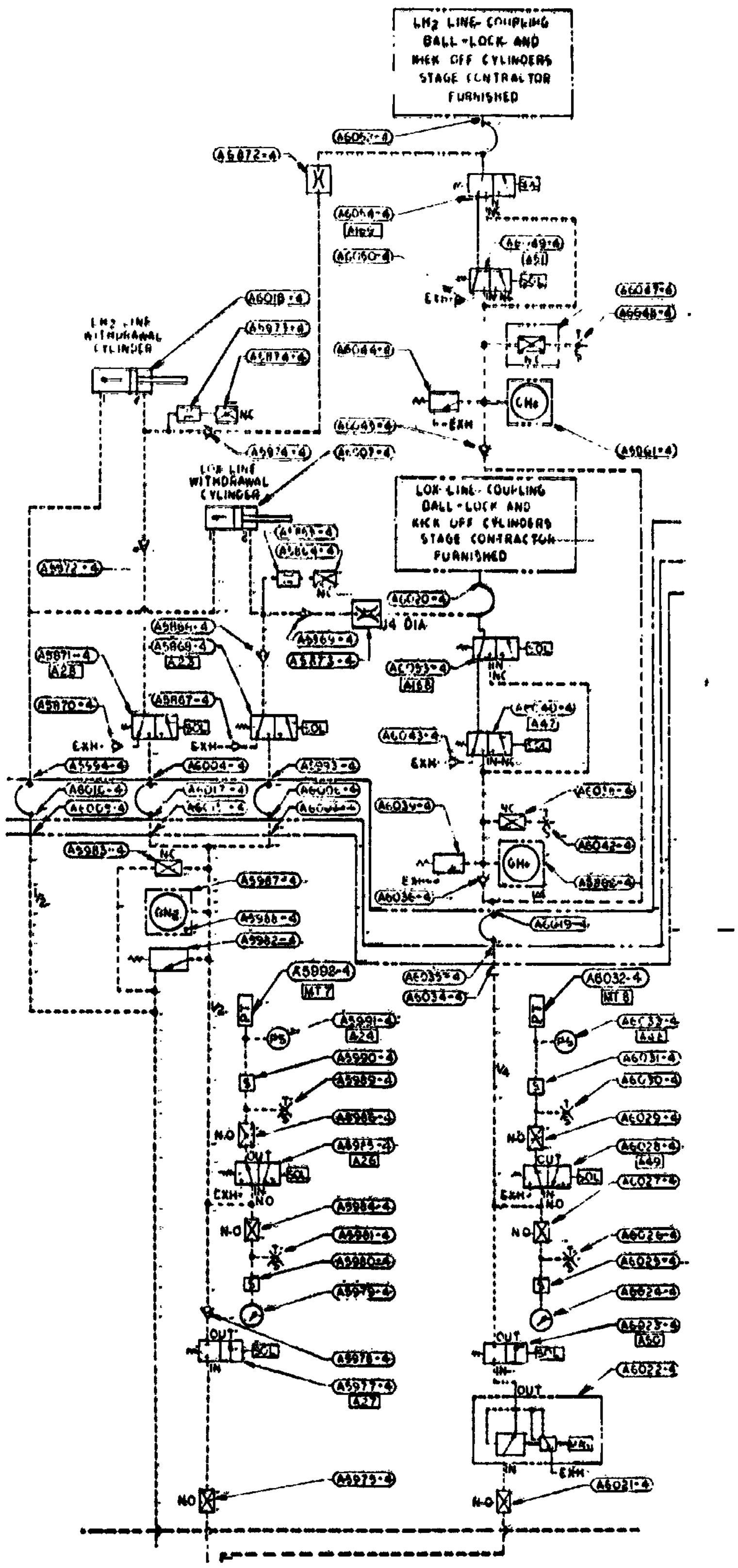


Figure III-19 Service Arm Function, Coupling Kickoff/Withdrawal, Arm 4 Only

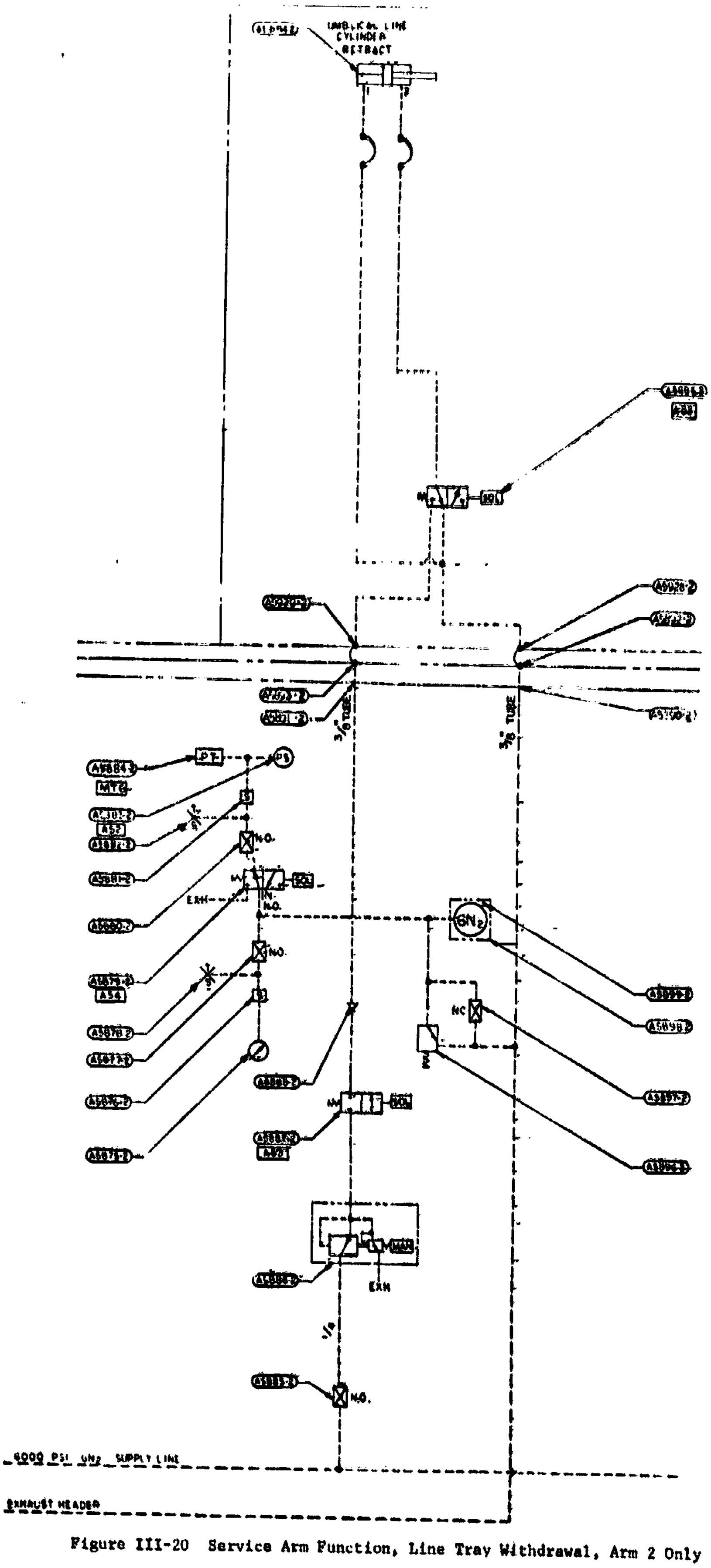


Figure III-20 Service Arm Function, Line Tray Withdrawal, Arm 2 Only

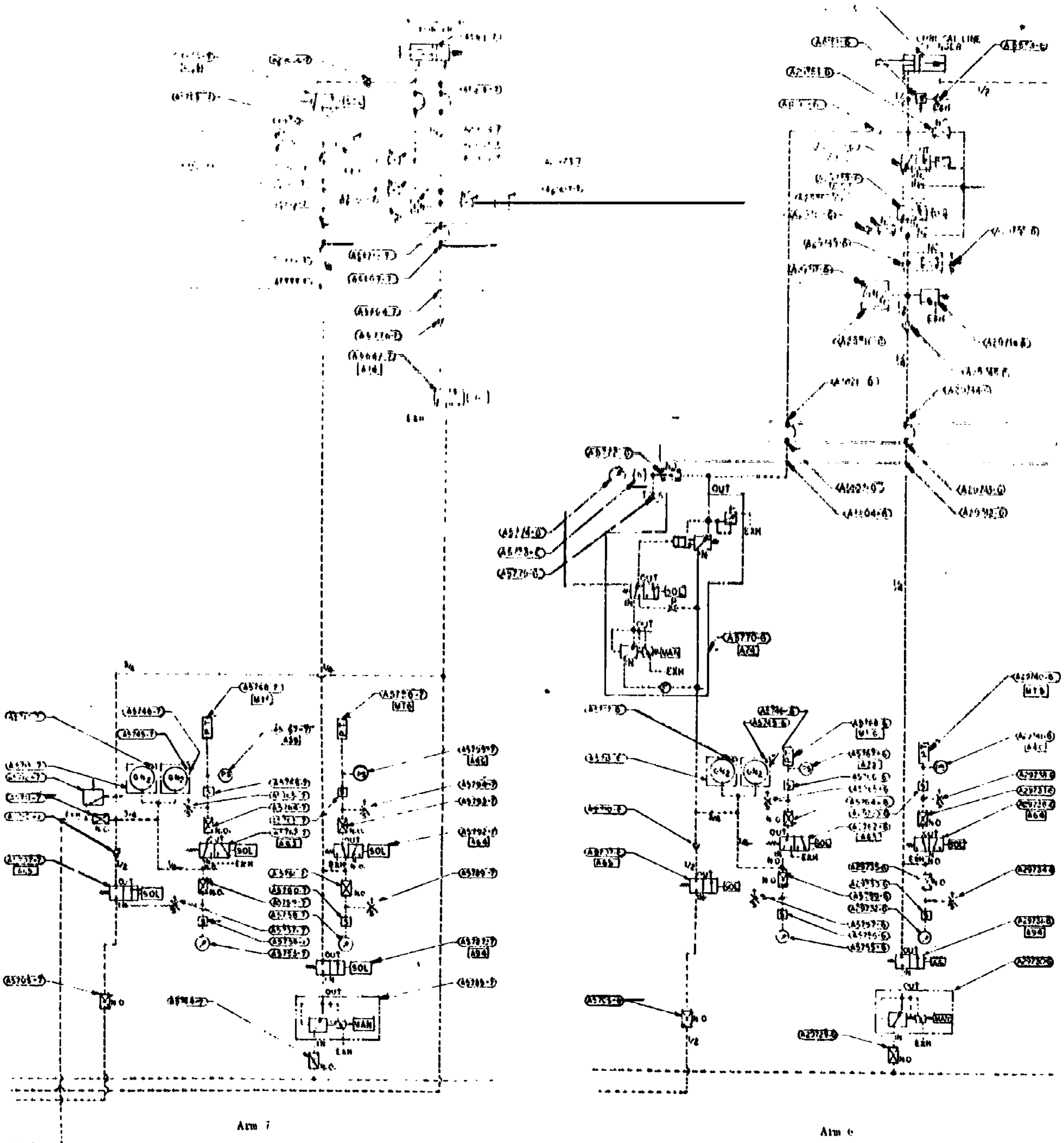


Figure III-21 Service Arm Function, Tray Withdrawal, Arms 6, 7

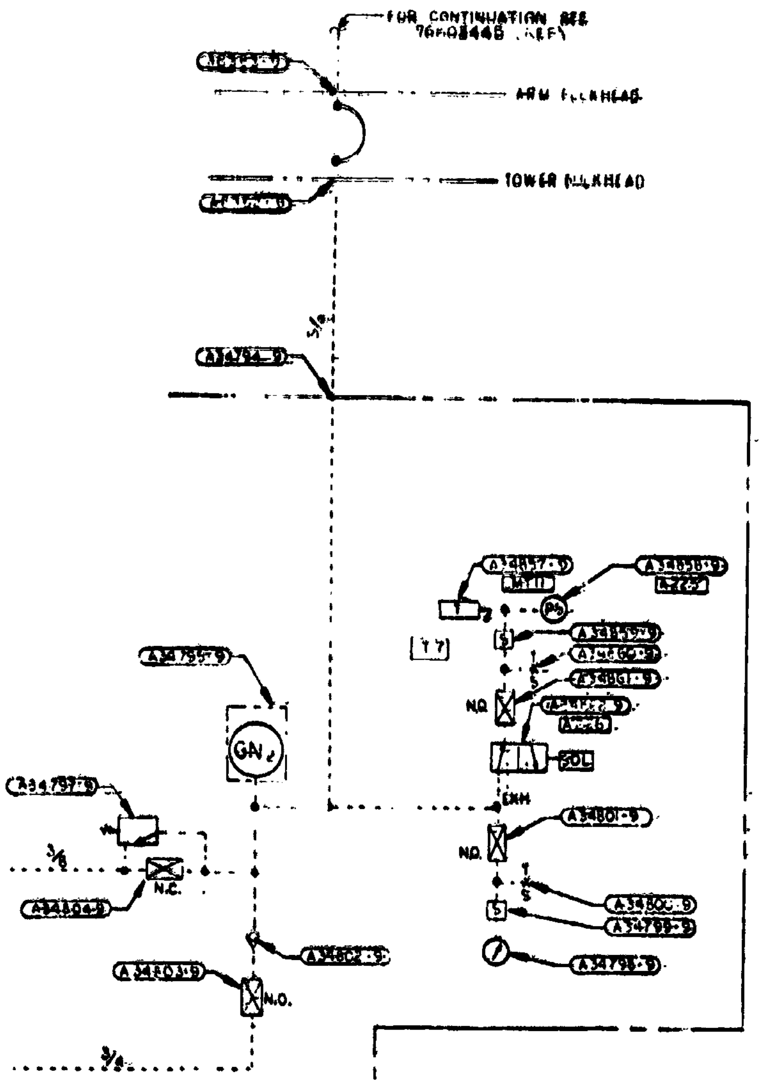


Figure III-22 Service Arm Function, Environmental Chamber, Arm 9 Only

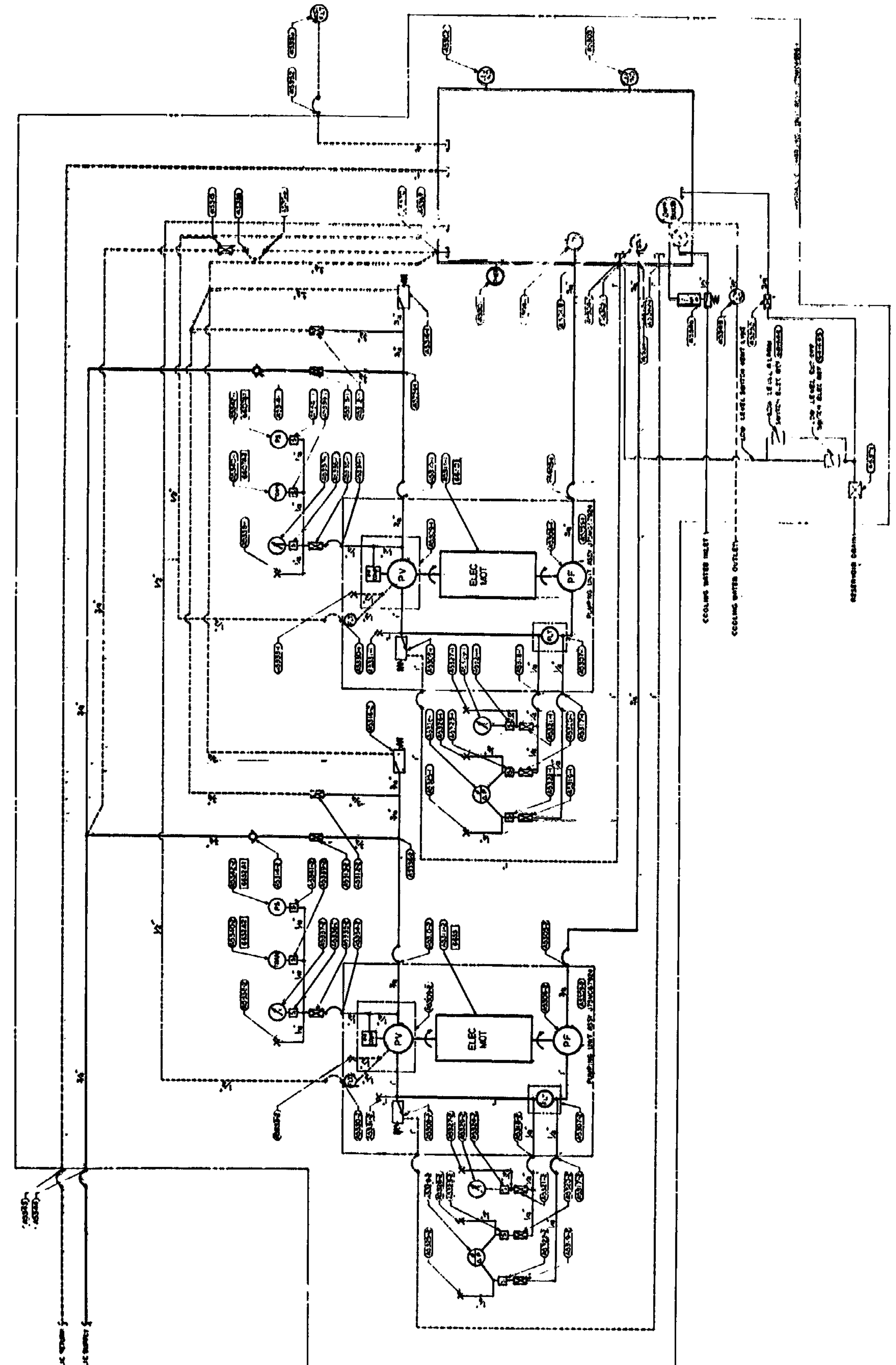
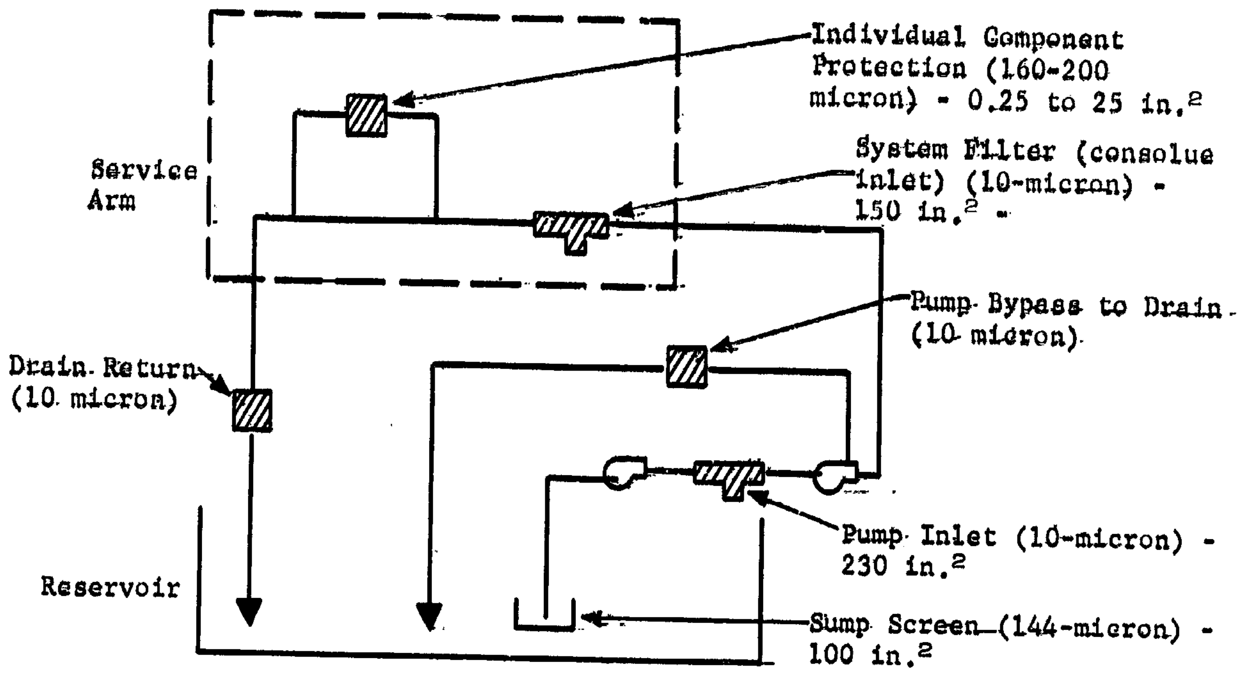
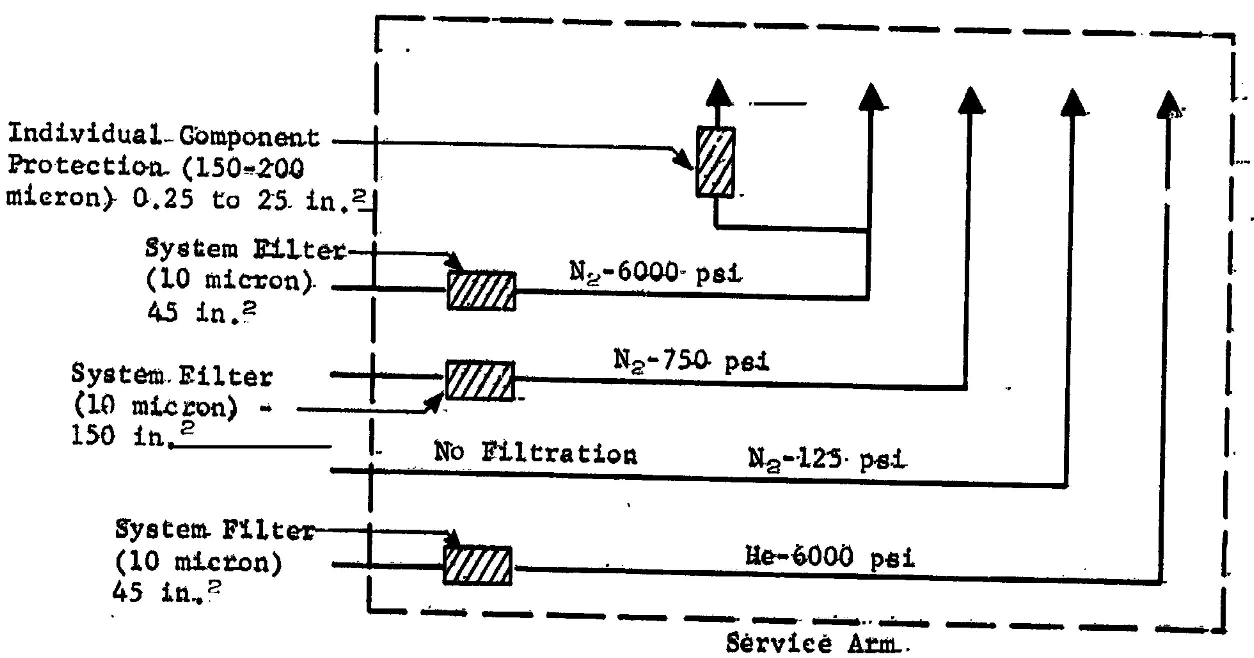


Figure III-23 Hydraulic Charging Unit

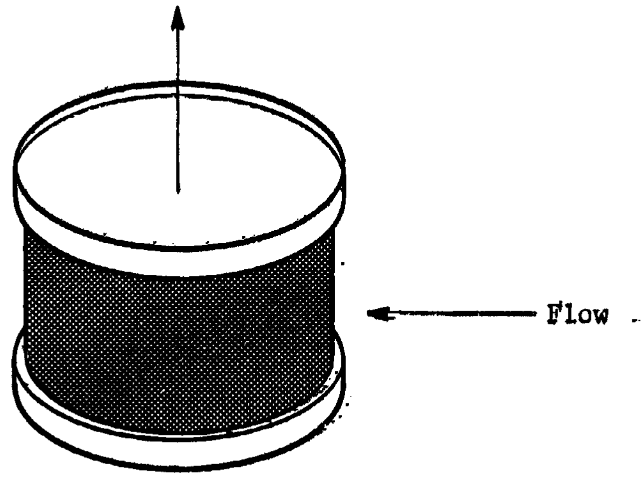


Typical Hydraulic System Filtration

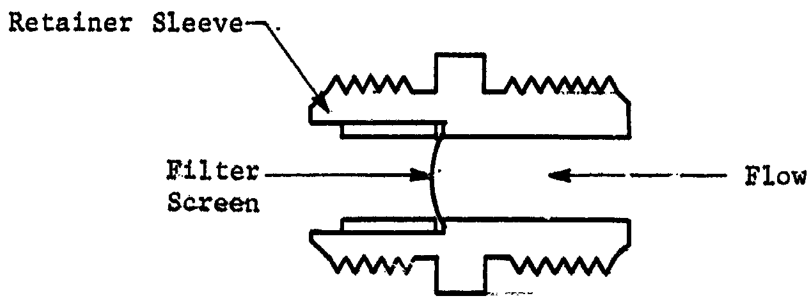


Typical Pneumatic System Filtration

Figure III-24 Service Arm Filtration



Integral Component Filter Screen



Fitting-Type Filter Screen

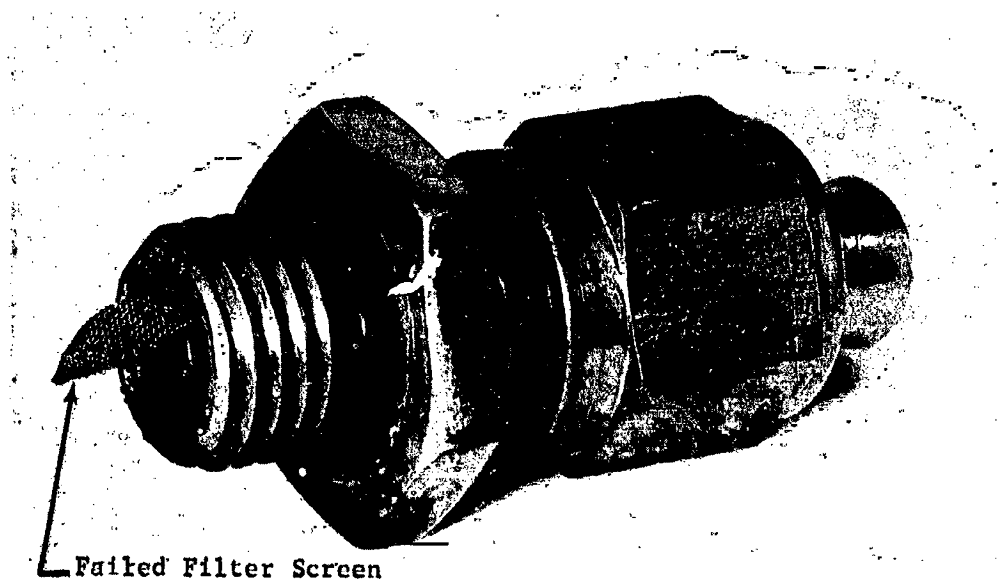


Figure III-25 Integral Filter Configurations

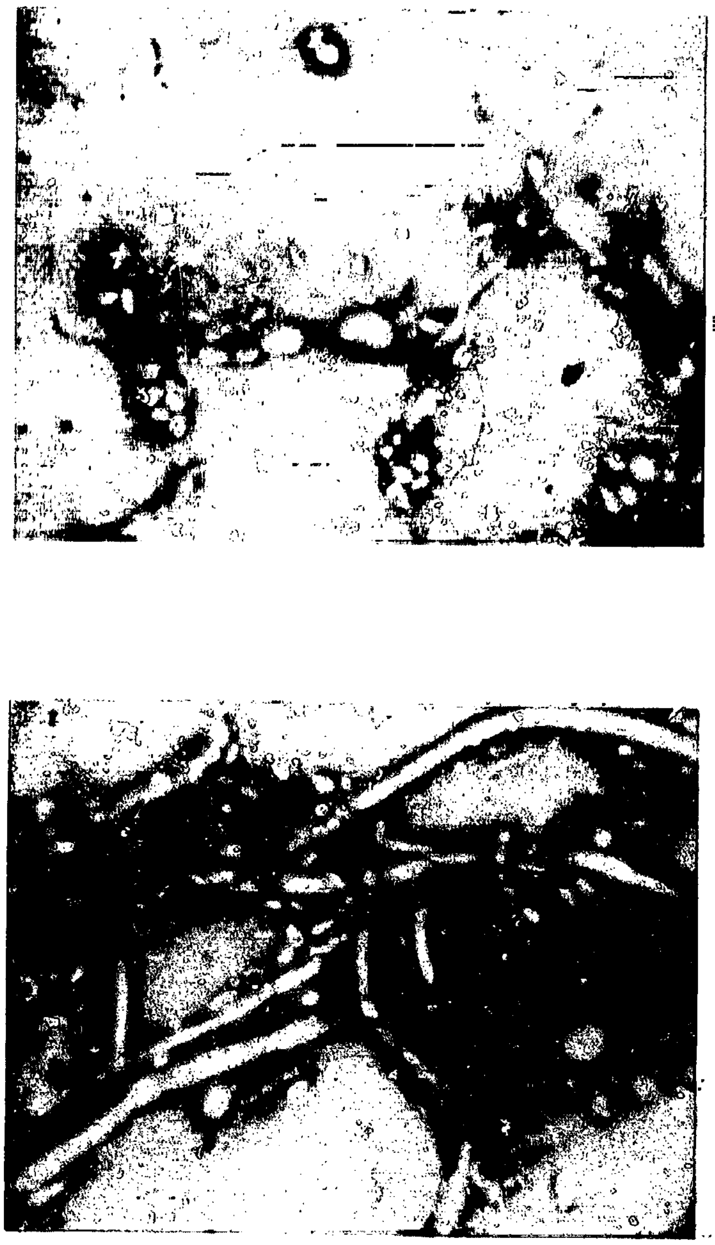


Figure III-26 Fungus Contamination in MIL-H-5606 Oil

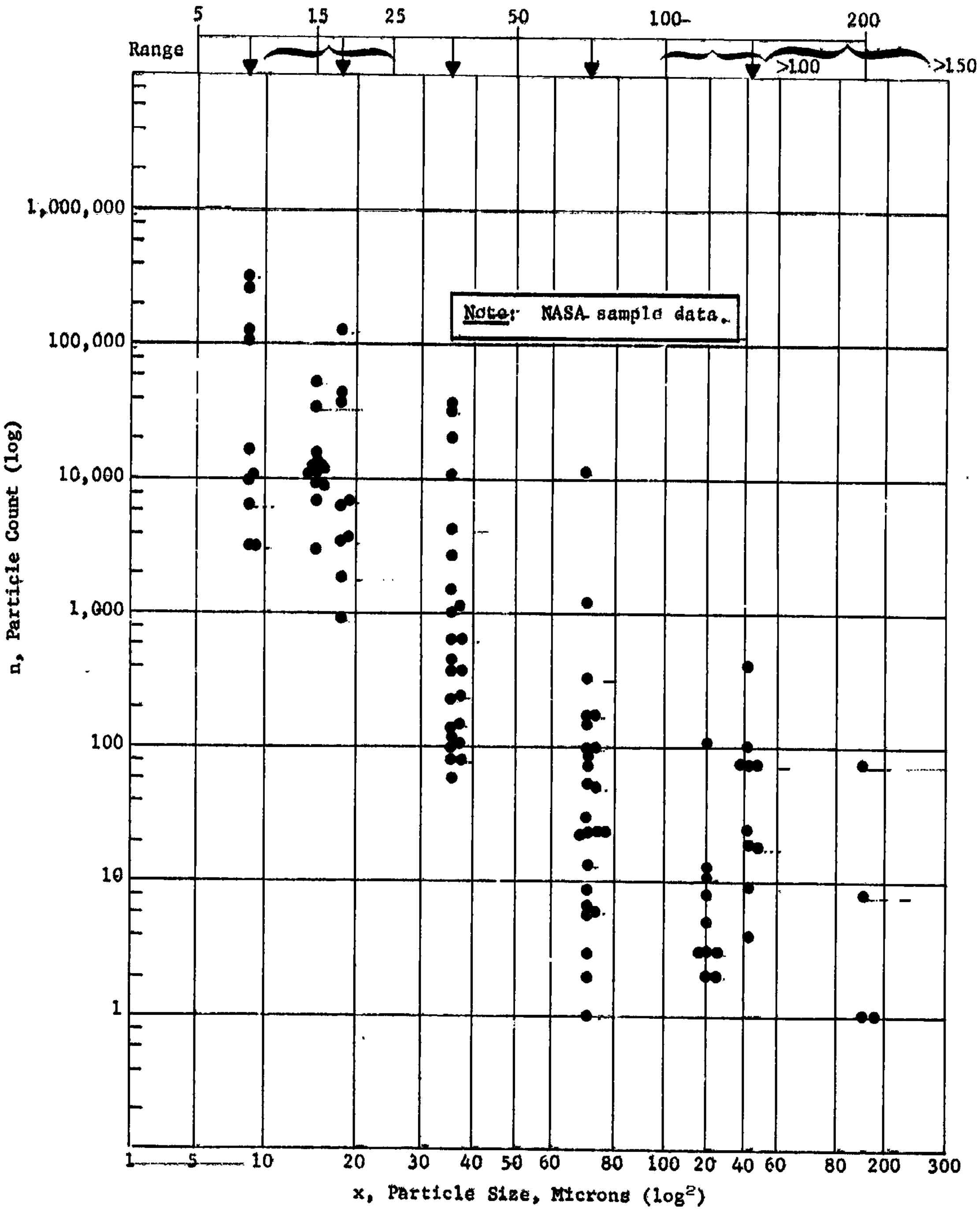


Figure III-27 Particle Count Analysis Plot
(service arm hydraulic systems)

IV. COMPONENT ANALYSIS

In any cleanliness level analysis, a detailed study of the components in the system is recognized as one of the most important functions. The purpose of this component analysis was to (1) determine the degree of complexity and sensitivity of the components; (2) determine those components deemed to be most prone to contamination failures; and (3) select critical components for test.

The categorized component list (Appendix A), developed as part of the systems analysis task, was used as the baseline list of components to be analysed in detail. The components contained therein were determined to be critical to the operation of the service arms and were possible candidates for a contamination failure.

A detailed analysis was conducted on each component to determine its sensitivity to contamination. The final product of the component analysis task is contained in the individual Component Analysis Sheets (Appendix B of this report). Each sheet lists the component specification number, vendor name, vendor part number, component location(s), possible contamination failure mode, and a detailed description of the component relative to contamination.

The following sources of information were used in the component analysis task:

1) Component Specifications;
2) Component Engineering Documentation;
3) Failure Analysis Summary and Reports;
4) Detailed Component Drawings;
5) Related Experience;
6) Contact with Vendors.

Each component specification was reviewed for materials, lubricant, pressures, flow rates, intended application, and vendor source. The failure analysis sheets were reviewed in detail to ascertain the past history of failures experienced with each particular component. Component drawings were obtained from the vendors and examined in detail. The engineers' experience played a strong role in this task. Basically, their evaluation concerned:

1) Past experience with the valve or the particular design;

2) Clearances between moving parts;

3) Hardness of materials in contact with each other;

4) Orifice diameters;

5) Seal location and configuration;

6) Flow areas and velocities;

7) Quantity or volume of fluid as seen by the valve;

8) Adaptability to cleaning, dead-legs, etc;

9) Actuation forces available;

10) Intended design application versus the actual application;

11) Relation of the component to other components in the system;

12) Surface finishes;

13) Degree to which the component would generate particulate.

The majority of the vendors of the components in question were contacted to gain specific information as to recommended cleaning levels, part failure history, cleaning procedures, part costs, and cleaning costs.

One comment was expressed by all vendors contacted; that their components used in the service arm systems could be reliably operated at less stringent cleanliness levels than are required by NASA. The Marotta Valve Corporation indicated that they felt their "commercial clean procedure" would yield components that would come very close to meeting the MSFC-164 specification, and that the Marotta components would operate satisfactorily in the service arm systems at this level of cleanliness.

Another fact revealed through vendor contact was that the costs associated with the cleanliness levels now specified for the service arm components were very high. Table IV-1 shows the approximate base cost for the component and the costs for cleaning. It should be noted that a fixed price or "set-up charge" is incurred each time a process is set up to clean a component, whether for one component or for many components. It is recommended that these costs be taken into account when purchasing or cleaning components; thus, it is more economical to clean several components at a time rather than just one component.

Table IV-1 Cleaning Costs

Specification No.	Cost with No Specification Cleaning or Cleanliness Testing (commercial clean)	Cost with Specification Cleaning, Cleanliness Tests + Cleaning Setup Charge per Lot
75M06116	$ 397.00	$547.00 + $175.00
75M08823	380.00	530.00 + 175.00
75M08824	265.00	310.00 + 175.00
75M08825	310.00	360.00 + 175.00
75M08826-X	2100.00	2350.00 + 250.00
75M08827-X	2650.00	2800.00 + 250.00
75M08829	330.00	375.00 + 175.00
75M08830	295.00	360.00 + 175.00
75M08831	285.00	355.00 + 175.00
75M08836	395.00	450.00 + 175.00
75M09285	348.00	520.00 + 175.00
75M10090	1350.00	1435.00 + 175.00
75M13255	285.00	355.00 + 175.00
75M51630-XXX	25.00	30.00 + 25.00
76K00187	470.00	520.00 + 175.00
B10425701-2	490.00	535.00 + 175.00
Marotta P/N 800262-19	115.00	140.00 + 150.00
Marotta P/N 204002	90.00	110.00 + 150.00
Marotta P/N MV 583	285.00	335.00 + 175.00

Note: Approximate pricing for quantities of 1 to 3.

Another problem area that was encountered during the course of this study was component cleaning procedures. Several vendors, who were contacted during this study, did not perform their own cleaning operations, either because they did not have cleaning facilities or because their facilities did not meet the requirements of the NASA criteria. The usual case was that the vendor would build the part, assemble it, perform the necessary functional tests, and then send it to another vendor for cleaning.

The vendor performing the cleaning would then disassemble the component, perform the necessary cleaning, and reassemble the component. In the case of some components, no functional tests were performed after the component was assembled. In addition to the expense involved (Table IV-2), the final assembly may be performed by technicians who are not as familar with the component as is the manufacturer. One vendor found it necessary to send a technician along with the part to maintain component integrity on final assembly. The ideal solution would be to select vendors who perform their own cleaning operations.

Table IV-2 Component Cleaning Costs

Specification No.	Base Price	Single Item Clean Cost	Cleaning Costs as a Percentage of Base Price (%)
75M06116	$397.00	$325.00	82
75M08823	380.00	325.00	86
75M08824	265.00	220.00	83
75M08825	310.00	225.00	73
75M08826	2100.00	500.00	24
75M08827	2650.00	400.00	15
75M08829	330.00	220.00	67
75M08830	295.00	240.00	81
75M08831	285.00	245.00	86
75M08836	395.00	230.00	58
75M09285	348.00	347.00	100
75M10090	1350.00	260.00	19
75M13255	285.00	245.00	86
75M51630	25.00	[illegible]	120
76K00187	470.00	225.00	48
B10425701-2	490.00	220.00	45
800262-19	115.00	175.00	152
204002	90.00	170.00	189
MV583	285.00	225.00	79
75M06606	550.00	723.00	131
75M10992-1	210.00	370.00	176
75M10992-2	279.00	380.00	136
75M08053	421.00	743.00	176
75M08822	2800.00	200.00	7

The following 16 components (Table IV-3) were selected for the contamination tests, Task II of this program. Other components were deemed critical but were of the same configuration as those shown below. The cylinders, accumulators, and check valves were not determined to be particularly contamination critical, but did represent the remaining broad categories of components contained in the service arm systems. They were also necessary to complete the test circuits that were representative of the service arm function. The specific details of each component are noted in their respective Component Analysis Sheets, Appendix B.

Table IV-3 Test Specimens for Contamination Test

Nomenclature	Vendor	Part Number	Similar NASA Part No.	Qty
Regulator	Marotta Valve Corporation	227464-J11	75M08829	1
Regulator	Marotta Valve Corporation	219004-J151	75M08830	1
Regulator	Marotta Valve Corporation	230904-12	75M08831-1	1
Solenoid Valve	Marotta Valve Corporation	806097-1	75M08823-1	3
Solenoid Valve	Marotta Valve Corporation	228154-02	75M08824-1	1
Solenoid Valve	Marotta Valve Corporation	225884-02	75M08825-1	1
Solenoid Valve	Marotta Valve Corporation	806098	75M09285-1	2
Cylinder	Pathon Manufacturing Company	3H1X3SU101/2 ABR	75M06506-7	1
Cylinder	Pathon Manufacturing Company	QU4X3SU191/2 ABR	75M09014	1
Accumulator	American Bosch	ACG300281	75M08814	2
Check Valve	James Pond Clark	277-T1-8TT	75M05365-4	2

V. LITERATURE SE.RCH

As an intregal part of this study, a literature/industry search was made to obtain available information concerning contamination in hydraulic and pneumatic fluids. Particular emphasis was placed on information relating to contamination levels generally used in equipment and systems similar to those in use at Complex 39, and information concerning the relationship between contamination levels and equipment performance.

A computerized literature search was conducted by Martin Marietta and a listing of pertinent articles concerning contamination was obtained from NASA and the Defense Documentation Center. During the literature search 4,892 articles on contamination were surveyed. From this number, 170 articles were ordered through our Library. The abstracts for 43 of the most informative articles concerning this study are included in Appendix C.

Some general conclusions may be reached as a result of the literature search:

1) The major body of the literature concerns hydraulics; in particular, servo valves. Almost no information was found on contamination in pneumatic systems. This may indicate that the majority of contamination problems were associated with servo valves and flight control feedback circuits, and that no particular problems have been experienced in pneumatic systems;

2) Included in the abstracts are several papers that describe the actual operating contamination levels of aircraft and ground checkout carts. The majority of these samples indicates that aircraft are operating satisfactorily with very dirty systems;

3) Very few controlled contamination tests were described in the literature. Many tests have been conducted on filters, but not on components or systems;

4) The authors of literature on contamination in hydraulic and pneumatic systems are very definitely divided into two distinct camps -- "clean-clean" and "dirty."

VI. CLEANLINESS LEVEL RECOMMENDATIONS FOR TEST

In several of the reports and papers reviewed during our literature search, the authors either prefaced or concluded their remarks with a statement to the effect that "there are as many different cleanliness specifications in existence as there are persons writing on the subject." Everyone concerned with cleanliness problems seems to select a level that works in his own experience. All of the major technical societies are deeply involved, with numerous committees and subcommittees striving mightily with the question. Practically every major aerospace firm has its own cleaning specification; the military and the NASA each have several. Any study that undertakes to consolidate and compare this mass of requirements is immediately overwhelmed with the disparities between the various issuing organizations. Evidence of the same diversity of opinion was found during the literature search; those authors concerned with reliable component and system operation praised extraordinary cleanliness, whereas those saddled with the responsibility of attaining, maintaining, and certifying clean hardware or fluids were much less demanding. Both sides of course, can logically justify their positions; this, however, is of little consolation to the person attempting to appraise his own position.

On the following pages all of the pertinent cleanliness information applicable to this program is tabulated. Table VI-1 lists actual specification cleanliness levels from NASA and the Military, as well as recommended standards published by technical societies. Table VI-2 lists information found in the literature concerning various company specifications and successful operating experience. An examination of these tables reveals several areas of particular interest:

1) Many conflicting NASA specifications exist, a situation that has been discussed in Chapter III of this report;

2) Many of the specifications and standards are closed-ended, that is, allow zero particles above some cut-off size, whereas others are open-ended, allowing a small number of particles of any size;

3) Virtually all of the specifications and literature are concerned with hydraulics -- in fact, during this program practically no information was found regarding cleanliness of pneumatic systems;

4) All parties apparently use the longest particle dimension as criteria, except North American who uses the smallest dimension;

5) All parties rely on manual particle counting methods per ARP-598, except Boeing who relies solely on a mass measurement;

6) In general, the specifications and proposed standards contain criteria that are much more stringent than the cleanliness levels encountered in fully operational equipment as reported by several surveys in the literature.

With all of this diverse information in hand, our task was to interpret the specifications with regard to the specific Saturn V service arm systems, and supplement them with other factors that in our opinion are essential to the determination of a satisfactory cleanliness program for any system. The following specifications and factors that were investigated during this task are listed below and are discussed in detail in the following pages:

1) Existing NASA and Military specification requirements as shown in Table VI-1;

2) Technical Society recommended standards as shown in Table VI-1;

3) Company specifications of users in similar applications, as shown in Table VI-2;

4) Actual condition recommendations from similar systems as shown in Table VI-2, and actual fluid sample reports from the service arm systems;

5) Consideration of the fluids used in the systems, as discussed in Chapter III;

6) Consideration of the components and the configuration of the actual service arm systems, as discussed in Chapters III and IV;

7) Vendor recommendations and Martin Marietta experience;

8) Assessment of the component function and the criticality assigned to that function.

1. NASA and Military Specifications

Six different NASA Specifications and four Military Specifications are listed in Table VI-1.

The NASA Specifications are divided into the following categories:

1) Hydraulic -

75M09467 - Fluid, components, and assemblies,
MSFC-166 - Fluid, components, and assemblies;

2) Pneumatic -

10M01671 - Components and assemblies,
MSFC-164 - Components and assemblies,
MSFC-234 - Liquid and gaseous nitrogen;

3) Fluids, liquid or gas -

KSC-C-123 - Components and assemblies.

Cleanliness Specification KSC-C-123 is identical to 10M01671 except that it has been rewritten to be used for either hydraulic or pneumatic applications.

The Military Specifications categories are as follows:

1) Hydraulic -

ORD 10425040 - Components and assemblies,
MIL-H-5606B - Hydraulic oil,
MIL-H-6083C - Hydraulic oil;

2) Pneumatic -

AFBS 61-3C - Components and systems.

Considering the hydraulic specifications first, we found that in general the component specification sheets originally referenced ORD 10425040. This was, in most cases, later amended to allow MSFC-166 or KSC-C-123 as an alternate. By referring to the tables, it can be seen that appreciable differences exist between these three specifications; the cleaning vendor thus has considerable freedom of choice. Hydraulic fluid from the service arm system samples is normally checked to 75M09467 or MIL-H-5606B which contain still different levels from the three specifications used for component verification.

The criteria for pneumatics are less complex. It was found that most component specification sheets originally called for 10M01671 and were later amended to allow KSC-C-123 as an alternate. However, these two specifications are essentially identical. One or two isolated components were found that referenced MSFC-164; this is a very loose specification and has limited usage. Nitrogen gas is procured per MSFC-234, but no evidence was found of any specifications used for pneumatic system sampling.

Several components were found for which usage was specified for either hydraulic or pneumatic applications; these generally referenced the 10M01671 specification, later amended to allow KSC-C-123 as an alternative.

All but one of the above specifications (MSFC-166) are closed-ended; that is, zero particles are allowed above a certain cutoff size. In our experience the imposition of such a requirement, for a system the size and complexity of the service arm systems is very restrictive. The service arm fluid samples that we received through NASA substantiate this position. In many instances, the samples easily met the appropriate specification level, except for one or two particles above the cutoff size. We have found that this condition is virtually impossible to eliminate. An open-ended specification such as MSFC-166, with adequate filtration techniques, was recommended by many of the vendors whom we contacted during this program.

In addition, all of the above specifications except two (MSFC-164, which has very limited usage, and 10M01671/KSC-C-123) are felt to impose restrictions that are unnecessarily stringent for the service arm systems and components. Our experience with hydraulic systems associated with Titan ground support equipment, and numerous surveys on operational aircraft reported in the literature, indicate that much higher contamination levels are tolerable than present service arm specifications allow.

2. Technical Society Standards

The Society of Automotive Engineers (SAE), the American Society for Testing Materials, (ASTM) and the Aerospace Industries Association (AIA) have all been concerned with cleanliness determinations for the past several years. The approach has generally been to establish a particle size/quantity distribution curve by one of several available mathematical methods. The resulting curve, when plotted on log-log^2 coordinates, is essentially a straight line.

Differing levels are established by creating multiples, such as any successive level doubling the previous one. The slope of the line on a log-log^2 plot will vary depending on which distribution curve formula was chosen. Several papers were found in the literature which attempted to prove that one particular curve fitted the available experimental data better than others; this appears to be a very nebulous concept to prove. The various societies have created, revised, and combined several versions, but three have been widely circulated and are constantly found referenced in the literature and in vendor catalogs. These are ARTC-28, NAS-1638, and a combined tentative standard of the SAE, ASTM, and AIA (unnumbered). All of these are hydraulic specifications and are open-ended with a cutoff level at 100 microns. Reference to Table VI-1 reveals that none of these standards agrees with the others, or with any of the Military or NASA specifications. The NAS-1638 is, however, the most widely recognized throughout the industry, and since it contains 14 levels it is also the most widely applicable. It was our decision then that in recommending a cleanliness level, we would attempt to use an existing class from NAS-1638 rather than add still another independent specification to the collection already in existence.

3. Industry Specifications

Industry cleanliness specifications are listed in Table VI-2. Without excepti n, the authors s ated that these levels were determined from actual test and experience with specific equipment. General Electric utilizes Levels 6 and 8 directly from NAS-1638. Perusal of this table reveals two generalizations that can be made: (1) the majority of the specifications are open-ended, again substantiating our position, and (2) the majority of the specifications have cutoff points in the 100 to 300 micron range. All of these companies use the ARP-598 particle counting method except Boeing who, for their GSE, relies solely on mass measurements. Also, all companies use the longest particle dimension except North American, who reportedly utilized the shortest dimension as criteria. While these specifications are quite diverse, taken together they illustrate an industry trend toward open-ended specifications with emphasis on the lower micron ranges, implying reliance on system filtration for removal of the larger size particles.

4. Operations Experience

During the literature search, four field surveys were found of operational aircraft hydraulic systems; one included several samples from tactical missiles. We have plotted the tabular data from these surveys on log-log^2 coordinates and superimposed the levels from NAS-1638 (see Fig. VI-1 through VI-4). Figure VI-5 is a similar plot of hydraulic samples taken by NASA at various points in the service arm system. It is re-emphasized that all of these plots represent satisfactorily operating hydraulic systems, the majority of which contain sensitive servo valves that are not present in the service arm system.

As would be expected in such a large sample population, a large variation in system cleanliness is evident. However, the agreement in slope between NAS-1638 and the Kinney, Robinson, and NASA data is quite remarkable. The Parker data, while evidencing a somewhat different slope, still falls well within the range of several levels of the NAS-1638 and could readily be controlled to that criteria.

The correlation between such a large cross section of operational data with NAS-1638 is felt to be another strong argument in favor of using this document as a cleanliness criteria for the service arm hydraulic systems, rather than creating a new specification. Without applying statistical procedures to this data, Level 8 is representative of the field samples, as well as an acceptable compromise of the recommendations of both Kinney and Wiley (Fig. VI-4) for avoidance of silting problems. General Electric (Table VI-2) also utilizes Level 8 as an acceptable operational level for their engine controls.

5. Fluid Considerations

Two aspects of hydraulic fluids should be noted with respect to cleanliness Level determinations. First, since MIL-H-6083C is a relative newcomer to this technology, the vast bulk of experience noted in the literature is with MIL-H-5606 oil. Because of the presence of the additive methacrylate as a viscosity improver, MIL-H-5606 hydraulic oil has a proved tendency toward particle agglomeration; that is, small particles tend to stick to one another forming, in effect, large particles. Methacrylate is identified as the adhesive. It has been shown that vibration actually aggrevates this phenomenon by increasing the force with which particles strike each other. If the agglomerates are broken up by agitation and then subjected to a further inactive period, they will reform. MIL-H-6083C does not contain methacrylate, and does not exhibit this phenomenon.

Second, the corrosion inhibitive properties of MIL-H-6083C are important to the service arm systems from three aspects: (1) the fact that adequate measures are not available for prevention of moisture entrance into the HCU, (2) the fact that thorough system flushing is not possible due to many dead-ended lines, and (3) the long inactive periods between launches. Formation of corrosion products (particulate matter) within the system due to these three factors must be considered as a potential source of contamination problems. Martin Marietta's experience with MIL-H-6083C has been very satisfactory, and literature found on the subject has all been quite favorable.

6. System and Component Configuration

During the first half of this study, the major effort involved detailed studies of the service arm systems and components. Manufacturer's drawings were obtained for many different components, and personal discussions were held with several vendors concerning the operation of their product and its susceptability to contamination. The details of these investigations are fully discussed in Chapters III and IV, but certain aspects relate directly to the determination of a cleanliness level and are reiterated here.

Table III-9 presents a compilation of all orifices, both hydraulic and pneumatic, that exist as individual find numbers in the service arm systems. Diameters are shown both in inches and in microns. The minimum orifice diameter encountered was 500 microns, which is not too small for the cleanliness levels recommended for the service arms.

Filtration techniques have been discussed in detail in Chapter III of this report. The point to be made here is that a cleanliness level determination cannot be made purely on the basis of orifice diameters or blueprint clearances, but must consider also that adequate and sufficient filtration techniques are employed. In general, the service arm systems contain adequate system filtration. The necessity of opening any given system for component replacement or when taking system fluid samples, plus the probability of internal contamination generation by certain components, demands that filters be included as an integral part of the system design. The presence of adequate filtration is also assumed when open-ended cleanliness specifications are proposed. Other techniques that should be implemented to ensure maintenance of any given level of system cleanliness include the use of blanket pressurization throughout, particularly in the hydraulic reservoir to prevent moisture intrusion, and prefiltering fluid prior to filling or adding fluid to the reservoir.

During the detailed component investigation, only two components were found that contained internal clearances that might be considered out of the ordinary; both of these are spool-type solenoid-valves, one from Sterer (75M08841) and the other from General Controls (75M08839). Both are used in hydraulic systems. The Sterer valve only supplies fluid to the pilot of another control valve; thus the flow is insignificant. The General Controls valve is used only in the manual operation system and does not have a failure history. This valve is not a critical component. In spool-type valves, no seals are used on the spool; metal-to-metal fit is relied on to hold leakage to an acceptable level, and as a consequence the clearances are quite small. In such a component, it is contamination in the extremely small range (0 to 5 microns) that should be considered troublesome; the larger particles simply cannot enter the clearance space. However, for silting problems to result from the small particulate, large flows must be present if the contaminate is to build up. Neither of these components is susceptible to these conditions. All other components are compatible to an open-ended cleanliness specification as long as adequate filtration is present.

7. Vendor Recommendations and Industry Experience

During the component investigation, many vendors were contacted by telephone and several were visited in order to discuss in detail the type of construction of their product and its mode of operation. In these discussions, not one single vendor indicated that extraordinary cleanliness procedures were necessary for reliable operation of their components. Many were familiar with MSFC-SPEC-164 and felt that this was a reasonable requirement for pneumatic systems, both from the standpoint of attainability and of reliable performance. This is one of the most liberal NASA specifications, but also the one to which the fewest references are made. Many vendors quote long histories of satisfactory performance on aircraft hydraulic systems where no as-procured cleanliness requirements are imposed. In summary, no data was obtained by vendor contact which indicated a need for presently imposed levels of NASA cleanliness specifications to ensure functional adequacy. This conclusion includes the Sterer and General Controls spool-type solenoid valves mentioned earlier.

Martin Marietta has considerable experience with both hydraulic and pneumatic contamination control. Flight control systems for the complete family of Titan vehicles are hydraulic, and include ground charging and checkout equipment. Martin Marietta-designed

Titan vehicle launch stands both at Cape Kennedy and at Vandenberg AFB contain major hydraulic stand actuation systems as well as ground pressurization systems both for ground control purposes and for vehicle requirements. The level of our corporate cleanliness specifications used for the pneumatic applications is similar in content to MSFC-SPEC-164, and our level for hydraulic components is much less stringent than either MSFC-PROC-166 or 10425040 (see Table VI-1). Using these cleanliness levels we have attained an eminently successful record throughout the Titan II weapon system, the Gemini program, and the Titan IIIA, Titan IIIC, and Titan IIIB series of launches for the Air Force.

8. Recommendations for Test

Considerations of all the data and other information obtained during the analysis portion of this program, and a careful weighing of all other factors discussed herein that we feel are pertinent to this question, led us to propose the following cleanliness levels as recommendations to the test phase of this program:

1) Hydraulic Tests

NAS-1638, Level 8

Size Range (microns)	0-5	5-15	15-25	25-50	50-100	Over 100
Quantity per 100 Milliliters of Fluid	No limit	64,000	11,400	2025	360	64

2) Pneumatic Tests

Particles

Size Range (microns)	0-300	300-500	500-1000	Over 1000
Quantity per 100 Grams of Gas	Unlimited*	10	2	None

Fibers

Length (microns)	0-750	750-2000	2000-6000	Over 6000
Quantity per 100 Grams of Gas	Unlimited*	20	2	None

*Total filterable solids limitation, 0.3 mg/100 grams of gas.

Longest Dimension (microns) → 1μ 5μ 10μ 50μ 100μ

Hydraulic Specification, NAS 1638, January 1964

Class						
Class 00	Unlimited	125	22	4	1	None
Class 0		250	44	8	2	None
Class 1		500	89	16	3	1 →
Class 2		1000	178	32	6	1 →
Class 3		2000	356	63	11	2 →
Class 4		4000	712	126	22	[illegible] →
Class 5		8000	1425	253	45	8 →
Class 6		16000	2850	506	90	16 →
Class 7		32000	5700	1012	180	32 →
Class 8		64000	11400	2025	360	64 →
Class 9		128000	22800	4050	720	128 →
Class 10		256000	45600	8100	1440	256 →
Class 11		512000	91200	16200	2880	512 →
Class 12		1024000	182400	32400	5760	1024 →

Hydraulic Specification, Tentative Standard (SAE, ASTM, AIA)

Class							
Class 0	Unlimited	Pending	2700	670	93	16	1 →
Class 1			4600	1340	210	28	3 →
Class 2			9700	2680	380	56	5 →
Class 3			24000	5360	780	110	11 →
Class 4			32000	10700	1510	225	21 →
Class 5			87000	21400	3130	430	41 →
Class 6			128000	42000	6500	1000	92 →
Class 7 thru 10		← Pending →					

Hydraulic Specification, ARTC-28, December 1964

Class							
Class 1	Unlimited	TBD	220	20	5	None	+2 Fibers
Class 2		TBD	530	60	10	1 →	+3 Fibers
Class 3		TBD	1530	150	19	1 →	+4 Fibers
Class 4		TBD	5530	420	40	3 →	+7 Fibers
Class 5		TBD	1650	320	25	None	+1 Fibers

Hydraulic Specification, 75M09467, 7 November 1965

					(Particles + Fibers)	
Fluid - GSE	Unlimited	1340	210	28	3	None
Fluid Level I		5360	780	110	11	None
Fluid Level II		23680	3640	555	52	None
Fluid Level III		42000	6500	1000	92	None
Components		1340	210	28	3	None
Assemblies		2150	530	[illegible]	10	None

Hydraulic Specification, MSFC-PROC-166, 15 March 1967

Fluid	Unlimited	1340	210	28	3 →
Components		600	100	16	2 →
Assemblies		2150	530	60	10 →

Hydraulic Specification, ORD-10425041, 25 April 1960

Subassembly	Unlimited	10	2	None	
Assembly and System		530	60	None	+10 Fibers

Pneumatic Specification, 10M01671, 28 April 1964

Particles							
Level I	Unlimited	40	3	1	None		
Level II		40	10	3	2	1	None
Level III		40	10	3	2		
Level IV		40					
Level V							
Level VI							
Fibers							
Level I	Unlimited	10	1	None			
Level II		10					
Level III							
Level IV							
Level V							
Level VI							

FOLDOUT FRAME

Pneumatic and Hydraulic Specification, KSC-C-123, 14 March 1968

Particles							
Level I	Unlimited	40	3	1	None		
Level II		40	10	3	2	1	None
Level III		40	10	3	2		
Level IV		40					
Level V							
Level VI							
Fibers							
Level I	Unlimited	10	1	None			
Level II							

Table VI-1 Cleanliness Specifications

100μ 200μ 500μ 1000μ 2000μ 4000μ 6000μ | Sample

None
None
1
1
2
4
8
16
32
64
128
256
512
1024

100 ml

1
3
5
11
21
41
92

100 ml

None +2 Fibers
1 +3 Fibers
1 +4 Fibers
3 +7 Fibers
None +1 Fibers

100 ml

(Particles + Fibers)

3	None
11	None
52	None
92	None
3	None
10	None

100 ml

3 — 100 ml
2 — ft² Area
10 — 100 ml

None — 100 ml
None +10 Fibers — 100 ml

None
2 1 None
3 2 1 None
40 10 3 2 1 None
40 10 3 2 1 None
40 10 3 2 1 None

ft² Area

FOLDOUT FRAME

None
10 1 None
10 1 None
10 1 None
10 1 None
10 1 None

N/A
N/A

None
2 1 None
3 2 1 None
40 10 3 2 1 None
40 10 3 2 1 None
40 10 3 2 1 None

ft² Area

None

1000μ 2000μ 4000μ 6000μ	Sample Size	Total Filterable Solids (Max)	Application
	100 ml Vol	Class 100-0.02 mg/100 ml Class 101-0.05 mg/100 ml Class 102-0.10 mg/100 ml Class 103-0.30 mg/100 ml Class 104-0.50 mg/100 ml Class 105-0.70 mg/100 ml Class 106-1.0 mg/100 ml Class 107-2.0 mg/100 ml Class 108-4.0 mg/100 ml (No Correlation with Particulate)	Hydraulic Fluid Effluent from Parts, Assemblies, Lines and Fittings
	100 ml Vol	N/A ↓ N/A	Class 0 - Rarely Attained Class 1 - MIL-H-5606B Oil Class 2 - Good Missile System Class 3 - Critical System, in General Class 4 - Critical System, in General Class 5 - Poor Missile System Class 6 - Fluid as Received Class 7 - Industrial Service
	100 ml Vol	Class 11-0.1 mg/100 ml Class 12-0.3 mg/100 ml Class 13-0.5 mg/100 ml Class 14-1.0 mg/100 ml	Class 1 - Ground Test Units Class 2 - Servo and Power Systems Class 3 - Aerospace Ground Equipment Class 4 - Aerospace Ground Equipment Class 5 - Refinery Supplied Fluid
	100 ml Vol	N/A ↓ N/A	Components, Assemblies, and Fluids Level I - Servo Valves Level II - Actuators and Cylinders Level III - Accumulators and Reservoirs
	100 ml Vol ft^2 Area 100 ml Vol	N/A ↓ N/A	Components, Assemblies and Fluid
	100 ml Vol 100 ml Vol	N/A N/A	Systems, Assemblies and Subassemblies
1 None 10 3 2 1 None	ft^2 Area	1.0 mg/ft^2 1.0 mg/ft^2 1.0 mg/ft^2 2.0 mg/ft^2 2.0 mg/ft^2 3.0 mg/ft^2	FOLDOUT FRAME Parts, Assemblies, Systems and Subsystems
1 None 10 1 None 10 1 None	N/A ↓ N/A	N/A ↓ N/A	
1 None 10 3 2 1 None	ft^2 Area	1.0 mg/ft^2 1.0 mg/ft^2 1.0 mg/ft^2 2.0 mg/ft^2 2.0 mg/ft^2 3.0 mg/ft^2	Parts, Assemblies, Systems and Subsystems

Class 1	Unlimited	Pending	2700	670	93	10	1	→	
Class 2			4600	1340	210	28	3	→	
Class 3			9700	2680	380	56	5	→	
Class 4			24000	5360	780	110	11	→	
Class 5			32000	10700	1510	225	21	→	
Class 6			87000	21400	3130	430	41	→	
Class 7 thru 10			128000	42000	6500	1000	92	→	
		← Pending →							
Hydraulic Specification, ARTC-28, December 1964									
Class 1	Unlimited								
Class 2			TBD	220	20	5	None		+2 Fibers
Class 3			TBD	530	60	10	1	→	+3 Fibers
Class 4			TBD	1530	150	15	1	→	+4 Fibers
Class 5			TBD	5530	420	40	3	→	+7 Fibers
			TBD	1650	320	25	None		+1 Fibers
Hydraulic Specification, 75M09467, 7 November 1965									
Fluid - SSE		Unlimited					(Particles + Fibers)		
Fluid Level I				1340	210	28		3	None
Fluid Level II				5360	780	110		11	None
Fluid Level III				23680	3640	555		52	None
Components				42000	6500	1000		92	None
Assemblies				1340	210	28		3	None
				2150	530	60		10	None
Hydraulic Specification, MSFC-PROC-166, 15 March 1967									
Fluid		Unlimited							
Components				1340	210	28	3	→	
Assemblies				600	100	16	2	→	
				2150	530	60	10	→	
Hydraulic Specification, ORD-10425041, 25 April 1960									
Subassembly		Unlimited							
Assembly and System				10		2	None		
					530	60	None		+10 Fibers
Pneumatic Specification, 10M01671, 28 April 1964									
Particles									
Level I		Unlimited			40	3	1	None	
Level II					40	10	3	2	1 None
Level III					40	10		3	2
Level IV								40	
Level V									
Level VI									
Fibers									
Level I		Unlimited			10	1	None		
Level II								10	
Level III									
Level IV									
Level V									
Level VI									
Pneumatic and Hydraulic Specification, ~~KSC-C-123~~, 14 March 1968									
Particles									
Level I		Unlimited			40	3	1	None	
Level II					40	10	3	2	1 None
Level III					40	10		3	2
Level IV								40	
Level V									
Level VI									
Fibers									
Level I		Unlimited			10	1	None		
Level II								10	
Level III									
Level IV									
Level V									
Level VI									
Pneumatic and Hydraulic Specification, EPS-50403, Martin Marietta									
Level A (Airborne Hydraulics)		Unlimited				250	10	→	
Level C Particles (Ground Pneumatics)									
Level C Fibers (Ground Pneumatics)									
Pneumatic, MSFC-SPEC-164, 27 July 1964									
Components		Unlimited							
Assemblies									
Pneumatic, AFBS Exhibit 61-3C, 5 March 1962									
Components Particles		Unlimited							
Components Fibers									
Systems Particles									
Systems Fibers									
Nitrogen, MSFC-SPEC-234, 21 September 1964									
Type I Gaseous	12μ Filtration Between Manufacturing Plant and Shipping Container						None		
Type II Liquid	40μ Filtration Between Manufacturing Plant and Shipping Container						None		
MIL-H-5606B, 26 June 1963	Unlimited		2500	1000	250	25	None		
MIL-H-6083C, 11 September 1967	Unlimited		2500	1000	250	25	5	→	

FOLDOUT FRAME

FOLDOUT FRAME

100 ml Vol

+2 Fibers
+3 Fibers
+4 Fibers
+7 Fibers
+1 Fibers

100 ml Vol

3 None
11 None
52 None
92 None
3 None
10 None

100 ml Vol

100 ml Vol
ft^2 Area
100 ml Vol

+10 Fibers

100 ml Vol
100 ml Vol

1 None
3 2 1 None
40 10 3 2 1 None
40 10 3 2 1 None
40 10 3 2 1 None

ft^2 Area

FOLDOUT FRAME

N/A

10 1 None
10 1 None
10 1 None
10 1 None
10 1 None

N/A

1 None
3 2 1 None
40 10 3 2 1 None
40 10 3 2 1 None
40 10 3 2 1 None

ft^2 Area

N/A

10 1 None
10 1 None
10 1 None
10 1 None
10 1 None

N/A

10 2 None
20 2 None

100 ml Vol
ft^2 Area
ft^2 Area

5 1 None
5 1 None

ft^2 Area
ft^2 Area

15 None
None
None
None

ft^2 Area
ft^2 Area
N/A
N/A

100 Liters
as Required

100 ml Vol
100 ml Vol

FOLDOUT FRAME

	100 ml Vol	N/A N/A	Class 1 - MIL-H-5606B Oil Class 2 - Good Missile System Class 3 - Critical System, in General Class 4 - Critical System, in General Class 5 - Poor Missile System Class 6 - Fluid as Received Class 7 - Industrial Service
	100 ml Vol	Class 11-0.1 mg/100 ml Class 12-0.3 mg/100 ml Class 13-0.5 mg/100 ml Class 14-1.0 mg/100 ml	Class 1 - Ground Test Units Class 2 - Servo and Power Systems Class 3 - Aerospace Ground Equipment Class 4 - Aerospace Ground Equipment Class 5 - Refinery Supplied Fluid
	100 ml Vol	N/A N/A	Components, Assemblies, and Fluids Level I - Servo Valves Level II - Actuators and Cylinders Level III - Accumulators and Reservoirs
	100 ml Vol ft^2 Area 100 ml Vol	N/A N/A	Components, Assemblies and Fluid
	100 ml Vol 100 ml Vol	N/A N/A	Systems, Assemblies and Subassemblies
1 None 10 3 2 1 None 1 None 10 1 None 10 1 None	ft^2 Area N/A N/A	1.0 mg/ft^2 1.0 mg/ft^2 1.0 mg/ft^2 2.0 mg/ft^2 2.0 mg/ft^2 3.0 mg/ft^2 N/A N/A	FOLDOUT FRAME Parts, Assemblies, Systems and Subsystems
1 None 10 3 2 1 None 1 None 10 1 None 10 1 None	ft^2 Area N/A N/A	1.0 mg/ft^2 1.0 mg/ft^2 1.0 mg/ft^2 2.0 mg/ft^2 2.0 mg/ft^2 3.0 mg/ft^2 N/A N/A	Parts, Assemblies, Systems and Subsystems
2 None 20 2 None	100 ml Vol ft^2 Area ft^2 Area	2.0 mg/100 ml 2.0 mg/ft^2 2.0 mg/ft^2	Effluent Fluid and Blowdown Gas
1 None 1 None	ft^2 Area ft^2 Area	1.0 mg/ft^2 1.0 mg/ft^2	Components and Assemblies
None None None	ft^2 Area ft^2 Area N/A N/A	2.0 mg/ft^2 2.0 mg/ft^2 N/A N/A	Components and Systems
	100 Liters as Required	N/A N/A	Liquid and Gaseous Nitrogen
	100 ml Vol 100 ml Vol	N/A N/A	Hydraulic Fluid

			1μ 5μ	10μ	
F-111 Aircraft Flight Control Servo Actuator (Appendix C, Items 42 and 43)	Operational Level		Unlimited	20,000	4,000
General Electric, Engine Hydraulic Control System (Appendix C, Item 19)	System Cleaned to Operational Level		Unlimited	16,000	2,850
			Unlimited	64,000	11,400
Titan II Hydraulic Platform Systems (Appendix C, Item 5)	Operational Level	Particles	Unlimited		
		Fibers	Unlimited		
North American (Apollo) Hydraulic Systems	Level 1		Unlimited		
	Level 2		Unlimited		
	Level 3		Unlimited		
	Level 4		Unlimited		
	Fibers		Unlimited		
Three Unidentified Airframe Manufacturers. Hydraulic Oil Requirements – (Appendix C, Item 35)	Manufacturer A		Unlimited	16,000	4,800
	Manufacturer B		Unlimited	10,000	4,000
	Manufacturer C		Unlimited	2,500	1,500
Survey of 143 Navy Planes Hydraulic Systems (Appendix C, Item 38)	Recommended Level		Unlimited	87,000	21,400
Contamination in Aircraft Hydraulic Systems, Wright Patterson AFB (Appendix C, Item 33) (Appendix C, Item 33)	Maximum Sampled		Unlimited	101,300	47,150
North American Nitrogen Specification			Unlimited		100
Convair Hydraulic Specification (Appendix C, Item 45)			Unlimited		9,000
Hydraulic Specifications for Servo Systems	**Systems**	**Company**			
	GSE	Boeing	No Particulate Requirement —Weight, 0.3 mg		
	New Oil	Hughes	Average of 4 Largest Particles 50μ, None >1		
	All	North American	Unlimited		2,875
	Missile	Martin-Marietta	Unlimited		4,500
	All	ABMA	Unlimited		2,150
	All	SAE	Unlimited	50,000	20,000
	GSE	Lockheed	Unlimited	3,500	1,250
	All	Westinghouse	Unlimited	5,000	None
(Appendix C, Item 29)	Missile Fluid	BuWeps	Unlimited	10,000	4,000
	Flight Control	Lockheed	Unlimited	10,000	2,500
	Missiles	Boeing	No Particulate Requirement - Weight, 0.5 mg		

FOLDOUT FRAME

Table VI-2 Industr

10µ		50µ	100µ	200µ	500
20,000	4,000	1,000	55		
16,000	2,850	506	90	16 →	
64,000	11,400	2,025	360	64 →	
		1,050	250	70	
			100 10	None	
			100	10 None	
				5	1 None
					Particles + Fibers
,000	4,800	1,200	240	16 4 →	
10,000	4,000	1,000	100		50 3 →
2,500	1,500	150	20	5 →	
,000	21,400	3,130	430	41 →	
,300	47,150	24,380	8,340	3,590 →	
	100	10	5	1 None	
	9,000	900	90	9	None + 1 Fiber
- Weight, 0.3 mg/100 ml					
les 50µ, None >150µ					
2,875		1,375	350 100	None	(Rated by Smallest Dimension)
	4,500	700 450 →	+ 20 Fibers		
	2,150	530	60	None + 10 Fibers	
0,000	20,000	5,000	500	250 →	
3,500	1,250	250	25	3 →	
5,000	None				
0,000	4,000	1,000	100		50 3 →
0,000	2,500	500	50	10 →	
- Weight, 0.5 mg/100 ml					

FOL

Table VI-2 Industry Experience and Specification

200μ	500μ	1000μ	2000μ	
	11	Particles + Fibers 5	None	
70	20	3	None	
		25	5	None
10 None				
5	1 None			
	Particles + Fibers	6 None		
			1 None	
16 4 →				
	50 3 →			
→				
1 None				
9	None + 1 Fiber			
(Rated by Smallest Dimension)				
bers				
	50 3 →			

FOLDOUT FRAME

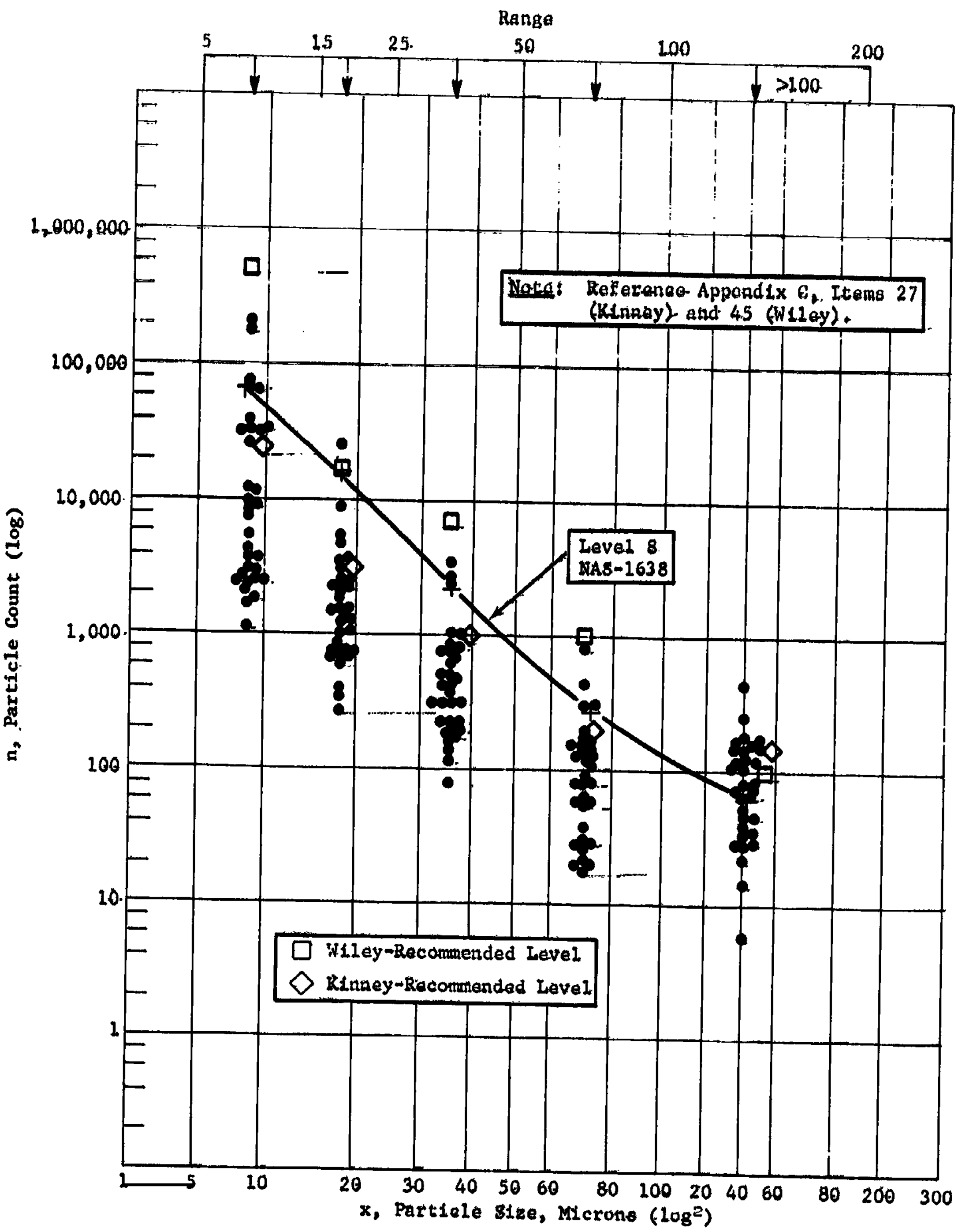


Figure VI-1 Particle Count Analysis (31 operational aircraft and missiles)

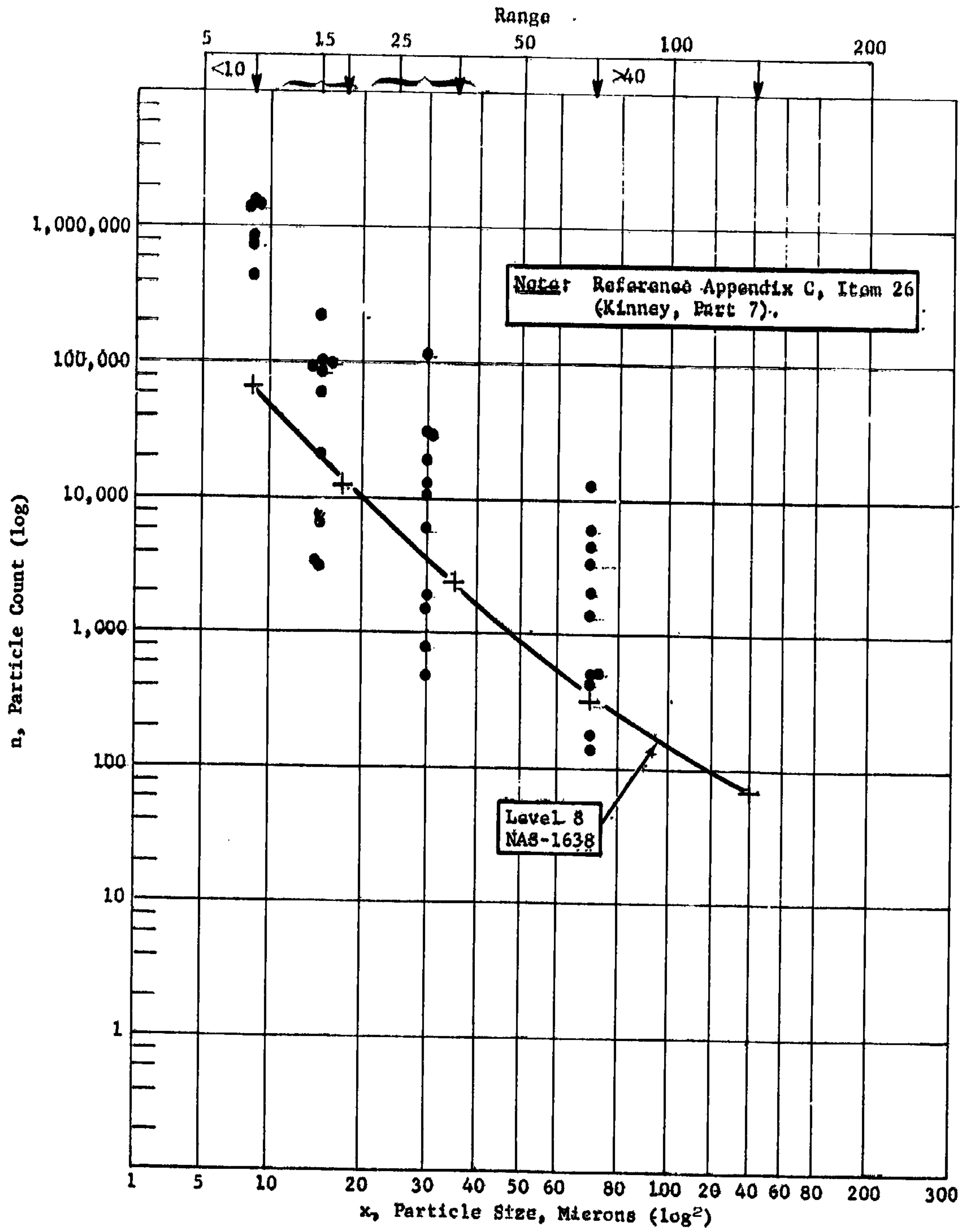


Figure VI-2 Particle Count Analysis (11 AF aircraft)

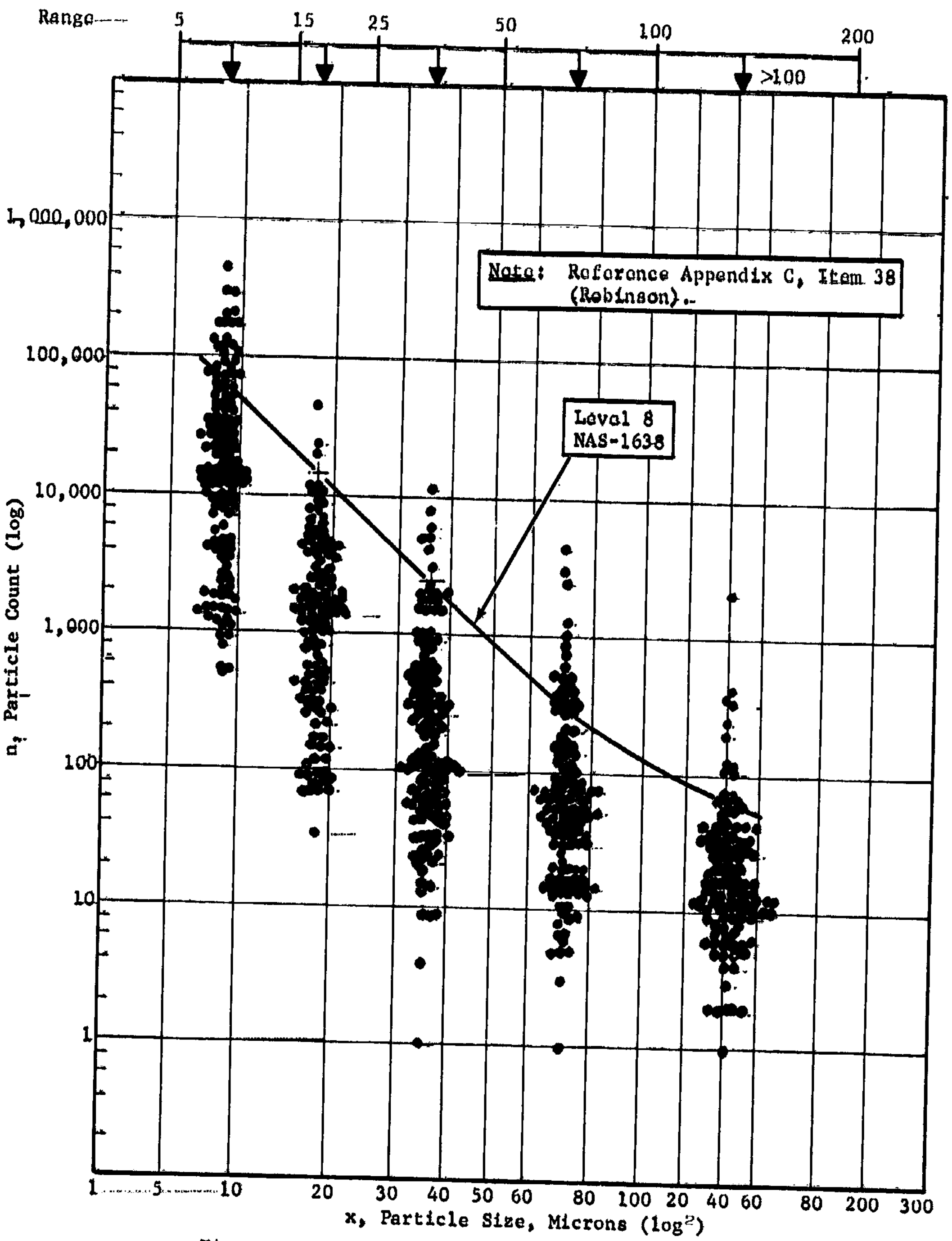


Figure VI-3 Particle Count Analysis (143 naval aircraft)

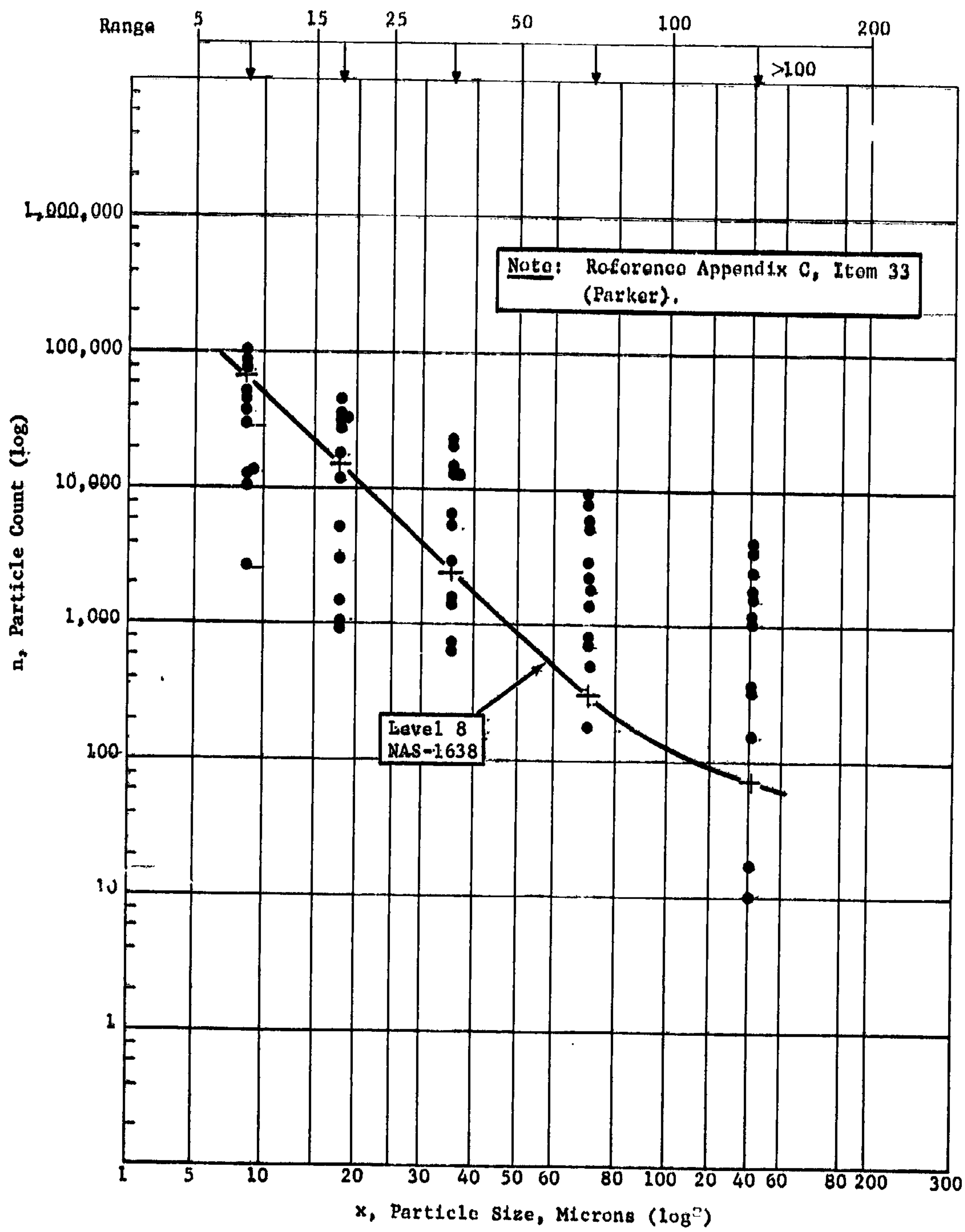


Figure VI-4 Particle Count Analysis (17 AF aircraft)

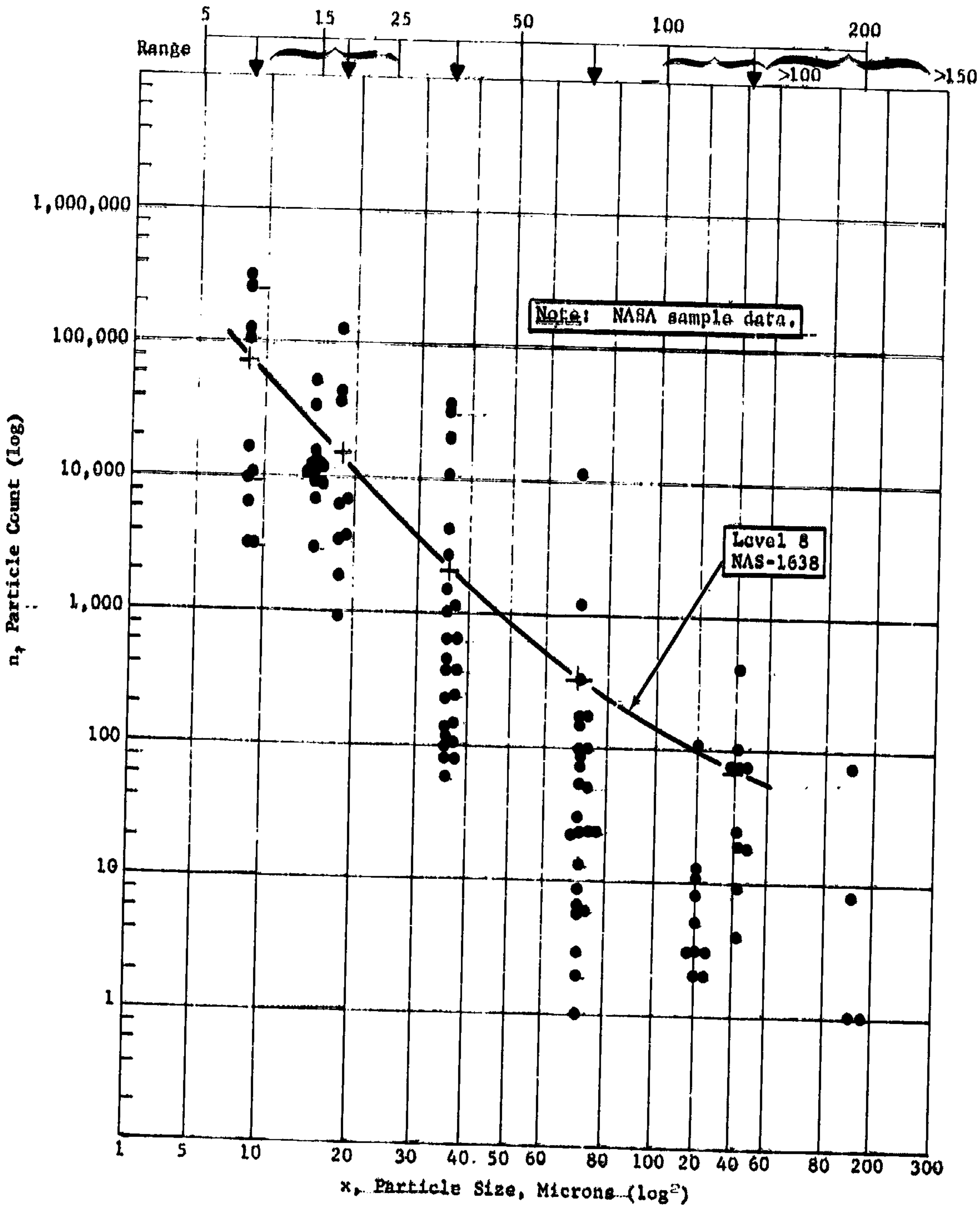


Figure VI-5 Particle Count Analysis
(Service Arm Hydraulic Systems)

VII. ESTABLISHMENT OF CONTAMINANT CLASSES

Chapter VI describes the methodology used in arriving at the contamination level to be used in the contamination tests. This chapter describes the constituents and quantity of each, used to make up the contamination that was injected into the test circuits.

The following types of contaminant were used to make up the contamination in both the hydraulic and pneumatic tests:

1) A. C. "course" road dust;
2) Red iron oxide particles;
3) Teflon particles;
4) Cotton lintner fibers.

A photograph of each contaminant is shown in Figures VII-1 through VII-4.

The A. C. road dust (Fig. VII-1) is a composite of screened and graded dust particles, primarily quartz. It is natural road dust from Arizona. The basic composition in each size range is:

Particle Size (microns)	Percent by Weight
0 to 5	12 ± 2
5 to 10	12 ± 3
10 to 20	14 ± 3
20 to 40	23 ± 3
40 to 80	30 ± 3
80 to 200	9 ± 3

The road dust was used because it represents a hard crystalline particle of an irregular shape similar to wind blown atmospheric contamination normally found in fluid systems at Cape Kennedy. It is also comparative to lapping compounds, filter test media, and other contaminants found in hydraulic and pneumatic systems. The hardness of these dust particles will also simulate metal particles.

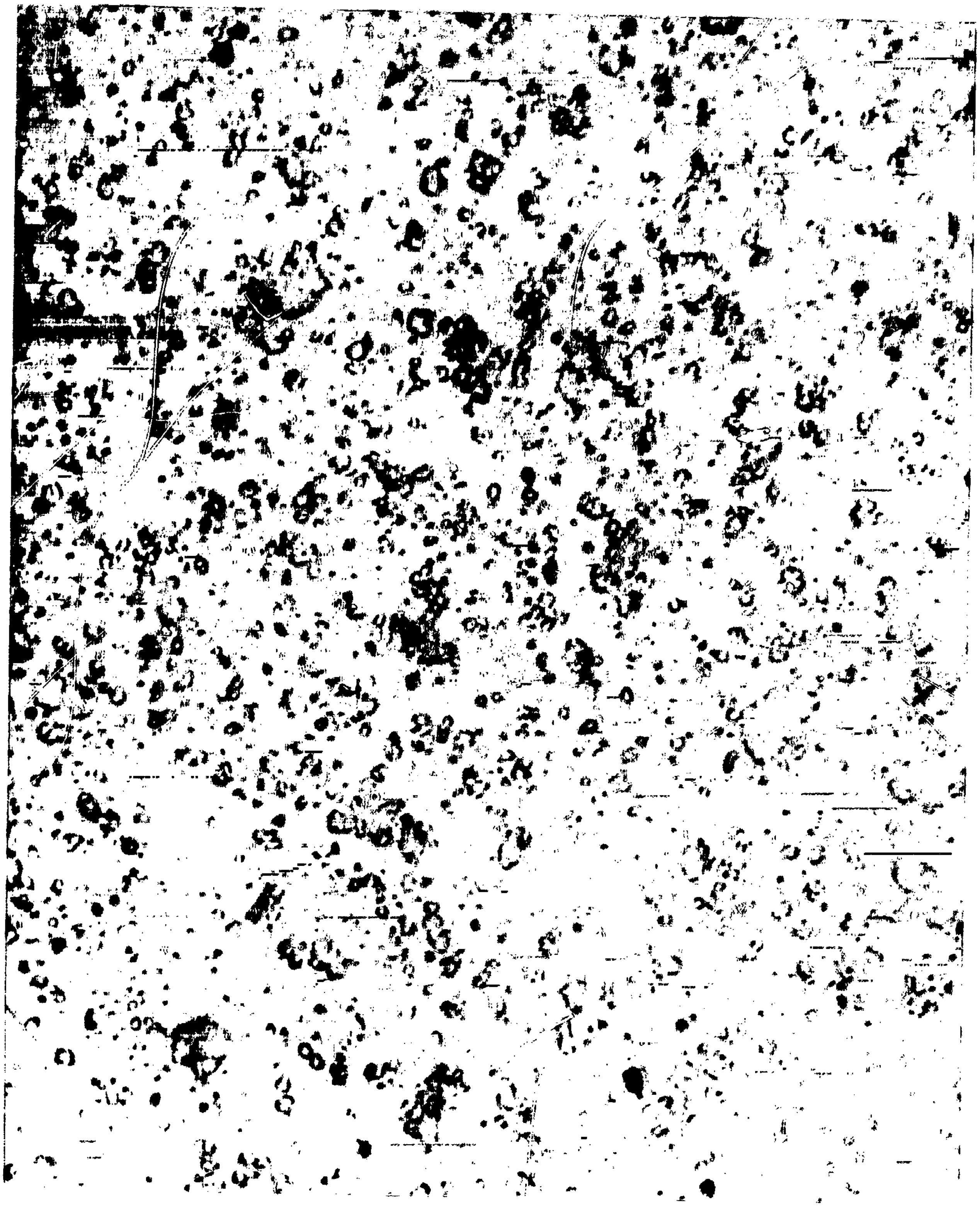


Figure VII-1 A.C. "Coarse" Road Dust - 870X

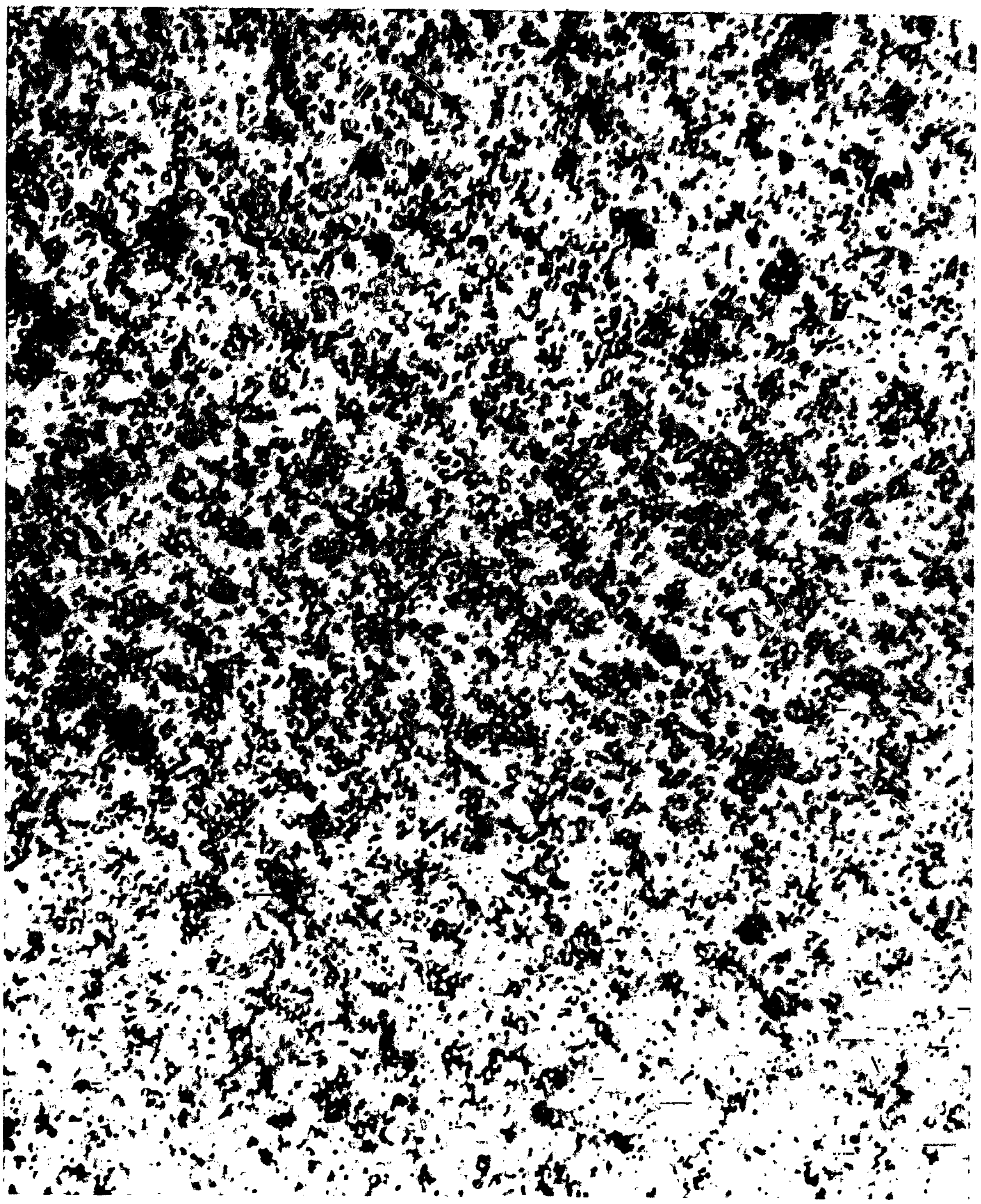


Figure VII-2 Red Iron Oxide Particles - 350X

Figure VII-3 Teflon Particles - 140X

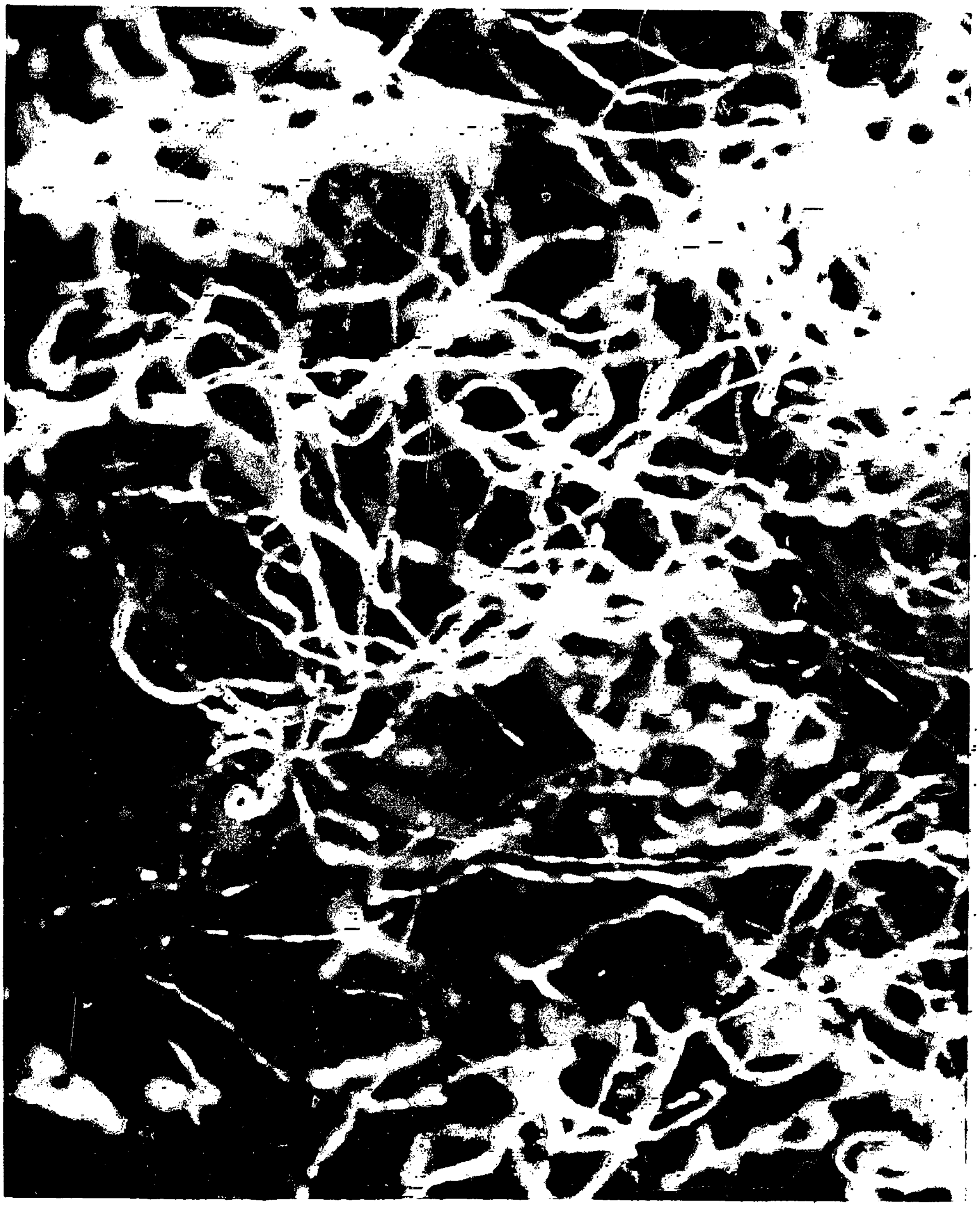


Figure VII-4 Cotton Lintner Fibers - 140X

The red iron oxide particles (Fig. VII-2) are uniform spheres approximately 5 microns in diameter. These small spheres were used to evaluate the effects of silting, stiction, and wear caused by small particles. The hardness of these particles is also similar to metal.

The teflon particles (Fig. VII-3) are a composite of irregular shaped particles ranging in size from 30 to 1000 microns. The teflon represents particles that are internally generated from the many plastic and teflon parts used in the service arm systems as lubricants (base derivative), seals, seats, hose liners, and sealant tape.

The cotton lintner fibers (Fig. VII-4) range in size from 50 to 4000 microns and were used to simulate a soft fiber commonly found in atmospheric contamination.

In order to accurately establish the number of particles in each size range for the total contaminant to be used in the tests, it was necessary to ascertain the number of particles for each constituent as a function of weight. With the exception of the iron oxide, none of the suppliers of contaminant were able to supply this information. The number of particles per given weight was required in order to establish particle counts and total weight of contaminant per 100 ml of oil or 100 grams of gas. Weight conversions were also required because of the large amounts of contamination injected in each test; thus a manual microscopic count would be an extremely lengthy procedure and would not be as accurate.

Automatic particle counters were used to determine particle count for a given weight. The HIAC automatic particle counter was used initially but did not prove to be adaptable to our tests; the ROYCO automatic particle counter was adaptable. The ROYCO counter is based upon the principle of light refraction, and like most counters it integrates the area of each particle and categorizes it as a round sphere in each respective size range. In manual microscopic techniques, the particle is sized by its longest dimension; thus some differences exist in the criteria baseline between manual and automatic techniques.

The initial procedure used was to weigh a sample of the constituent, place this sample in 100 ml of prefiltered Freon (carrier fluid), and then introduce the contaminant to the counter.

The initial tests, using the above procedure, produced an unacceptable amount of scatter in data. As a result the tests were inconclusive. The majority of the problems were due to operational techniques. Samples weighing 1.5 mg were first used but it was found that the particles were conglomerating. Smaller samples (0.048 to 0.3 mg) produced large errors in weighing inaccuracies which magnify themselves in terms of particle counts. A highly accurate electronic weighing device was used to weigh the samples. This device can differentiate to 1×10^{-5} grams but even this order of accuracy was not sufficient. Dilutions were tried, but the dilutions did not prove to be representative of the total mix prior to dilution. Other problems were experienced in particle settling, traps, etc.

The final series of tests was conducted using gravity flow through the top of the ROYCO counter. The flow configuration to the inlet of the counter was designed to eliminate traps and settling points, and to prevent air bubbles from entering the counter during the initial flow process. Automatic counters, which operate on a light principle, will readily interpret air bubbles as particles and will count them as such. An ultrasonic bath was used to prevent conglomeration of the particles. It was also necessary to use large quantities of flush fluid (filtered Freon) to completely wash all of the particles from the test beaker and through the tubing to the counter. The above techniques provided highly repeatable data from sample to sample. Figure VII-5 shows the particle count for 1.0 mg of A.C. "coarse" road dust and Figure VII-6 shows the composition of the OX60 teflon.

Table VII-1 shows the composition of the contamination level used in the contamination tests. The pneumatic and hydraulic contamination levels that are being used in the contamination tests are approximately 30% higher than those recommended for the service arm systems. Increased levels of contamination were used in the contamination tests to ensure a margin of conservatism. The composite level includes large amounts of hard abrasive contaminants. System contamination, as observed in the field, will not include such large amounts of these particles. The whole intent was to over-test the components to ensure a margin of reliability.

Particle Count Analysis Plot

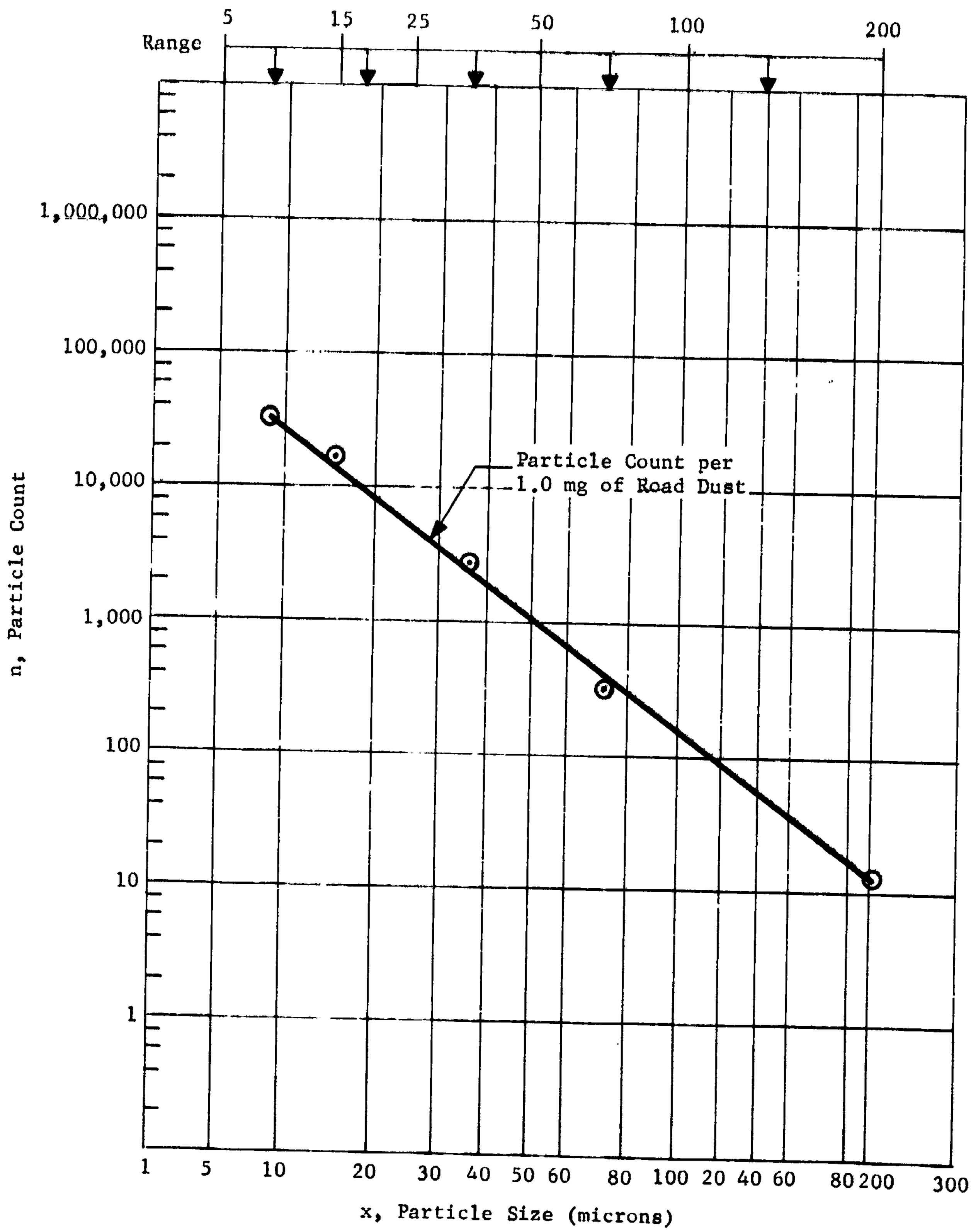


Figure VII-5 Particle Count Composition A.C. "Coarse" Road Dust

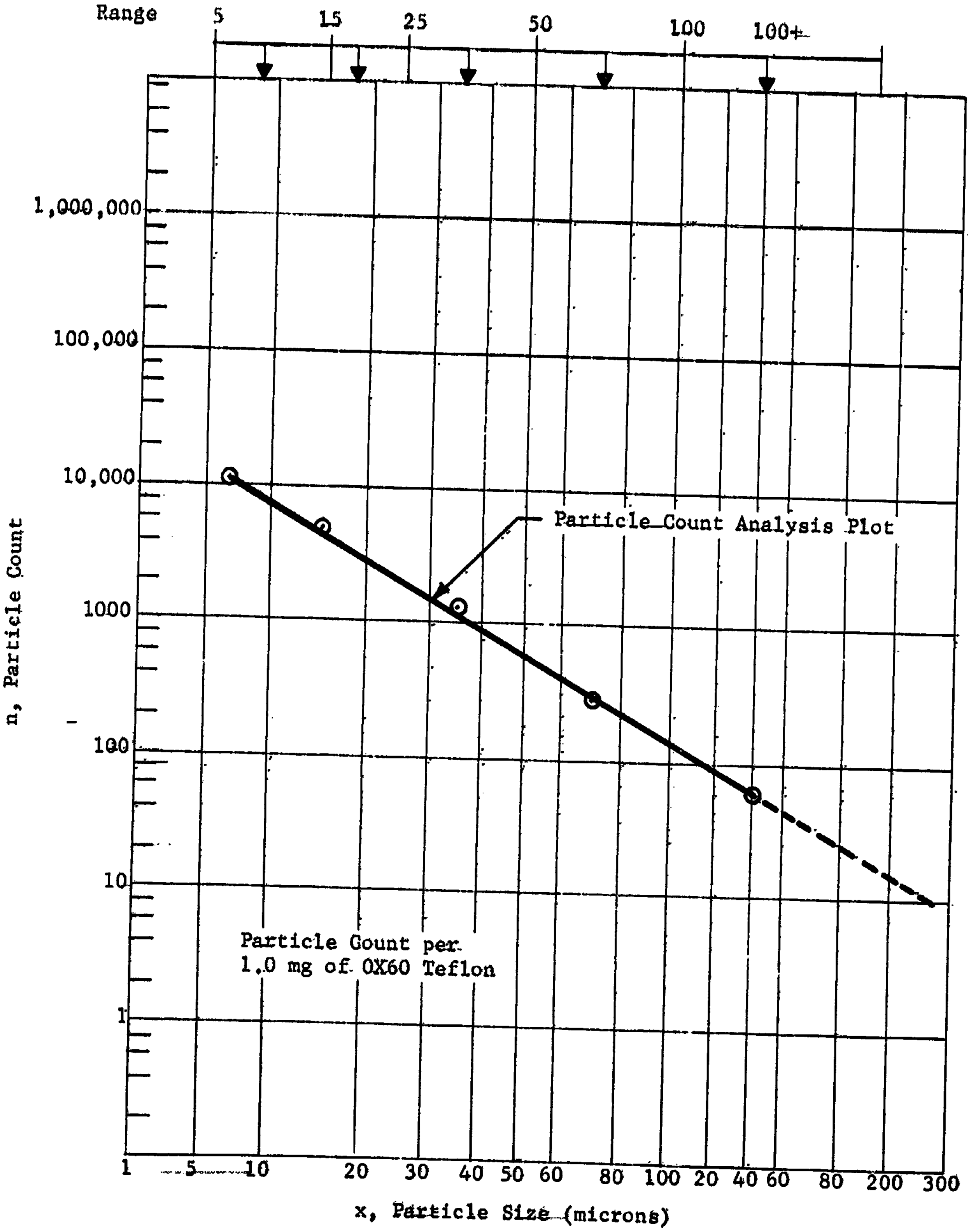


Figure VII-6 Particle Count Composition OX60 Teflon

Table VII-1 Contamination Test Levels

	Size Range				
	6 - 10μ	11 - 25μ	26 - 50μ	51 - 100μ	100 +
OX60 Teflon 0.24 mg/100 grams gas	2670	1130	300	70	13
A.C. "Coarse" Road Dust 0.06 mg/100 grams gas	1940	1030	170	20	1
Red Iron Oxide <0.1 mg/100 grams gas	3700	0	0	0	0
Cotton Lintner Fibers <0.1 mg/100 grams gas	--	--	--	--	(4000μ maximum)
Total Particle Count 0.30 mg/100 grams gas	8310	2160	470	90	14 + fibers

Pneumatic Contamination Test Level

	Size Range				
	6 - 10μ	11 - 25μ	26 - 50μ	51 - 100μ	100 +
OX60 Teflon 2.0 mg/100 ml oil	22,200	9,400	2,500	564	108
A.C. "Coarse" Road Dust 0.2 mg/100 ml oil	6,460	3,420	565	67	3
Red Iron Oxide <0.01 mg/100 ml oil	3,710	0	0	0	0
Cotton Lintner Fibers <0.1 mg/100 ml oil	--	--	--	--	(4000μ maximum)
Total Particle Count 2.2 mg/100 ml oil	32,370	12,820	3,065	631	111 + fibers

Hydraulic Contamination Test Level

Figure VII-7 shows the composite level of contamination used in the hydraulic tests. The cleanliness level (Level 8 of NAS1638) tentatively recommended for the hydraulic systems is superimposed upon the test level. Figure VII-8 shows the contamination level used in the pneumatic tests. Both of these cleanliness levels are considerably less stringent than the levels presently specified for the service arm systems.

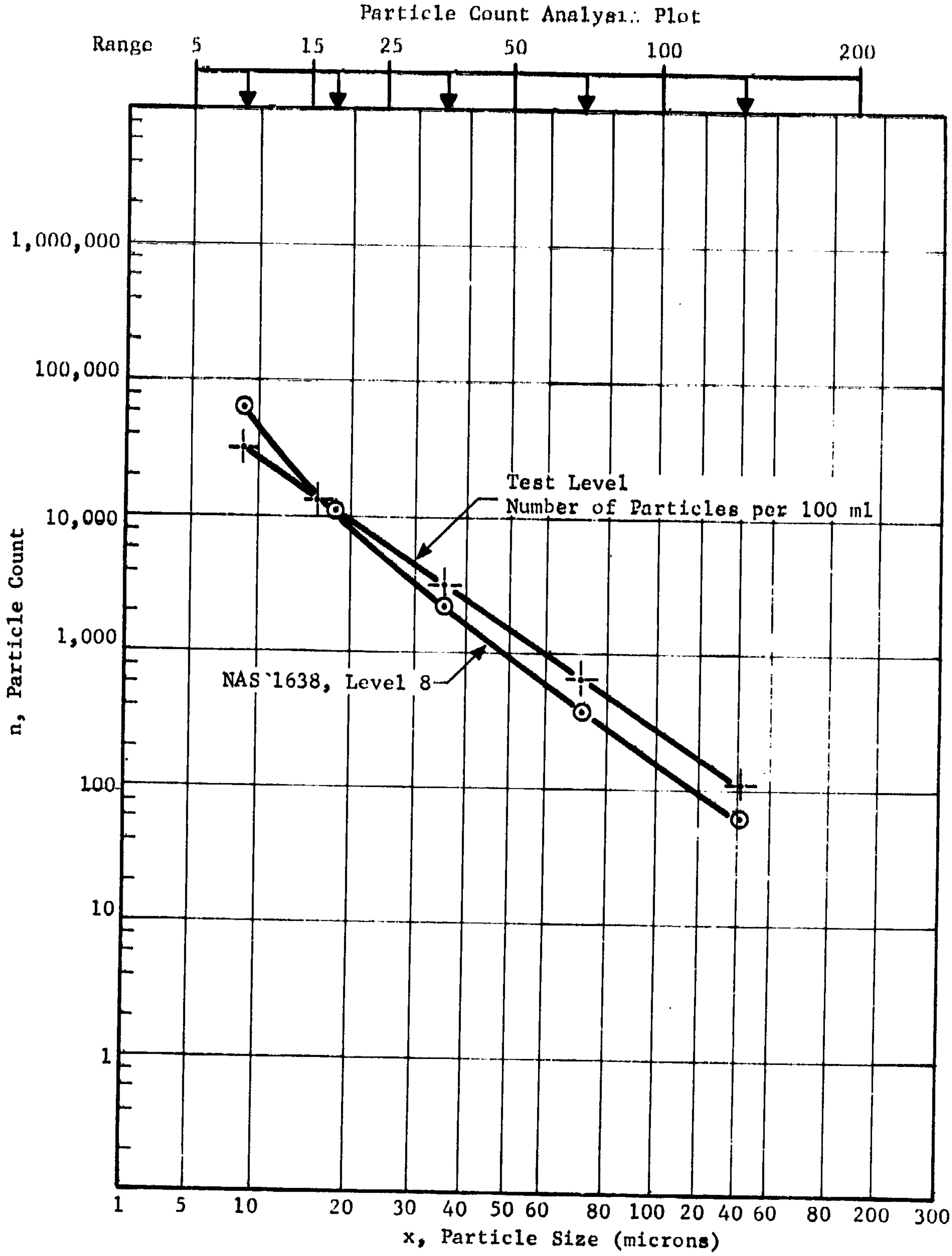


Figure VII-7 Contamination Level for Hydraulic Tests

Particle Count Analysis Plot

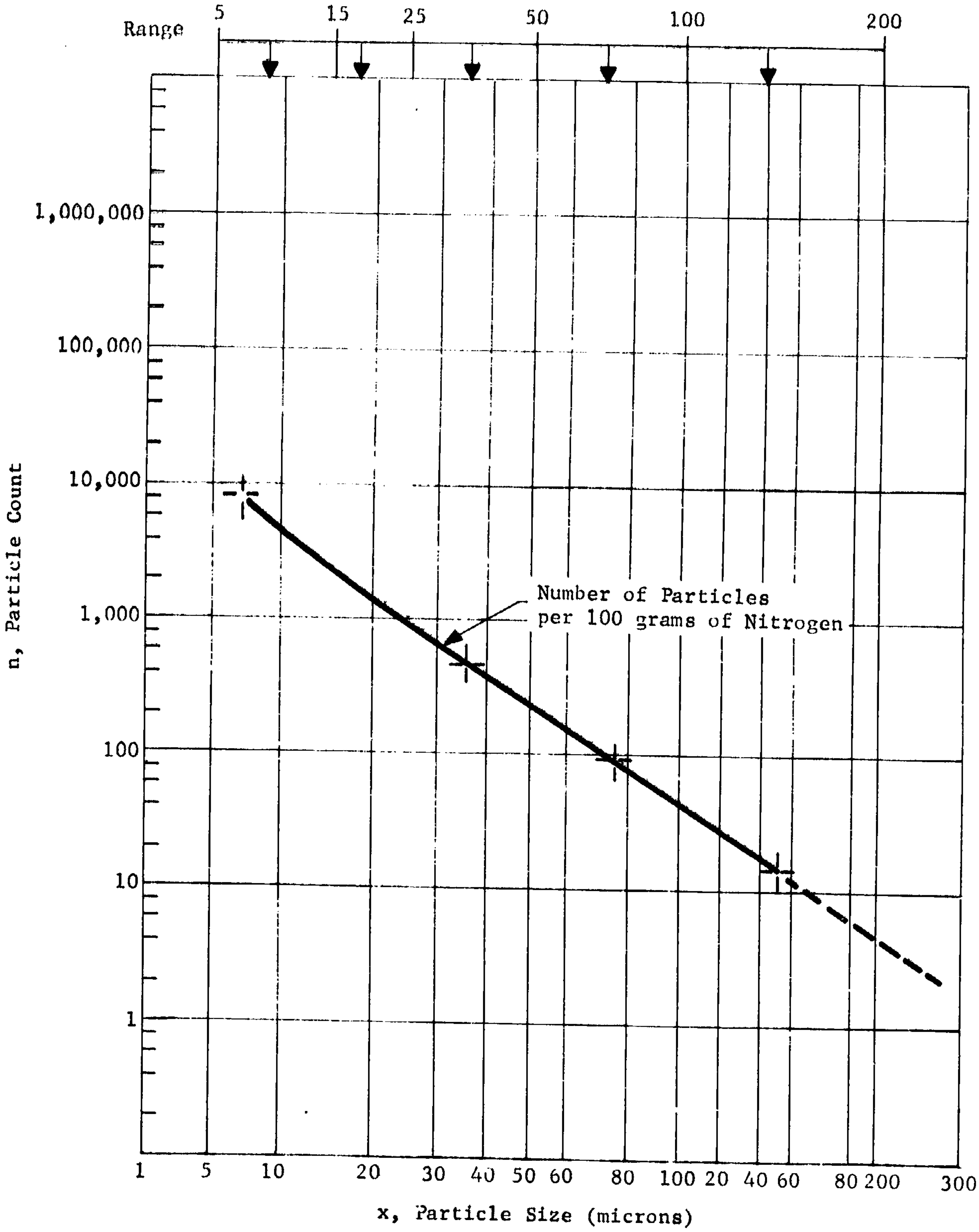


Figure VII-8 Contamination Level for Pneumatic Tests

VIII. CONTAMINATION TEST PROGRAM

The objective of the study was to evaluate the cleanliness requirements for the pneumatic and hydraulic components in the service arm systems at Complex 39 in an effort to relax the cleanliness levels, and their associated high cost, while maintaining service arm reliability. A test program was included to confirm the functional performance of components subjected to the final cleanliness levels to be recommended.

Tests were performed on pneumatic and hydraulic components arranged in a system typical of the service arm applications. Each component in both the pneumatic and hydraulic systems was subjected to 1500 operational cycles, a number selected after consideration of all of the scheduled tests, launches, and anticipated checkout on the service arms for the duration of the Apollo program. The 1500 operational cycles are four times the maximum cycles expected on the service arm systems.

A. TEST CRITERIA

The test criteria were established prior to procurement of components and the subsequent test effort. The criteria, which formed the basis for the contamination tests, are quoted in the following paragraphs.

1. Component Procurement

Test specimens will be procured to the vendor part number which corresponds to the similar NASA service arm specification. The test specimens will be procured commercial clean.

2. Receiving and Inspection

Components shall be inspected for general conformance. The components shall also be visually inspected, with magnification, for contamination. The valve shall not be disassembled to perform this inspection. The contamination observed shall be recorded.

The internal flow path of the hydraulic components will be flushed with clean hydraulic oil and sampled to determine the contamination level of the valve as procured. The component will not be cleaned in the flush mode unless the component exhibits extreme contamination.

3. Functional Test

A bench functional test will be performed on each component to ensure its integrity and also to establish baseline functional performance for comparison during the contamination test. Performance criteria shall be recorded prior to and during testing. Fluids used in the functional test shall be filtered prior to the test specimen.

4. System Cleanliness

The test system shall be cleaned to test level "A" (Table VIII-1) or better, prior to installing the test specimens. Care shall be taken to minimize exterior contamination when installing the test specimens. The effluent count of the flush fluid shall be recorded.

5. System Functional

A functional check of the system shall be performed subsequent to the test specimen installation to ensure proper system operation prior to conducting the 1500 cycle test. The fluids used during the system functional check shall be clean filtered fluids. The hydraulic loop shall be drained after the functional check. Photographs of the system shall be taken.

6. Test Fluid

Hydraulic Test - The test fluid shall be MIL-H-5606 hydraulic oil prefiltered to 3 microns. After filtration, a quantity of oil equal to the volume of the system shall be prepared. Contamination shall be mixed into the oil to ensure a homogeneous mixture. Precautions shall be taken to prevent further contamination of the oil by exterior contamination.

Table VIII-1 Cleanliness Levels

Level A - System Cleanliness

Particles

Size (microns)	0-300	301-500	501-1000	Over 1000
Quantity per ft^2 of significant surface area	Unlimited*	10	2	0

Fibers

Length (microns)	0-750 x 25	751-2000 x 25	2001-6000 x 40	Over 6000
Quantity per ft^2 of significant surface area	Unlimited*	20	2	0

*Total Filterable Solids Limitation, 0.25 mg/ft^2

Level B - System Fluid Contamination

Contaminant Type	Size Range				
	6 - 10μ	11 - 25μ	26 - 50μ	51 - 100μ	100 +
0X60 Teflon 0.24 mg/100 grams gas	2670	1130	300	70	13
A.C. "Coarse" Road Dust 0.06 mg/100 grams gas	1940	1030	170	20	1
Red Iron Oxide <0.1 mg/100 grams gas	3700	0	0	0	0
Cotton Lintner Fibers <0.1 mg/100 grams gas	--	--	--	--	4000μ maximum
Total Particle Count 0.30 mg/100 grams gas	8310	2160	470	90	14 + fibers

*Total Filterable Solids Limitation, 0.3 mg/100 grams of gas

7. Criteria for Success

The test system shall be cycled for 1500 cycles. At intervals of 300 cycles the leakage of each component shall be verified. Component leakage and regulator set pressure shall be the primary criteria for determining component failure. Pressure levels and component response shall also be monitored for indication of component failure. After the completion of the test each component shall be subjected to a functional test and the data recorded.

8. Component Failure

If a component shall fail prior to the end of the test, the program manager shall be notified and he shall make one of three determinations: (1) repair the valve, (2) continue the test without repairing the valve, or (3) discontinue the test. The main objective will be to continue the test, if possible.

9. Failure Analysis

At the conclusion of the test, and prior to repairing any internal component parts, each component shall be disassembled. Contamination shall be noted and recorded. Photographs shall be taken to note contamination, valve failure, or general condition of the component. A failure analysis shall be conducted if the valve failure was due to contamination.

B. PNEUMATIC CONTAMINATION TESTS

The pneumatic testing effort was started on 10 March 1969 and was completed on 4 June 1969. All testing was performed at the Martin Marietta Cold Flow Laboratory at Denver, Colorado.

The functional characteristics of eight components determined to be critical to control arm operation were established by functional test. The specimens were then assembled into an operational system, and operated 1500 cycles using deliberately contaminated nitrogen gas. The functional tests were repeated to establish any functional degradation, and the specimens were disassembled for inspection.

All specimens operated properly throughout the testing, with the exception of specimen 1, Marotta Regulator 227464-J11. This regulator was found to be extremely sensitive to contamination and failed as a result of poppet seat erosion. This regulator has a history of nine failures on the service arm systems.

Disassembly of the specimens showed a major amount of contaminant present and little component degradation.

1. Objectives

The objectives of the pneumatic contamination tests were to:

1) Test selected control arm components in a typical flow system. Component selection was based upon susceptibility to contamination combined with possession of a critical function in the control arm system;
2) Demonstrate the reliability of the components at an increased level of contamination by subjecting them to 1500 operational cycles;
3) Perform functional tests on each test component before and after the 1500 operational cycles, in order to determine component degradation;
4) Maintain cleanliness of the test fluid at a prescribed level;
5) Disassemble and inspect the components following the test, to determine the effect of test fluid contamination.

2. Test Specimens

Test specimens were procured to the vendor part number which corresponds to the similar NASA service arm specification. The test specimens were procured commercial clean.

Specimen	Manufacturer	Part Number	NASA Equivalent Part Number	Name
1	Marotta	227464-J11	75M08829	Regulator
2	Marotta	228154-02	75M08824-1	2-way solenoid valve
3	Marotta	806098	75M09285-1	3-way solenoid valve
4	Marotta	806098	75M09285-1	3-way solenoid valve
5	Pathon	QU4X3SU191/2ABR	75M09014	Pneumatic cylinder
6	Marotta	230904-12	75M08831-1	Regulator
7	Marotta	806097-1	75M08823-1	2-way solenoid valve
8	Marotta	225884-02	75M08825-1	3-way solenoid valve

3. Test Equipment

a. Instrumentation

The recorded instrumentation functions and the gages used in the pneumatic tests are specified on the schematics given in Figures VIII-1 through VIII-5. A Consolidated Electrodynamics Corporation Type 5-124 recorder was used for all recorded data. Accuracy of all readouts was ±2% full scale.

b. Test Fixture

The test fixture schematics used for functional and system testing are included as Figures VIII-1 through VIII-5. Each test installation was cleaned to the level shown in Level A in Table VIII-1. The cleanliness was verified by a nitrogen flush at a higher flowrate than anticipated during test fixture operation. Photographs of the system test installation and control panel appear as Figures VIII-6 and VIII-7, respectively.

c. Contaminant Injector

During system test operation, a known contaminant was injected into the system periodically. The device used for adding the contaminant to the flow stream consisted of an AN-827-6 cross, oriented as shown in Figure VIII-8. With the cross oriented vertically, the contaminant was loaded through the upper port into the capped lower one. The upper port was capped and the cross oriented as shown in the figure. The velocity of the nitrogen passing over the contaminant filled port caused sufficient turbulence to draw contamination into the flow stream. The angle at which the crosses were set was determined during development tests in a separate contamination injector development system.

The components in this system were sized to approximate the flow that would exist in the system test fixture during pressurization of the cylinder. The approximate injection rates, with the injector angles, are shown in Figure VIII-8. Although the majority of the contamination is consumed early in the flow, the overall injection schedule is much less severe than the "batch" technique, and more closely duplicates the contamination distribution rate that might be found in a typical system. The injection rate was sized in this manner to ensure that all of the contaminant would be removed from the injector and distributed throughout the test system in the remaining cycles.

d. Contaminant

The contaminant used was a mixture of ground teflon particles, A.C. coarse dust, red iron oxide, and cotton lintner fibers. The particles were mixed to form a composite level equivalent to Level B of Table VIII-1. The contaminant mixture was injected at a rate of 0.3 mg per 100 grams of gaseous nitrogen.

4. Test Method and Procedure

a. Functional Test Method and Procedure

Each test specimen was subjected to a functional test to establish its operating characteristics prior to the system test.

The 2-way and 3-way solenoid valves were tested for internal and external leakage and response time. Inlet pressure on all valves was 2000 psig of gaseous nitrogen.

The test specimen 1 regulator was tested at an inlet pressure of 4500 psig of gaseous nitrogen for internal and external leakage, for ability to regulate pressure at a given setting, and for capability of venting downstream pressure in excess of the set pressure.

The test specimen 6 regulator was tested for external leakage, set pressure, and ability to vent downstream pressure in excess of the set pressure. The regulator was tested with an inlet pressure of 1000 psig of gaseous nitrogen, and was purchased with a preset and lockwired outlet pressure setting of 120 psig.

The test specimen 5 pneumatic cylinder was tested at a pressure of 1000 psig of gaseous nitrogen for internal leakage, external leakage, and breakaway pressure.

b. System Test Method and Procedure

The eight test specimens were combined with a minimum of additional components to form the operating system shown schematically in Figure VIII-5. The gaseous nitrogen inlet pressure to the system was adjusted to 4500 psig, and the outlet pressure of test specimen 1 adjusted to 1000 psig. The system was operated automatically through 1500 cycles, using the logic sequence in Table VIII-2.

Table VIII-2 System Test Cycle Logic

			Test Specimen									
			2		3		4		7		8	
	Sequence	Duration Seconds	Open (+28V)	Close	Vent (+28V)	Pressurize	Vent (+28V)	Pressurize	Open (±28V)	Close	ILFHC (+28V)	Millipore
	Initial Condition	--		X	X		X			X	X	
One Cycle	1	9	X		X			X		X		X
	2	11	X			X	X			X		X
	3	35		X		X	X		X			X
	4	1		X		X	X		X		X	
	5	1		X	X		X			X	X	

Notes: 1. Refer to Figure VIII-5 for System Test Fixture Schematic.

2. The logic above performs the following:

Sequence 1 - extends the pneumatic cylinder.
Sequence 2 - retracts the pneumatic cylinder.
Sequence 3 - vents the system through the millipore filter.
Sequence 4 - diverts residual N_2 three ILFHC, and exercises specimen 8.
Sequence 5 - returns the system to its initial condition.

Prior to each set of 50 cycles, contaminant was added to the system at the two points indicated on Figure VIII-5. For a description of the contaminant used and the contaminant injection technique, consult paragraphs VIII, B, 3, c and VIII, B, 3, d.

All effluent gaseous nitrogen from the system was passed either through a Millipore filter tool, Model XX45-047-00, or a Martin Marietta developed in-line filter holder and counter (ILFHC) tool. This tool allows examination of the filter paper without removing it from the flow system. The vent from the initial 195 cycles of each set of 200 cycles was passed through the Millipore tool. The Millipore paper was then analyzed for particle size and size distribution. The vent from the remaining 5 cycles was then passed through the ILFHC and used as a verification of particle size and size distribution.

After cycles 100, 300, 600, 900, 1200 and 1500, internal leakage tests were performed on all test specimens to establish any degradation. All of these leakage tests were performed at the system pressures used during the cycling test.

Table VIII-3 gives a summary of test operations during the 1500 cycles.

c. Final Inspection Test Method and Procedure

Following completion of the system and functional tests, each test specimen was carefully disassembled for inspection. The component parts were inspected for evidence of abrasion, contamination, lubricant deposits, etc. Photographs were taken of significant items.

5. Test Results and Discussion

a. Initial Functional Test Results and Discussion

Test data from the initial functional tests are presented in Tables VIII-4, VIII-5, and VIII-6. For discussion of the data that do not meet the test criteria, see paragraph VIII, B, 6, d.

Table VIII-3 System Test Run Schedule

After Cycle Number	Inspect ILFHC	Inspect Millipore	Add Contaminant	Leak Check
0			X	X
50			X	
100			X	X
150			X	
195		X		
200	X		X	
250			X	
300			X	X
350			X	
395		X		
400	X		X	
450			X	
500			X	
550			X	
595		X		
600	X		X	X
650			X	
700			X	
750			X	
795		X		
800	X		X	
850			X	
900			X	X
950			X	
995		X		
1000	X		X	
1050			X	
1100			X	
1150			X	
1195		X		
1200	X		X	X
1250			X	
1300			X	
1350			X	
1400			X	
1450			X	
1495		X		
1500	X			X

Table VIII-4 Solenoid Valve Functional Test Data

Test	Cycle	Criteria	Functional Test Data									
			Specimen 2 (75M08824)		Specimen 3, S/N 281 (75M09285)		Specimen 4, S/N 280 (75M09285)		Specimen 5 (75M08823)		Specimen 6 (75M08825)	
			Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Ext Leakage	1	No Leakage	0	0	0	0	0	0	0	0	0	0
Int Leakage	1	No Leakage	0	0	0	0	0	0	0	0	0	0
Ext Leakage	1	No Leakage	--	--	0	0	0	0	--	--	0	0
Int Leakage	1	No Leakage	--	--	0	0	0	0	--	--	0	0
Response Time	1	100 MS Max Open	35.4	34.0	182*	190*	111*	128*	75.8	81.3	33.5	35.6
		100 MS Max Close	5.6	1.2	11.0	8.8	14.5	11.7	18.3	15.1	7.7	7.0
	2	100 MS Max Open	33.5	36.6	159*	138*	105*	125*	73.5	71.3	32.0	35.8
		100 MS Max Close	6.1	2.4	10.9	7.7	14.0	12.5	17.6	12.6	7.4	8.0
	3	100 MS Max Open	33.7	36.6	157*	135*	103*	115*	72.0	71.9	31.5	33.6
		100 MS Max Close	7.6	1.2	10.6	8.5	12.9	11.7	17.8	15.1	8.4	7.7
	4	100 MS Max Open	33.5	36.6	159*	133*	103*	111*	71.5	73.2	32.2	34.0
		100 MS Max Close	5.6	1.2	10.6	8.3	13.2	12.1	17.6	13.2	8.4	7.7
	5	100 MS Max Open	33.6	36.6	158*	170*	102*	110*	70.9	71.9	31.8	33.8
		100 MS Max Close	4.5	2.4	10.6	8.3	13.9	12.6	16.8	12.8	8.5	7.7
Operational Voltage	1	8 to 18V Pull-In	15.5	17.0	22.5*	21.0*	17.6	17.4	15.4	16.4	12.2	13.0
		1 to 17V Drop-Out	2.2	2.2	3.5	2.0	2.7	2.0	2.0	2.0	3.1	3.2
	2	8 to 18V Pull-In	15.5	17.3	22.2*	21.2*	17.6	18.0	16.3	16.2	12.2	13.2
		1 to 17V Drop-Out	2.2	2.3	3.5	2.6	2.5	2.2	2.0	2.6	3.1	3.1
	3	8 to 18V Pull-In	15.0	17.6	22.2*	21.0*	17.6	17.9	16.2	16.3	12.2	13.3
		1 to 17V Drop-Out	2.2	2.4	3.5	2.8	2.6	2.6	2.0	2.4	3.0	3.2
	4	8 to 18V Pull-In	15.2	17.6	22.1*	21.0*	17.6	17.8	16.2	16.1	12.2	13.3
		1 to 17V Drop-Out	2.0	2.4	3.4	2.9	2.5	2.8	2.0	2.5	3.1	3.6
	5	8 to 18V Pull-In	15.1	17.6	22.2*	21.0*	17.7	18.0	16.3	15.8	12.2	13.6
		1 to 17V Drop-Out	1.9	2.5	3.6	2.9	2.4	2.3	2.0	2.3	3.1	3.2

*Indicates a value that fails to meet criteria. See paragraph VIII, B, 6, d.

Table VIII-5 Regulator Functional Test Data

Test	Cycle	Specimen 1 (75M08829)			Specimen 6 (75M08831)		
		Criteria	Initial	Final	Criteria	Initial	Final
Lockup Pressure	1	1000 ± 100 psi	1015	1030	120 ± 15 psi	120	120
	2	1000 ± 100 psi	1020	1030	120 ± 15 psi	120	120
	3	1000 ± 100 psi	1020	1030	120 ± 15 psi	120	120
	4	1000 ± 100 psi	1020	1030	120 ± 15 psi	120	120
	5	1000 ± 100 psi	1020	1030	120 ± 15 psi	120	120
Venting Pressure	1	1160 psi max	1140	*	155 psi max	130	130
Reseat Pressure	1	900 psi min	1080	*	105 psi min	125	125
Vent Leakage	1	0	0.2 cc/min	*	0	0	0
External Leakage	1	0	0	0	0	0	0
Internal Leakage	1	0	0	*	N/A†	N/A†	N/A†

*Gross failure of poppet seal during system test made these items impractical to measure.

†Test specimen was purchased adjusted to 120 psig and lockwired.

Table VIII-6 Pneumatic Cylinder Functional Test Data (75M09014)

Test	Criteria	Initial	Final
Piston Leakage-Retract	73,600 SCCM	3,080 SCCM	32 SCCM
Piston Leakage-Extend	73,600 SCCM	12,141 SCCM	1,410 SCCM
External Leakage-Cylinder	20 SCCM	0	0
External Leakage-Rod	28,320 SCCM	111 SCCM	137 SCCM
Breakaway Pressure-Extend	30 psig max	9 psig	7 psig
Breakaway Pressure-Retract	30 psig max	8 psig	3 psig

The data shown for the internal leakage test of the cylinder were obtained after washing the hydraulic fluid from the interior of the cylinder and relubricating the seals with Atlantic 54 lubricant. It was felt that the excess hydraulic fluid present in the cylinder as received might unduly trap the contaminant present in the system nitrogen, and prevent the contaminant from reaching other system components.

The following observations were made of the contamination existing in the components as received from the vendor. The components were procured in a commercial clean condition. Inspection was performed in the flow ports only, since it was a requirement that the valve was not to be disassembled for inspection prior to test.

Pressure Regulator (75M08829) - Upon removal of the inlet port fitting, one particle of dirt (125 microns) was attached to the fitting. Lube was found all around the diameter of the inlet port flow path. No lube or particles were observed in the outlet port.

Two-Way Solenoid Valve (75M08824) -

Inlet Port - Slight lube film and dust contamination were evident on the flare sealing surface. One particle, approximately 75 microns, was found on the end of the union (Fig. VIII-9).

Outlet Port - Lube film was found in the union flow path. Dirt was observed on the threads of the port. A 75 micron teflon particle was observed in the outlet port flow path. A large burr was attached at the bottom of the machined port. This large burr broke off and migrated to the outlet filter screen during functional tests.

Three-Way Solenoid Valve (75M09285, S/N 280) - The port closure plugs were clean. No burrs were observed on the port threads. The lube used on the O-ring seating surface (common port) was slightly dark from many small particles. The normally open and normally closed ports showed no visable contamination.

Three-Way Solenoid Valve (75M09285, S/N 281) - All port closure plugs were clean. On all three ports, burrs or catches were observed at three places spaced around the lower thread. No particles were observed.

Pneumatic Cylinder (75M09014) - Visual examination showed a large quantity of hydraulic oil in the cylinder. Slight contamination was observed which appears to be dirt or particles from pipe threads.

Pressure Regulator (75M08831) -

Inlet Port - A small (50 micron) metal colored flake was observed in the port cap together with approximately 100 small particles (50 microns maximum). A large (0.040 in.) piece of lube was observed in the flow path of the fitting. The valve inlet flow path looked clean with a slight lube film on the surface.

Outlet Port - Four lint particles (0.080 in. maximum) were observed on the interior of the port cap. Excessive lube was found in the fitting flow path and in the port. No particles were observed, but may have been present in the lube film.

Two-Way Solenoid Valve (75M08823) - At the base of the inlet port union some black particles (100 microns) were observed. Three particles (25 microns) were observed in the inlet port. No particles were observed in the outlet port, although a burr was observed on the valve body at the bottom of the port threads. This burr appears to be firmly attached and is a result of the thread tap.

Three-Way Solenoid Valve (75MI8825) - The valve was double-bagged but did not have plugs in the ports. The common port contained many small particles, the largest being approximately 75 microns. The normally-open port contained some very small particles less than 25 microns in size. The normally-closed port contained many small (less than 75 microns) particles at the bottom of the port.

b. System Test Results and Discussion

The system test was performed per the schedule in Table VIII-3. The Millipore and ILFHC sample data appear in Table VIII-7. The result of the interim leakage tests appears on Table VIII-8.

Table VIII-7 Millipore Particle Count Data

	ILFHC Data						Millipore Data						
	Number of Particles at Cycle No:						Number of Particles at Cycle No:						
Particles Micron Ranges	200	400	600 800*	1000	1200	1500	200	400	600	800	1000	1200	1500
100-200	15	3	20	154	32			13	1	23	75		
200-300	14	1	10	28	18	‡	‡	3	0	2	20		
300-500	1	1	4	32	4			2	0	1	11	‡	‡
500-1000	0	1	1	4	0			0	0	0	0		
Over 1000	0	0	1*	0	0			0	0	0	0		
Fibers Micron Ranges													
0-750	0	0	0	0	1			4	2	3	1		
750-2000	0	0	0	0	0	‡	‡	0	0	0	0	‡	‡
2000-6000	1†	0	0	0	0			0	0	0	1		
Over 6000	0	0	0	0	0			0	0	0	0		

*Appears to be a conglomeration of TFE particles.
†Metallic fiber, not a part of injected contaminant.
‡Sample void, filter paper broken.

Table VIII-8 System Test-Interim Internal Leakage Test Data

Internal Leakage (SCCM)									
	Test Specimen								
Cycle Number	1	2	3 and 4	4	5 Extend	5 Retract	6	7	8
0	0	0	0	0	7250	565	0	0	0
100	NA*	0	0	0	4200	4	0	0	0
300	13,500	0	0	0	3340	30	0	0	0
600	60,000	0	0	0	3120	14	0	0	0
900	60,000	72	0	0	2110	20	0	0	0
1200	60,000+	2	0	0	1800	250	0	0	0
1500	60,000+	0	0	0	1410	110	0	0	0

*Specimen failed at cycle 1, was removed from the system at cycle 50, was refurbished and replaced in the system at cycle 200.

At the initiation of system cycling, specimen 1 failed by leakage through the seat. Results of a failure analysis showed the stainless steel poppet seat was eroded as if sandblasted. Examination of the contaminant injector upstream of this specimen showed that essentially all the contaminant was still in the injector, so the test specimen had not been "slugged" with the contaminant. While the failure analysis was being conducted, the system was run through 200 cycles. The refurbished specimen was then returned to the system, and the cycles continued. Immediately on resumption of the cycling, test specimen 1 failed again in the same manner. Since the seat leakage allowed downstream pressure to increase until the built-in relief device relieved, system pressures were still maintained near those required with external venting from specimen 1 being the only obvious system problem. The system was allowed to continue in this manner through the duration of the 1500 cycles.

The contaminant injectors performed adequately during the 1500 cycles.

Figure VIII-10 shows the condition of the Millipore filter papers used in the contamination tests. The correlation between sample numbers and test cycles is tabulated.

Sample No.	Test Cycle	Material
B2057	200 Cycles	Paper
B2058	600 Cycles	Teflon
B2059	800 Cycles	Teflon
B2060	1000 Cycles	Teflon
B2061	1200 Cycles	Teflon
B2062	1400 Cycles	Paper

Millipore data were not obtained at 200, 1200, and 1500 cycles because the filter pads were blown out by the high velocity particle impingement. The standard filter paper was replaced with high pressure teflon filters after the first failure. These teflon filters are designed to take high pressure surges and high velocity impingement and are considered to be the strongest filter pads available. Even the teflon filters would not take the high levels of contaminant introduced into the system and resultant particle impingement.

Table VIII-7 lists the particle counts obtained on the Millipore samples. The data is not representative because of filter pad erosion. On samples B2058 and B2059, the center of the filter pad is badly eroded implying that many of the particles passed through the filter. The technician in the laboratory reported that sample B2060, at 1000 cycles, was highly charged with static electricity and that when he disassembled the Millipore holder, approximately 50% of the particles "jumped" off of the filter pad and thus were not counted.

The filter pads were weighed to determine the total weight of contaminant in the sample. The weights, in all cases, were less than the tare weights taken prior to test and contaminant weight was therefore not obtainable. The decrease in weight is attributed to filter pad erosion.

c. Final Functional Test Results and Discussion

Following completion of the system test, each test specimen was subjected to a functional test identical to that performed prior to the system test. The final functional test results appear on Tables VIII-4, VIII-5, and VIII-6. The most significant result was the improvement in the pneumatic cylinder leakage rates and breakaway pressure. With the exception of specimen 1 regulator, the remaining test specimens showed very little change in characteristics from initial to final functional tests.

d. Test Specimen Failure Discussion

During the system test, the specimen 1 regulator failed twice, the second failure occurring after a complete refurbishment. This regulator is very sensitive to contamination.

The solenoid valve specimens 3 and 4 exhibited response times that often failed to meet the criteria established for functional testing. The criteria were based on the valve manufacturer's acceptance criteria, with one major exception. The manufacturer uses the valve position indicator switch for response measurements, while for this test, the solenoid current trace with its characteristic indications of poppet motion was used. It is felt that this method, while yielding longer response times, is a more consistent and accurate measure of a valve's response.

During system interim leakage testing, specimen 2 solenoid valve exhibited internal leakage at two of the seven prescribed measurement intervals. The leakage was zero at all other measurement intervals, and was at zero at the completion of all testing. Refer to Table VIII-4 for these data.

e. Final Inspection Test Results and Discussion

Following completion of the final functional test, each test specimen was completely disassembled for inspection. Figures VIII-11 through VIII-35 are included to show the disassembled components of each specimen. Residual contaminant was present in all the test specimens. The majority of the contaminant added to the system evidently lodged in the test specimens. Relatively little contamination reached the sample tools downstream of the system, and an inspection of the system tubing did not reveal any significant quantities of contaminant adhering to the tubing walls.

A detailed description of the observations made for each component on final disassembly follows, and is in sequence with the component photographs.

Pressure Regulator (75M08831-1) - The interior of the regulator was completely filled with contaminant which appeared to be primarily teflon particles rather than road dust. The envelope shown in Figure VIII-12 contains the contaminant which dropped out of the component upon disassembly. The filter screen appeared to be completely clogged with large teflon particles. The poppet, spool, and inlet screen are fully coated with contaminant (Figure VIII-13).

Both the inlet and outlet fittings contained large amounts of contamination trapped in the lube on the end of the fitting (Figure VIII-14). The condition shown in the figure was also observed on many of the other components. No indication of wear on the O-rings or sliding surfaces and no erosion or wear on the poppet seat were observed.

Two-Way Solenoid Valve (75M08824-1) - The filter screen on the inlet fitting was pushed out of the flow path and the screen on the outlet fitting was gone (Figure VIII-17). The screen was later found in the 1/4-inch tubing downstream of injector #2. The valve was heavily loaded with contaminant. A great quantity of particles were trapped in the lube on the spool. The poppet seat and all software were in good condition.

Three-Way Solenoid Valve (75M08825-1) - Very little contamination was trapped in this valve as compared to the other components. Both the inlet and outlet ports were relatively clean. The flow path into the "cylinder port" makes a 90-deg bend prior to entering the component. The bulkhead at this point was badly eroded indicating impingement on the 90-deg surface. Very few particles were observed on the spool but two vertical scratches were observed on each side of the spool at 180 deg (Figure VIII-20). The matching surface on the valve was not scratched. No further degradation was observed on the poppet, software, O-rings, or sliding surfaces.

Pressure Handloader (75M08829) - The inlet port was relatively clean. Dark colored particles (road dust and red iron oxide) were observed in the outlet port. The main seat sealing surface on the poppet stem was badly eroded (Figure VIII-23 and VIII-24). It is concluded that the eroded seat was caused by particle impingement and is the cause of the leakage past the main seat. Erosion on this valve was greater than that observed on the initial failure of this handloader. Many particles were trapped in the lube on the retaining spool and sensing piston (Figure VIII-25). No galled or worn surfaces were evident. The O-rings and software looked good. There was a considerable amount of contaminant trapped in the valve body.

Three-Way Solenoid Valve (75M09285-1, S/N 280) - Contamination was observed in all ports. A solid film of dust particles was trapped in lube around the outside diameter of the spool (Figure VIII-28). Particles were entrapped in the heavily lubricated poppet stem. Although this valve did not leak, a fine ring of erosion was found on the poppet seat due to particle impingement. Figure VIII-31 shows the contamination and eroded poppet seat on valve serial number 281, which is similar to that observed on valve serial number 280. The O-rings and seats did not show any evidence of wear or failure.

Three-Way Solenoid Valve (75M09285-1, S/N 281) - Many particles, observed on the normally closed inlet port, appear to be road dust; not as many particles were found in the other two ports. The valve was heavily lubricated and particles were trapped in the lubricant. Many large teflon particles were trapped in the lube on the poppet stem (Figure VIII-31). The fine line of erosion on the poppet seat was caused by particle impingement, although this valve did not leak (Figure VIII-31). No galling, wear, or degradation of software was observed.

Two-Way Solenoid Valve (75M08223-1) - The inlet fitting, inlet port and outlet port were relatively clean. Many road dust particles were trapped in the lubricant on the poppet stem and spool piece. No wearing surfaces or degradation of software was evident.

Pneumatic Cylinder (75M09014) - The retract side of the cup seal was full of lubricant and particles. A ring of lubricant and particles existed on the barrel at the end of travel on the retract stroke. Lubricant and particles were observed on the cylinder head on the retract side. The extend side of the piston was relatively clean, although contaminated. No scoring, galling, or wear was visible in the barrel. The brass piston ring showed normal and even wear. The cup seals were not damaged.

C. HYDRAULIC CONTAMINATION TESTS

The testing effort was started on 4 April 1969 and was completed on 11 July 1969. The hydraulic tests were performed at the Martin Marietta Hydraulics Laboratory at Denver, Colorado.

The functional characteristics of nine components determined to be critical to control arm operation were established by functional test. The specimens were then assembled into an operational system, and operated through 1500 cycles using deliberately contaminated MIL-H-5606 hydraulic oil. The functional tests were repeated to establish any functional degradation, and the specimens were disassembled for inspection.

Several O-ring failures occurred during system checkout and also during the contamination tests. None of these failures can be attributed to contamination. It is recommended that consideration be given to improving O-ring design, such as O-ring diameter clearances, groove cross-sectional areas, and assembly design, to those test components that displayed O-ring anomalies during the system contamination test.

During disassembly and inspection, contamination was found in every section of tube, fitting, and test component, particularly where hydraulic fluid residue was not completely drained from the component. This inspection showed that the injected contaminants were well distributed throughout the system.

Function tests were conducted on each component in order to accurately evaluate individual performance before and after the systems test. The test components operational characteristics, between the initial and final functional tests, for all practical purposes are the same. There was very little, if any, degradation in performance. It is therefore concluded that the service arm hydraulic components will function reliably at the contamination levels used in these tests.

1. Objectives

The purposes of the hydraulics tests were to:

1) Test selected control arm components in a typical flow system. The test specimens have been selected as being more susceptible to contamination;

2) Demonstrate the reliability of the test specimens at an increased level of contamination by subjecting them to 1500 operational cycles;

3) Functional test each test specimen before and after the 1500 operational cycles, in order to determine component degradation;

4) Maintain cleanliness of the test fluid at ~~a~~ prescribed level;

5) Disassemble and inspect the test specimens following the test, to determine the effect of test fluid contamination.

2. Test Components

The test specimens, listed in the tabulation, were procured to the vendor part number which corresponds to the similar NASA service arm specification. The test specimens were procured commercial clean.

Quantity To Be Tested	Test Specimen Number	Manufacturer	Part Number	NASA Equivalent Part Number	Name
2	6	James Pond Clark	277-T1-8TT	75M05365-4	Check valve
1	4	Pathon Manufacturing Company	3H1X3SU101/2ABR	75M065067	Cylinder
2	3	American Bosch	ACG300281	75M08814-1	Accumulator
2	5	Marotta Valve	806097-1	75M08823-1	Solenoid valve
1	7	Marotta Valve	219004-J151	75M08830	Regulator
1	8	Martin Marietta	None	---	0.020 Orifice

3. Test Equipment

a. Instrumentation

The test system schematic, Figure VIII-36, shows the instrumentation functions used during the test. The instrumentation accuracies are listed in Table VIII-9.

Table VIII-9 Test Instrumentation

Test Specimen	Gage Range (psig)	Gage Accuracy (% of dial range)	Transducer		System Fluid Temperature Range and Thermocouple Accuracy	Ampmeter Accuracy (% of full scale)	Timer Accuracy (msec)
			Range (psig)	Accuracy (% of full range)			
Check Valve (NASA-75M05365-4, James Pond Clark, P/N 277-T1-8TT)	0 to 5000	±½	0 to 5000	±1	Bristol Temperature Recorder		
Cylinder (NASA-75M06506-7, Pathon Manufacturing Company, P/N 3H1X3SU101/2 ABR)	0 to 5000	±½	0 to 5000	±1	Thermocouple Temperature Range 0 to 250°F		
Accumulator (NASA-75M08814-1 American Bosch P/N-ACG300251) (hyd both ends)	0 to 5000	±½	0 to 5000	±1	Accuracy within ±1% of Full Range		
Solenoid Valve (NASA-75M08823-1, Marotta Valve, P/N-806097-1)	0 to 5000	±½	0 to 5000	±1	Accuracy within ±1% of Full Range	±5	±5
Regulator (NASA-75M08830, Marotta Valve P/N-219004-J151)	0 to 5000	±½	0 to 5000	±1	Accuracy within ±1% of Full Range		

b. Test Fixture

The test fixture schematic used for systems testing is shown in Figure VIII-36. The test installation was flushed with MIL-H-5606 hydraulic fluid to that level shown in Table VIII-10. Table VIII-11 shows the system cleanliness level after the components were installed. The test fluid (MIL-H-5606 hydraulic oil) was prefiltered to 3 microns absolute prior to introducing the fluid into the test system. The cleanliness level of the prefiltered fluid is shown in Table VIII-12. The cleanliness data below was obtained by means of a HIAC automatic particle counter. Photographs of the system test installation appear as Figures VIII-37, VIII-38, and VIII-39.

Table VIII-10 HIAC Particle Counter Data, Test System prior to Component Installation

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	133	116	103	79	55
15 to 25	5	3	1	1	4
25 to 50	0	0	0	0	0
50 to 100	0	0	0	0	0
100 +	1	0	0	0	0

Table VIII-11 HIAC Particle Counter Data, Test System after Component Installation

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	283	143	144	95	81
15 to 25	1	2	1	0	2
25 to 50	1	1	0	0	0
50 to 100	0	0	0	0	0
100 +	0	0	0	0	0

Table VIII-12 HIAC Particle Counter Data, Prefiltered Test Fluid

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	14	3	7	3	4
15 to 25	2	1	1	0	0
25 to 50	0	0	0	0	0
50 to 100	0	0	0	0	0
100 +	0	0	0	0	0

c. Contaminant

The contaminant used was a composite mixture of ground teflon particles, A.C. coarse road dust, red iron oxide, and cotton lintner fibers. The composite level is shown in Table VIII-13.

The total quantity of contamination particles was gradually added to the system to obtain equal dispersal throughout the system.

Table VIII-13 Hydraulic Contamination Test Levels

	Size Range				
	6 - 10μ	11 - 25μ	26 - 50μ	51 - 100μ	100 +
OX60 Teflon 2.0 mg/100 ml oil	22,200	9,400	2,500	564	108
A.C. "Coarse" Road Dust 0.2 mg/100 ml oil	6,460	3,420	565	67	3
Red Iron Oxide <0.01 mg/100 ml oil	3,710	0	0	0	0
Cotton Lintner Fibers <0.1 mg/100 ml oil	--	--	--	--	4000μ maximum
Total Particle Count 2.2 mg/100 ml oil	32,370	12,820	3,065	631	111 + fibers

4. Test Method and Procedure

a. Receiving and Inspection

Test components were inspected for general conformance. The component flow ports were visually inspected using 3X magnification. No evidence of contamination was observed. Test components were not disassembled to perform this inspection. The internal flow path of the hydraulic components was flushed with clean filtered hydraulic fluid. The influent fluid was prefiltered to 3 microns absolute. A sample of effluent fluid from all test components was sampled with a HIAC automatic particle counter; the results are shown in Tables VIII-14 thru VIII-24. These samples were taken to evaluate the cleanliness level of each component as received from the manufacturer. There was no attempt to clean the test components during this flushing mode.

Table VIII-14 Effluent Particle Count, Hydraulic Accumulator (75M08814-1, S/N 6K3299)

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
Oil Side of Accumulator								
5 to 15	32,196	29,823	28,244	24,663	24,673	24,240	25,163	29,277
15 to 25	819	947	715	594	615	587	473	538
25 to 50	116	178	109	76	79	73	45	52
50 to 100	3	0	1	0	0	1	1	0
100 +	0	0	0	0	0	0	0	0
Gas Side of Accumulator								
5 to 15	13,873	14,733	14,718	16,387	15,309	14,232	15,364	15,471
15 to 25	83	97	99	117	119	100	121	120
25 to 50	5	6	[illegible]	9	5	12	14	7
50 to 100	0	0	0	0	1	1	0	0
100 +	0	0	0	0	0	0	0	0

Table VIII-15 Effluent Particle Count, Hydraulic Accumulator (75M08814-1, S/N 6K3300)

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
Oil Side of Accumulator								
5 to 15	22,824	20,023	27,913	38,636	21,755	21,642	21,897	19,330
15 to 25	484	355	539	702	294	353	352	323
25 to 50	38	43	60	94	43	37	28	30
50 to 100	1	1	0	1	4	0	0	1
100 +	1	0	0	0	0	0	0	0
Gas Side of Accumulator								
5 to 15	38,389	26,983	24,601	31,946	30,968	24,992	24,397	25,317
15 to 25	341.	215	177	280	332	199	171	210
25 to 50	47	19	22	31	52	37	21	20
50 to 100	1	1	0	0	10	0	0	0
100 +	0	0	0	0	0	0	0	0

Table VIII-16 Effluent Particle Count, Hydraulic Cylinder (75M06506-7)

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Last 53 ml*
Cylincer Extend Mode								
5 to 15	84,004	60,414	65,333	69,318	88,664	126,336	155,922	203,536
15 to 25	2,519	1,724	1,950	2,069	3,080	4,926	7,116	14,268
25 to 50	2,007	242	261	305	425	541	718	1,362
50 to 100	3	4	3	4	6	13	8	13
100 +	0	0	0	0	0	0	0	0
Cylinder Retract Mode								
5 to 15	81,531†	74,930	69,401	75,889	76,592	72,605	77,284	
15 to 25	1,747	1,078	1,094	1,399	1,192	947	1,064	
25 to 50	105	151	113	183	169	118	133	
50 to 100	12	4	1	1	4	6	4	
100 +	0	0	0	0	0	0	0	

*Data corrected to 100 ml sample.

†This was a 500 ml sample and was corrected to 100 ml.

Table VIII-17 Effluent Particle Count, Hydraulic Cylinder (75M06506-7), Initial Fluid Sample

Millisnore Sample Visual Count

Particle Range (microns)	Retract	Retract	Extend
5 to 15	13,400*	9,750*	14,300*
15 to 25	400*	150*	318*
25 to 5ບ	200*	159*	112*
50 to 100	11	4	9
100 +	11	3	4
Total Filterable Solids	0.9 mg/100 ml	0.9 mg/100 ml	0.9 mg/100 ml

*Data based upon statistical count of two squares.

Table VIII-18 Cylinder Influent Particle Count, Hydraulic Bench Oil Sample

Particle Range (microns)	Sample Number						
	1	N + 1	N + 2	N + 3	N + 4	N + 5	N + 6
5 to 15	1818	129	70	83	76	40	52
15 to 25	6	2	1	0	0	0	0
25 to 50	2	1	0	0	0	0	0
50 to 100	0	0	0	0	0	0	0
100 +	0	0	0	0	0	0	0

Table VIII-19 Effluent Particle Count, Two-Way Solenoid Valve (75M08823-1, S/N 398)

HIAC Particle Counter Data

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	48,780	29,830	16,775	8,068	3,877	2,197	1,397	1,071	867
15 to 25	21	18	32	8	6	12	8	4	19
25 to 50	10	3	5	0	0	2	0	0	1
50 to 100	1	0	0	0	0	0	1	0	0
100 +	0	0	0	0	0	0	0	0	0

Table VIII-20 Effluent Particle Count, Two-Way Solenoid Valve (75M08823-1, S/N 399)

HIAC Particle Counter Data

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	18,006	6,409	3,739	4,668	4,236	3,227	2,803	1,087	816
15 to 25	243	112	41	15	12	13	9	21	10
25 to 50	50	23	3	3	3	5	3	8	2
50 to 100	3	1	1	1	0	0	0	0	0
100 +	0	0	0	0	0	0	0	1	0

Table VIII-21 Effluent Particle Count, Check Valve (75M05365-4, S/N 9021312)

HIAC Particle Counter Data

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	20,616	39,816	51,894	52,073	66,050	102,069	102,709	71,162
15 to 25	147	22	8	6	5	3	3	4
25 to 50	36	2	0	0	1	0	0	0
50 to 100	5	0	0	0	0	0	0	0
100 +	0	0	0	0	0	0	0	0

Particle Range (microns)	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	49,304	27,859	12,999	5,129	2,037	955	583	252
15 to 25	3	2	1	1	3	1	6	1
25 to 50	0	0	0	0	0	1	0	1
50 to 100	0	0	0	0	0	0	6	0
100 +	0	0	0	0	0	0	0	0

Table VIII-22 Effluent Particle Count, Check Valve (75M05365-4, S/N 9021313)

HIAC Particle Counter Data

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	4,147	1,503	1,300	1,909	12,342	30,888	30,609	19,702	9,523	3,415	1,136	441	244	152	135	122
15 to 25	90	20	7	6	2	4	6	5	3	2	1	4	3	2	1	0
25 to 50	20	0	2	2	2	0	1	0	0	1	0	1	0	0	0	1
50 to 100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100 +	0	0	10	0	0	0	1	0	0	0	0	0	0	0	0	0

Table VIII-23 Effluent Particle Count, Check Valve (75M05365-4) Millipore Filter Visual Count

Particle Range (microns)	(S/N 9021312) Number of Particles per 100 ml*	Particle Range (microns)	(S/N 9021313) Number of Particles per 100 ml*
5 to 15	174	0 to 50	Too numerous to count
15 to 25	28	50 to 100	5
25 to 50	6	100 +	2
50 to 100	1.5		
100 +	0		
Total Filterable Solids	0.3 mg		0.4 mg

*200 ml sample taken, data corrected to 100 ml.

Table VIII-24 Effluent Particle Count, Hydraulic Pressure Regulator (75M08830-2)

HIAC Particle Counter Data

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	39,216	17,744	14,833	4,412	2,501	1,903	1,847
15 to 25	273	64	42	56	17	6	8
25 to 50	48	17	10	4	3	0	0
50 to 100	6	1	0	1	0	0	0
100 +	1	1	2	0	0	1	0

b. Functional Test Method and Procedure

An initial functional bench test was performed on each component to ensure its integrity and to establish a baseline performance criteria prior to the system contamination test. The component functional performance data were used as criteria to evaluate component degradation during system contamination tests. The test fluid was MIL-H-5606B hydraulic oil prefiltered to 3 microns absolute. Functional tests were performed on the test components using the test system identified in each NASA component specification.

The accumulators were tested for internal and external leakage for a period of five minutes with 4500 psig on one side of the piston and zero psig on the other.

The hydraulic cylinder was tested for internal and external leakage, and breakaway pressure at 4500 psig; leakage was monitored for 5 minutes at each condition.

The two-way solenoid valve was tested for internal and external leakage and for response time.

The check valves were tested for internal leakage, cracking, and reseat pressures.

The regulator was tested at an inlet pressure of 3000 psig for internal and external leakage, for ability to regulate pressure at a given setting, and for capability of venting downstream pressure in excess of the set pressure.

The flow rate of the orifice (0.20 in.) was calibrated at an inlet pressure of 3000 ± 25 psig.

c. System Test Method and Procedure

The nine test specimens were combined with a minimum of additional components to form the operating system shown schematically in Figure VIII-36.

The hydraulic test system was pressurized to 3000 psig using the fluid power of the hydraulic power supply. Flow to the test system was controlled by a hydraulic servo-selector valve. The following sequence of events describes a half cycle of the contamination test.

High pressure fluid flow was supplied to the test system by the hydraulic power unit supply. A low frequency functional generator supplied an amplitude and frequency signal to the electrical switching console. An input signal was emitted from the console to open the servo-selector valve to permit high pressure flow to accumulator 3_1, simultaneously emitting a signal to the solenoid valves, opening valve 5_1 and closing valve 5_2. The flow from accumulator 3_1 was then passed through solenoid valve 5_1 and to the piston side of cylinder 4. Flow from the solenoid valve (5_1) passed through test items 7, 8, and 9_2 and combined to flow through check valve 6_2 to accumulator 3_2. Discharge flow from the accumulator passed through the servo-selector valve into the return of the hydraulic power unit supply. The reverse sequence of events completed a full test cycle. The test system was operated through 1500 full test cycles.

Component internal leakage checks were performed every 300 cycles. System effluent was sampled every 100 cycles through the HIAC automatic particle counter. Millipore samples were also taken at intervals of 300 cycles. See Table VIII-25 for a summary of test operations during the 1500 cycles.

Table VIII-25 Sequence of Operation

Cycle Number	HIAC	Millipore	Leak Check after Last Cycle
0			X
1	X		
100	X	X	X
200	X		
300	X	X	X
400	X		
500	X		
600	X	X	X
700	X		
800	X		
900	X	X	X
1000	X		
1100	X		
1200	X	X	X
1300	X		
1400	X		
1500	X	X	X

d. Final Inspection Test Method and Procedure

Following completion of the system and functional tests, each test specimen was carefully disassembled for inspection. The component parts were inspected for evidence of abrasion, contamination, lubricant deposits, etc and photographs were taken of significant items (Fig. VIII-40 thru VIII-64).

5. Test Results and Discussion

a. Initial Functional Test Results and Discussion

Test data from the initial functional tests are presented in Tables VIII-26 through VIII-31. The effluent particle counts for each component are shown in Tables VIII-14 through VIII-24.

The internal leakage of accumulator S/N 6K3300, as tested prior to system test, was almost two times the specification criteria. Accumulator S/N 6K3299 exhibited zero leakage. The cracking pressure of regulator 75M08830 was 65 to 70 psig above specification in all cases. Additional tests were conducted when it was noticed that the vent cracking and reseat pressures were affected by the inlet pressure to the regulator. The test data for all remaining components was well within specification. The above anomalies did not affect the test program since the functional tests were conducted only to ensure basic component operation and to obtain baseline performance data for comparison after the contamination tests.

The effluent particle counts, shown in Tables VIII-14 through VIII-24, are comparable to Levels 7 and 8 of NAS 1638. The variety of components represented may provide some indication of a commercial clean condition, since all of the components were procured in a commercial clean condition. The influent background particle count of the hydraulic oil was generally below 25 particles in the 5 to 10-micron range, with no particles above 15 microns.

Table VIII-26 Functional Test Data, Hydraulic Accumulator (75M08814-1)

Test	Requirement	Functional Test Data			
		S/N 6K3299		S/N 6K3300	
		Initial*	Final*	Initial*	Final*
Internal Leakage Air to Oil Side	10 Drops per 15 Minutes Maximum	0	0	1.2	0.36
Internal Leakage Oil to Air Side	10 Drops per 15 Minutes Maximum	0	6.1	1.2	0
External Leakage	Bubble Tight	0	0	0	0

*Drops per minute.

Table VIII-27 Functional Test Data, Hydraulic Cylinder (75M06506-7)

Test	Maximum Allowable	Test Results	
		Initial	Final
Piston Leakage - Extend	5 cc/min	4 drops	5.6 drops
Piston Leakage - Retract	5 cc/min	8 drops	6.2 drops
External Barrel Leakage	0	0	0
Rod End External Leakage	1 drop/25 operating cycles	0	0
Breakaway Pressure Extend, psig	60	7	4.5
Breakaway Pressure Retract, psig	60	6	3.5

Table VIII-28 Functional Test Data, Pneumatic Two-Way Solenoid Valve (75M08823-1, S/N 398)

Test	Specification Criteria	Test Results	
		Initial	Final
External Leakage Solenoid Energized	Bubble Tight	No Leakage	No Leakage
Internal Leakage Solenoid De-energized	5 cc/min Maximum	No Leakage	3 drops/min
External Leakage Solenoid Energized	Bubble Tight	No Leakage	No Leakage
Internal Leakage Solenoid De-energized	5 cc/min Maximum	No Leakag	3 drops/min
Response Time Cycle No. 1	75 msec Maximum Opening 75 msec Maximum Closing	1.91 2.80	4.70 4.32
Response Time Cycle No. 2	75 msec Maximum Opening 75 msec Maximum Closing	2.04 1.91	3.90 3.78
Response Time Cycle No. 3	75 msec Maximum Opening 75 msec Maximum Closing	2.49 2.17	3.93 3.93
Response Time Cycle No. 4	75 msec Maximum Opening 75 msec Maximum Closing	2.02 2.60	4.32 4.06
Response Time Cycle No. 5	75 msec Maximum Opening 75 msec Maximum Closing	2.23 2.42	4.44 3.81
Actuation-Deactuation Voltage Cycle No. 1	8 to 18 vdc Pull-In 1 to 17 vdc Drop-Out	17.4 2.9	18.60 2.0

Table VIII-29 Functional Test Data, Pneumatic Two-Way Solenoid Valve (75M08823-1, S/N 399)

Test	Specification Criteria	Test Results	
		Initial	Final
External Leakage Solenoid Energized	Bubble Tight	No Leakage	No Leakage
Internal Leakage Solenoid De-energized	5 cc/min Maximum	No Leakage	1 drop/min
External Leakage Solenoid Energized	Bubble Tight	No Leakage	No Leakage
Internal Leakage Solenoid De-energized	5 cc/min Maximum	No Leakage	1 drop/min
Response Time	75 msec Maximum Opening	1.98	3.77
Cycle No. 1	75 msec Maximum Closing	2.84	3.89
Response Time	75 msec Maximum Opening	1.94	3.89
Cycle No. 2	75 msec Maximum Closing	2.79	3.76
Response Time	75 msec Maximum Opening	2.09	3.68
Cycle No. 3	75 msec Maximum Closing	2.84	3.81
Response Time	75 msec Maximum Opening	1.88	3.55
Cycle No. 4	75 msec Maximum Closing	3.00	4.06
Response Time	75 msec Maximum Opening	1.97	3.82
Cycle No. 5	75 msec Maximum Closing	2.98	4.08
Actuation-Deactuation Voltage	8 to 18 vdc Pull-In	16.8	14.3
Cycle No. 1	1 to 17 vdc Drop-Out	2.8	1.90

Table VIII-30 Functional Test Data, Hydraulic Check Valve (75M05365-4)

Test	Requirement (psig)	Test Data			
		S/N 9021312		S/N 9021313	
		Initial (psig)	Final (psig)	Initial (psig)	Final (psig)
Internal Leakage	Zero Leakage at 4500	0	0	0	0
Cracking Pressure	0.5 to 1.0	0.85	0.55	0.75	0.80
Reseat Pressure	0.5 to 1.0	0.60	0.50	0.70	0.75

Table VIII-31 Functional Test Data, Hydraulic Pressure Regulator (75M08830-2)

Step No.	Inlet Pressure	Test	Requirement (psig)	Test Results	
				Initial (psig)	Final (psig)
A-1	3000	Lockup Pressure	2900 ± 50 psig	2840	2840
C-1	3000	Lockup Pressure	2750 ± 50 psig	2750	2760
C-2	3000	Cracking Pressure	2810 Maximum	2875	2800
C-3	3000	Reseat Pressure	2690 Minimum	2850	2755
C-4	3000	Vent Leakage	Bubble Tight	Zero Leakage	Zero Leakage
C-5	3000	External Leakage	Bubble Tight	Zero Leakage	Zero Leakage
F-1	3000	Lockup Pressure	500	500	500
F-2	3000	Cracking Pressure	550 Maximum	615	520
F-3	3000	Reseat Pressure	475 Minimum	585	490
F-4	2750	Lockup Pressure	500	500	500
F-5	2750	Cracking Pressure	550 Maximum	620	515
F-6	2750	Reseat Pressure	475 Minimum	585	505
F-7	3000	Lockup Pressure	150	150	150
F-8	3000	Cracking Pressure	--	320	165
F-9	3000	Reseat Pressure	--	290	140
F-10	2750	Lockup Pressure	150	150	150
F-11	2750	Cracking Pressure	--	340	160
F-12	2750	Reseat Pressure	--	310	145
G-1	4500	Internal Leakage	Bubble Tight	Zero Leakage	Zero Leakage

b. System Test Results and Discussion

The system cleanliness particle count data appear in Tables VIII-32 through VIII-48. The results of the interim leakage tests are shown in Table VIII-49.

Test System Functional Checkout Test - After filling the test system with hydraulic fluid, and prior to contaminant injection, several operational problems were encountered, and as a result the system testing was delayed until the problems could be solved. The problem areas were primarily heat buildup, air entrainment, and component O-ring failures.

During system checkout tests, it was found that the energy introduced to operate the system was heating up the hydraulic oil substantially, and ice packs did not provide enough heat sink to dissipate the heat. To solve the problem it was necessary to build cooling coils into the test system and immerse the coils in a dry ice/alcohol bath. This method stabilized the system temperature at approximately 120 to 150°F. Air jets were used to cool the solenoids on the two-way valves.

Air entrainment was a problem, since the HIAC automatic particle counter will not differentiate between contaminant particles and air bubbles, and will readily count all air bubbles that pass the sensor. Air bleeds were installed at the high points of the system but this did not solve the problem completely. By cycling of the test system, in conjunction with the use of the air bleeds, it was possible to eliminate the majority of the entrained air in the system fluid. In addition to the high point bleeds, an accumulator (Fig. VIII-38) was installed in the system upstream of the automatic counter. Hydraulic oil from the system was admitted to the accumulator, and then the flow from the accumulator was directed to the counter. The purpose of the accumulator was to allow the entrained air to rise to the top of the accumulator, thus minimizing air entrainment in the first 1000 ml of the sample.

The air entrainment problem was not in evidence when performing the initial component effluent particle counts. Effluent counts were performed with an open loop system rather than the closed loop used in the systems contamination test.

Before starting the contamination tests and prior to introducing contaminant, 200 cycles were run on the test system in checking out the system operation. At 195 cycles, the pressure handloader (75M08830) started leaking at the top of the handloader.

The handloader was disassembled and it was found that the main piston O-ring (P/N J200A16) was rolled over and chewed up on the inside diameter. The adapter pilot for this O-ring has a very sharp 90 deg edge with no chamfer. The manufacturer of this handloader stated that similar failures have been experienced in the assembly of this part. The failure analysis concluded that the O-ring failure was initiated upon assembly. Figure VIII-43 shows the main piston O-ring failure. The light colored particles on the piston in Figure VIII-44 are lubricant.

The poppet stem O-ring also failed at 195 cycles. This failure and subsequent failures were a result of excessive O-ring groove width (Fig. VIII-45).

The handloader (75M08830) was repaired and reinstalled in the test system.

Test System Component Discrepancy - The pressure handloader (75M08830) leaked through the top of the handle at 935, 1113, and 1326 cycles. In each of these failures the poppet stem O-ring (P/N J200A2) was chewed up (Fig. VIII-45). New O-rings were installed after each failure and prior to continuing the test. The O-ring failures are attributed to a rolling and spiraling action in the O-ring groove with subsequent nibbling on the inside and outside diameters. The failure analysis concluded that these O-ring failures were not due to contamination, but to excessive O-ring groove width which permitted the O-ring to roll and spiral.

The O-ring (J20016A), in the main piston of the handloader, had two failures: (1) just prior to test, and (2) after 1326 cycles (Fig. VIII-40).

At 1113 cycles it was observed that the filter screen on the inlet fitting had been dislodged from the fitting and had migrated to the retaining spool in the handloader. The screen was removed from the component prior to continuing the test. At 1326 cycles the filter screen in the outlet fitting was laid back parallel to the flow stream. This screen was also removed. The filter screens failed as a result of contaminant loading and subsequent ΔP across the screen, even though the screen is a very coarse mesh (Fig. VIII-46).

All of the remaining components functioned in a normal manner with no anomalies for the full duration of the system test.

Table VIII-32 HIAC Particle Counter Data, Test System after Checkout (0 Test Cycles)

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	28,728	33,347	13,580	7,679	6,688
15 to 25	579	655	353	197	154
25 to 50	60	77	52	37	26
50 to 100	1	1	1	0	1
100 +	0	0	0	0	0

Table VIII-33 HIAC Particle Counter Data, 100 Test Cycles

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	114,941	114,670	112,663	111,478	129,715	112,084	111,833	111,110
15 to 25	10,484	10,279	10,031	10,002	10,820	10,043	10,063	10,027
25 to 50	1,041	1,018	1,003	1,000	1,088	1,006	1,006	1,001
50 to 100	105	101	101	100	111	100	100	100
100 +	0	0	0	0	0	0	0	0

Table VIII-34 HIAC Particle Counter Data, 200 Test Cycles

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	216,628	201,454	176,419	163,576	168,911	142,177	123,234	121,724	120,039
15 to 25	14,061	13,495	12,371	12,224	12,059	1,732	9,327	9,109	8,720
25 to 50	1,766	1,670	1,388	1,422	1,390	1,186	1,007	961	970
50 to 100	47	53	57	41	57	34	23	22	23
100 +	0	0	0	0	0	0	0	0	0

Table VIII-35 HIAC Particle Counter Data, 300 Test Cycles

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	181,467	151,585	121,571	116,556	185,166	136,804	135,449	135,139	139,450
15 to 25	15,656	13,734	11,314	1,896	6,340	2,507	2,250	2,241	2,582
25 to 50	1,788	1,519	1,178	1,105	781	272	227	250	252
50 to 100	152	133	107	104	38	9	10	9	14
100 +	0	1	0	0	1	0	0	0	0

Table VIII-36 HIAC Particle Counter Data, 400 Test Cycles

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	184,036	195,988	165,303	164,976	146,524	144,627	142,370	141,582
15 to 25	11,626	14,321	13,000	12,737	11,699	11,401	11,142	11,203
25 to 50	1,964	1,351	1,939	1,930	1,655	1,703	1,602	1,621
50 to 100	153	161	188	90	176	183	173	166
100 +	2	5	5	2	1	2	0	2

Table VIII-37 HIAC Particle Counter Data, 500 Test Cycles

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	183,020	182,065	172,401	141,580	112,815	112,670	111,855	114,318
15 to 25	11,571	14,812	15,337	12,989	10,339	10,092	10,132	10,013
25 to 50	1,174	1,591	1,652	1,336	1,144	1,031	1,000	1,000
50 to 100	109	119	121	106	102	100	100	100
100 +	0	0	0	0	0	0	0	0

Table VIII-38 HIAC Particle Counter Data, 600 Test Cycles

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	197,573	178,170	173,178	141,040	112,406	111,304	111,442	112,086
15 to 25	17,063	16,199	16,045	13,249	10,422	10,246	10,223	10,203
25 to 50	1,898	1,713	1,670	1,325	1,044	1,013	1,017	1,021
50 to 100	131	128	124	110	102	100	100	100
100 +	0	0	0	0	0	0	0	0

Table VIII-39 HIAC Particle Counter Data, 700 Test Cycles

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	151,212	153,024	155,587	151,687	148,945	149,625	150,363	151,254
15 to 25	10,517	11,456	12,194	12,392	12,304	12,440	12,561	12,744
25 to 50	1,081	1,164	1,175	1,167	1,127	1,154	1,169	1,157
50 to 100	105	104	103	105	101	102	102	104
100 +	0	0	0	0	0	0	0	0

Table VIII-40 HIAC Particle Counter Data, 800 Test Cycles

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	180,308	167,887	168,091	166,531	166,667	166,777	164,899	165,279
15 to 25	13,538	13,577	13,674	13,856	13,953	14,092	13,979	14,062
25 to 50	1,227	1,258	1,264	1,288	1,312	1,329	1,333	1,320
50 to 100	103	105	103	109	104	107	103	102
100 +	0	0	0	0	0	0	0	0

Table VIII-41 HIAC Particle Counter Data, 900 Test Cycles

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	69,419	95,140	100,243	102,458	98,551	98,084	98,925	99,597
15 to 25	11,058	12,130	12,846	13,226	13,425	13,718	13,724	13,984
25 to 50	1,135	1,221	1,322	1,325	1,320	1,366	1,350	1,395
50 to 100	106	110	109	108	107	107	109	113
100 +	0	0	0	0	0	0	0	0

Table VIII-42 HIAC Particle Counter Data, 1000 Test Cycles

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	89,865	95,682	101,769	87,886	85,688	84,661	82,926	74,538
15 to 25	1,322	5,144	7,372	6,669	6,408	6,340	6,240	5,573
25 to 50	257	756	992	875	818	761	767	672
50 to 100	12	58	44	31	30	26	26	19
100 +	0	0	1	0	0	0	0	0

Table VIII-43 HIAC Particle Counter Data, 1100 Test Cycles

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	110,750	91,983	78,050	68,516	61,070	51,529	47,371	44,242
15 to 25	6,726	7,579	6,649	5,827	5,325	4,319	3,856	3,587
25 to 50	866	1,016	871	717	617	484	506	410
50 to 100	32	23	28	11	10	16	4	8
100 +	0	0	0	0	0	0	0	0

Table VIII-44 HIAC Particle Counter Data, 1200 Test Cycles

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	90,709	95,067	92,260	71,332	60,736	61,052	64,895	60,171
15 to 25	6,586	7,606	8,079	6,537	5,713	5,813	6,264	5,695
25 to 50	834	928	955	834	637	617	672	632
50 to 100	30	24	29	20	21	16	25	12
100 +	0	0	0	0	0	0	0	0

Table VIII-45 HIAC Particle Counter Data, 1300 Test Cycles

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	90,475	61,371	57,287	52,639	33,655	29,278	31,147	31,002
15 to 25	1,811	3,880	4,693	4,677	2,862	2,424	2,826	2,638
25 to 50	235	461	581	535	332	270	314	263
50 to 100	13	11	10	10	5	3	3	8
100 +	0	0	0	0	0	0	0	0

Table VIII-46 HIAC Particle Counter Data, 1400 Test Cycles

Particles Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	46,451	46,680	47,123	49,068	46,562			
15 to 25	806	769	801	816	664			
25 to 50	108	136	135	147	87			
50 to 100	2	8	5	3	7			
100 +	0	0	0	0	0			

Table VIII-47 HIAC Particle Counter Data, 1500 Test Cycles

Particle Range (microns)	First 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml	Next 100 ml
5 to 15	67,781	48,434	38,426	33,378	32,678	32,131	28,888	26,364
15 to 25	5,748	5,179	4,220	3,713	3,723	3,658	3,278	2,966
25 to 50	831	759	678	524	510	525	437	427
50 to 100	32	30	17	15	15	7	11	4
100 +	0	1	0	0	0	0	0	0

Table VIII-48 Hydraulic Oil Particle Count (Millipore)

Sample Number	69M3041		69M3042	69M3043	69M3044	69M3045
Volume of Sample Counted (ml)	10	5	10	100	100	100
Sample Taken at Test Cycle No.	300	300	600	900	1200	1500
Particle Range (micron)						
6 to 10	TNTC	TNTC	TNTC	TNTC	TNTC	TNTC
11 to 25	TNTC	14,400	TNTC	TNTC	TNTC	TNTC
26 to 50	TNTC	6,600	6,600	9,000	3,100	17,400
51 to 100	930	900	1,500	1,240	650	1,500
Over 100	420	700	840	695	385	480

Note: 1) TNTC - Too Numerous To Count.
2) Sample volumes diluted from total sample taken.

Table VIII-49 System Test Interim Internal Leakage Test Data

Test Components	Serial Number	Pressure Applied to (3000 + 150 - 0)	Pressure Decay After Five Minutes (psig)/Regulator Set Pressure						
			Cycle Number						
			0	100	300	600	900	1200	1500
Cylinder	75M06506	Piston Rod Side Piston Side	0 0	0 0	0 0	0 0	2.0 1.5	3.5 3.1	5.0 4.6
Regulator	1592	Inlet	0 2960	0 2969	0 2940	0 2920	0 2920	0 2935	0 2960
Accumulator	3300	Oil Test Side Air Side	6.0 6.0	6.0 6.0	6.0 6.0	6.0 6.0	5.5 5.5	4.5 4.5	3.0 3.0
	3299	Oil Test Side Air Side	0 0	0 0	0 0	1.0 1.0	2.0 2.0	4.0 4.0	6.0 6.0
Solenoid Valve	399	Inlet Outlet	0 0	0 0	0 0	0 0	0 0	0 0	0 0
	398	Inlet Outlet	0 0	0 0	0 0	0 0	0 0	0 0	0 1.0
Check Valves	9021312	Outlet	0	0	0	0	0	0	0
	9021313	Outlet	0	0	0	0	0	0	0

c. Final Functional Test Results and Discussion

After the system contamination test was completed, functional tests were conducted for each component in order to accurately evaluate component performance after testing. Performance was measured against the initial functional test results obtained prior to the contamination tests. Tables VIII-26 through VIII-31 present the results of each component final functional test.

The test results between the prefunctional and postfunctional tests are very nearly the same in all respects. The following conclusions may be reached from the data:

1) The data comparison prior to and after the contamination tests are nearly the same showing very little if any, degradation in performance;
2) The cylinder leakage is comparable, and the breakaway force decreased;
3) Solenoid response time increased slightly, and internal leakage increased but is still within the service arm specification;
4) The check valves had zero leakage and the cracking and reseat pressures decreased;
5) The regulator performance improved and was within specification, whereas the initial performance prior to the contamination tests was out of specification in some instances;
6) The accumulator internal leakage decreased on S/N 6K3300. The leakage on S/N 6K3299 increased from zero leakage to 6.1 drops per minute. NASA criteria are 10 drops per 15 minutes for this accumulator. The leakage was due to O-ring laminations, not contamination;
7) The 0.020 bleed orifice flow rate performance was identical (0.48 gpm at 3000 psig).

d. Final Component Disassembly and Inspection

Following completion of the final functional test, each test specimen was completely disassembled for inspection. Contamination was found in every component, particularly where hydraulic oil residue was not completely drained from the component. Each piece of the system test tubing was disassembled, and again contamination was found in each piece of tube where oil residue was found. The inspection showed that the contaminant was well distributed throughout the system. Figures VIII-40 through VIII-46 show the hydraulic test specimens prior to disassembly, an exploded view showing the piece parts of each component, and selected photographs exhibiting the extent of contamination and/or anomalies.

A detailed description of the observations made for each component follows and is in sequence with the component photographs.

Pressure Handloader (75M08830) - Many fine particles of contaminant were found in all parts of the handloader, particularly where oil residue still remained. Figures VIII-42 and VIII-43 show the contaminant, which consisted of A.C. road dust, teflon, rubber particles, and fibers, remaining in the valve body and piston.

The O-ring (J200A16) in the main piston showed normal wear (Fig. VIII-44). Two previous failures of this O-ring occurred prior to and during the tests. The first O-ring failed prior to contaminant injection; the second at 1326 cycles. This O-ring failure is attributed to assembly problems and rolling and spiraling in the groove with subsequent nibbling on the inside and outside diameters. The cause of this O-ring failure is not attributed to contamination.

The sensing piston O-ring was not worn. Four longitudinal scratches were observed on the O-ring lands, but there were no scratches on the mating part. The teflon pilot on the sensing piston was burnished on one side of the outside diameter due to wear, and showed some longitudinal scratches. The corresponding inside diameter of the retaining spool showed wear marks for the full 360 deg with some longitudinal scratches. These indications of wear and scratches are attributed to contamination. The measured final clearance between these two parts is 0.001 in. (25 microns). A.C. road dust and metal particles were observed on the retaining spool.

The main seat of the poppet stem was badly eroded due to particle impingement, although this handloader did not leak. The erosion was similar to that evidenced in the pneumatic handloader which has a similar configuration. Deep scratches were observed on the mating nylon seat for the full diameter of the conical sealing surface. These scratches were caused by particles flowing over the seat of the poppet valve thus causing the gouges. The O-ring (J200A2) on the poppet stem was badly chewed up. During the contamination tests this O-ring failed four times (Fig. VIII-45). It is our conclusion that these O-ring failures are not due to contamination, but to excessive groove width which permits the O-ring to roll and spiral. It should be noted that this component, and the flow orifice, actually saw 3000 test cycles whereas the remaining components were run for 1500 test cycles.

Figure VIII-46 shows the inlet and outlet fittings and filter screens. The inlet filter screen dislodged from the fitting at 1113 cycles and had migrated to the retaining spool in the handloader. At 1326 cycles the filter screen in the outlet fitting was laid back parallel to the flow stream. This screen was removed from the system and is shown in Figure VIII-46. The filter screens failed as a result of contaminant loading and subsequent ΔP across the screen, even though the screen is a very coarse mesh. The outlet screen was loaded with a black residue that appeared to be either a rubber seal material or lubricant from the accumulators.

All of the remaining O-rings, seals, and piece parts in the handloader were in good condition.

<u>Check Valve (75M05365-4, S/N 9021312)</u> - Many small particles and long fibers were observed in the check valve body and poppet. When the valve was disassembled, it was found that the O-ring in the valve which forms one of the sealing surfaces was missing (Figure VIII-48). The valve did not leak during the contamination tests or postfunctional tests. This check valve design has a dual sealing action; it first forms a seal on the O-ring, then on the metal seat. It is believed that the O-ring was never assembled into the valve, and it was received in this condition. There was no sign of seat erosion or valve degradation due to contamination.

<u>Check Valve (75M05365-4, S/N 9021313)</u> - Many small particles and long fibers were observed in the check valve body and on the poppet. There was no evidence of degradation in the valve.

Two-Way Solenoid Valve (75M08823-1, S/N 399) - The solenoid body was fairly clean with a few large particles of teflon and residual lubricant in evidence.

Several particles were observed in the residual lube in the V-groove between the two top O-rings (Fig. VIII-51). All three O-rings on the stem showed normal wear and were not chipped or nibbled. The backup rings were not scratched and did not show any signs of wear. Long (0.25 in.) slivers of O-ring were observed in both of the two top O-ring grooves, but were not from this valve. The main poppet seat was not eroded. The main nylon seat was not eroded or scratched, but did show some evidence of cold flow. There was no evidence of wear in the valve.

A long sliver (0.625 inch by 200 micron) of stainless steel was still attached to the O-ring pilot edge of the O-ring support seat and is a result of machining (Fig. VIII-53). This edge was very sharp. The mating static O-ring was chewed up and its condition is believed to be the result of assembly over the sharp edge or because of a "pinching effect" during assembly.

Two-Way Solenoid Valve (75M08823-1, S/N 398) - The cleanliness condition of this valve was similar to S/N 399. All three O-rings on the poppet stem were in good condition. The nylon seat was in good condition, but showed evidence of some cold flow. There was no erosion on the main poppet seat. The bottom stem pilot showed indications of wear and longitudinal scratches for approximately 0.25 in. on the diameter. The mating inside diameter on the retaining spool also showed indications of wear and longitudinal scratches (Fig. VIII-52). The measured clearance between these two parts is 0.001 in. (25 microns). The wear and scratches were not severe, but can be attributed to contamination. Figure VIII-52 also shows many particles inside the spool, the majority of which were of O-ring material. These particles had to migrate from another component because the only O-ring failures in this valve were not in the flow path. The static O-ring that fits on the retaining spool (Fig. VIII-52) was chipped in one place for approximately 0.25 in. on the outside diameter. This failure is attributed to assembly problems.

The static O-ring on the support seat was nibbled in a manner similar to that described for valve S/N 399.

Hydraulic Cylinder (75M065067) - The sliding surface of the V-cup seal on the piston head was worn around the periphery of both seals. Large pieces of V-cup seal material were observed in the piston head V-groove, and large particles of metal were imbedded in the V-cup seal. A few longitudinal scratches were observed in the brass piston head. Although the cylinder leakage did not increase as a result of the contamination tests, all of the above anomalies can be attributed to contamination.

No scratches were visable on the cylinder bore, but the entire bore was coated with many fine particles of contaminant.

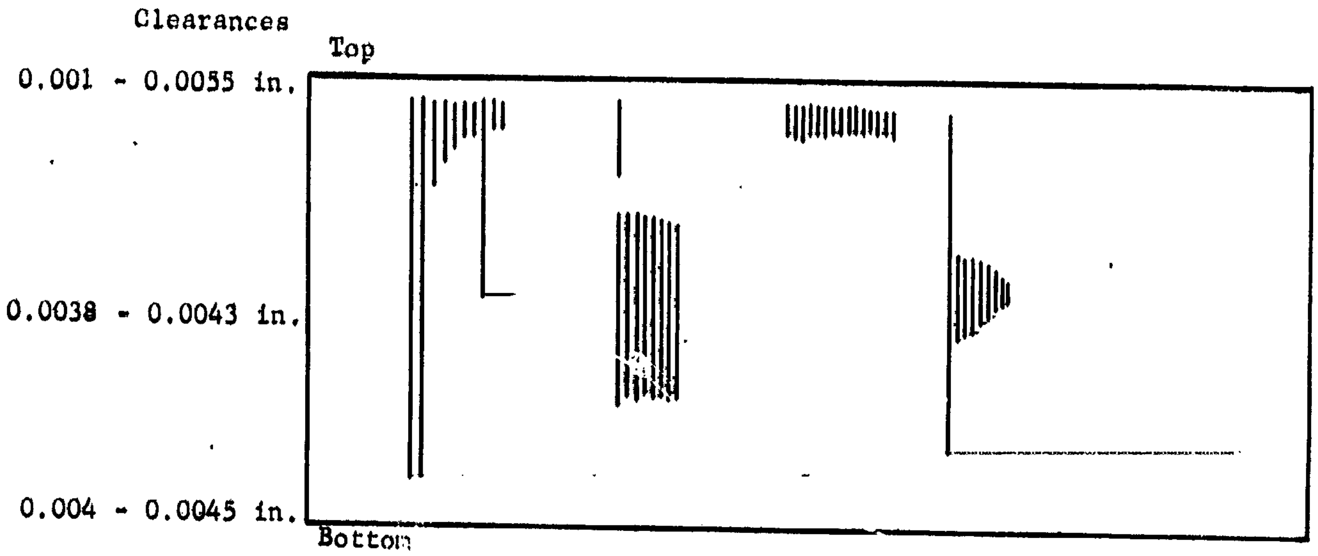
Many particles that appeared to be chevron seal material, brass chips, and test contaminant were observed on the retract head.

The chevron rod seals showed normal wear except for the last seal which was badly chewed up on the outside diameter. This seal lies next to the gland nut, and it is believed that this seal would be damaged every time on assembly because of the design (Fig. VIII-52). Very slight scratches were observed on the cylinder rod.

Hydraulic Accumulator (75M08814-1, S/N 3300) - Both heads of the accumulator were very heavily lubricated with a black lubricant (Fig. VIII-59) in the threads and on the static O-rings. Large slivers of O-ring material were observed in the thread relief. A large quantity of fine road dust, large teflon, brass, and metal particles was observed in the oil residue remaining in the lower head, which is the side seeing the injected contaminants.

The static O-rings on both heads were badly nibbled on the entire outside diameter (Fig. VIII-60). The O-ring failure could be due to one of two causes: (1) pressure pulsations and incorrect groove design, or (2) cutting by the threads upon assembly-disassembly.

The barrel of the accumulator contained many deep gouges, spaced at very equal intervals (0.125 in.), that could be a result of tool marks or contamination. The cylinder wear pattern is sketched on the following page and shown in Figure VIII-61. The sketch shows only the relative position and lengths rather than the exact number of gouges. The clearances are actual measurements between the piston and the barrel. The variation in clearances is due to some "egg-shape" in the barrel, as measured at 90 deg to each other. It should be noted that the leakage in this accumulator decreased during the contamination test.



Some very slight scratches that may be due to contamination were observed all around the inside diameter. The barrel walls were coated with fine particles that appear to be teflon, fine dust, and O-ring slivers.

The top land of the piston shows some wear and approximately 15 longitudinal scratches some of which may be due to the gouges in the bore and some to the contaminant. The extent of each cause is impossible to determine (Fig. VIII-62). The top O-ring showed normal wear with some rolling action. On the side of the O-ring opposite the backup ring there were approximately 26 pits in the O-ring that appear to be caused by laminations in the molding process. The pits were not on the sealing surface, even considering the rolling action, and were not due to contamination. The top backup ring was badly scratched around the outside diameter in a longitudinal direction. The scratches are a result of contamination with some effect due to the gouges in the bore (Fig. VIII-62).

The bottom O-ring on the piston looks very good with some very slight longitudinal scratches on the wearing surface. The condition of the bottom backup ring was the same as that of the top land. The bottom land showed normal wear with some slight burnish marks but no scratches or gouges.

Many particles of teflon, road dust, metal, and rubber were observed in the O-ring grooves and on the O-rings.

Hydraulic Accumulator (75M08814-1, S/N 3299) - Both heads of the accumulator were heavily lubricated and contained considerable contamination similar to S/N 3300 (Fig. VIII-63). The static O-rings were nibbled similarly to S/N 3300, but the ribbling was not as severe (Fig. VIII-60).

The accumulator bore contained one deep gouge approximately 12 in. long located in the middle of the stroke. There was indication that the bore had been polished or honed in this area after machining in an attempt to eliminate the scratch. Except for this scratch the bore was perfect, without even minor scratches (Fig. VIII-64).

The top O-ring on the piston was nibbled all around the outside diameter. One area (0.625 in. long) was nibbled out badly (Fig. VIII-62). The nibbled inclusions were shiny in appearance, indicating lamination problems in the manufacturing process. The leakage on this accumulator increased during the tests, and is probably a result of the deep nibbling that occurred in one area of the O-ring. The top land had approximately nine longitudinal scratches. Both the top and bottom backup rings contained longitudinal scratches, but not as many as on S/N 3300. The bottom O-ring was spiraled but showed normal wear with no pits or nibbling. This O-ring was on the contaminant side of the accumulator. A considerable number of particles of all types were entrapped in both O-ring grooves.

The measured clearances for the piston and accumulator were:

Top Clearance = 0.0024 to 0.0029 in.

Middle Clearance = 0.0024 to 0.0027 in.

Bottom Clearance = 0.0021 to 0.0024 in.

Orifice - This orifice (0.020 in. diameter) plate was constructed of aluminum and was placed in the system to determine the effects of clogging and erosion. The contaminant injected into the system contained particles as large as 750 microns and fibers up to 4000 micron, whereas the 0.020-in. orifice represents 500 microns. The inlet edge of the orifice was rounded to a radius. The inside diameter of the orifice contained gouges that appeared to be the result of hard particles passing through the orifice. The orifice was not plugged with particles.

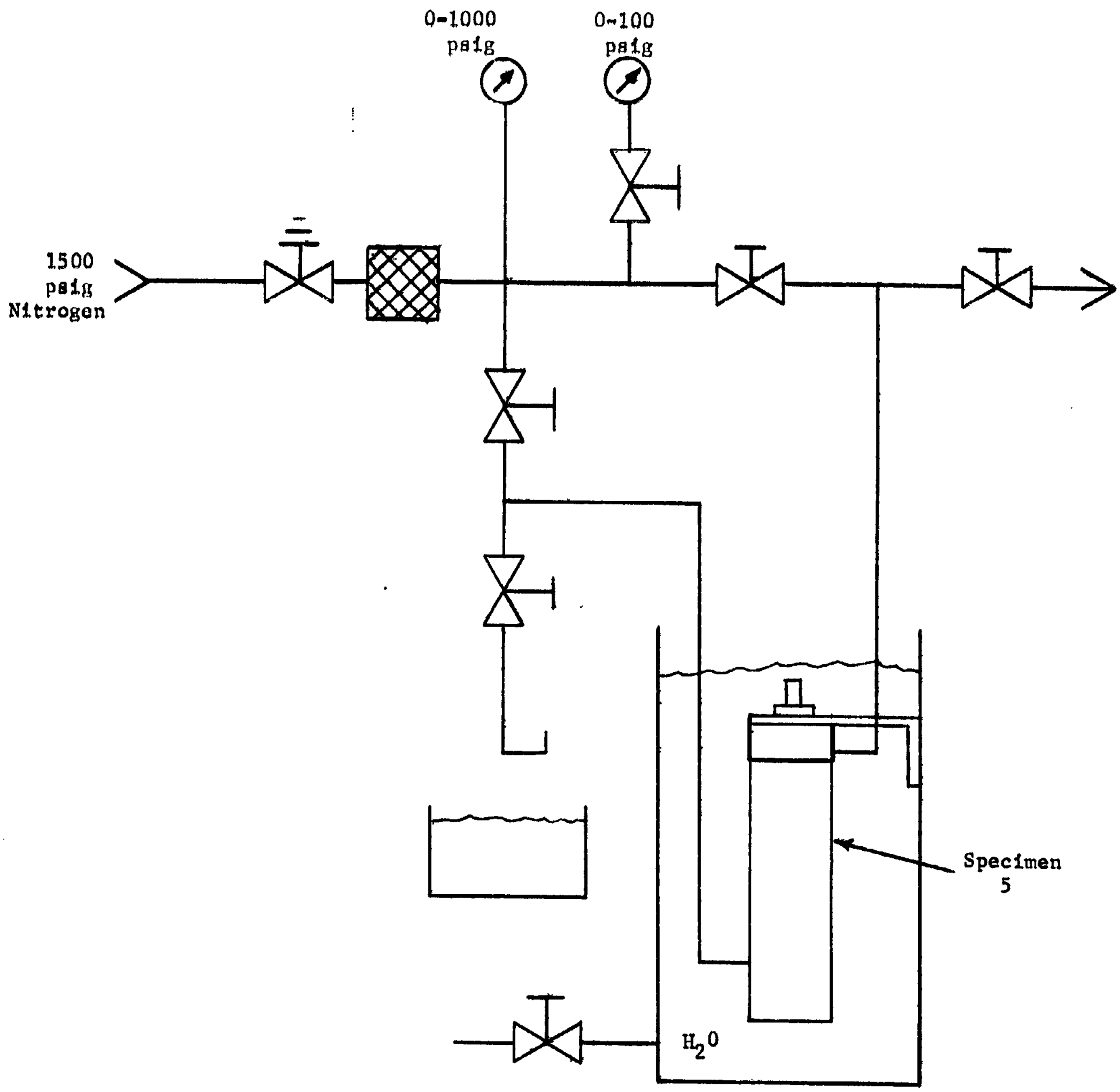
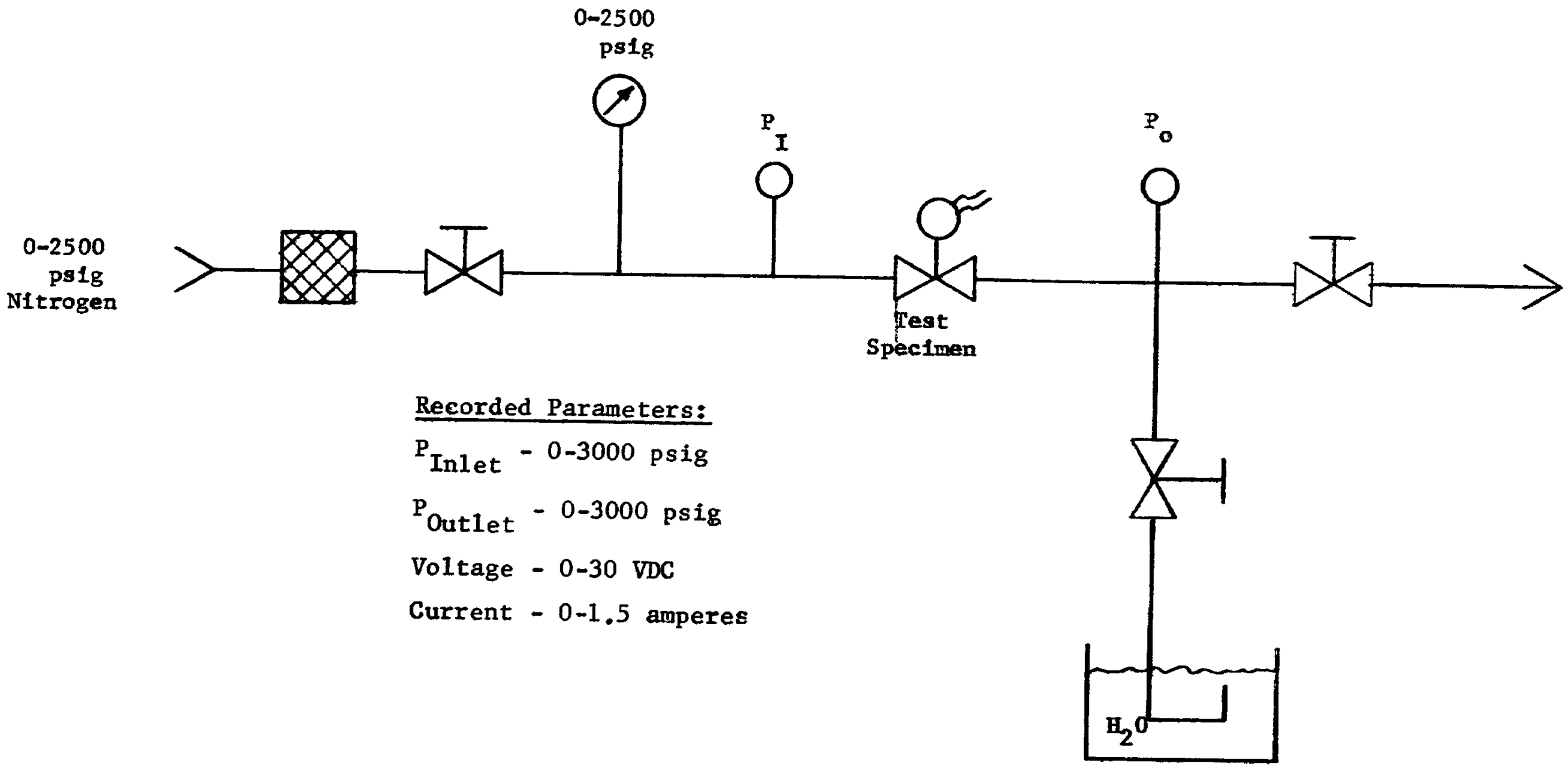


Figure VIII-1 Pneumatic Cylinder Functional Test Schematic



Recorded Parameters:

P_{Inlet} - 0-3000 psig

P_{Outlet} - 0-3000 psig

Voltage - 0-30 VDC

Current - 0-1.5 amperes

Figure VIII-2 Two-Way Solenoid Valve Functional Test Schematic

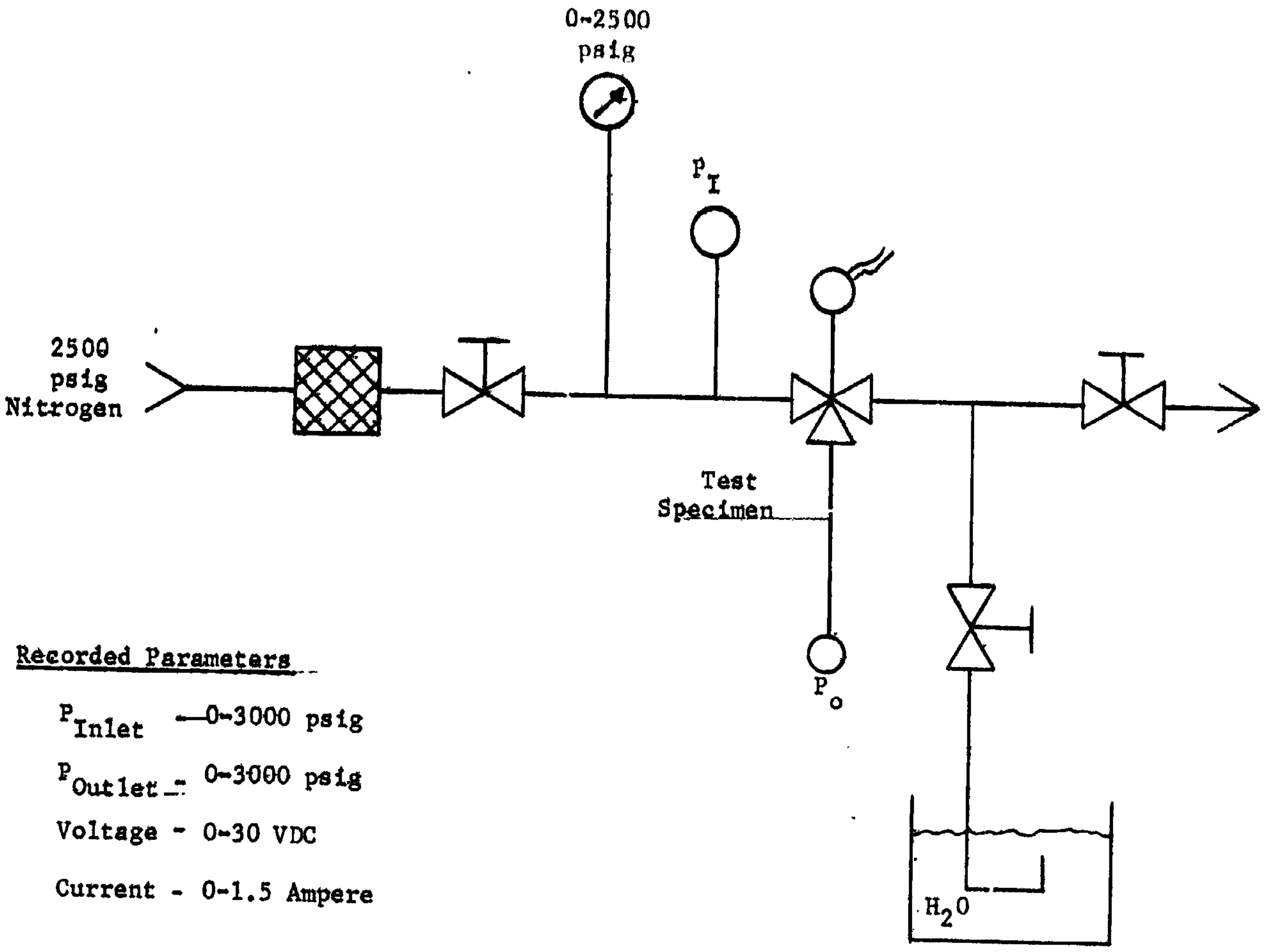


Figure VIII-3 Three-Way Solenoid Valve Functional Test Schematic

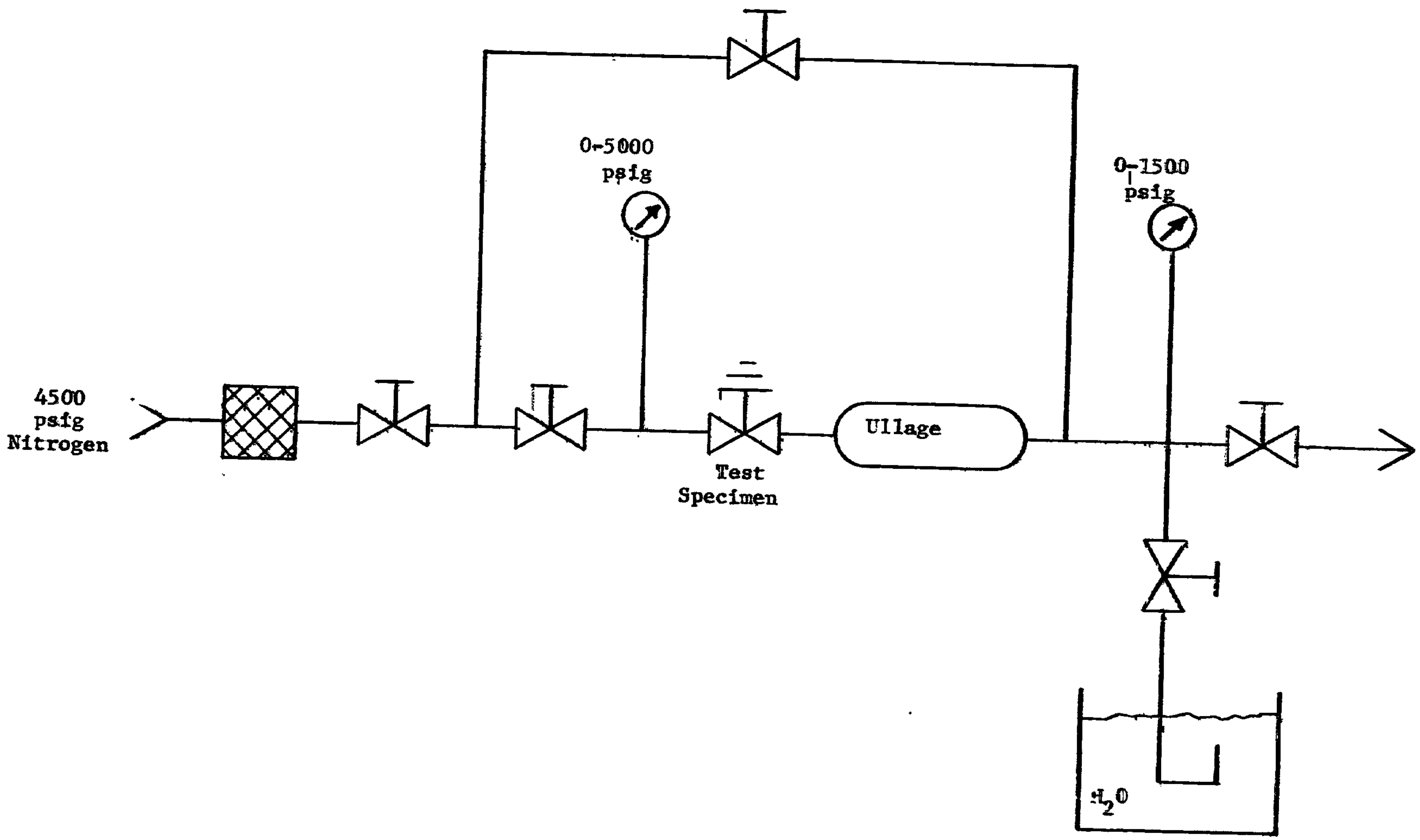


Figure VIII-4 Regulator Functional Test Schematic

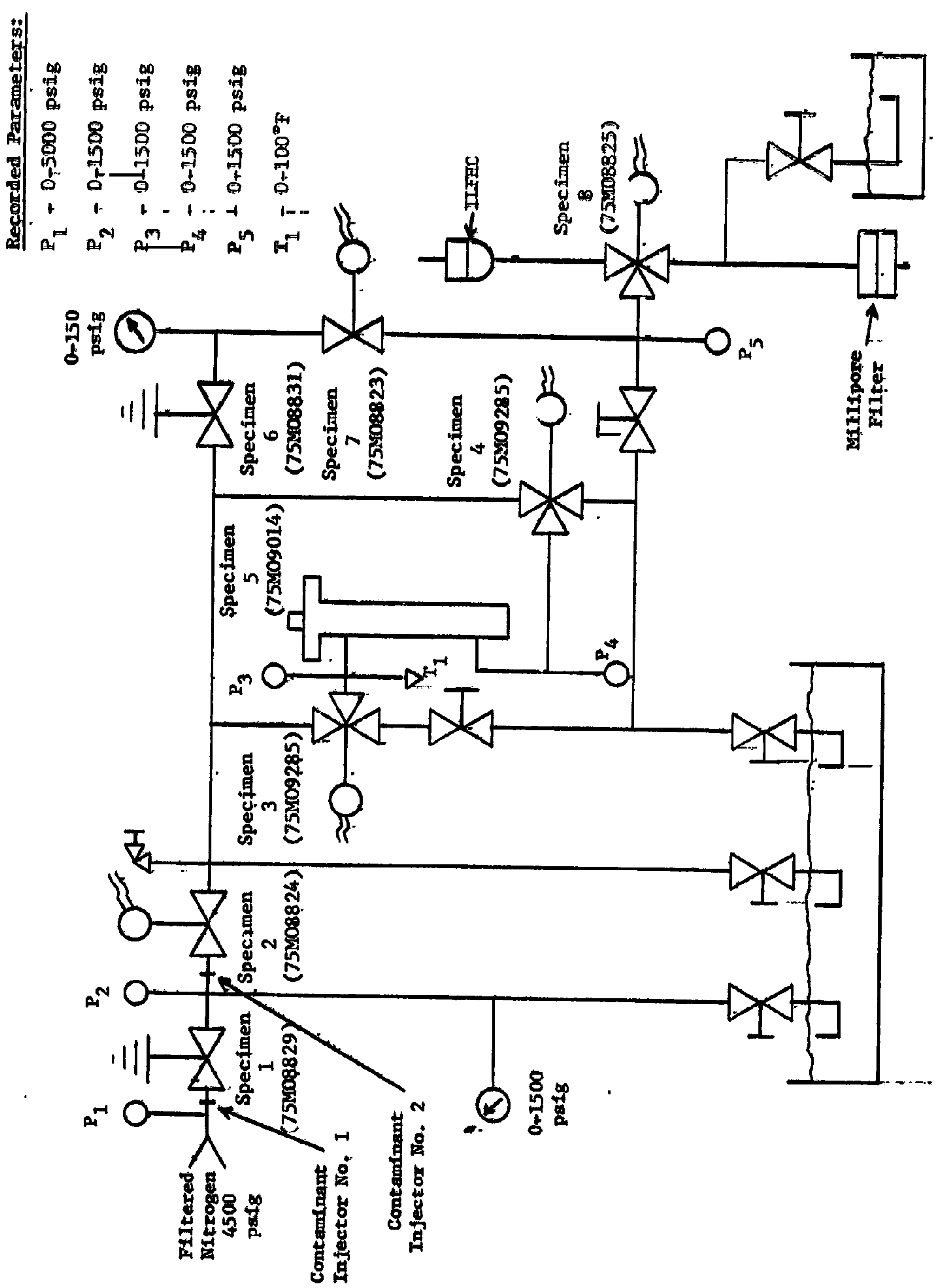


Figure VIII-5 System Test Fixture Schematic

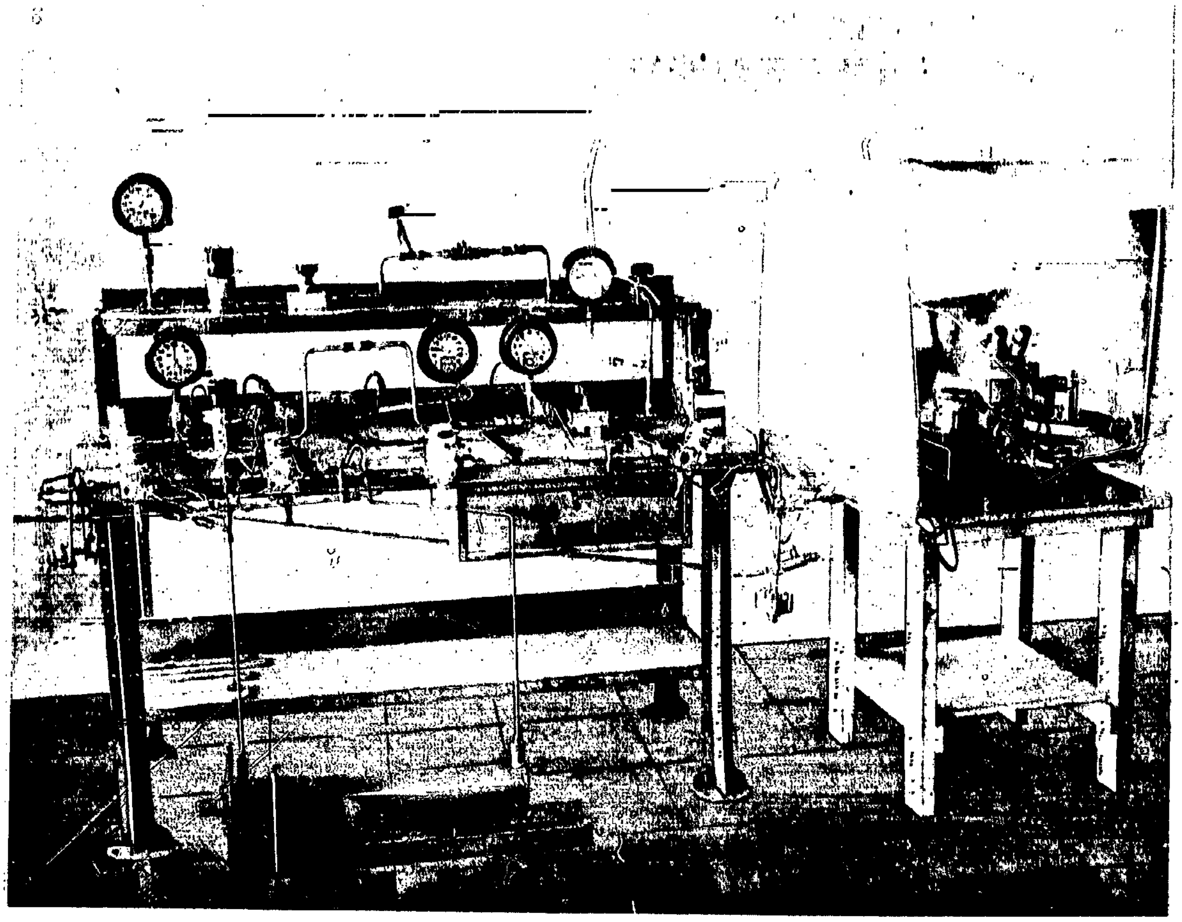


Figure VIII-6 Pneumatic Contamination Test System

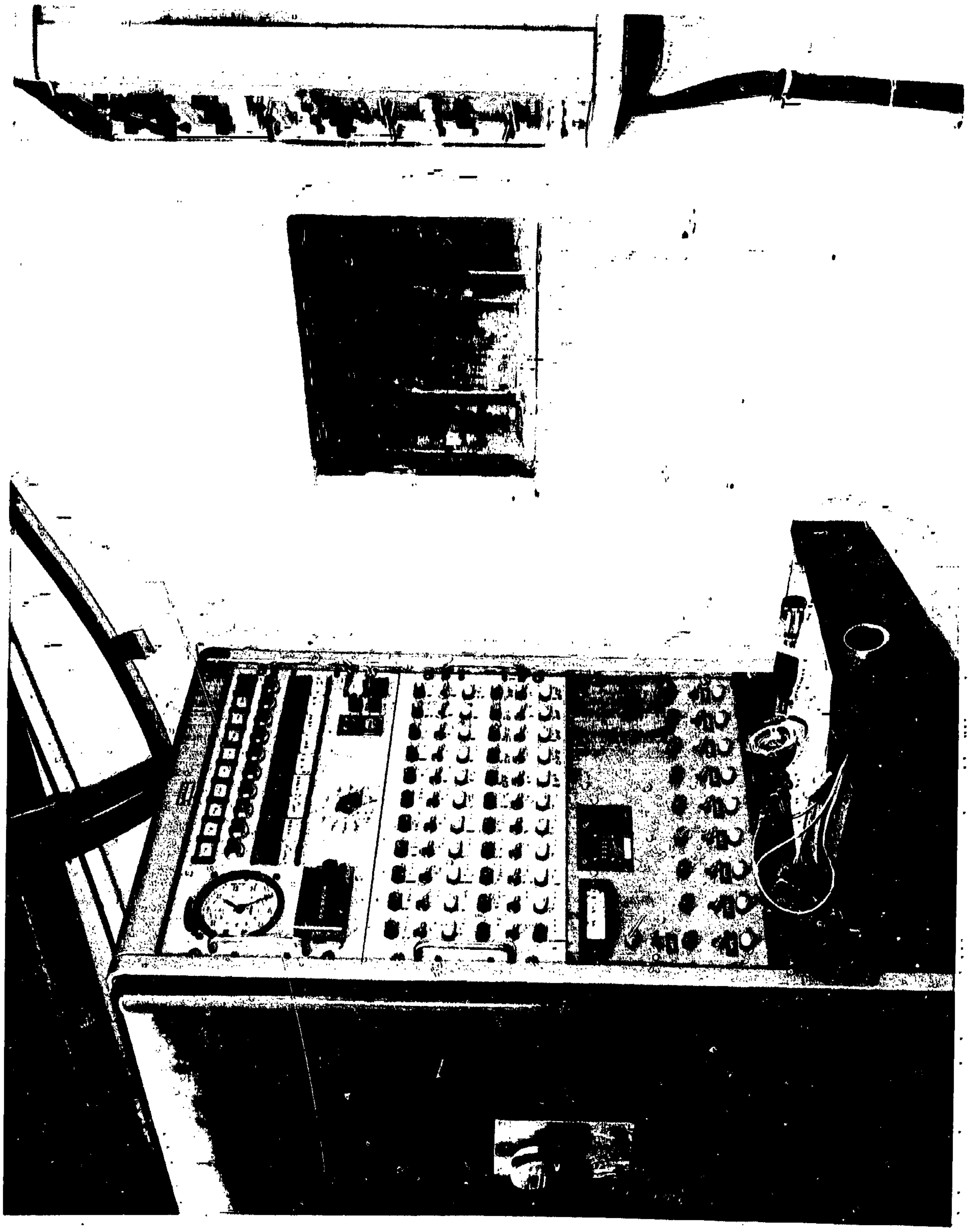


Figure VIII-7 Pneumatic Contamination Test Control Panel

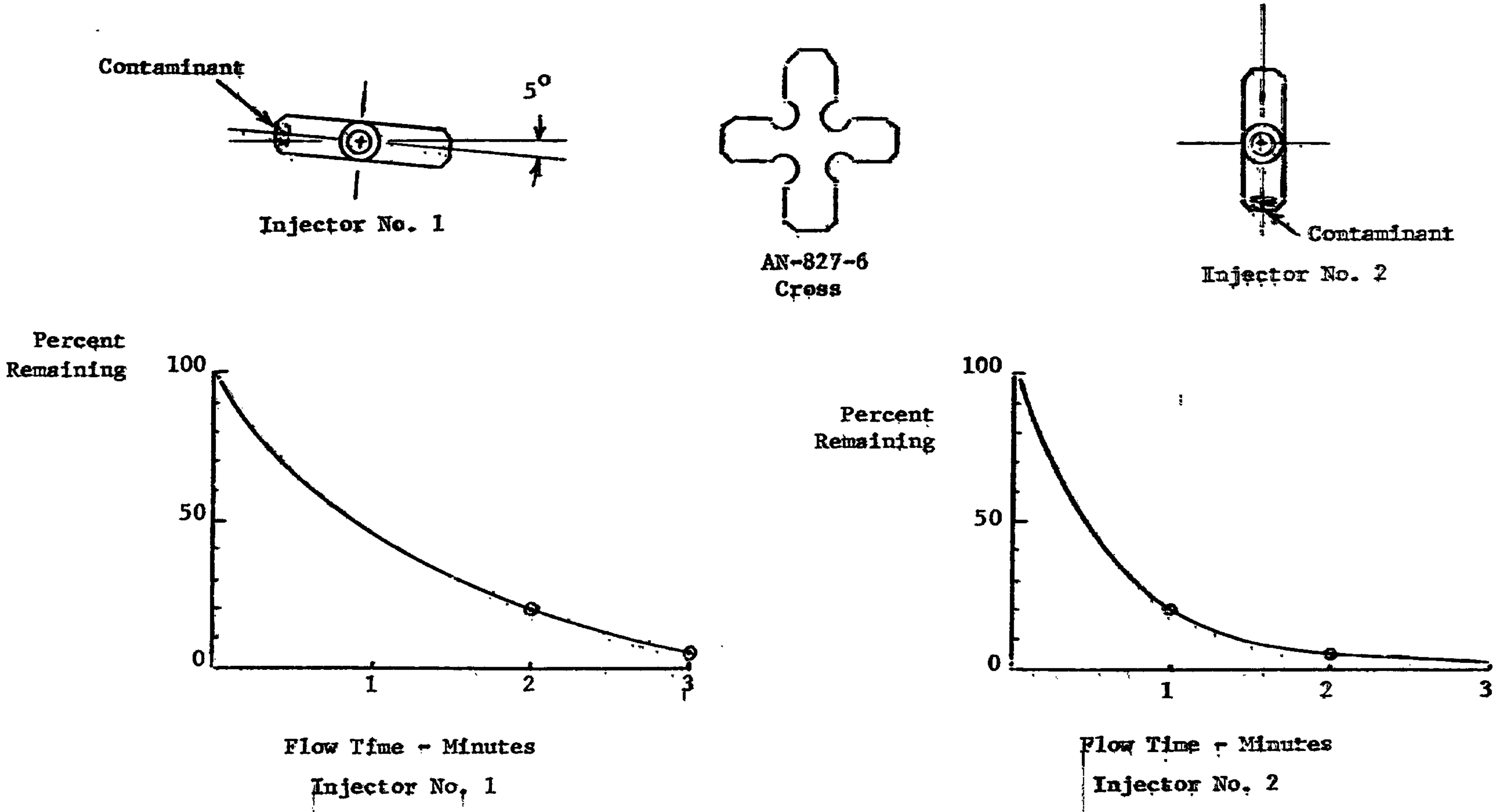
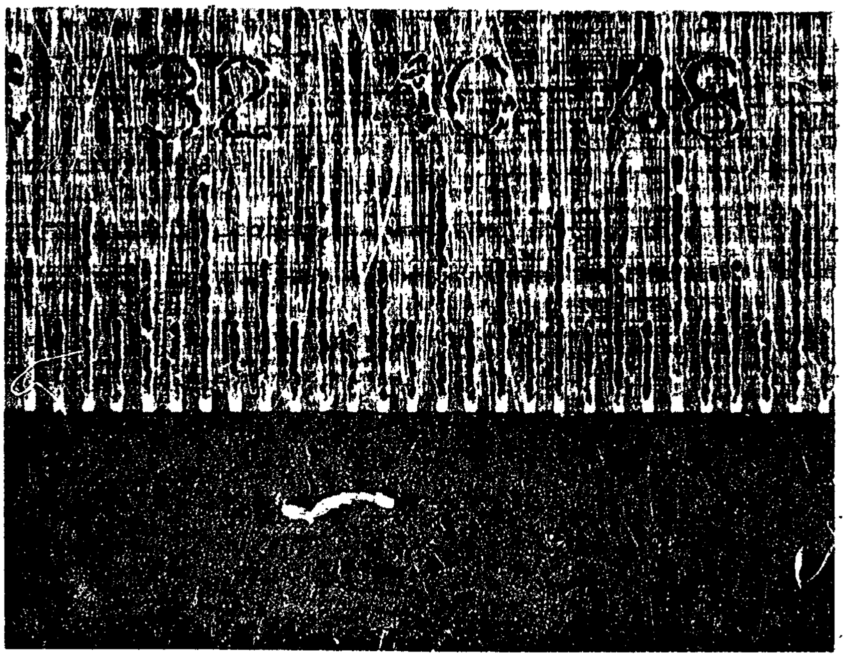


Figure VIII-8 Contamination Injector Development Data



Solenoid Valve (75M08824-1)
(Scale Division = 0.0156 in.)

Figure VIII-9 Metal Sliver

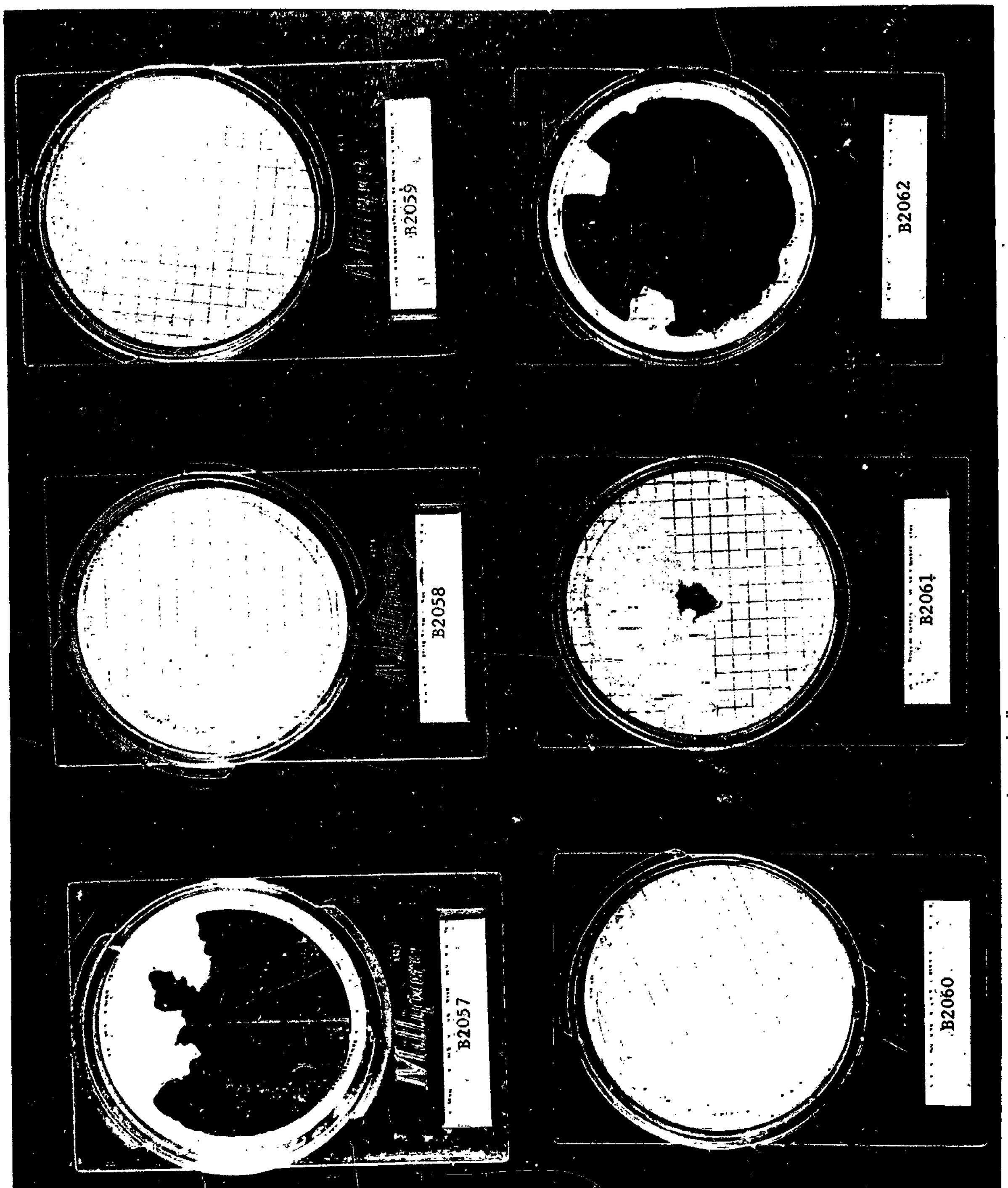


Figure VIII-10 Millipore Filter Pads from Pneumatic Contamination Tests

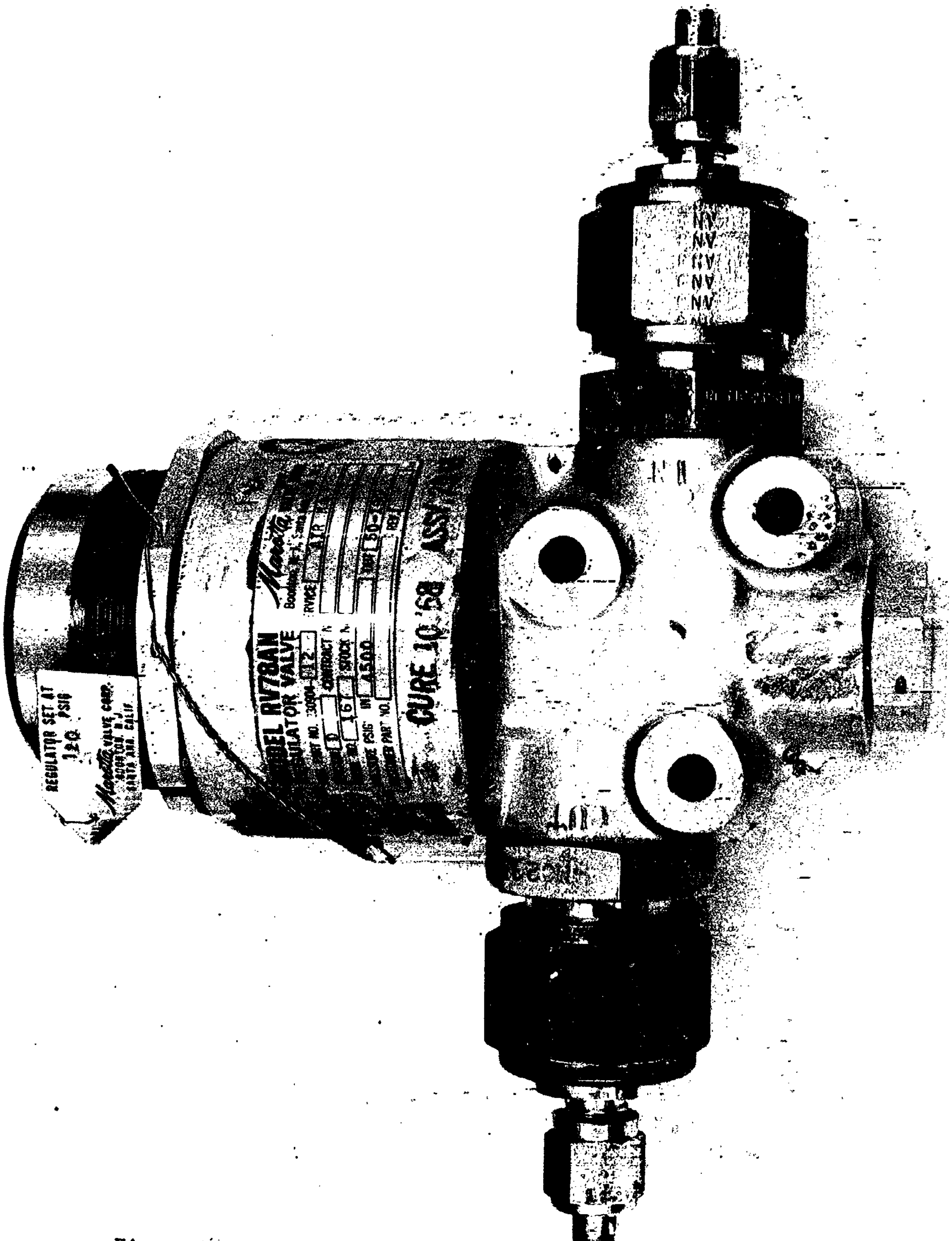


Figure VIII-11 Pressure Regulator (75M08831-1)

Figure VIII-12 Pressure Regulator (75M08831-1)

Figure VIII-13 Spool Piece and Filter Screen (75M08831-1)

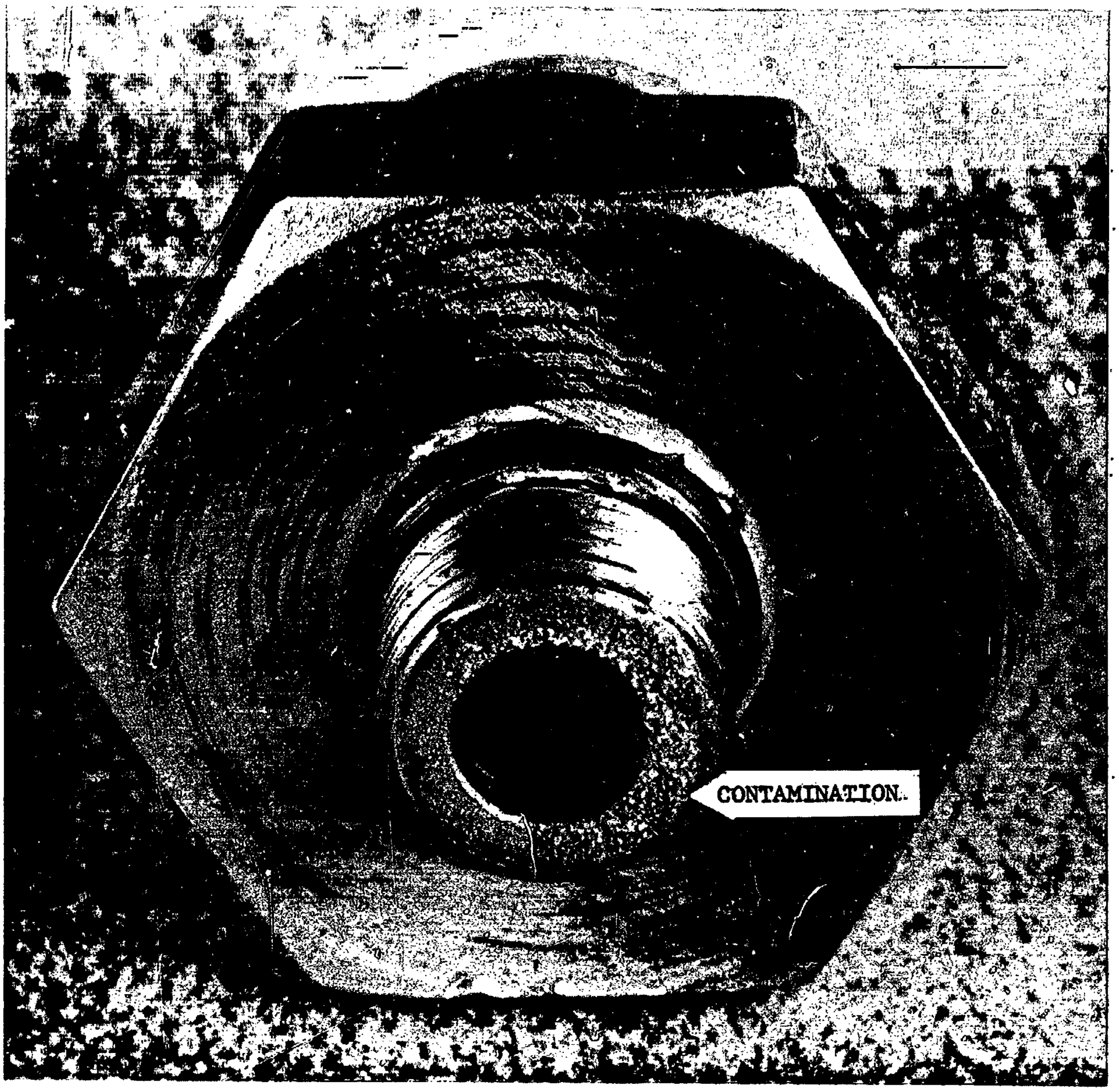


Figure VIII-14 Inlet Fitting (75M08831-1)

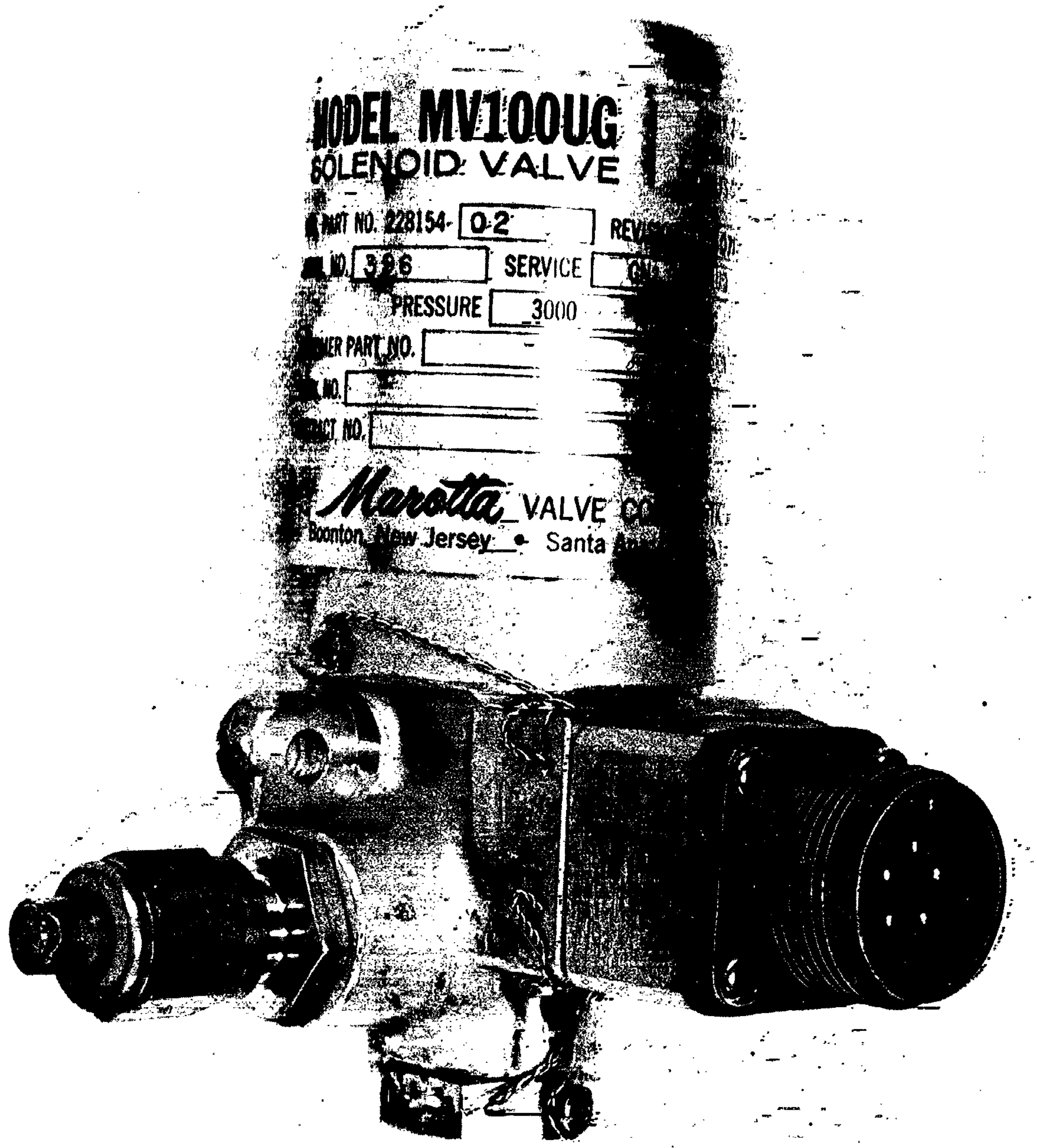


Figure VIII-15 Two-Way Solenoid Valve (75M08824-1)

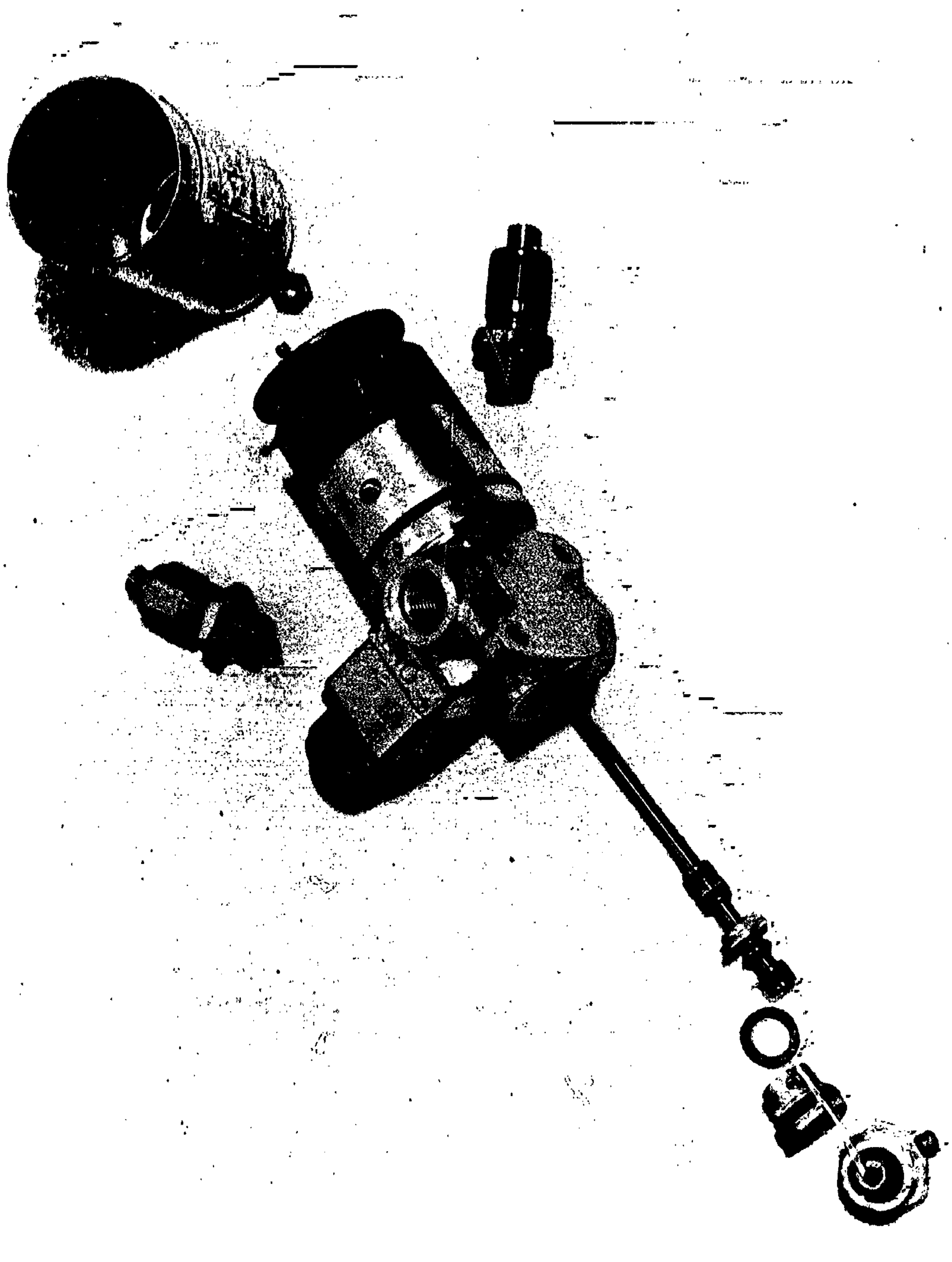


Figure VIII-16 Two-Way Solenoid Valve (75M08824-1)

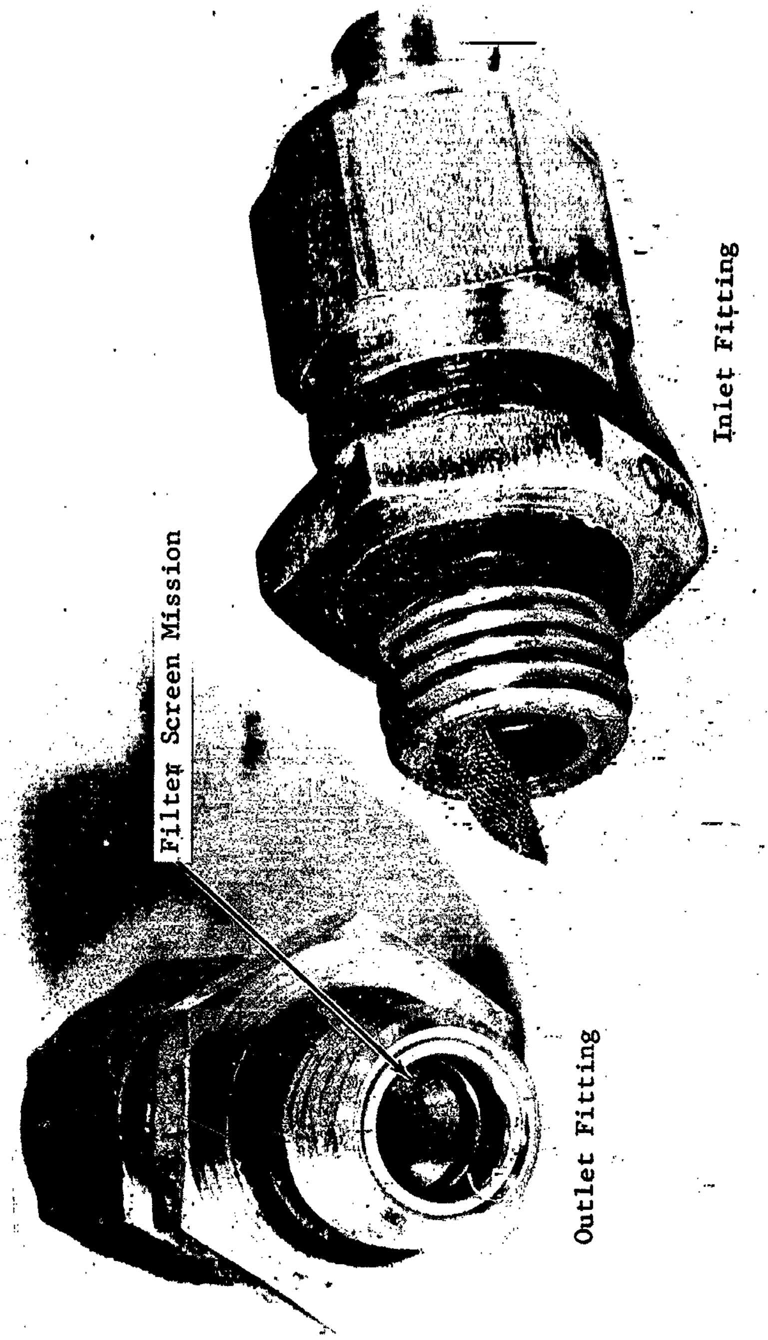


Figure VIII-17 Inlet and Outlet Filter Screens [illegible]

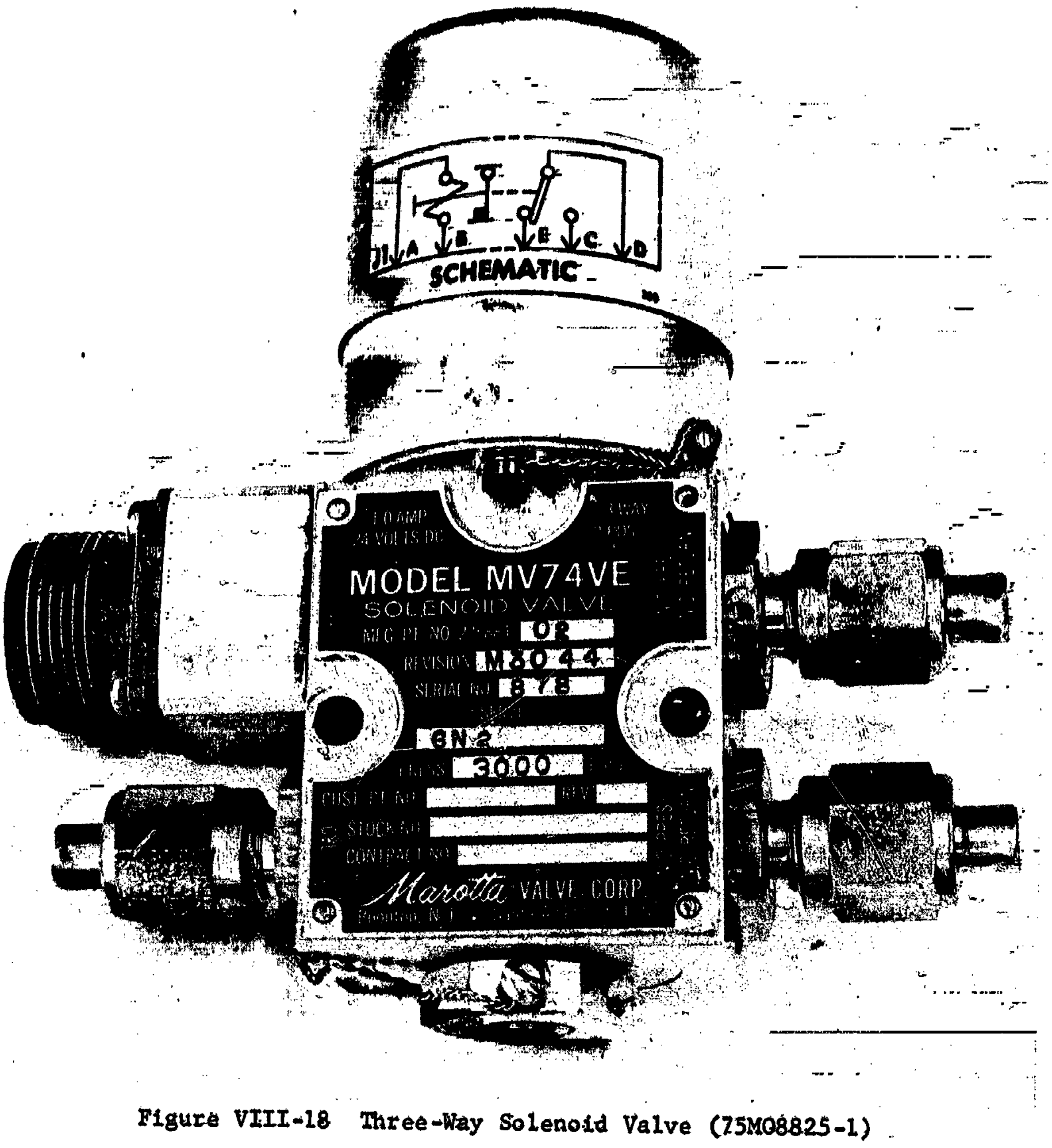


Figure VIII-18 Three-Way Solenoid Valve (75M08825-1)

Figure VIII-19 Three-Way Solenoid Valve (75M08825-1)

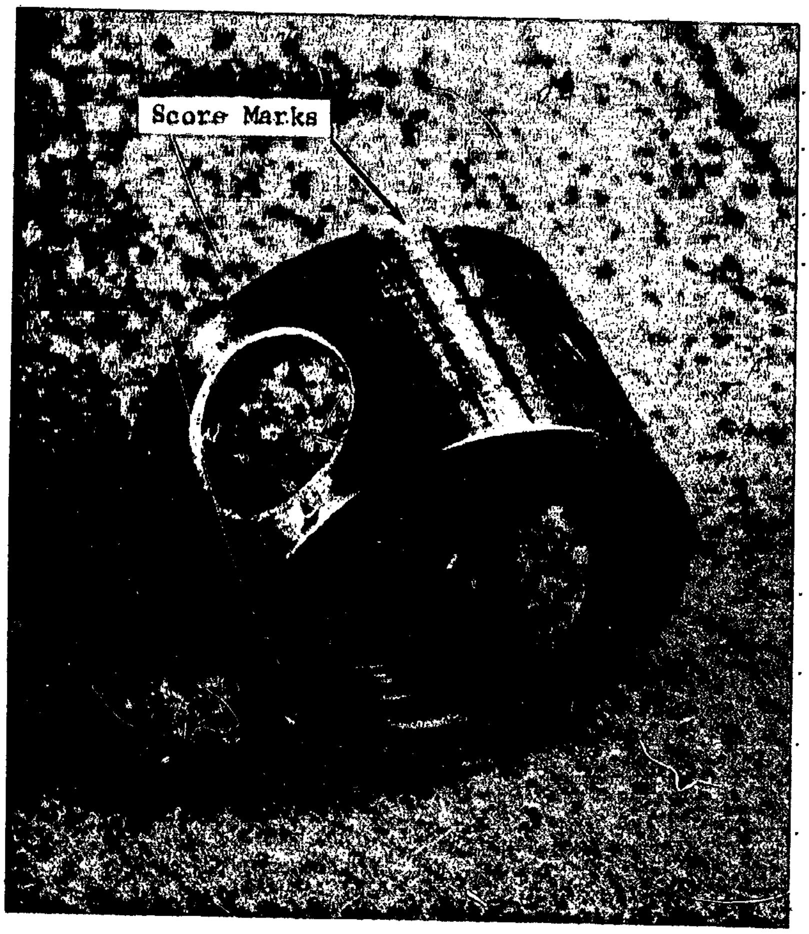


Figure VIII-20 Spool Piece (75M08825-1)

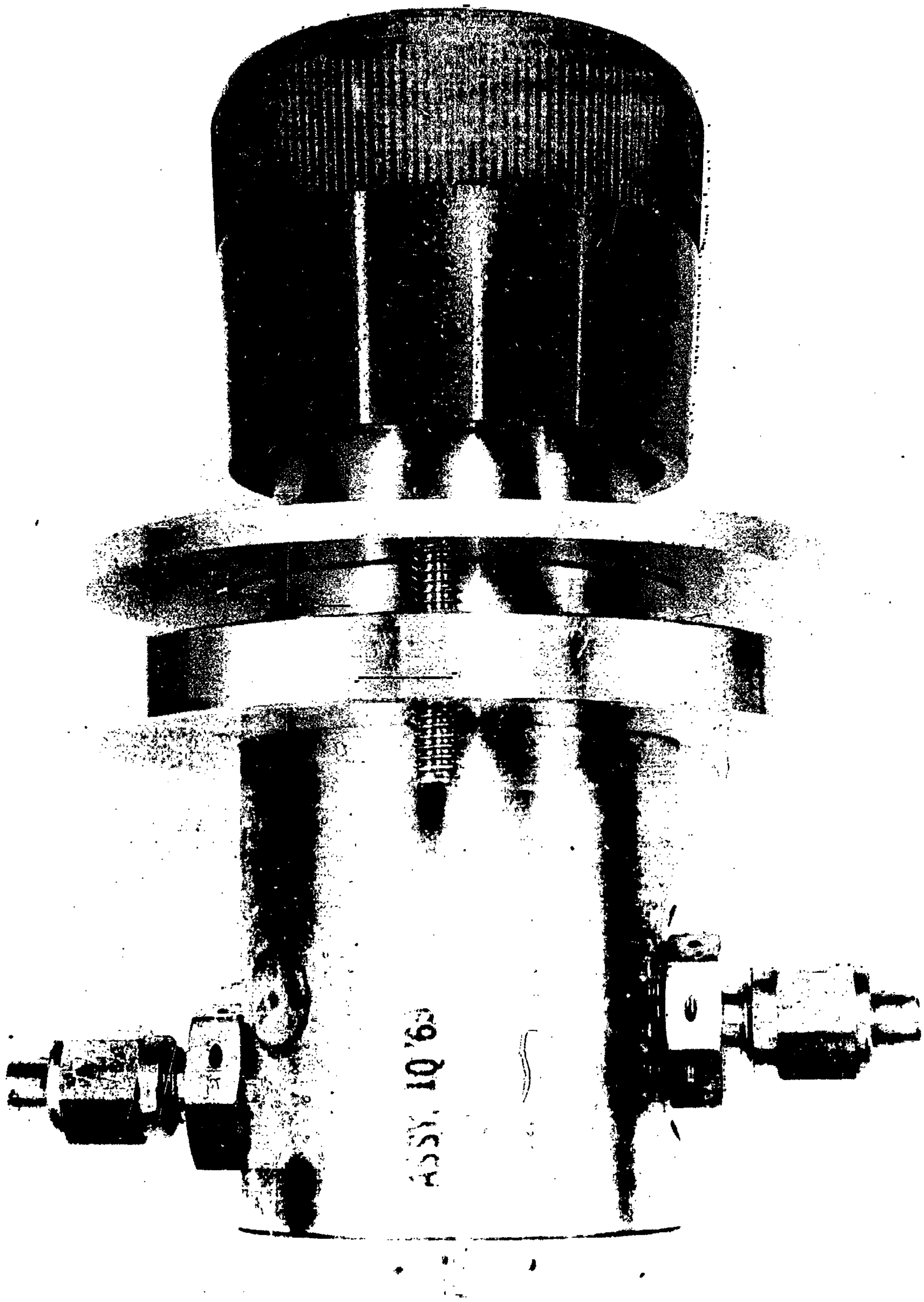


Figure VIII-21 Pressure Handloader (75M08829)

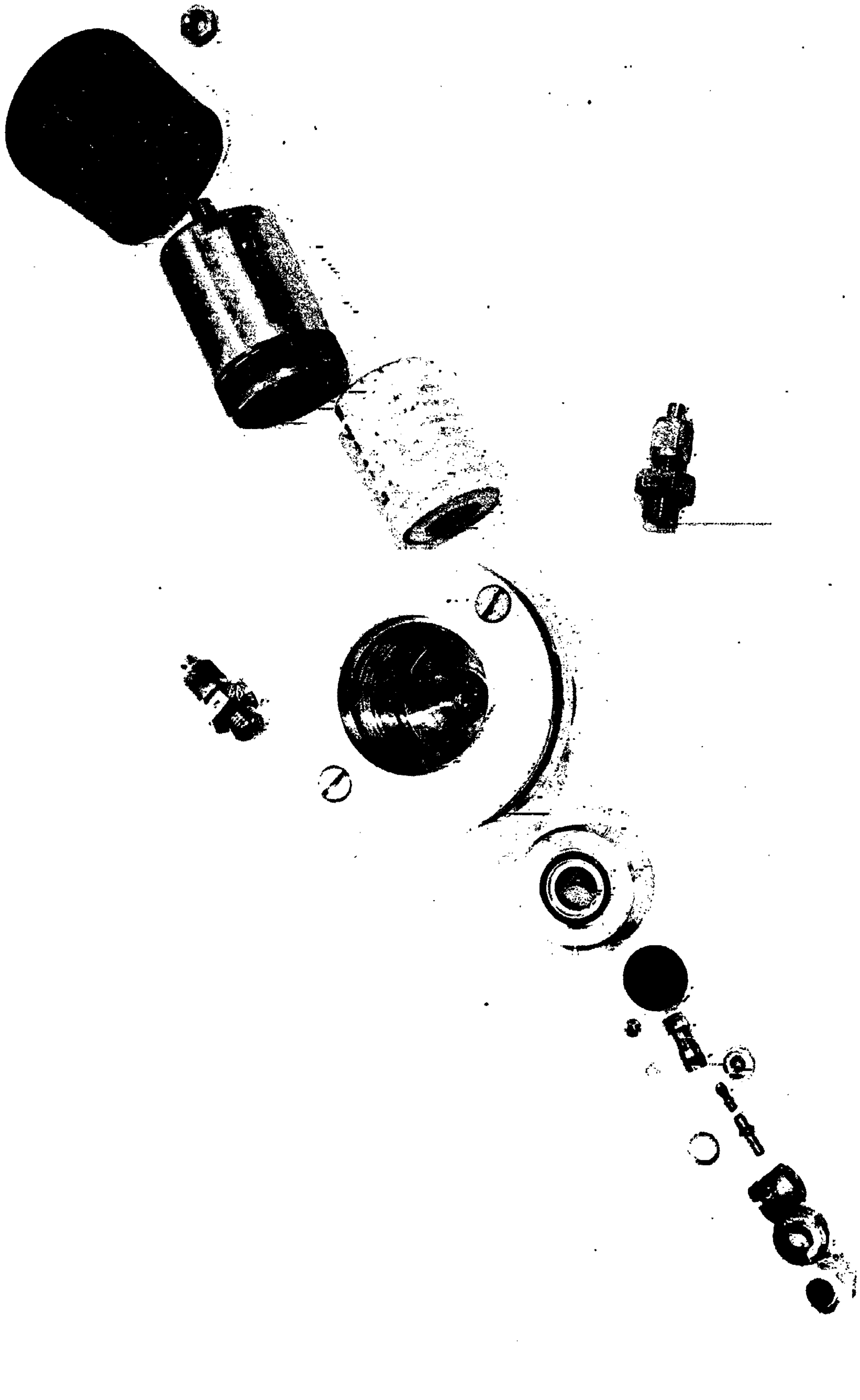


Figure VIII-22 Pressure Handloader (75M08829)

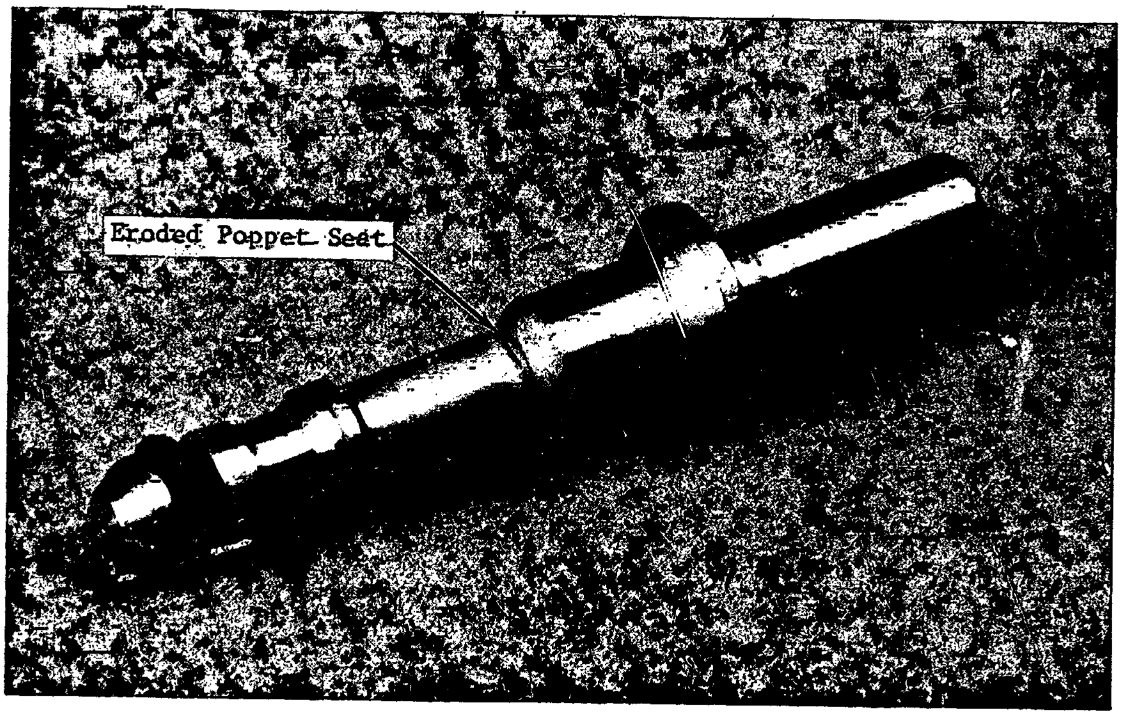


Figure VIII-23 Poppet Stem (75M08829).

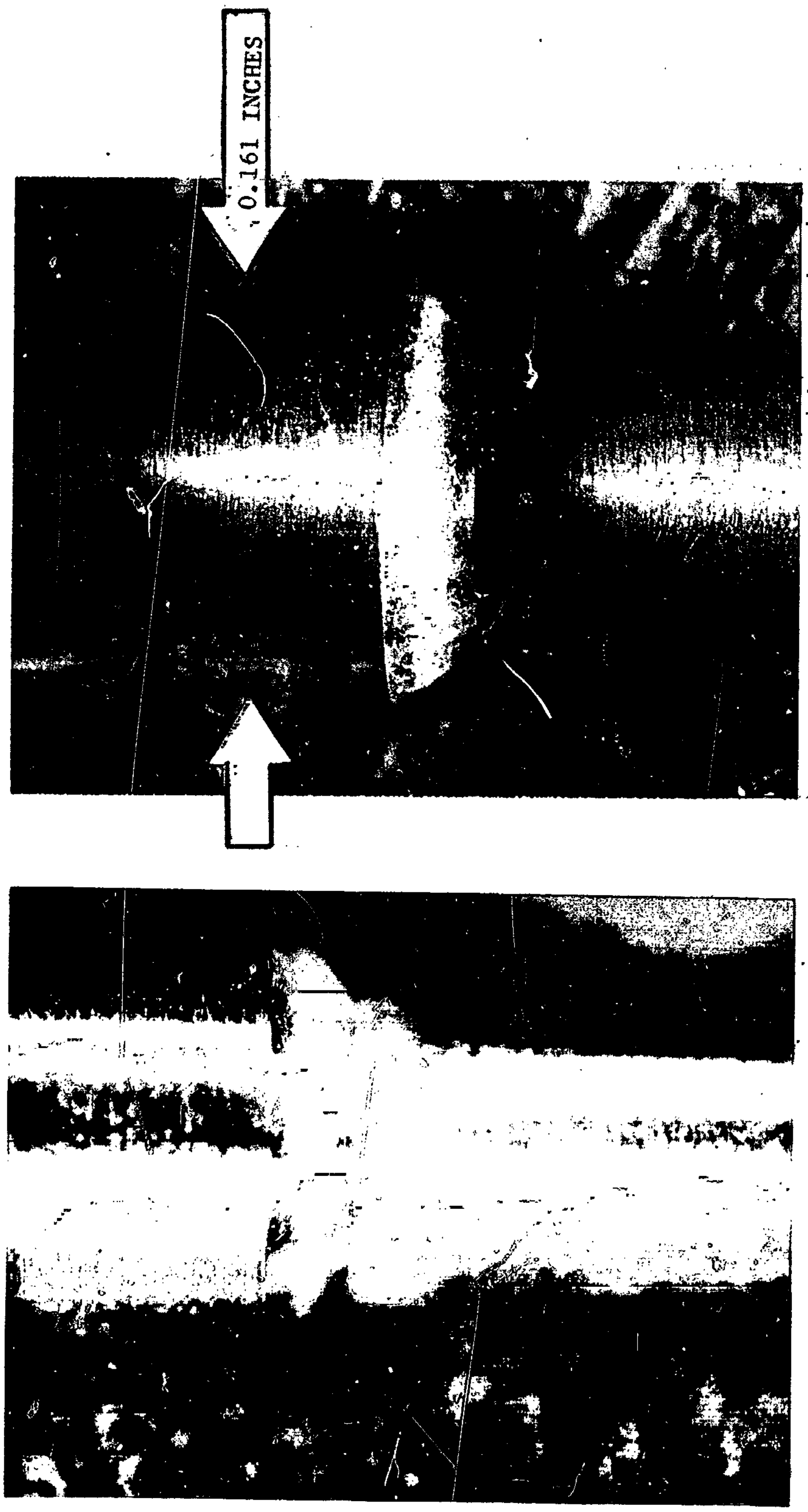


Figure VIII-24 Eroded Poppet Seat Nitrogen Handloader (75M08829), 15X Magnification

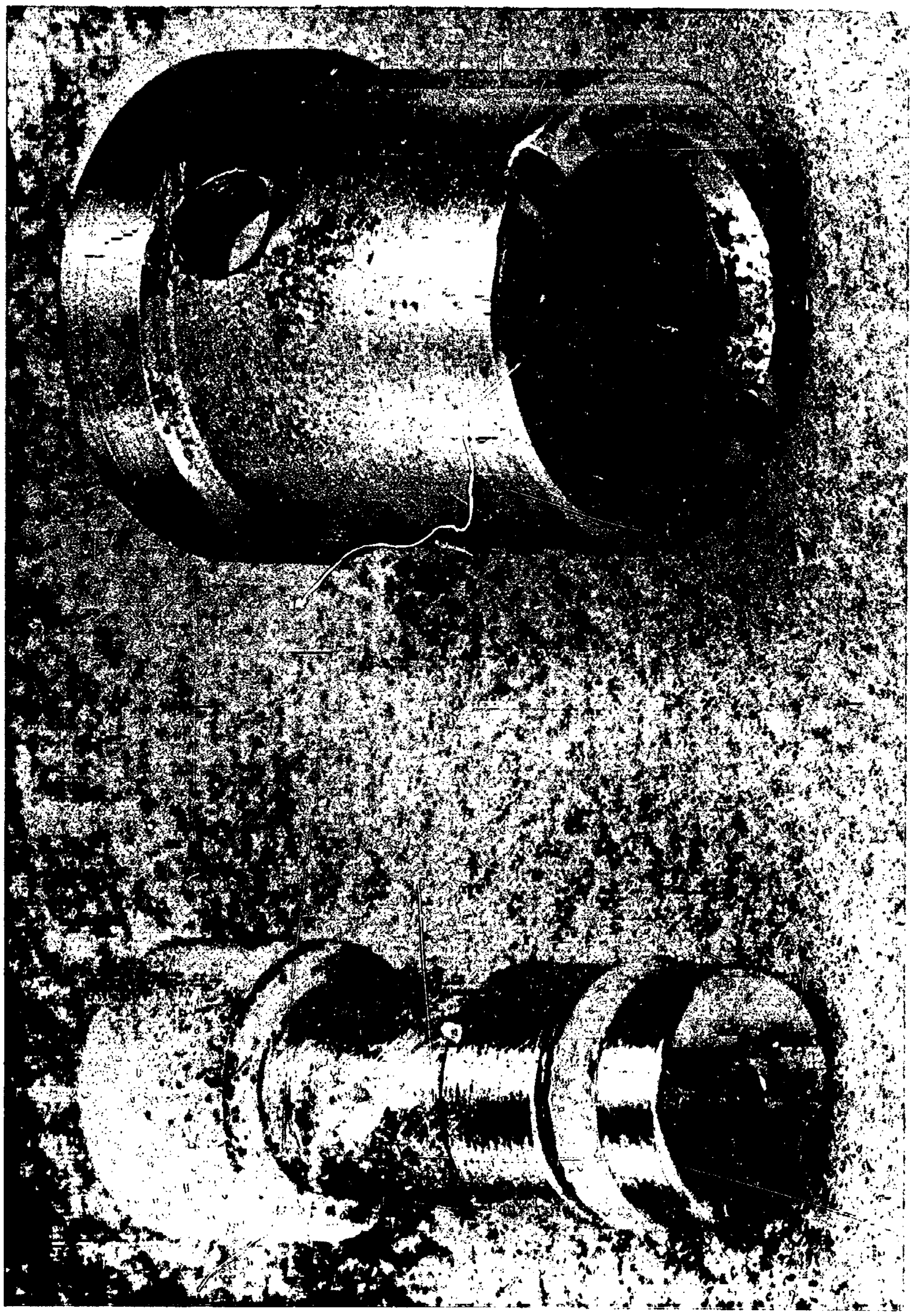


Figure VIII-25 Sensing Piston and Spool (75M08829)

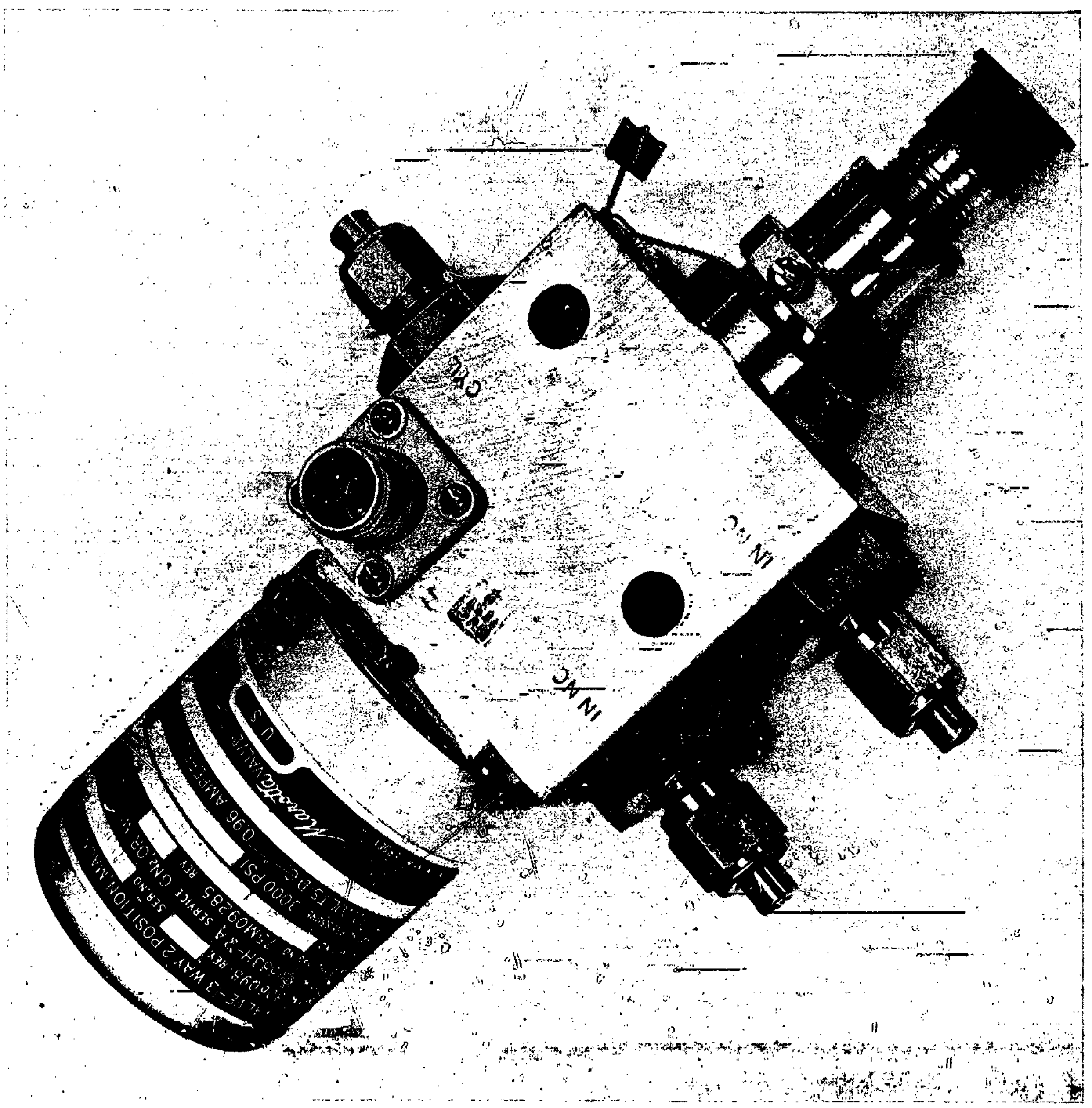


Figure VIII-26 Three-Way Solenoid Valve (75M09285-1, S/N 280)

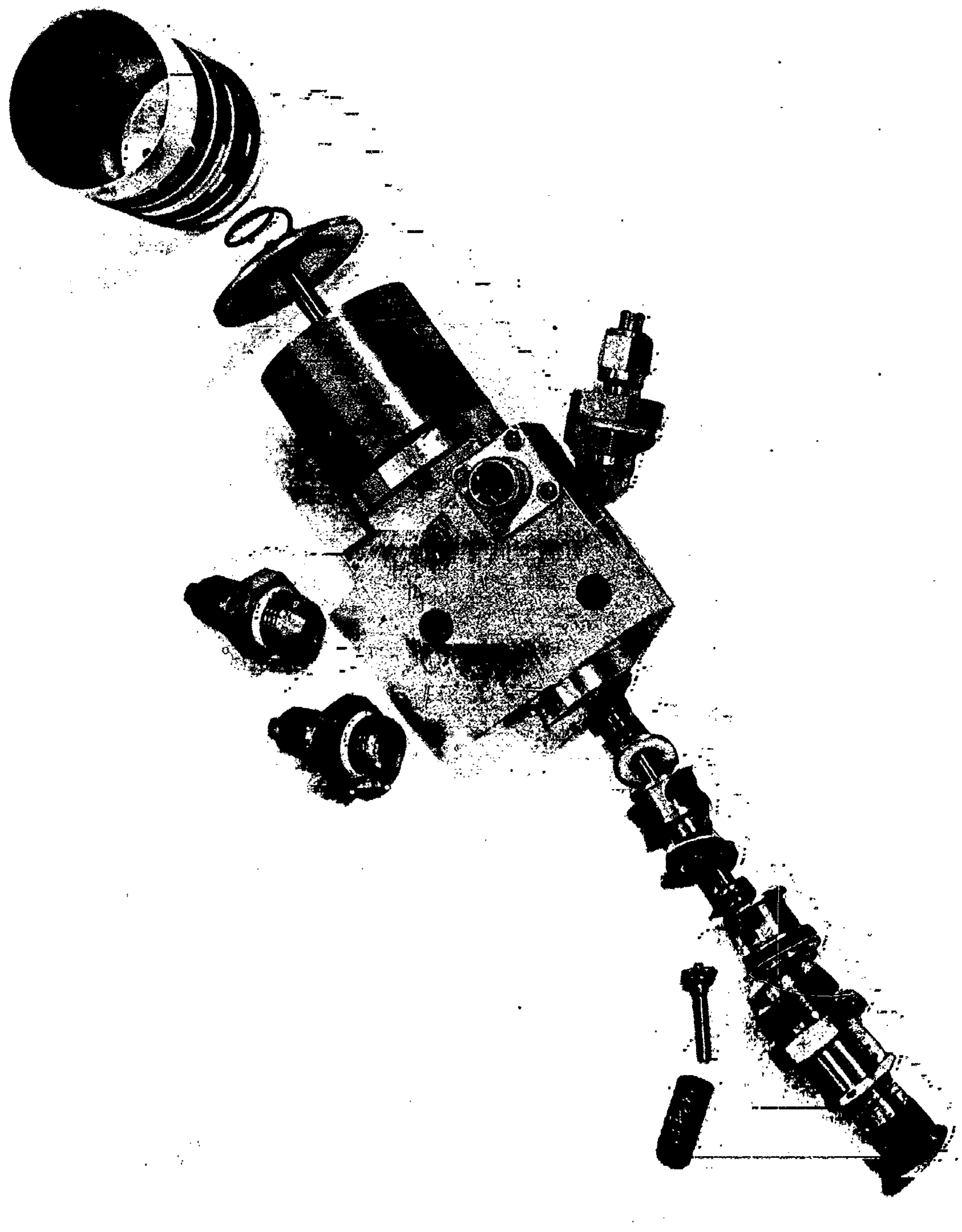


Figure VIII-27 Three-Way Solenoid Valve (75M09285-1, S/N 280)

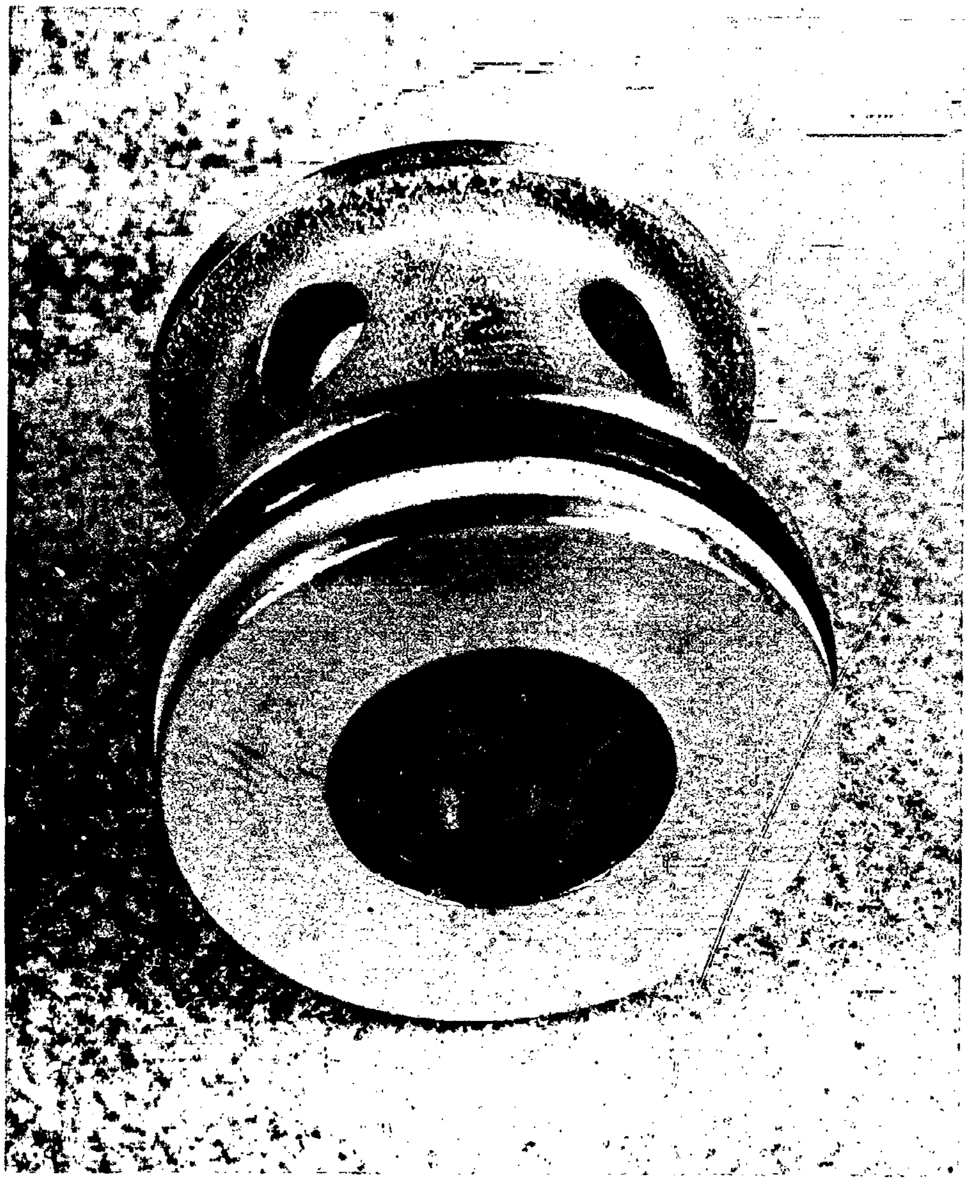


Figure VIII-28 Spool Piece (75M09285-1, S/N 280)

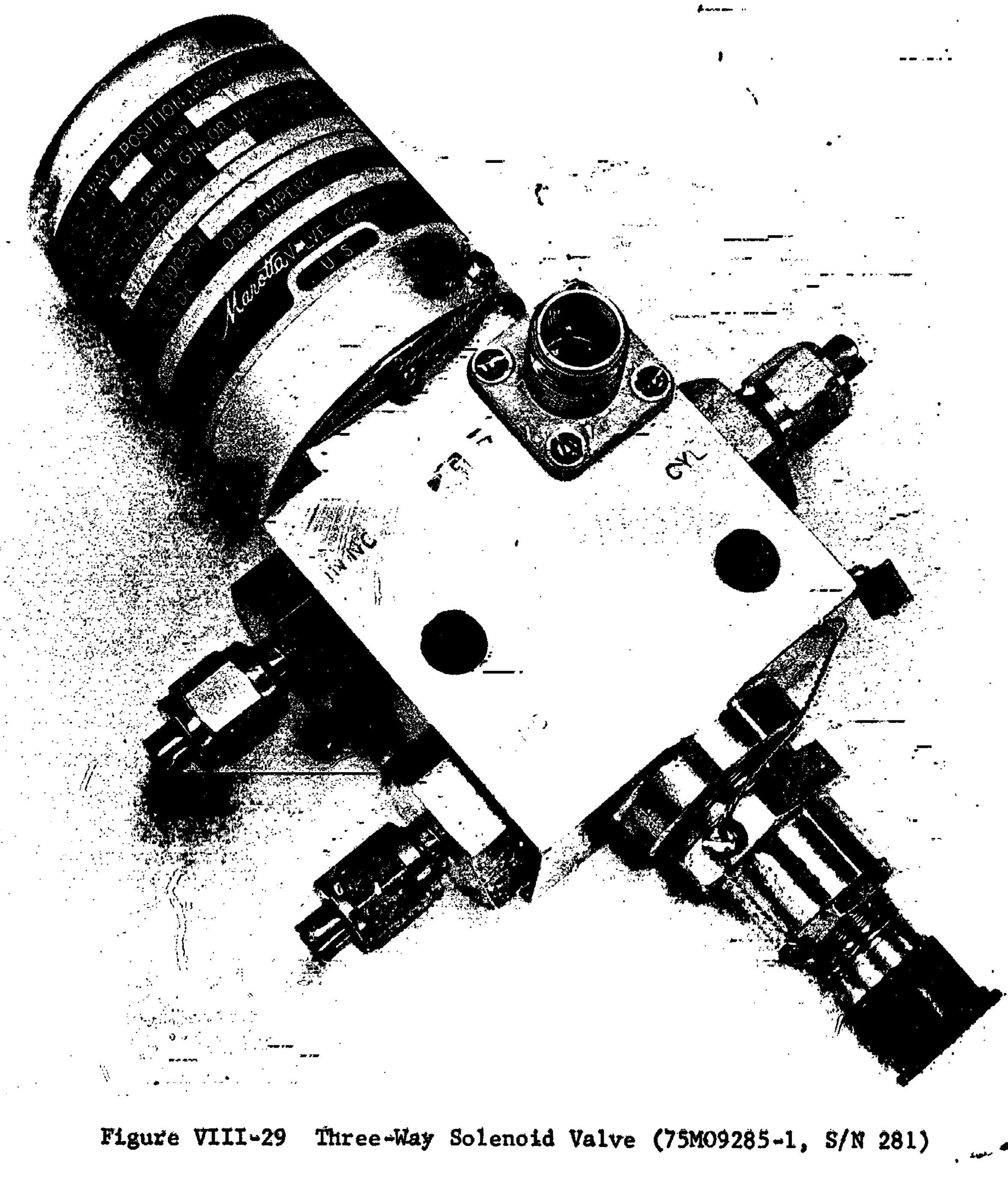


Figure VIII-29 Three-Way Solenoid Valve (75M09285-1, S/N 281)

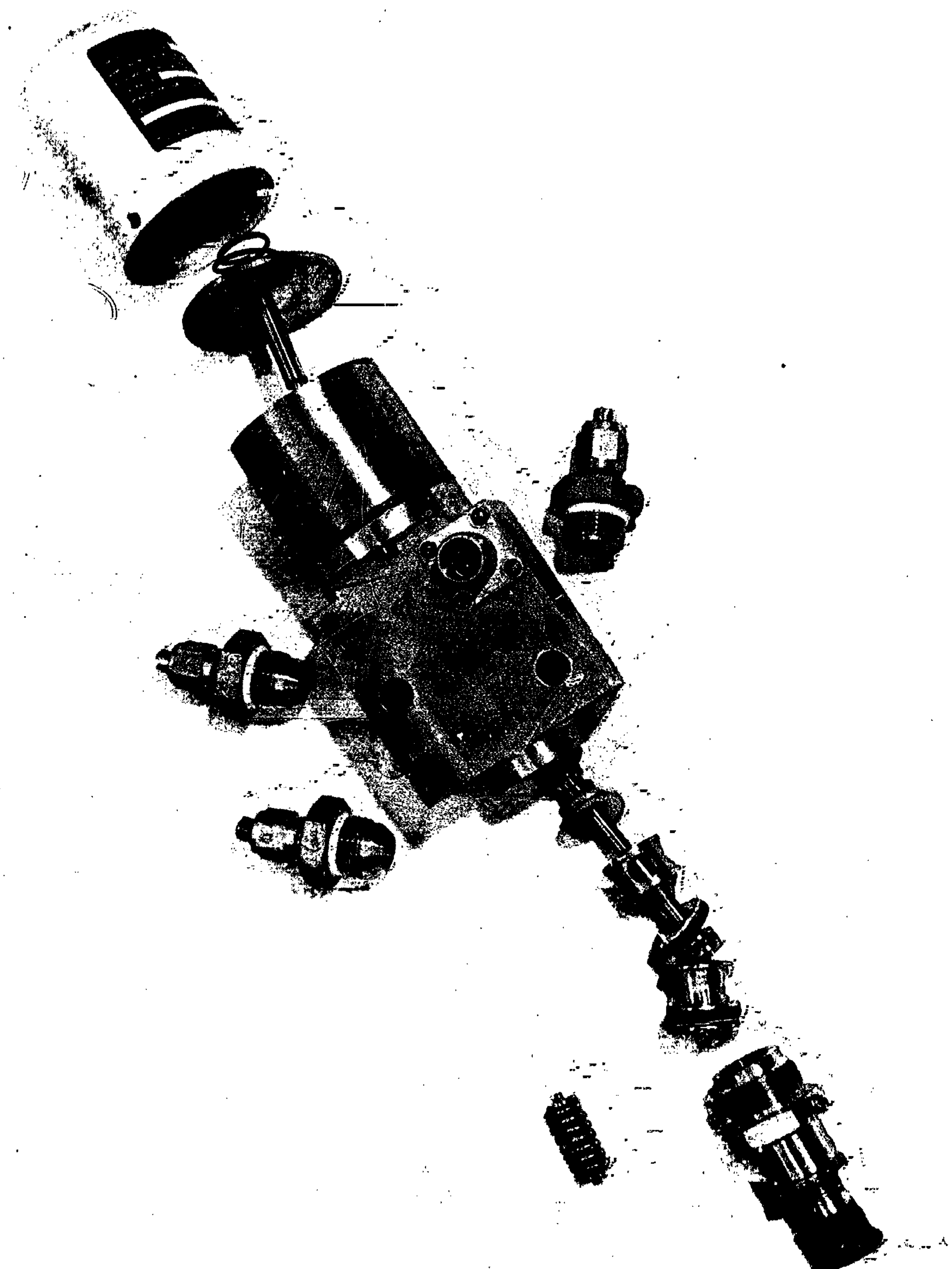


Figure VIII-30 Three-Way Solenoid Valve (75M09285-1, S/N 281)

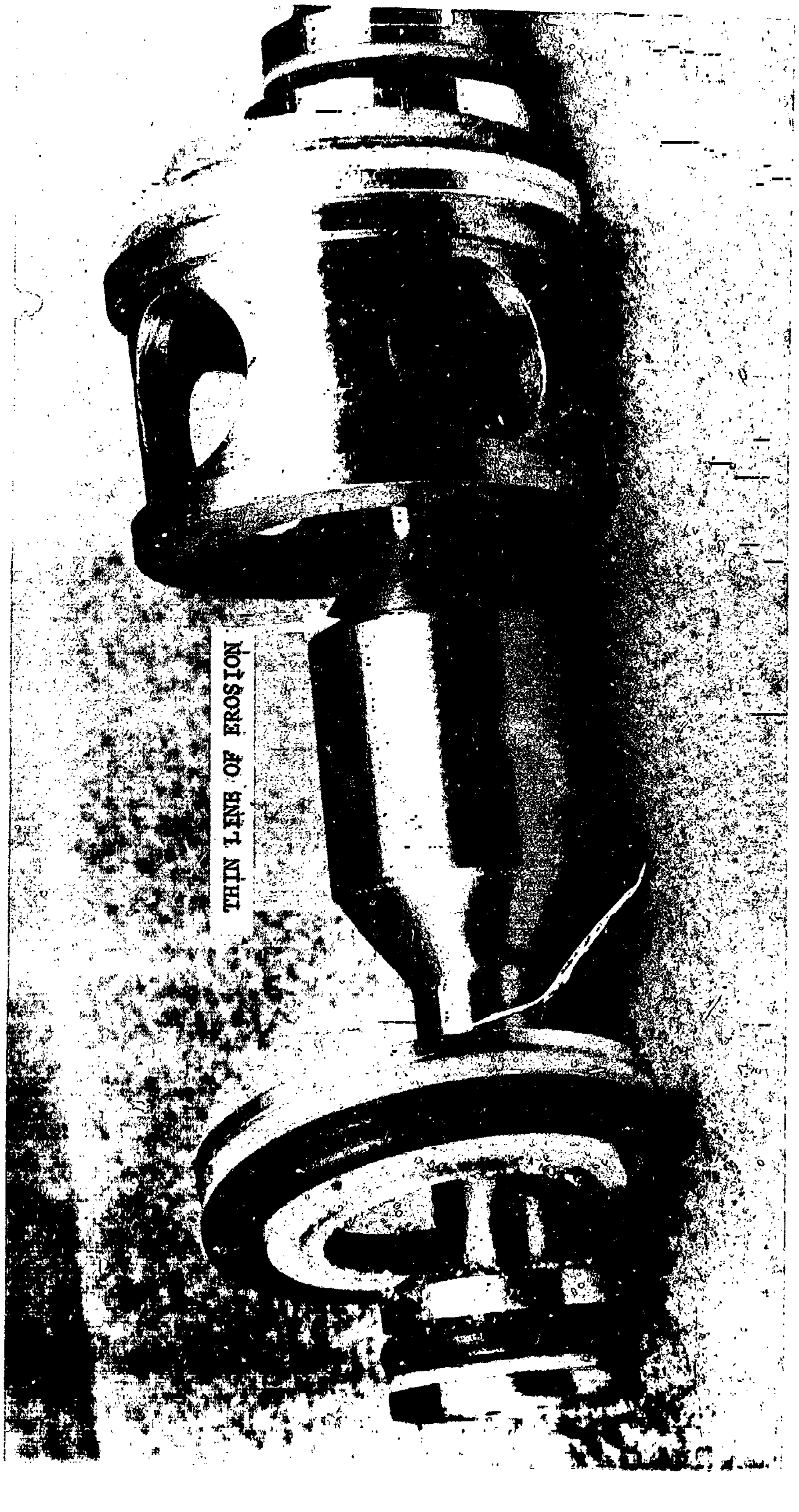


Figure VIII-31 Poppet Stem Assembly (75M09285-1, S/N 281)

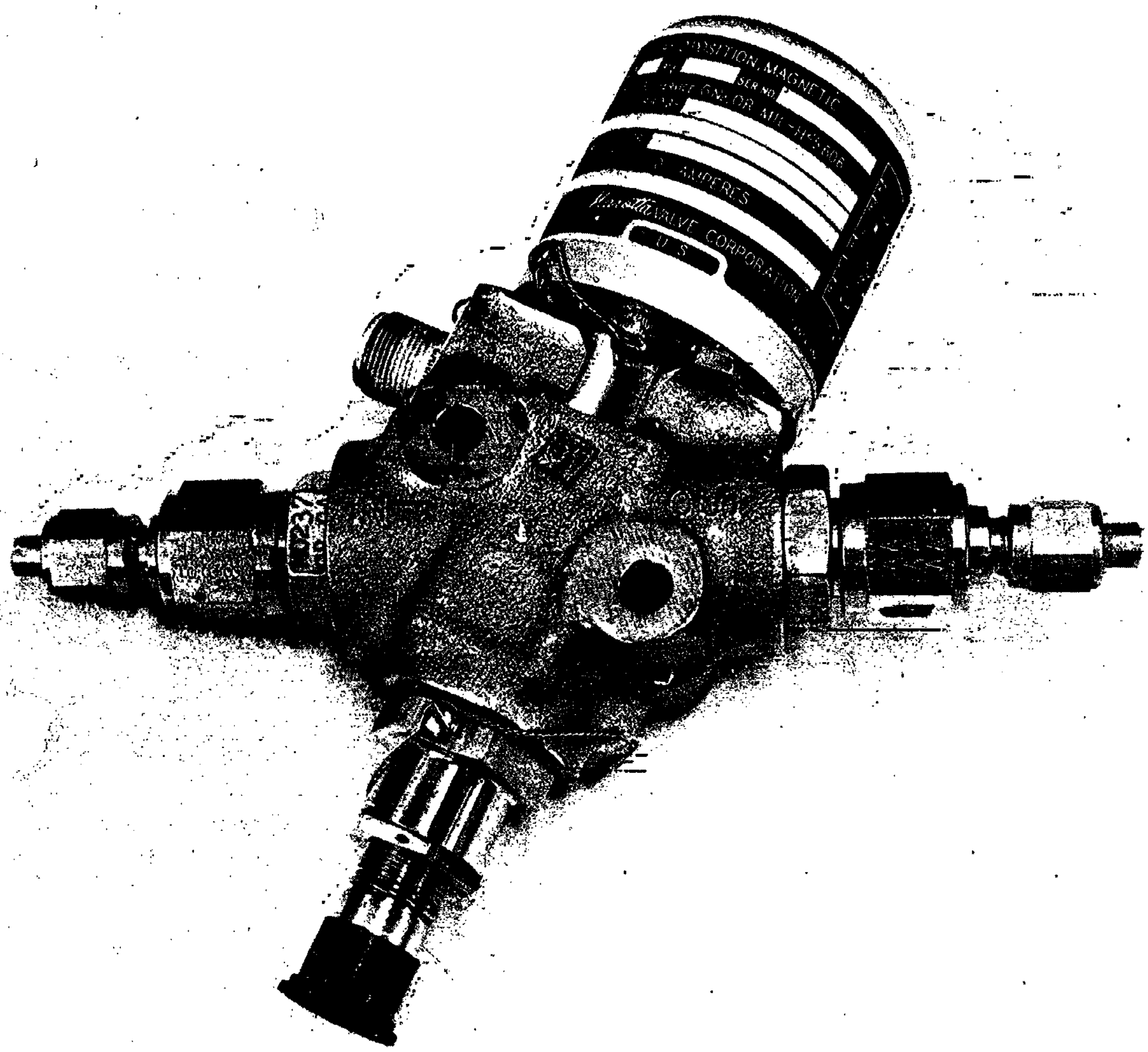


Figure VIII-32 Two-Way Solenoid Valve (75M08823-1)

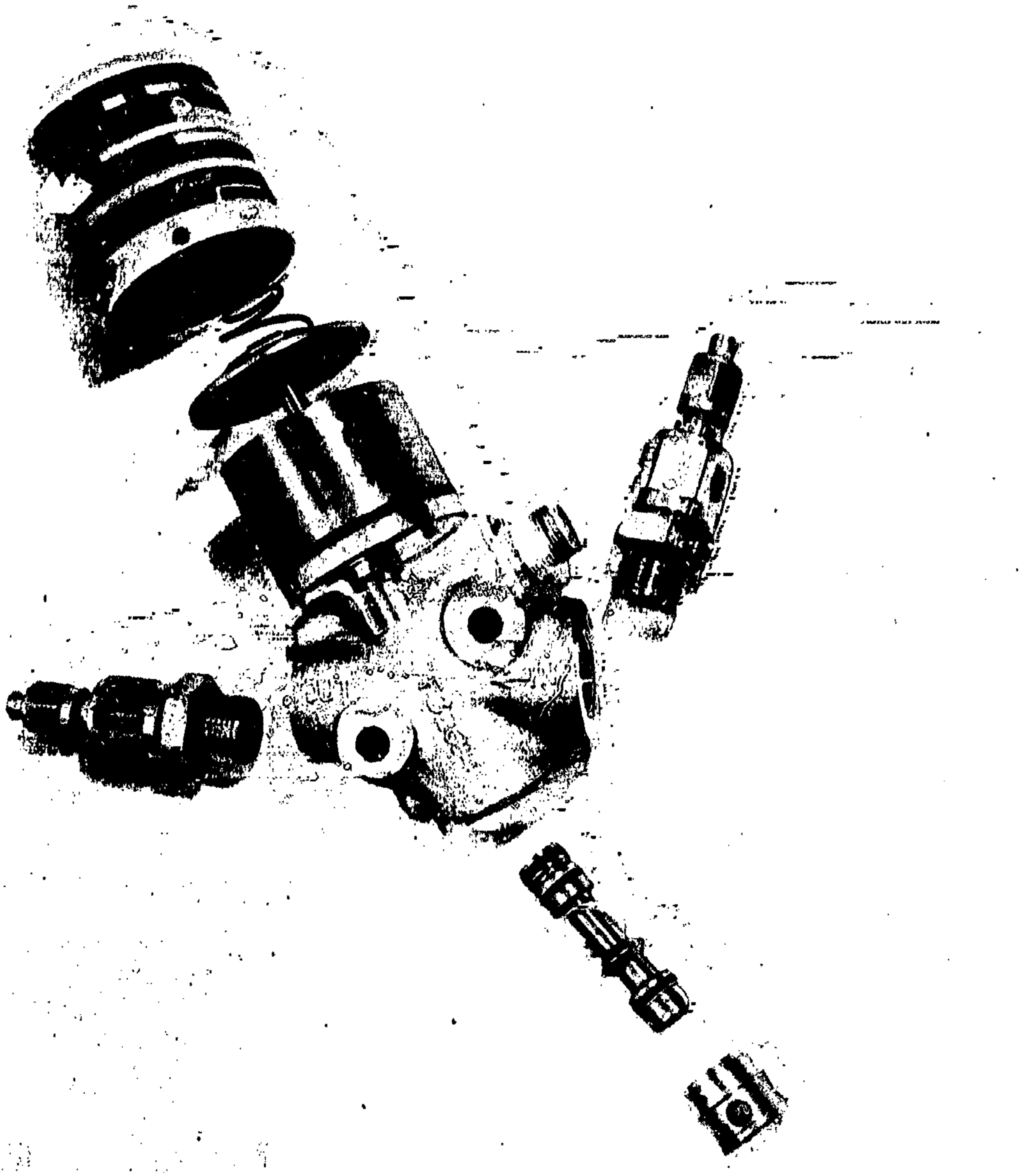


Figure VIII-33 Two-Way Solenoid Valve (75M08823-1)

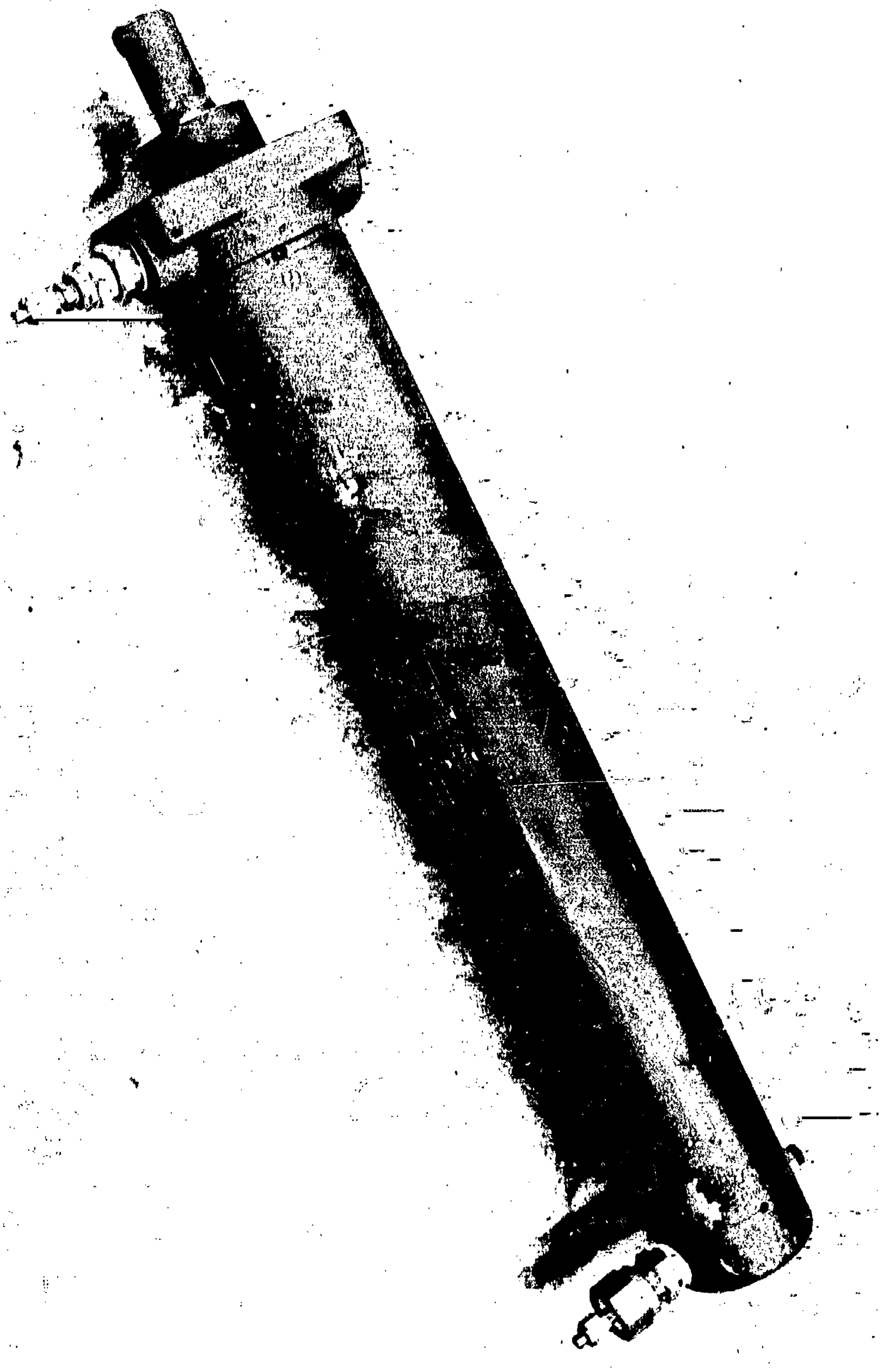


Figure VIII-34 Pneumatic Cylinder (75M09014)

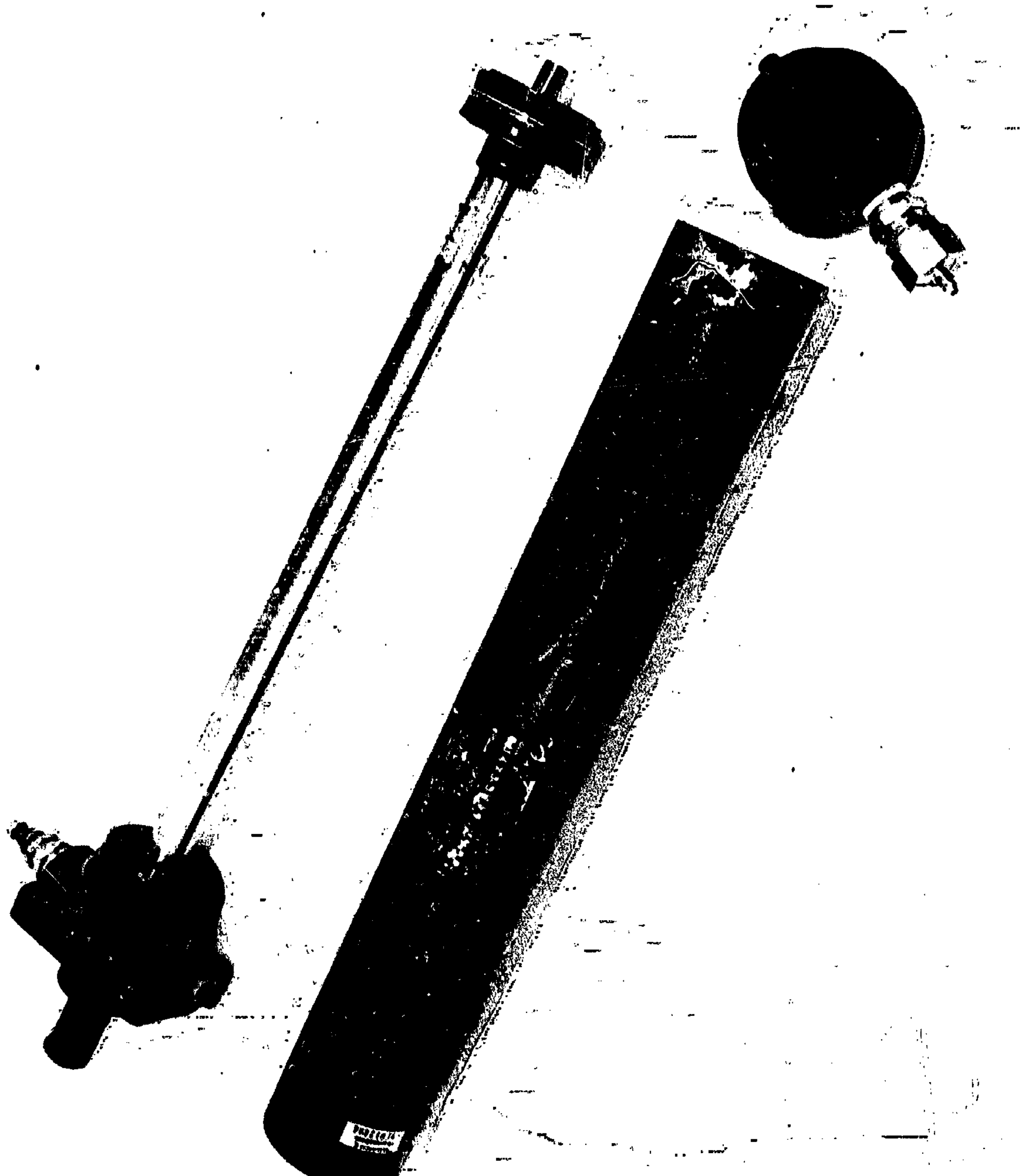


Figure VIII-35 Pneumatic Cylinder (75M09014)

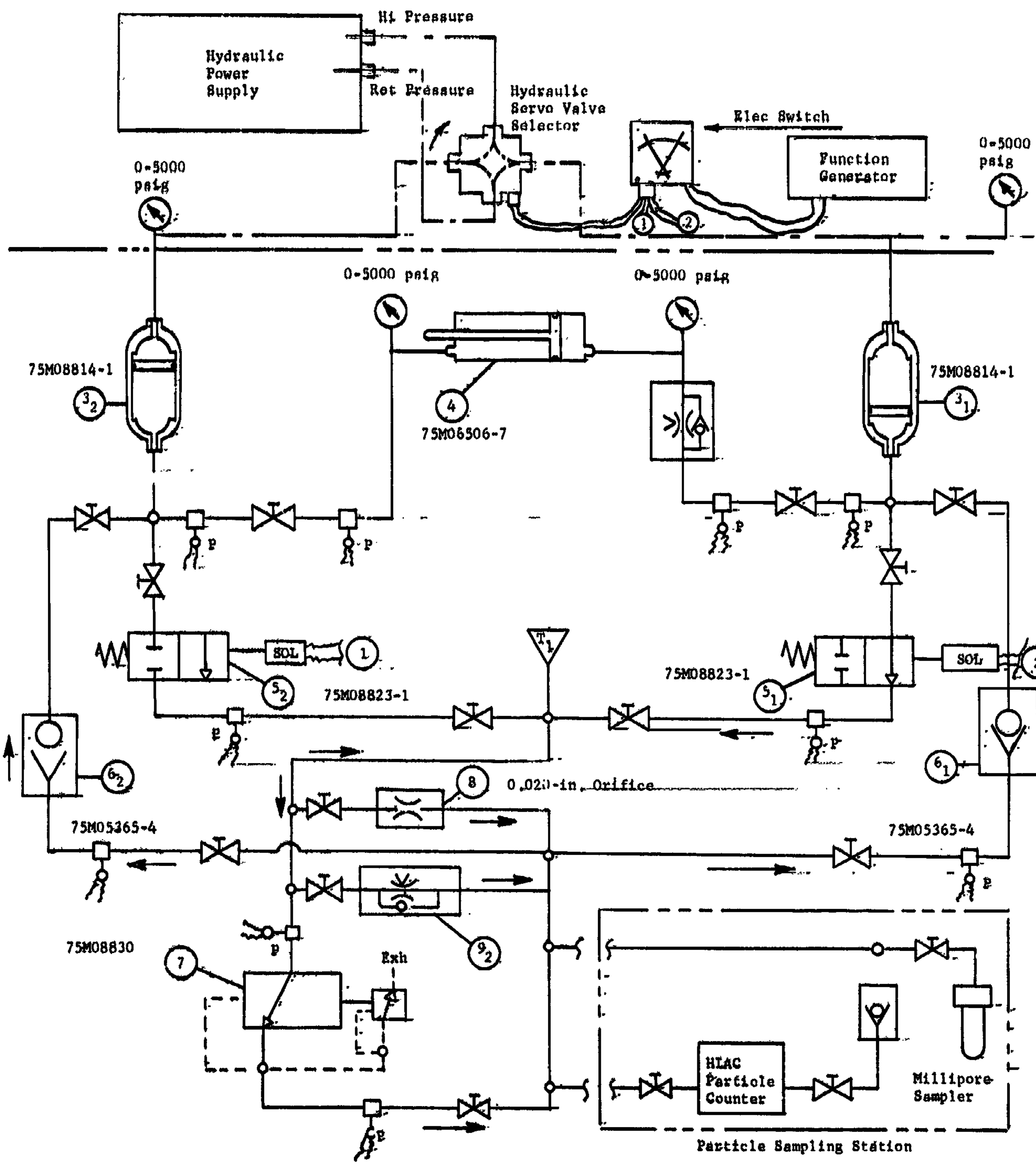


Figure VIII-36 Hydraulic Systems Test Schematic

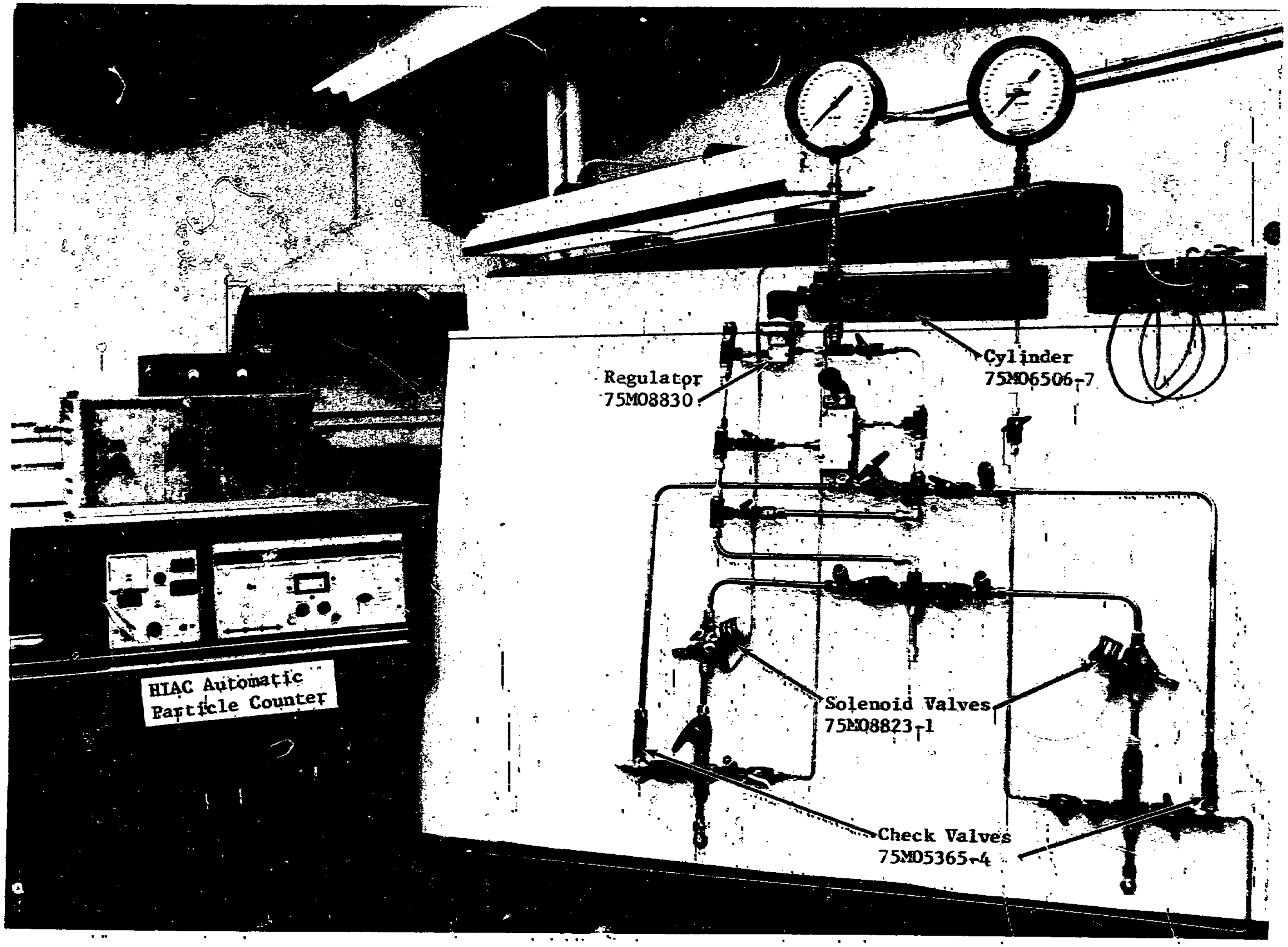


Figure VIII-37 Test System Hydraulic Contamination Tests (front view)

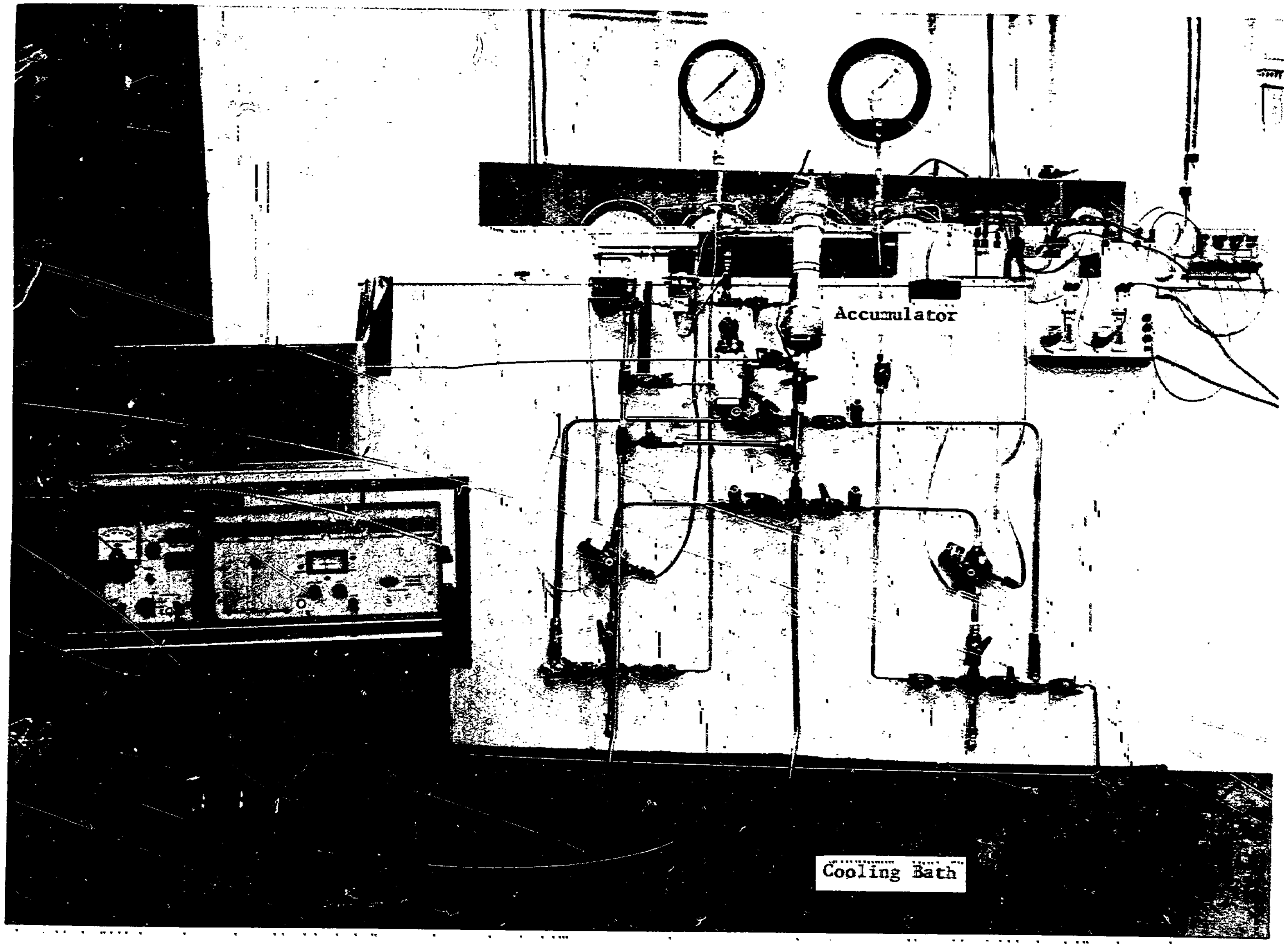


Figure VIII-38 Hydraulic Test System (with accumulator and cooling coils)

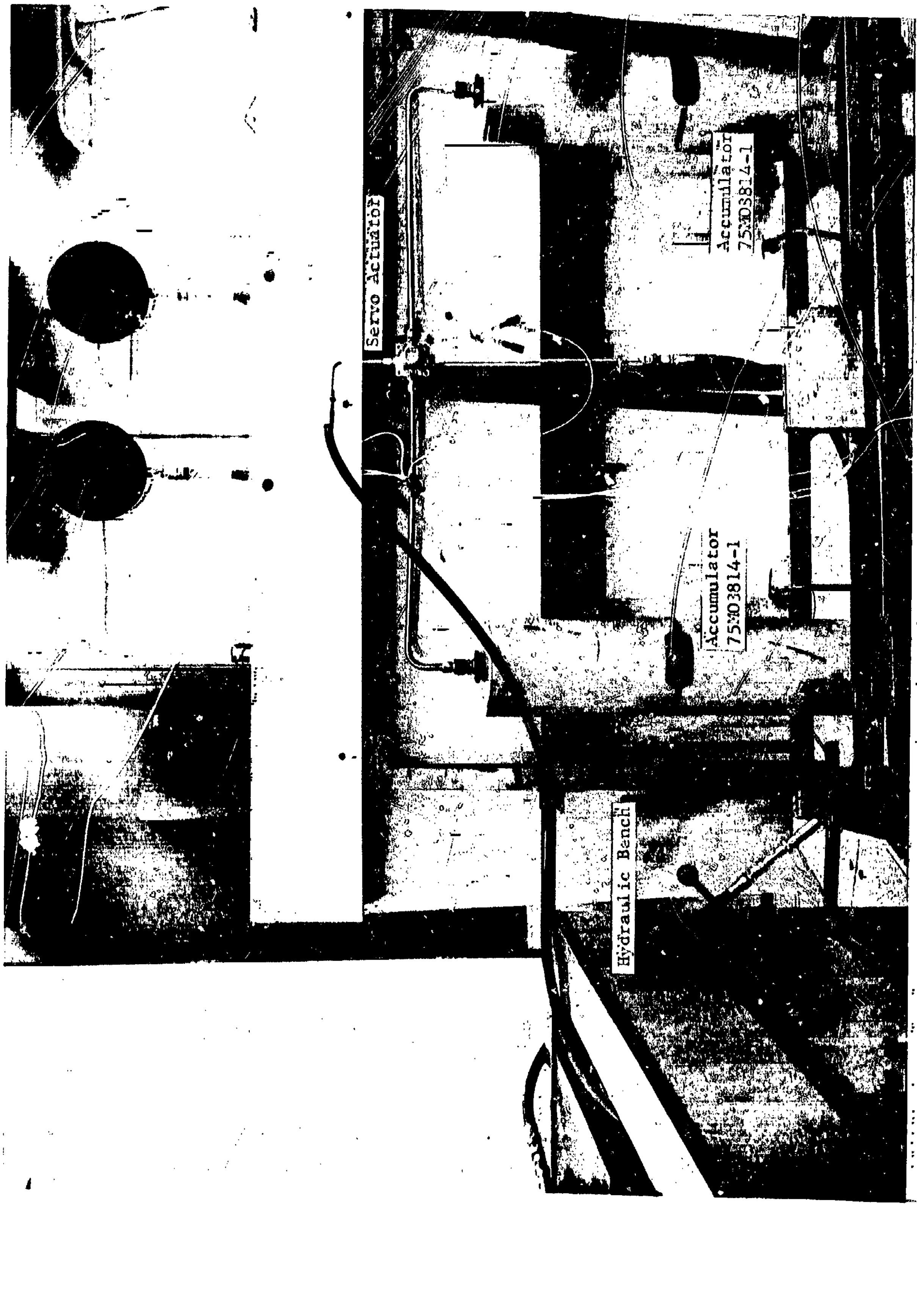


Figure VIII-39 Test System Hydraulic Contamination Tests (rear view)

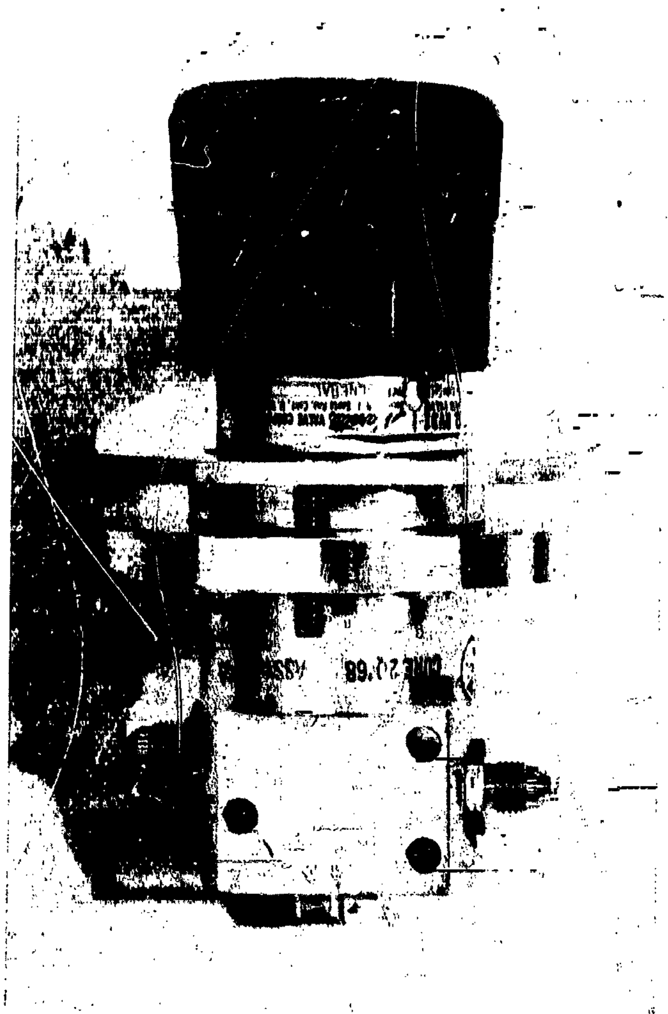


Figure VIII-40 Pressure Handloader (75M08830)

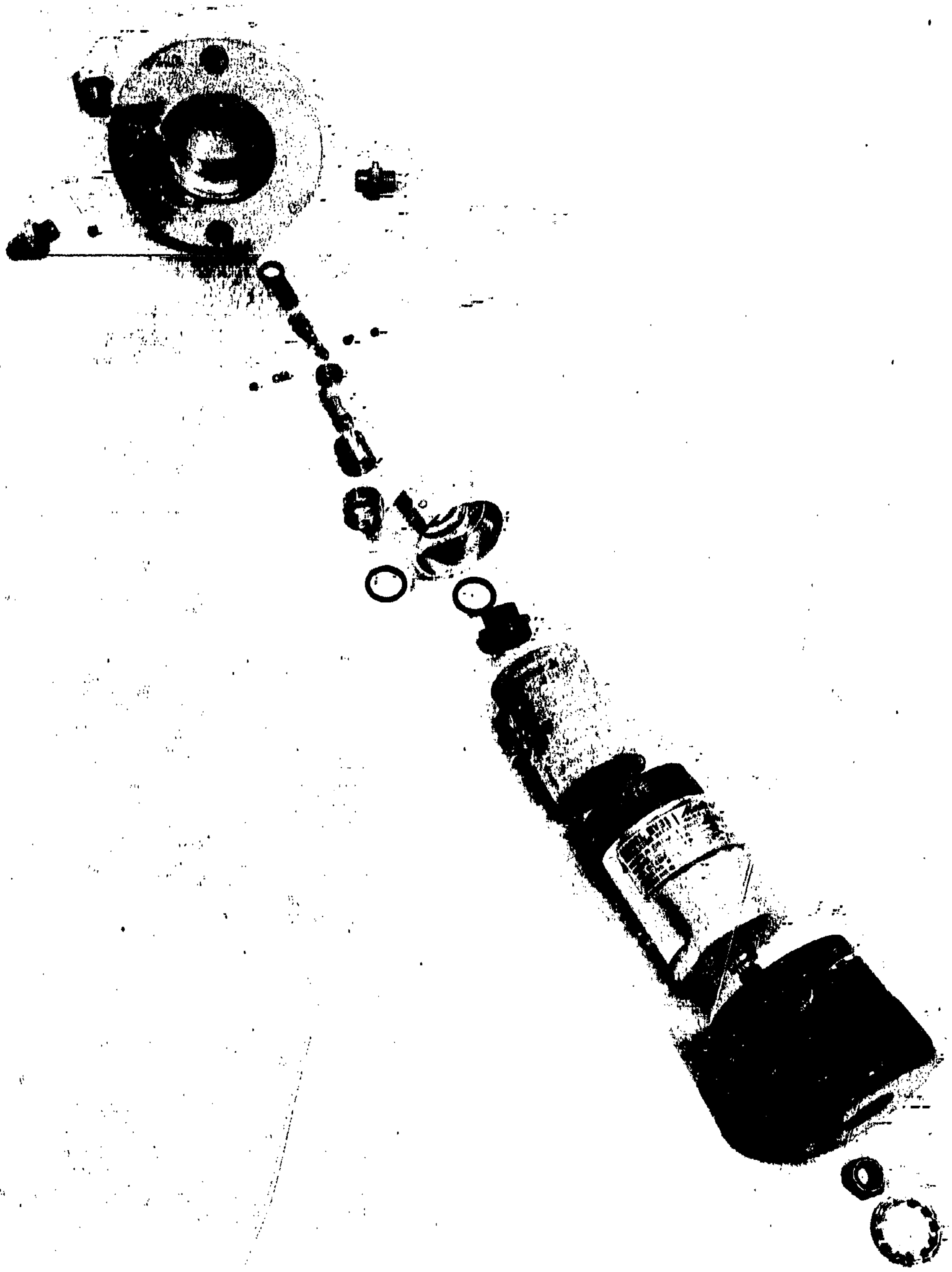


Figure VIII-41 Pressure Handloader (75M08830)

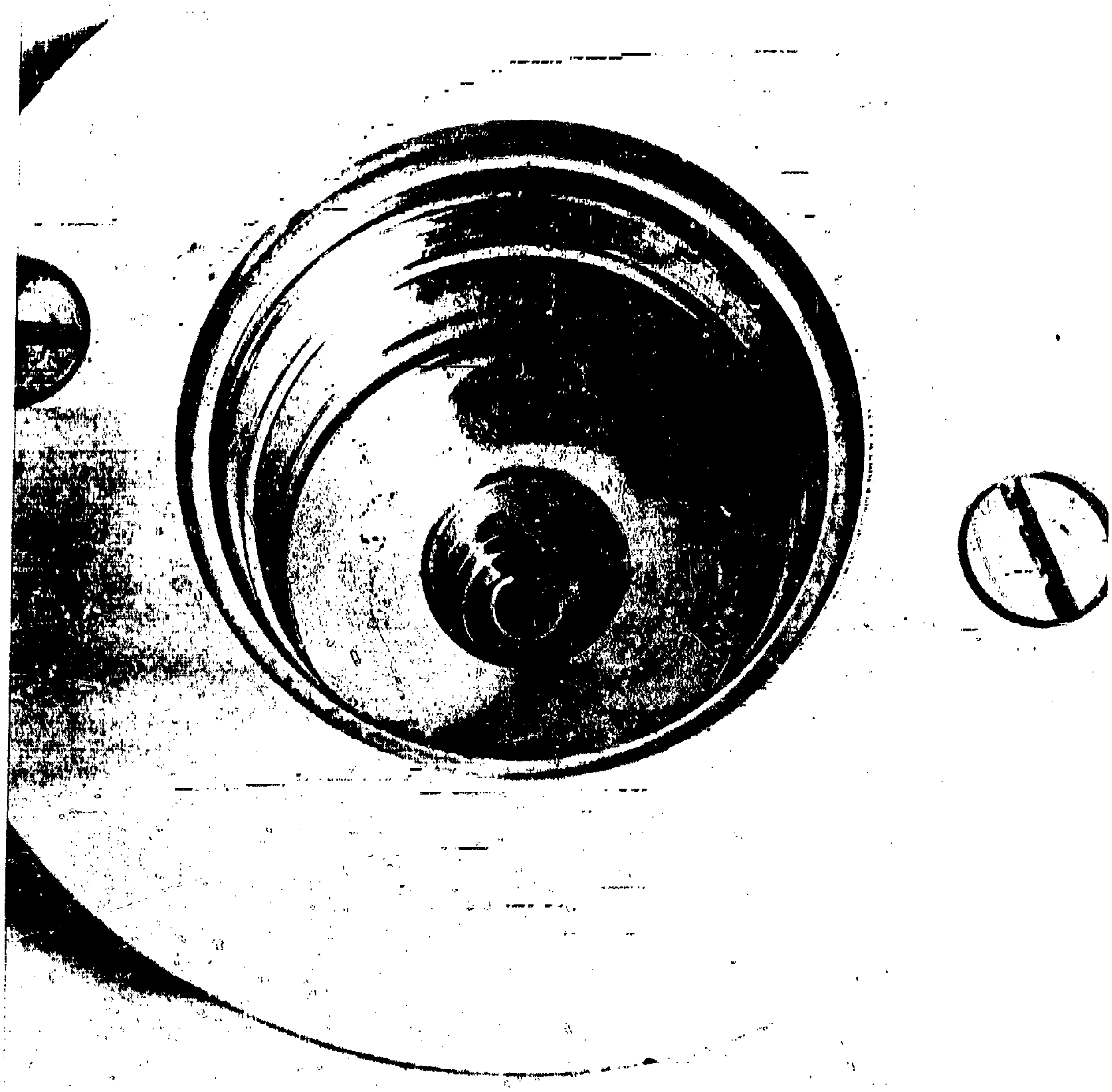


Figure VIII-42 Valve Body (75M08830)

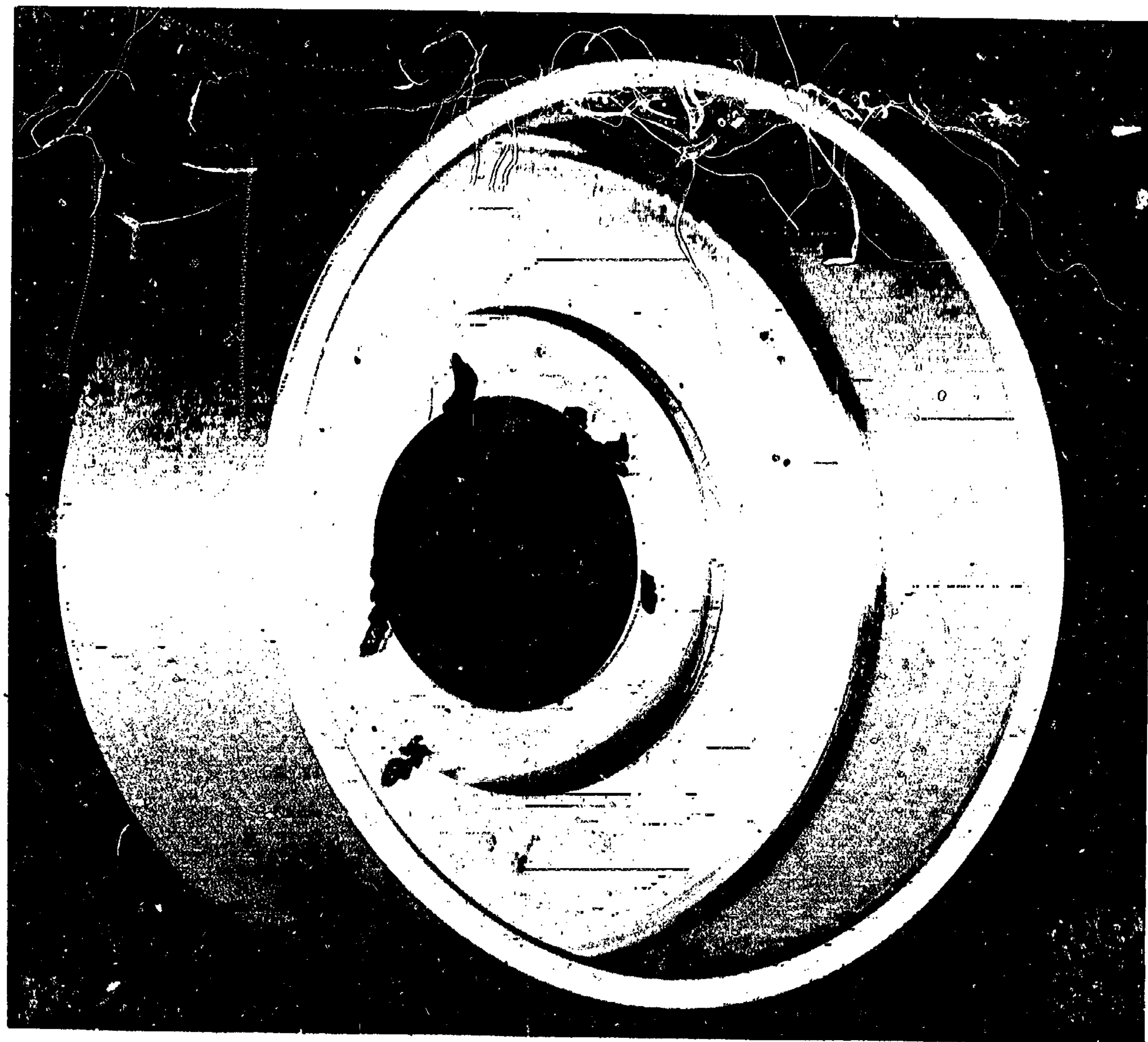


Figure VIII-43. O-Ring Failure Pressure Handloader (75M08830)

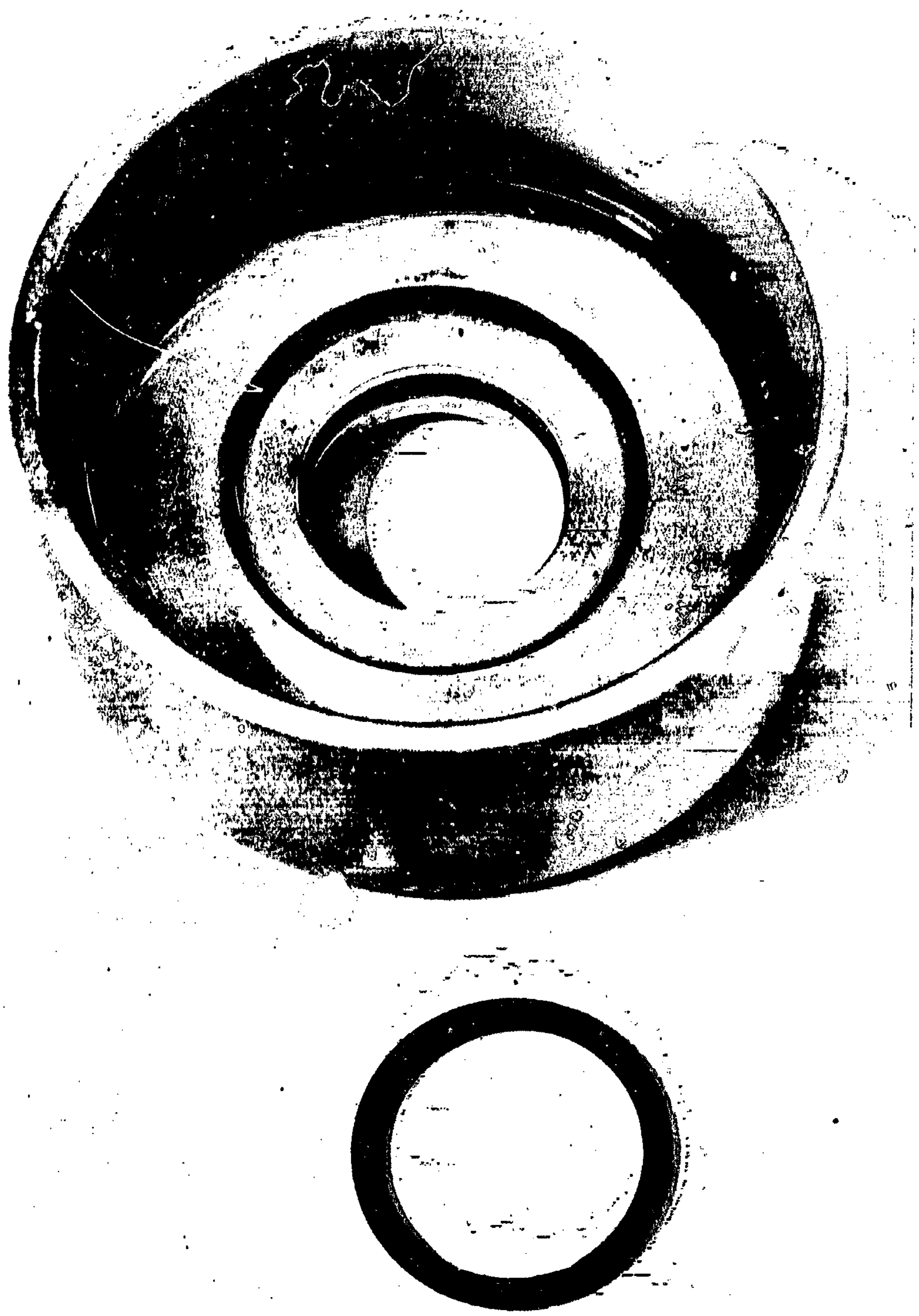


Figure VIII-44 Piston (75M08830)

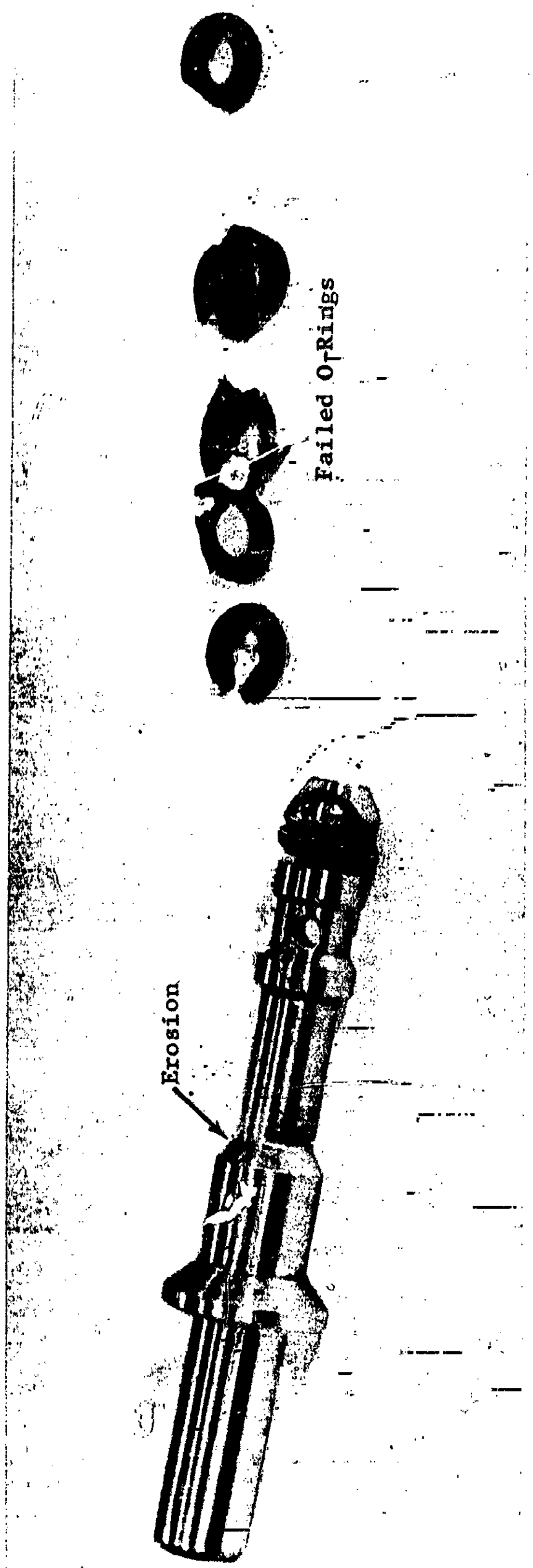
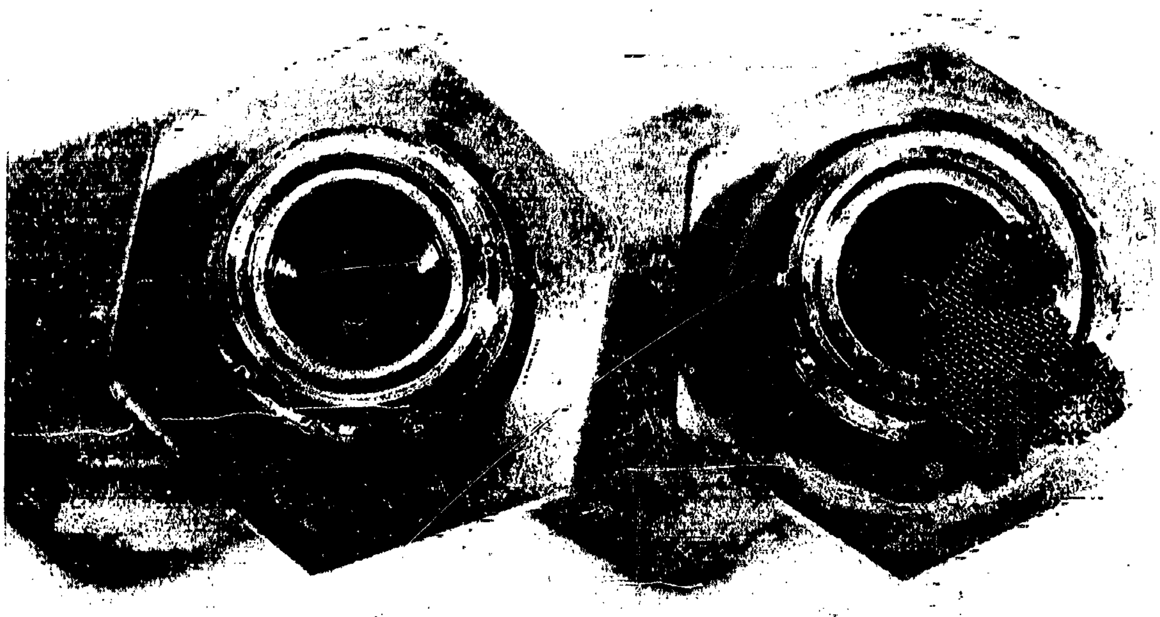


Figure VIII-45 Poppet Stem (75M08830)



Inlet Fitting

Outlet Fitting

Figure VIII-46 Fittings and Filter Screens (75M08830)

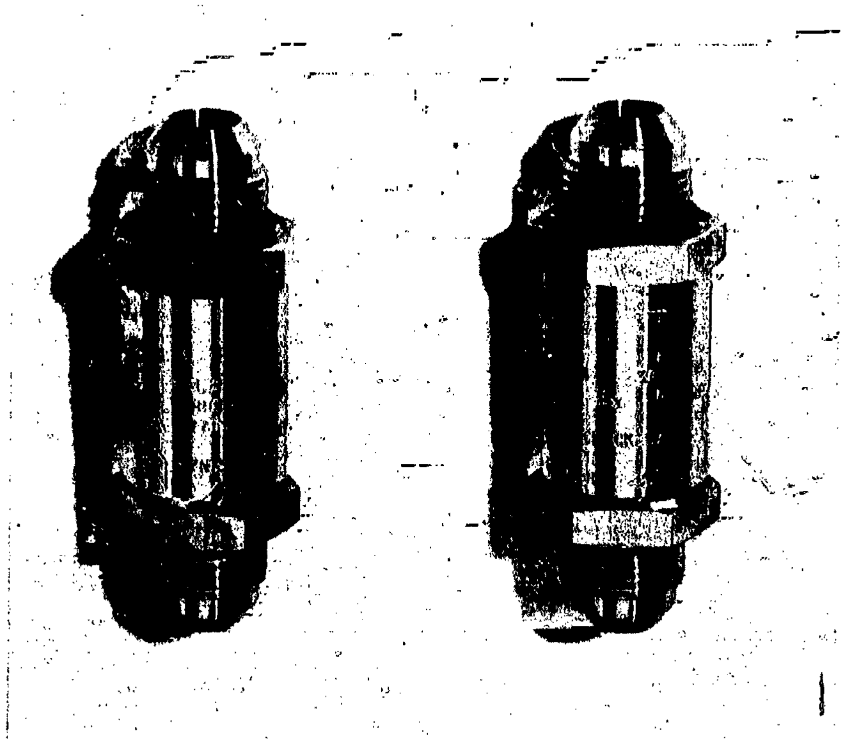


Figure VIII-47 Check Valves (75M05365-4)

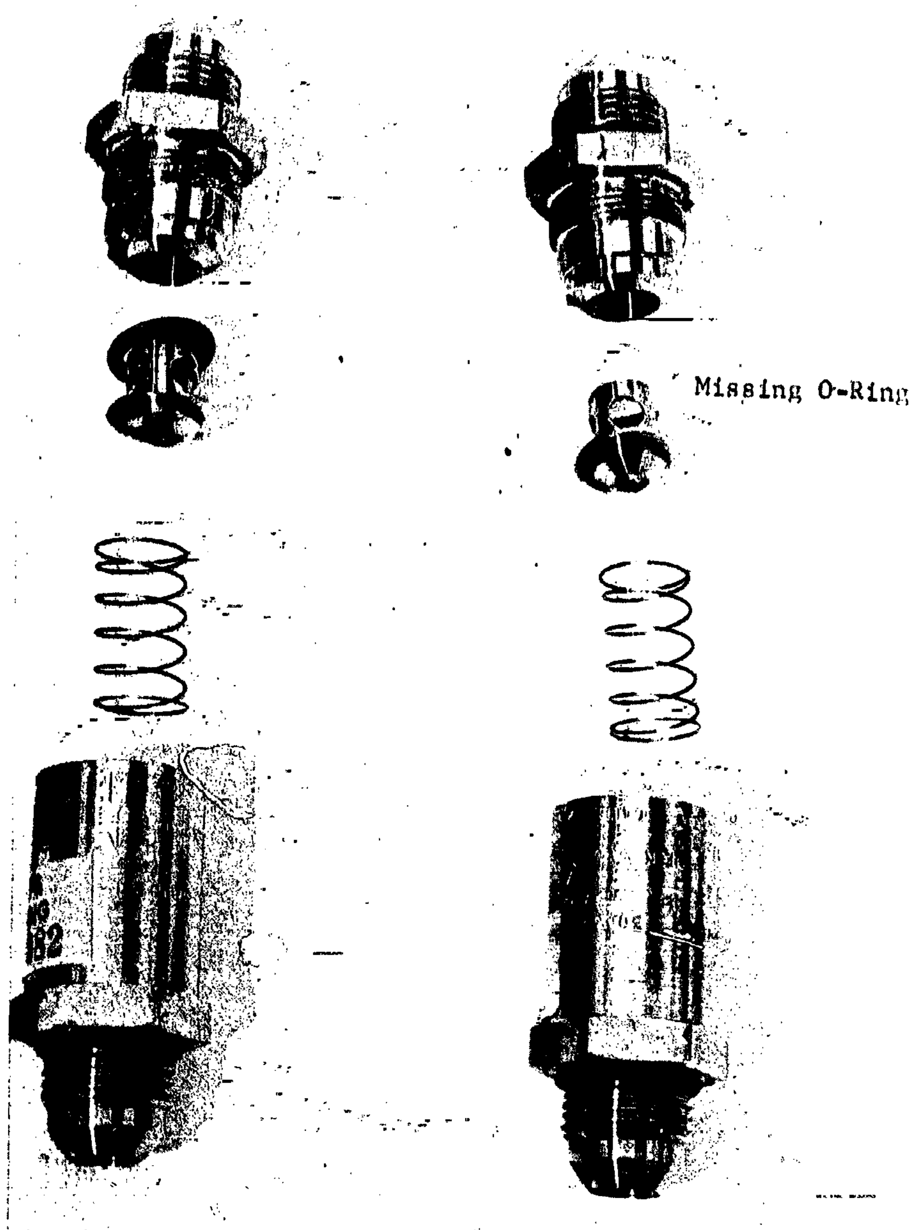


Figure VIII-48 Check Valves (75M05365-4)

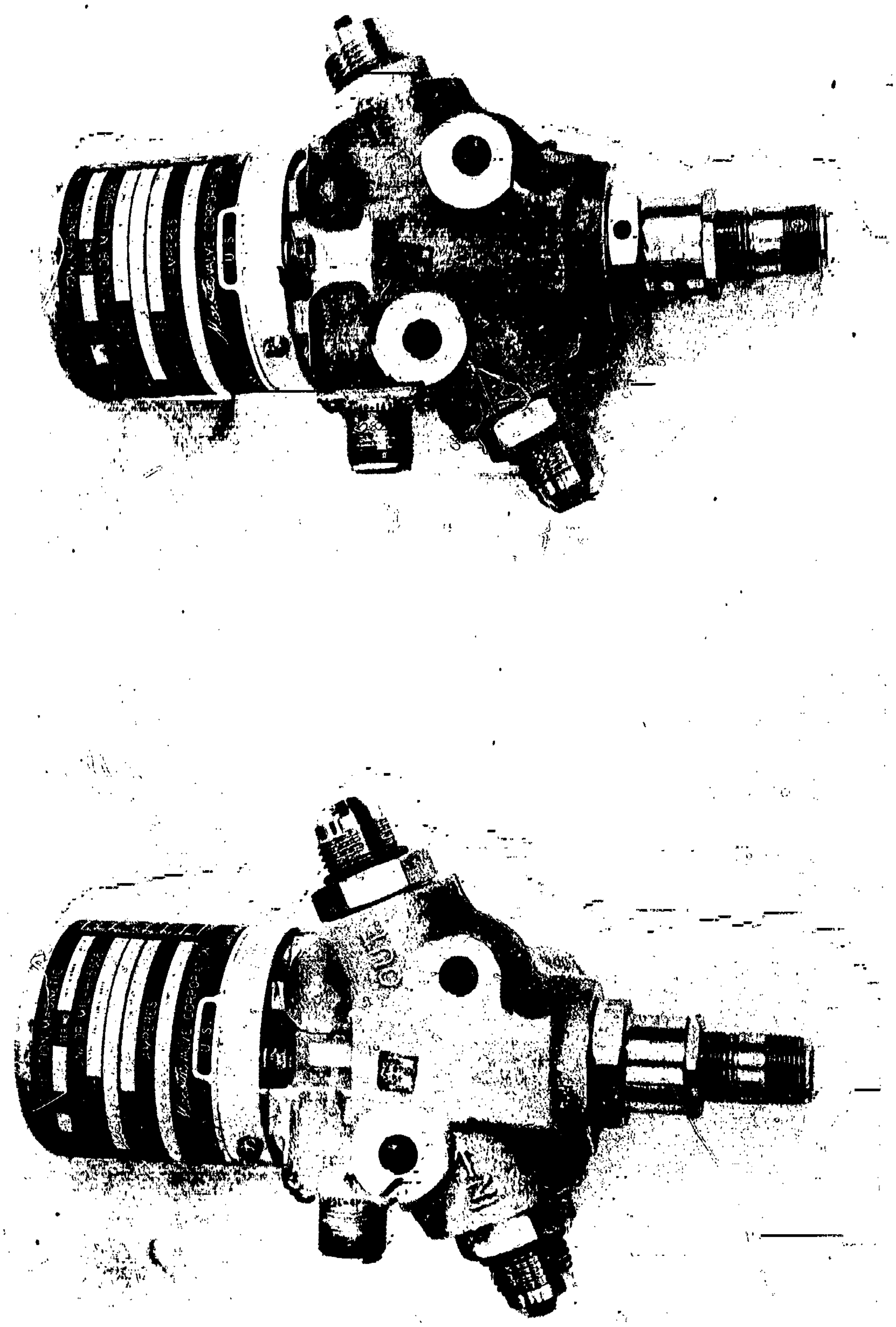


Figure VIII-49 Two-Way Solenoid Valves (75M08823-1)

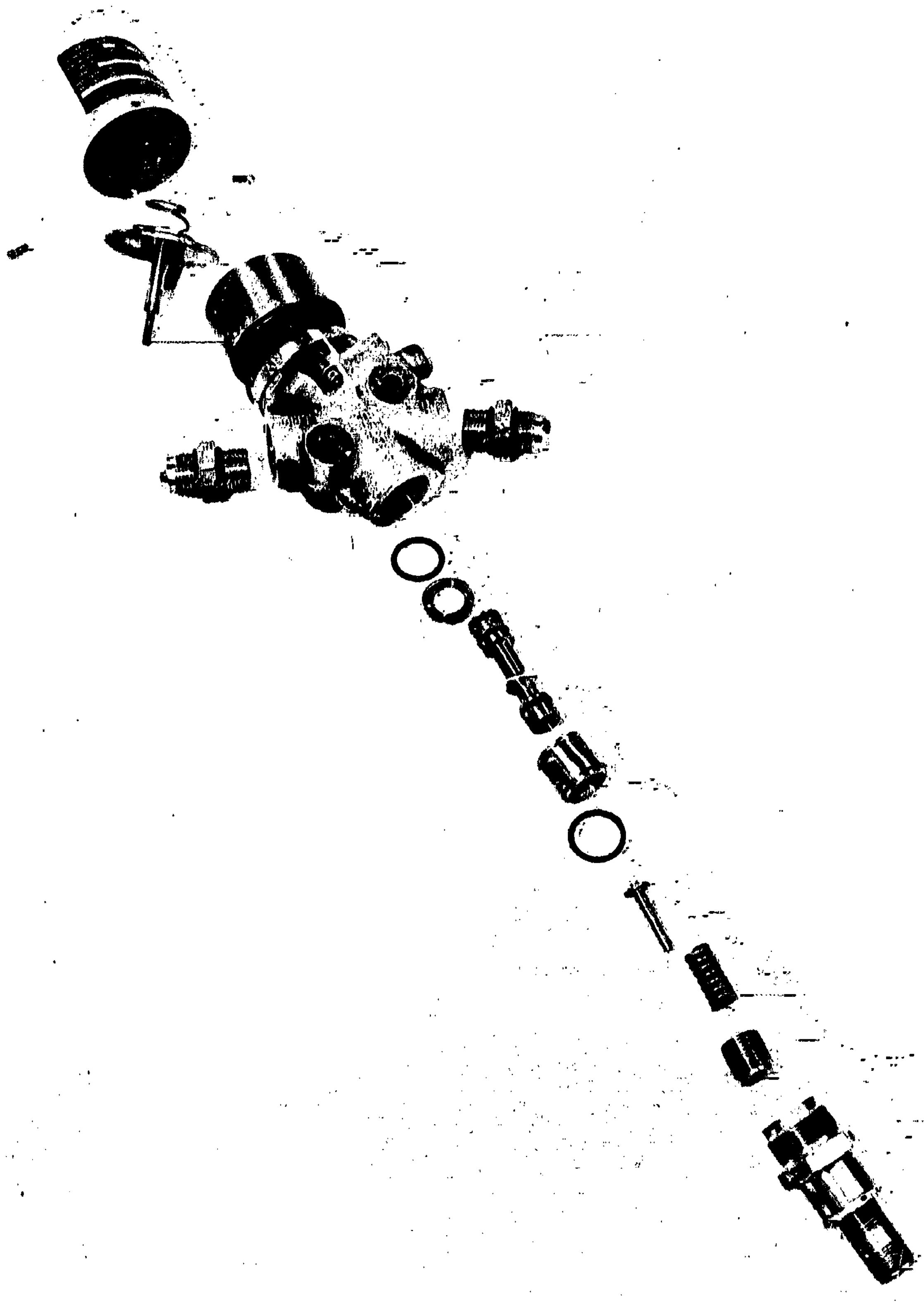


Figure VIII-50 Two-Way Solenoid Valve (75M08823-1)

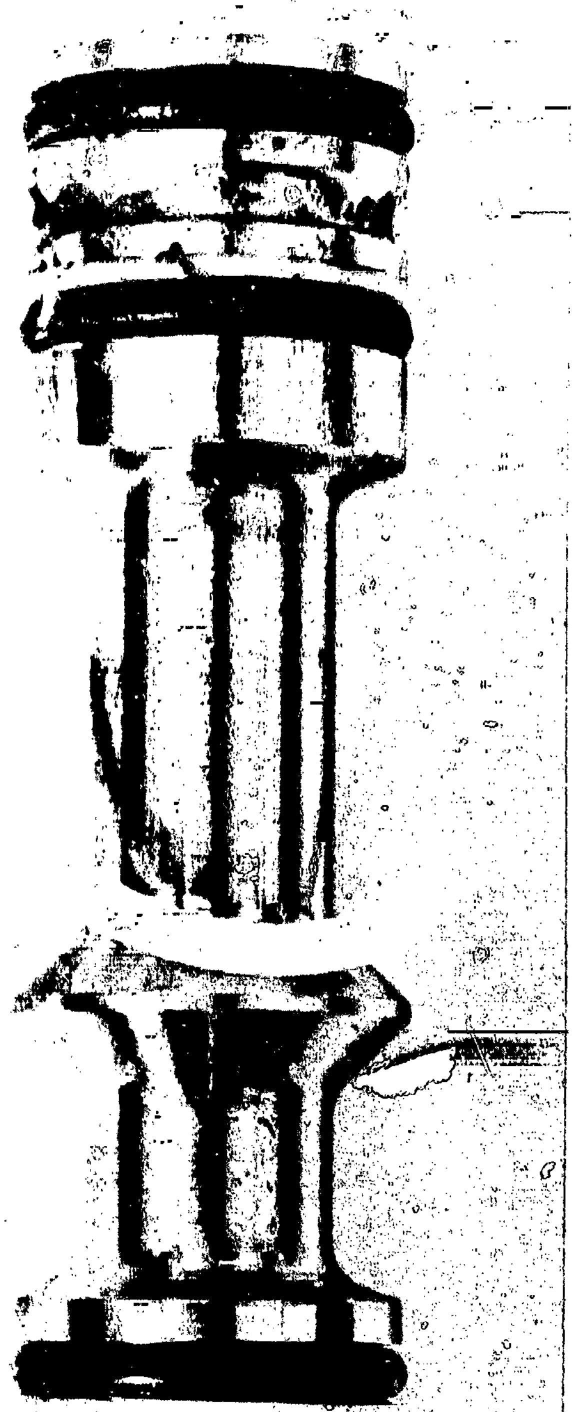
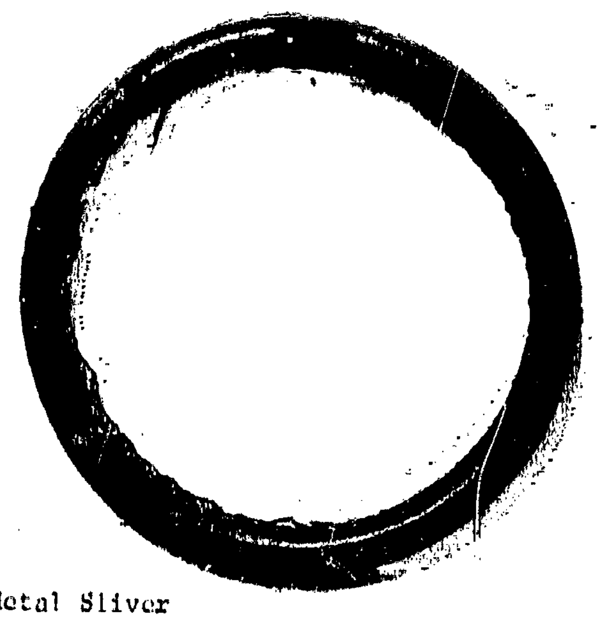


Figure VIII-51 Poppet Stem (75M08823-1)

Figure VIII-52 Retaining Spool (75M08823-1)



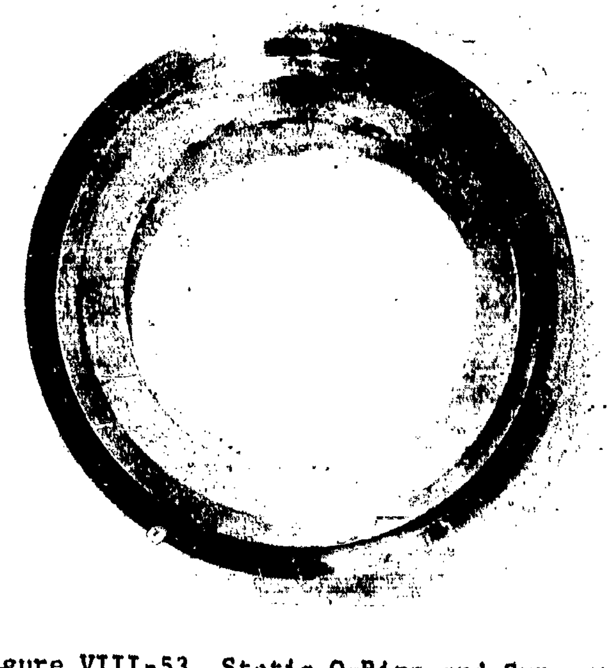


Figure VIII-53 Static O-Ring and Support Seat (75M08823-1)

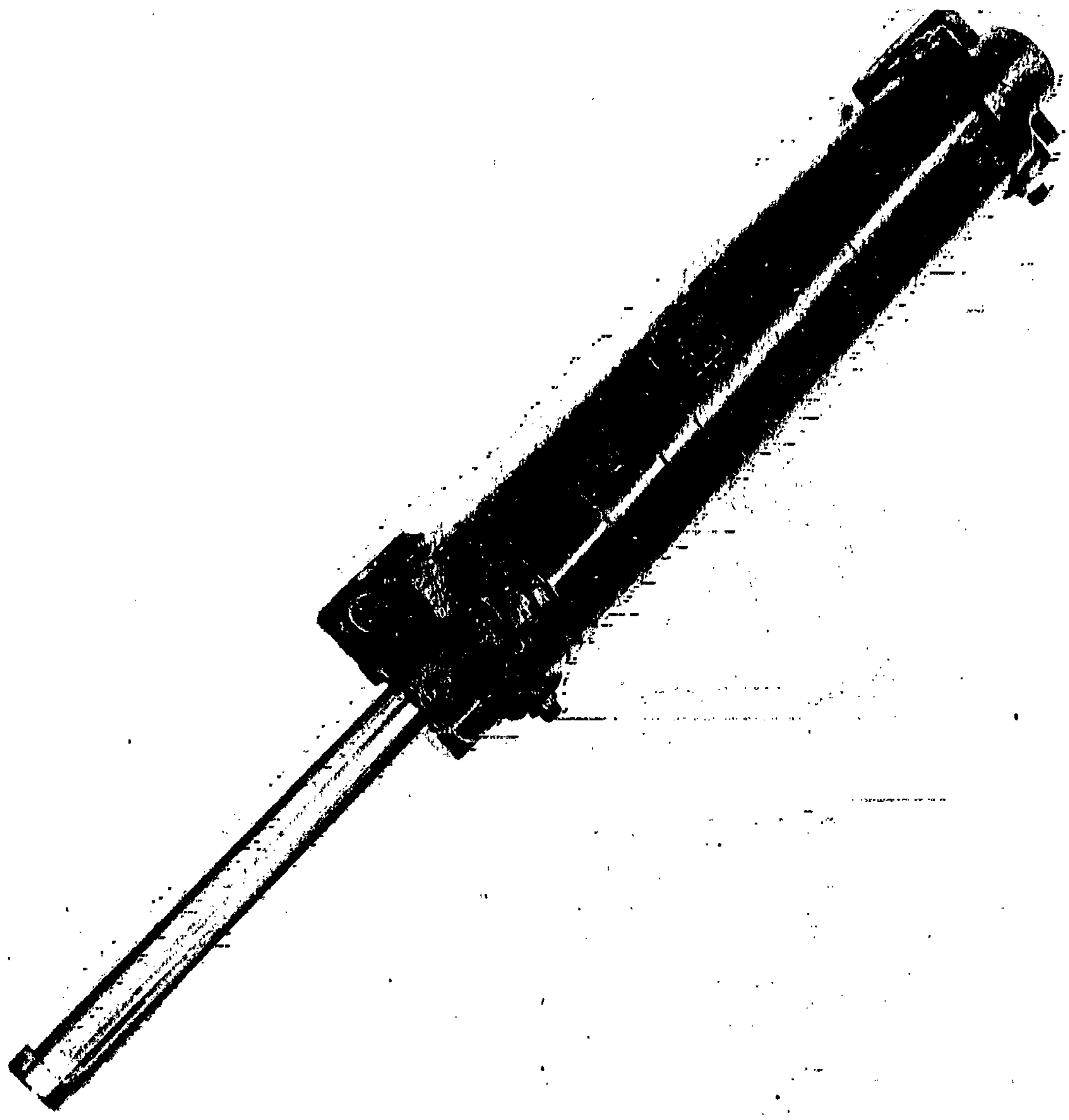


Figure VIII-54 Hydraulic Cylinder (75M065067)

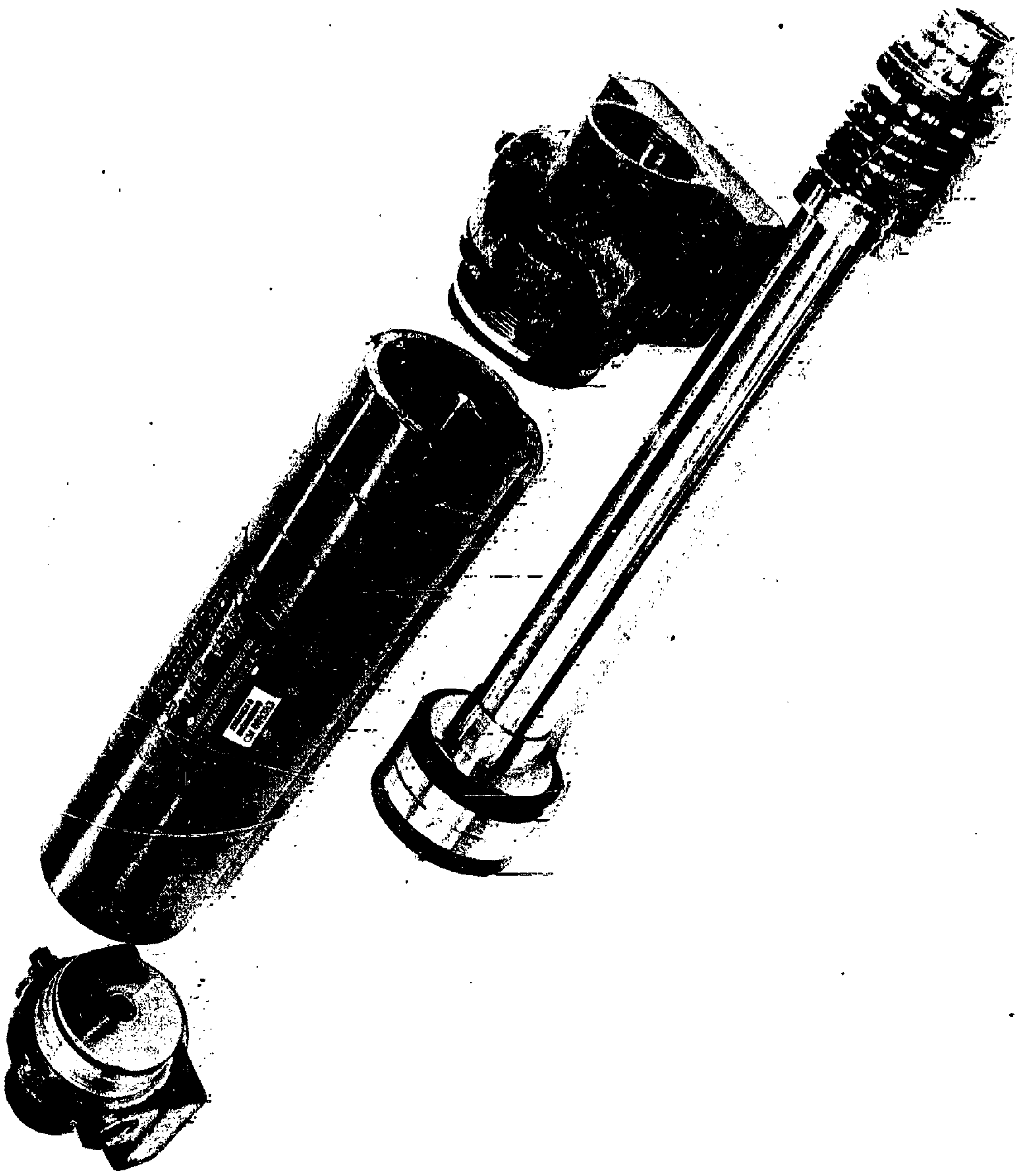


Figure VIII-55 Hydraulic Cylinder (75M065067)

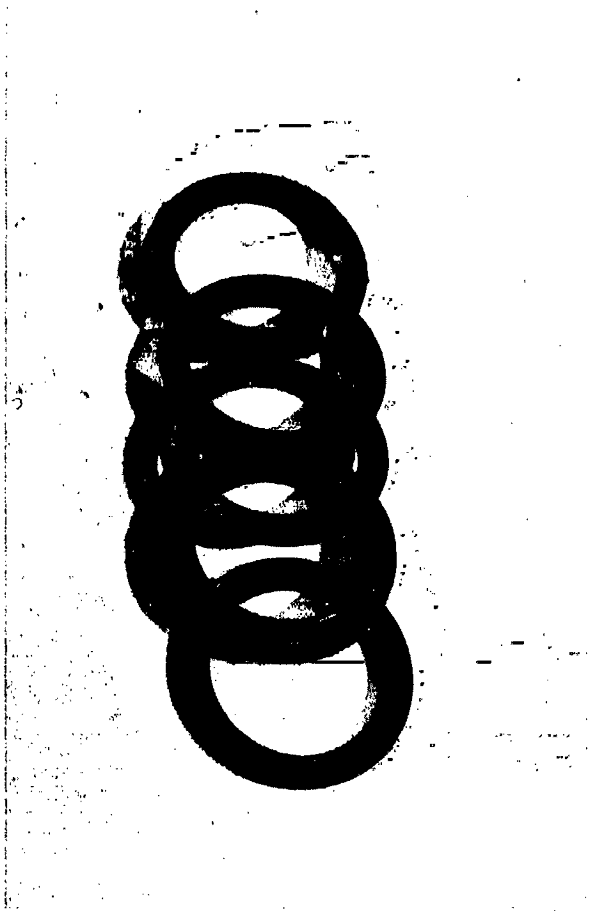


Figure VIII-56 Cylinder Chevron Packing (75M065067)

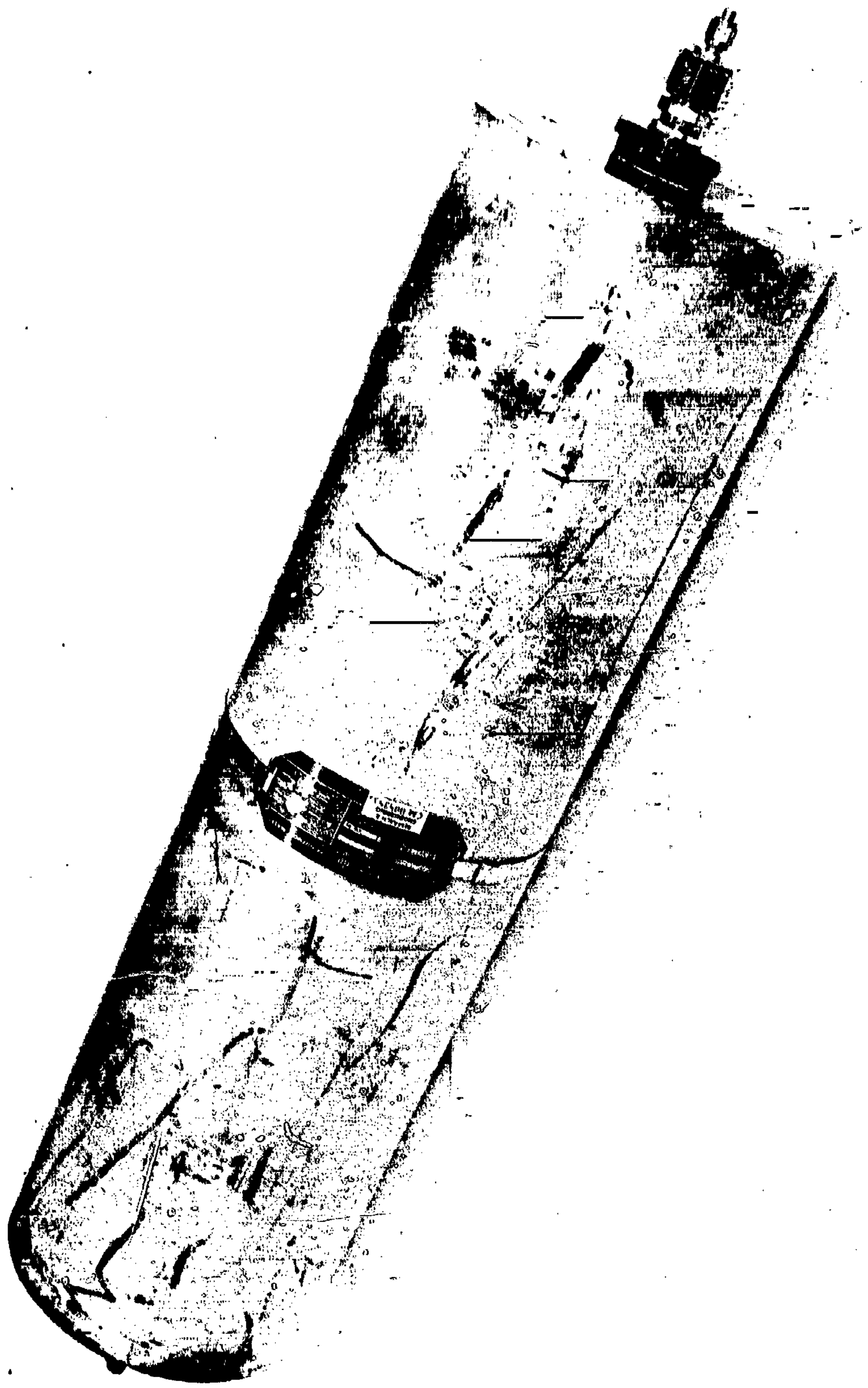


Figure VIII-57 Accumulator (75M08814-1)

Figure VIII-58 Accumulator (75M08814-1)

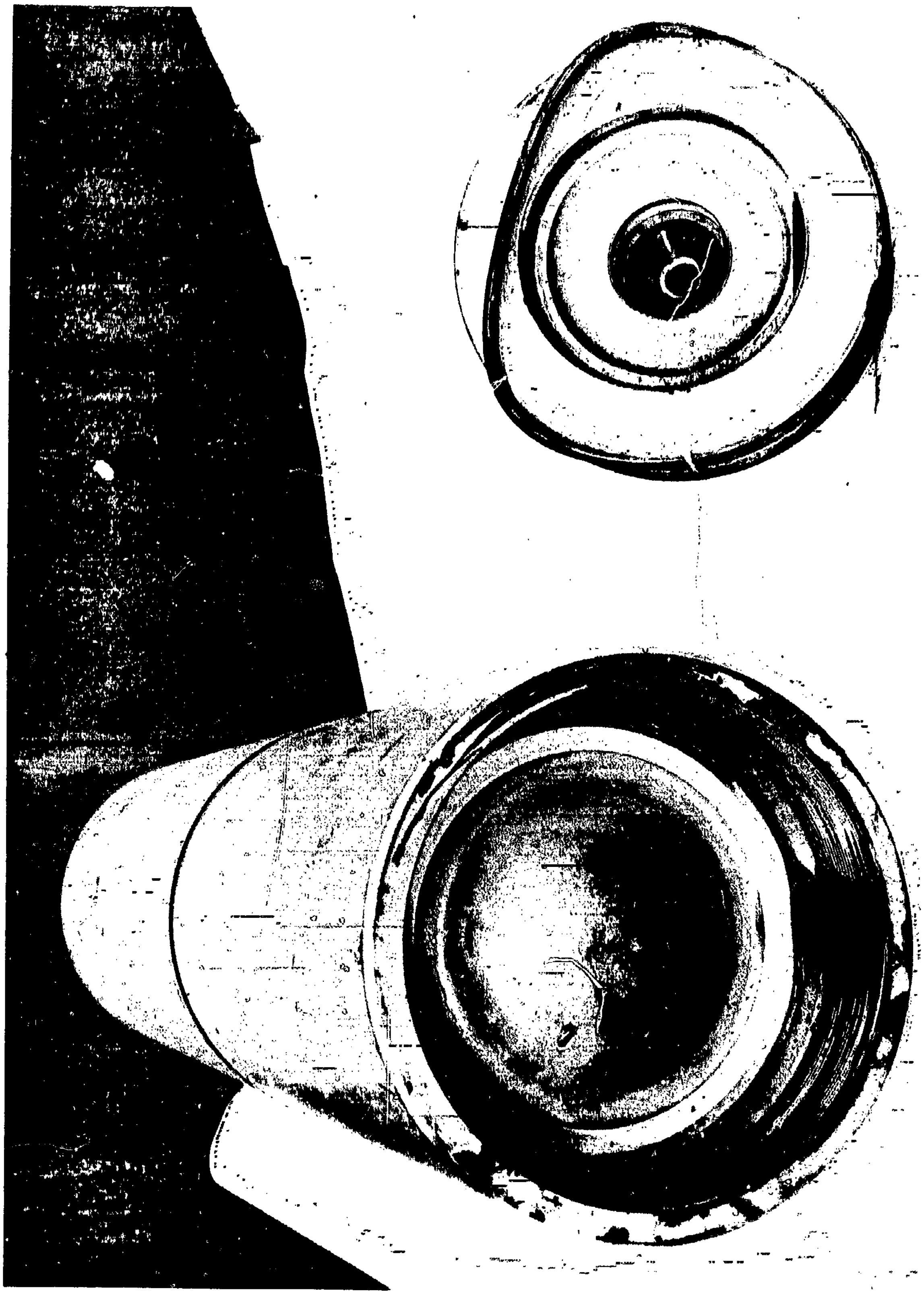


Figure VIII-59 Accumulator (75M08814-1, S/N 3300)

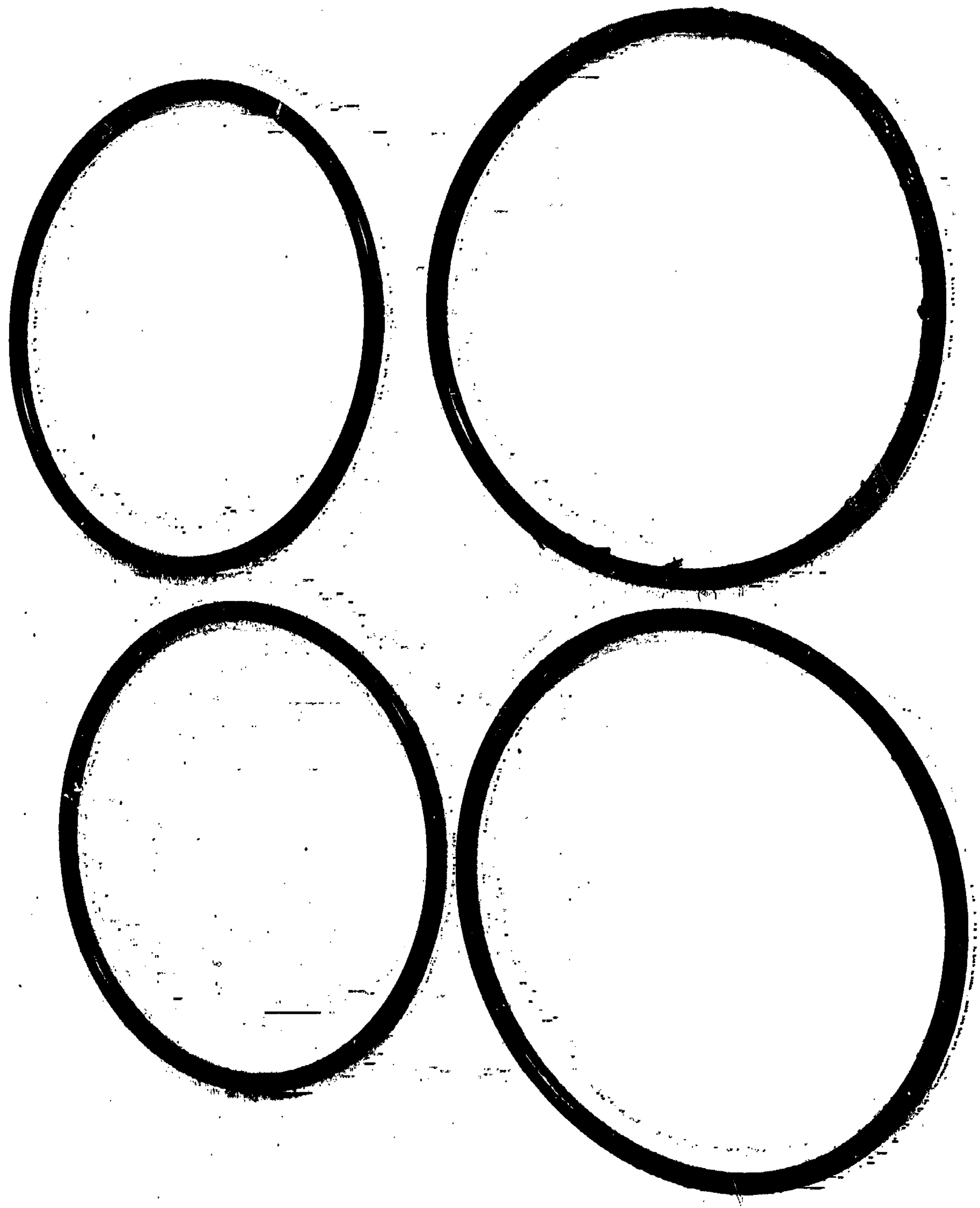


Figure VIII-60 Static O-Rings (end caps)(75M08814-1)

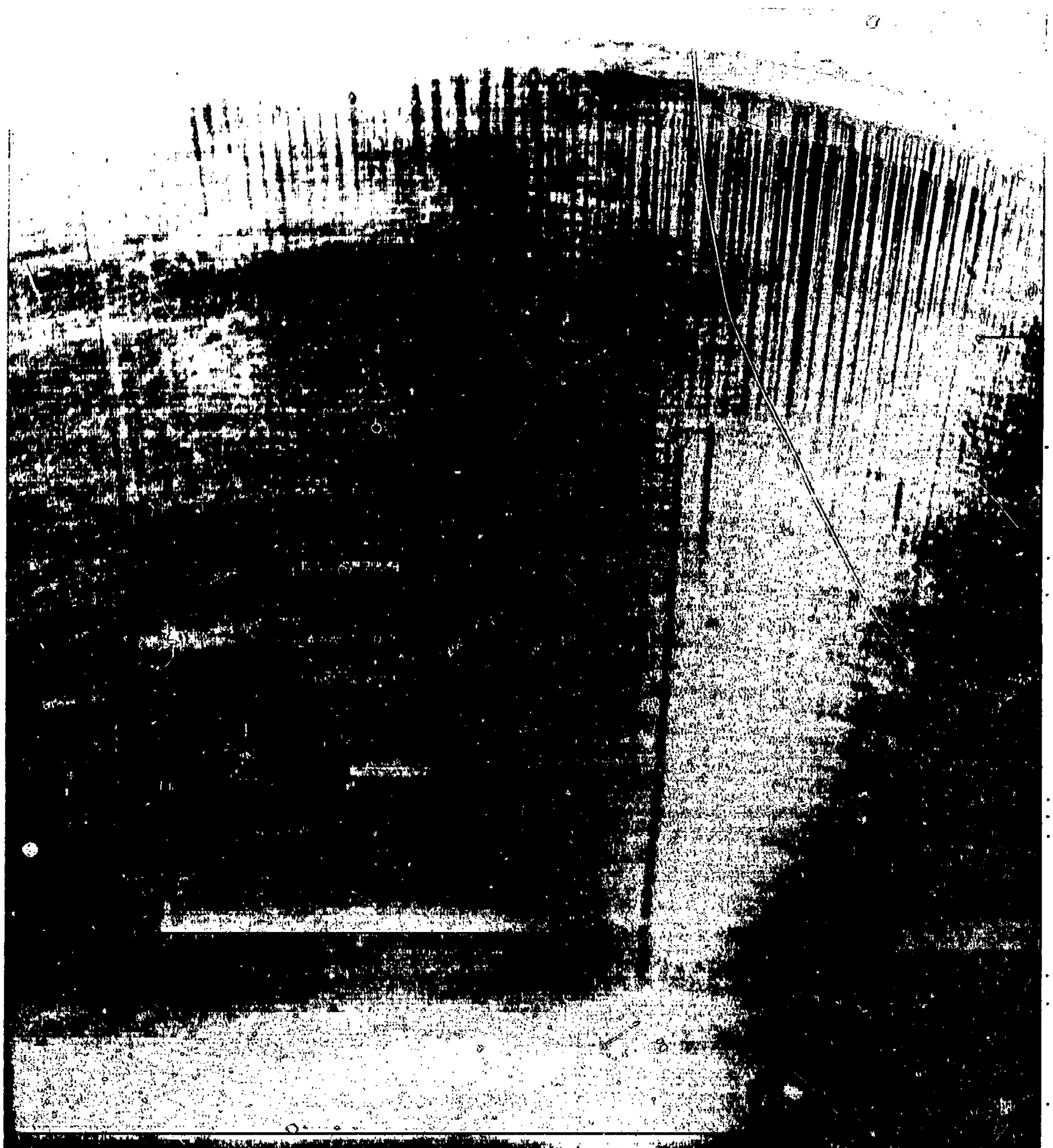


Figure VIII-61 Accumulator Bore (75M08814-1, S/N 3300)

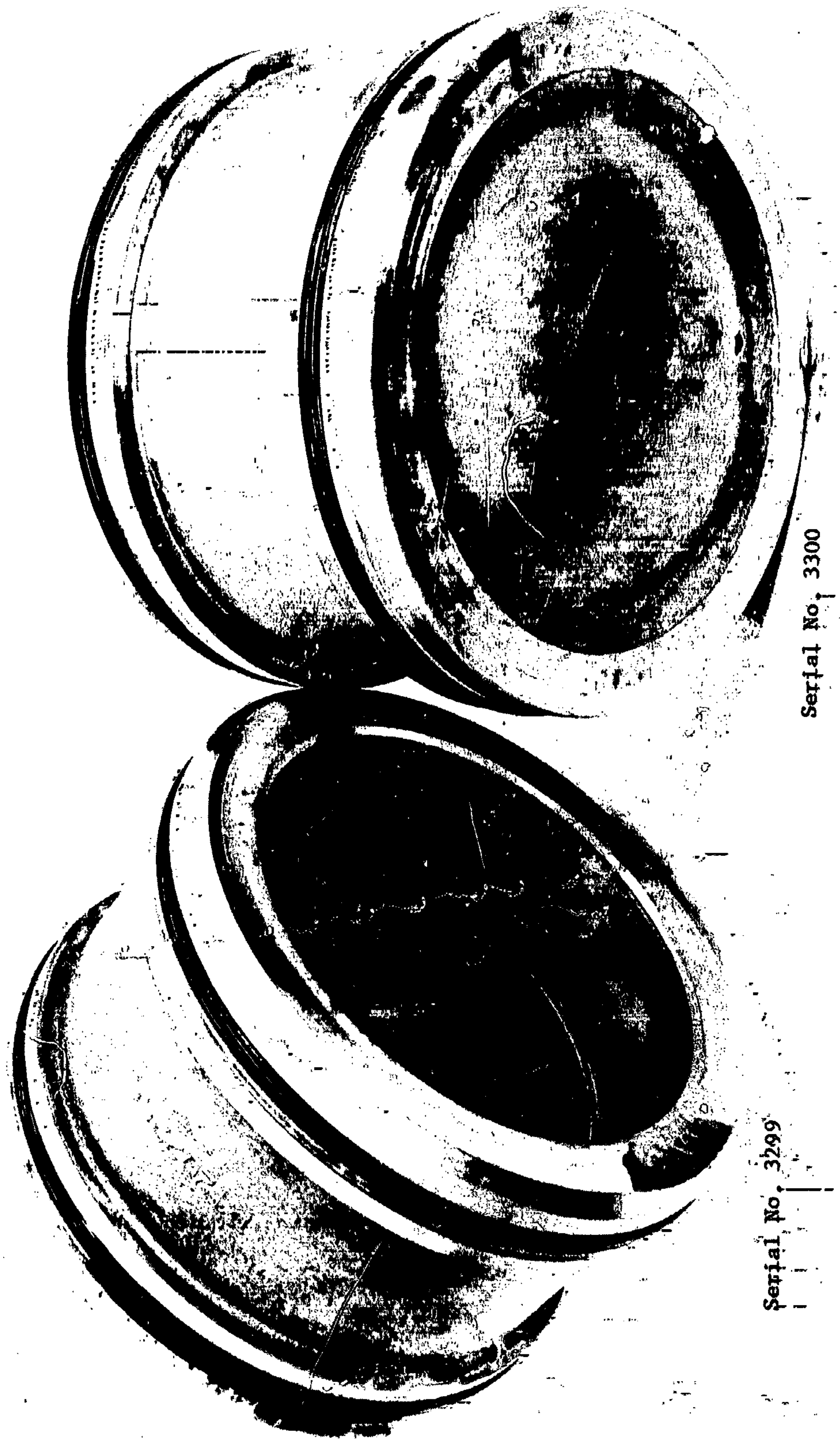


Figure VIII-62 Accumulator Pistons (75M08814-1)

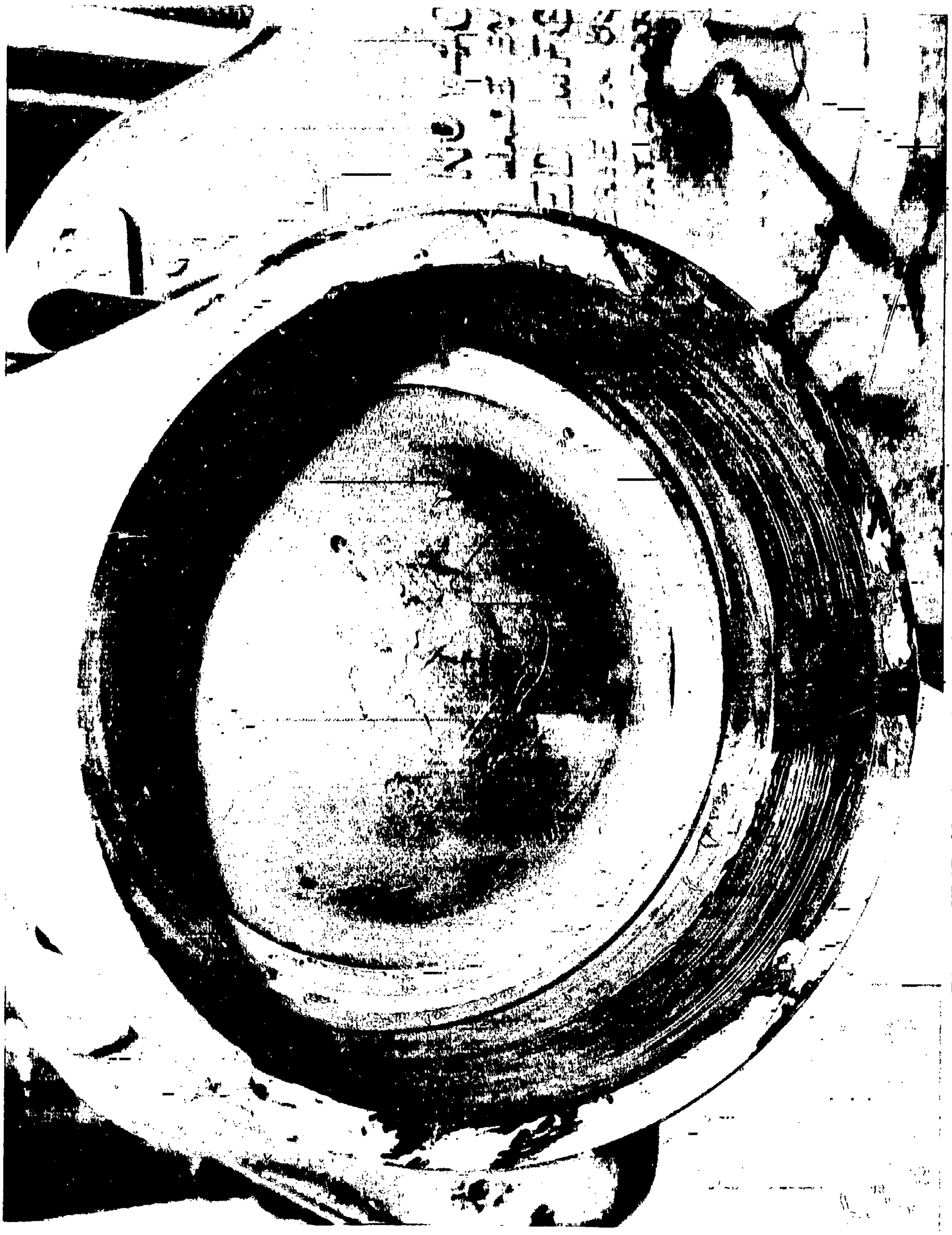


Figure VIII-63 Accumulator (end view) (75M08814-1, S/N 3299)

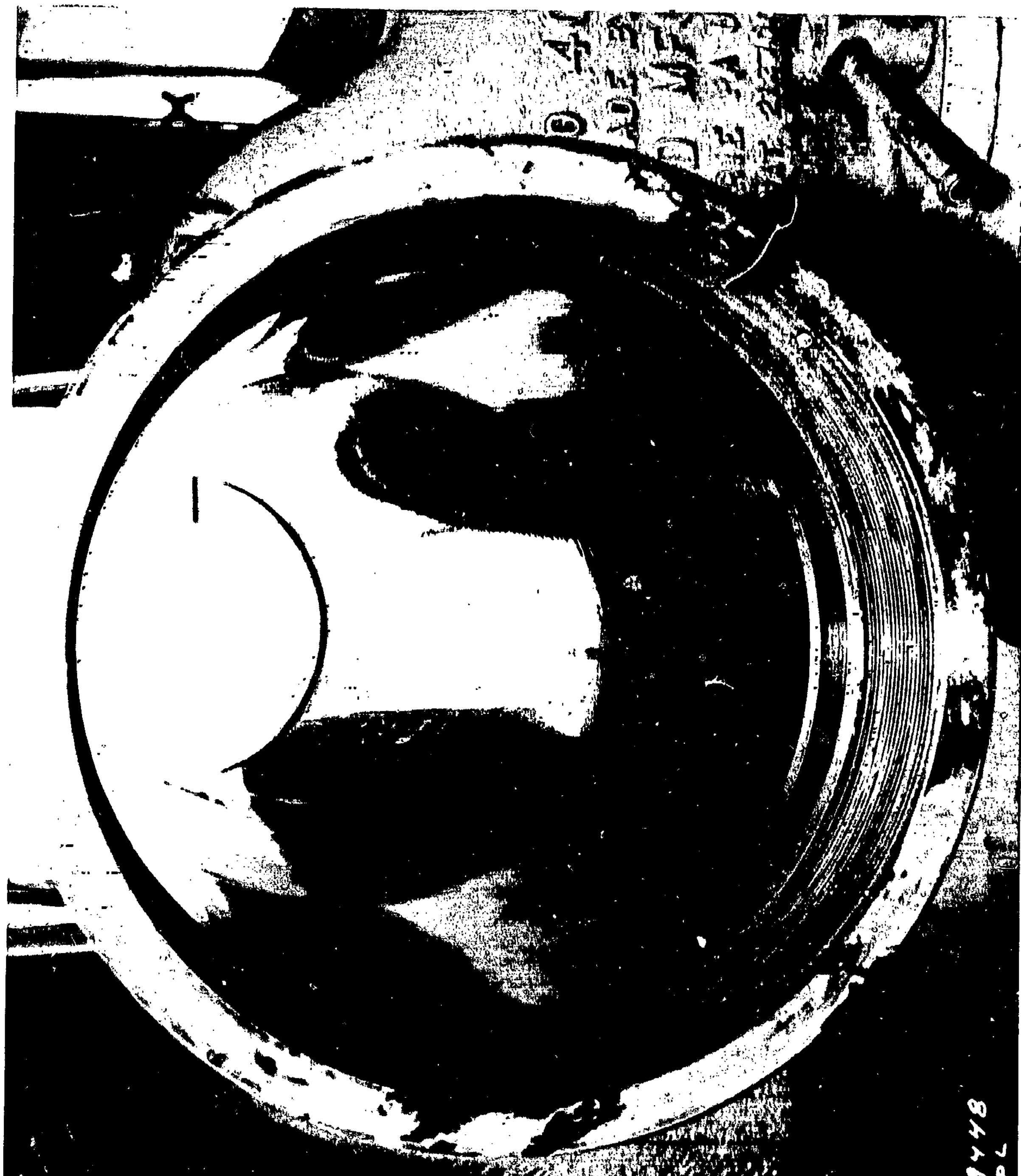


Figure VIII-64 Accumulator Bore (75M08814-1, S/N 3299)

APPENDIX A

CATEGORIZED COMPONENT LIST

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SPECIFICATION NUMBER	ITEM	FIND NUMBER LOCATION	CATEGORY A	CATEGORY B
B75M05365	Check Valve	5418 (1-8)		X
		5441 (1-8)	X	
		5484 (4-8)	X	
		5651 (4-7)		X
		5680 (4-7)		X
		34732 (9)		X
		34756 (9)		X
		34757 (9)		X
		34760 (9)		X
		34763 (9)		X
		34821 (9)		X
75M06116	Solonoid Valve	34701 (9)		X
75M06118	Check Valve	34703 (9)		X
75M06201	Flow Control Valve	5521 (1-8)	X	
75M06350	Pump	5306 (HCU-1-2)		X
75M06506	Cylinder, Hydraulic	5702 (4-7)	X	
75M06597	Pump	5309 (HCU-1-2)		X
75M06604	Check Valve	5314 (HCU-1-2)		X

SPECIFICATION NUMBER	ITEM	FIND NUMBER LOCATION	CATEGORY	
			A	B
75M06605	Relief Valve	5308 (HCU-1 -2)		X
75M06606	Filter	5307 (HCU-1 -2)		X
75M06607	Filter	5304 (HCU-1 -2)		X
75M06660	Relief Valve	5316 (HCU-1 -2)		X
75M06706	Snubber	5341 (HCU-1 -2)		X
75M07505	Pressure Switch	5342 (HCU-1 -2)		X
75M07725	Cylinder, Pneumatic	5894 (2)		X
75M07998	Cylinder, Pneumatic	5811 (6-7)	X	
75M08053	Filter	5395 (1-8) 29692 (3) 34747 (9)		X X X
75M08142	Valve, 3 Way	29694 (3)		X

SPECIFICATION NUMBER	ITEM	FIND NUMBER LOCATION	CATEGORY A	CATEGORY B
75M08231	Cylinder	5583 (4-8)	X	
75M08323	Pressure Switch	5432 (1-8)		X
		5511 (1-8)		X
		5533 (4-8)		X
		5691 (4-7)		X
		5767 (6)		X
		5795 (7)		X
		5852 (4-8)		X
		5883 (2)		X
		5908 (2)		X
		5944 (1)		X
		5991 (4)		X
		6033 (4)		X
		6072 (8)		X
		6104 (8)		X
		6132 (8)		X
		6377 (7)		X
		29741 (6)		X
75M08325	Check Valve	5461 (1-8)		X
		5561 (4-8)		X
		5687 (4-7)		X
		5710 (6-7)		X
		5776 (7)	X	
		5823 (4-6)		X
		5888 (2)		X
		5917 (2)		X
		5953 (1)		X
		5978 (4)		X
		6036 (4)	X	
		6045 (4)	X	
		6060 (8)		X
		6082 (8)	X	
		6092 (8)		X
		6142 (8)		X
		6143 (8)	X	
		6387 (7)	X	
		6399 (7)		X
		6419 (7)		X
		29606 (7)	X	
		29607 (7)	X	
		29875 (4-6)	X	
		34802 (9)		X

SPECIFICATION NUMBER	ITEM	FIND NUMBER LOCATION	CATEGORY A	CATEGORY B
75M08326	Check Valve	5782 (7)	X	
		29745 (6)	X	
75M08409	Snubber	5431 (1-8)		X
		5510 (1-8)		X
		5532 (4-8)		X
		5690 (4-7)		X
		5763 (7)		X
		5766 (6)		X
		5849 (4-7)		X
		5881 (2)		X
		5907 (2)		X
		5943 (1)		X
		6031 (4)		X
		6070 (8)		X
		6102 (8)		X
		6131 (8)		X
		6379 (7)		X
		29739 (6)		X
		34693 (9)		X
		34726 (9)		X
75M08414	Metering Valve	5924 (2)		X
		5957 (1)	X	
		5478 (1-8)	X	
		6251 (9)	X	
75M08415	Relief Valve	5476 (1-8)	X	
		5486 (1-8)	X	
		5727 (1-7)		X
		5896 (2)		X
		29691 (3)		X
		29693 (3)		X
		29774 (4-7)		X
		34665 (9)	X	
		34680 (9)	X	
		34753 (9)		X
		34754 (9)		X
		34797 (9)	X	

SPECIFICATION NUMBER	ITEM	FIND NUMBER LOCATION	CATEGORY A	CATEGORY B
75M08617	Check Valve	5610 (5-7)		X
75M08814	Accumulator	5468 (1-8)	X	
		5654 (4-7)		X
75M08819	Counterbalance Valve	5502 (1-8)	X	
		5503 (1-8)	X	
		34808 (9)	X	
75M08820	Pilot Operated Valve	5481 (1-8)	X	
		5482 (1-8)	X	
		29675 (1-2)	X	
		29676 (1-2)	X	
		34767 (9)	X	
		34768 (9)		X
		34771 (9)	X	
		34774 (9)	X	
		34776 (9)	X	
		34778 (9)	X	
		34780 (9)		X
		34783 (9)		X
75M08821	Pilot Operated Valve	5513 (1-8)	X	
75M08822	Pilot Operated Valve	5537 (4-8)	X	
75M08823	Solenoid Valve	5417 (1-8)		X
		5420 (1-8)		X
		5460 (1-8)		X
		5560 (4-8)		X
		5578 (4-8)	X	
		5650 (4-8)		X
		5667 (4-7)		X
		5707 (6)		X
		5977 (4)		X
		34814 (9)	X	
		34822 (9)		X

SPECIFICATION NUMBER	ITEM	FIND NUMBER LOCATION	CATEGORY	
75M08824	Solenoid Valve	5787 (7)		X
		5837 (4-7)		X
		5887 (2)		X
		5914 (2)		X
		5952 (1)		X
		6023 (4)		X
		6058 (8)		X
		6090 (8)		X
		6138 (8)		X
		6400 (7)		X
		29731 (6)		X
75M08825	Solenoid Valve	5507 (1-8)	X	
		5528 (4-8)	X	
		5688 (4-7)		X
		5762 (4-7)		X
		5792 (4-7)		X
		5844 (4-7)		X
		5879 (2)		X
		5895 (2)	X	
		5904 (2)		X
		5940 (1)		X
		5985 (4)		X
		6028 (4)		X
		6066 (8)		X
		6099 (8)		X
		6128 (8)		X
		6382 (7)		X
		29736 (6)		X
75M08826	Pilot Operated Valve	5663 (4-8)	X	
		6081 (8)	X	
		6113 (8)	X	
		6368 (7)	X	
		6405 (7)	X	
75M08827	Pilot Operated Valve	5730 (4-7)	X	

SPECIFICATION NUMBER	ITEM	FIND NUMBER LOCATION	CATEGORY	
			A	B
75M08829	Regulator	5785 (7)		X
		5835 (4-7)		X
		5886 (2)		X
		5913 (2)		X
		5951 (1)		X
		5956 (1)	X	
		6022 (4)		X
		6057 (8)		X
		6089 (8)		X
		6136 (8)		X
		6401 (7)		X
		29730 (6)		X
		34705 (9)		X
75M08830	Regulator	5419 (1-8)		X
		34734 (9)		X
75M08831	Regulator	6075 (8)	X	
		6108 (8)	X	
		6373 (7)	X	
		6410 (7)	X	
75M08836	Automatic Valve	6396 (7)	X	
		6374 (7)	X	
75M08839	Solenoid Valve	5439 (1-8)	X	
75M08841	Solenoid Valve	5479 (1-8)	X	
		6254 (9)	X	
		6296 (9)	X	
		29677 (1-2)		X
		34660 (9)	X	
		34661 (9)	X	
		34769 (9)	X	
		34772 (9)	X	
		34779 (9)	X	
		34784 (9)	X	

SPECIFICATION NUMBER	ITEM	FIND NUMBER LOCATION	CATEGORY A	CATEGORY B
75M09007	Check Valve	5475 (1-8)	X	
		5553 (4-8)	X	
		34698 (9)	X	
		34770 (9)	X	
		34773 (9)	X	
		34775 (9)		X
		34777 (9)		X
		34809 (9)	X	
75M09014	Cylinder	6007 (4)	X	
		6018 (4)	X	
75M09283	Level Switch	5470 (1-8)		X
		5656 (4-7)		X
		6249 (9)		X
		6250 (9)		X
		6290 (9)		X
		6292 (9)		X
75M09285	Solenoid Valve	5642 (7)	X	
		5809 (7)	X	
		5829 (4-7)	X	
		5860 (4-7)	X	
		5868 (4)	X	
		5871 (4)	X	
		5923 (2)	X	
		6040 (4)	X	
		6049 (4)	X	
		6053 (4)	X	
		6054 (4)	X	
		6147 (8)	X	
		6150 (8)	X	
		6413 (4-7)	X	
		6420 (4-7)	X	
		29753 (6)	X	
75M09362	Cylinder, Hydraulic	5492 (1-8)		X
		5497 (1-8)		X

SPECIFICATION NUMBER	ITEM	FIND NUMBER LOCATION	CATEGORY A	CATEGORY B
75M10090	Solenoid Valve	5770 (6)	X	
75M10272	Regulator	5611 (5-7)		X
75M10807	Cylinder	5626 (5-7)		X
75M10992	Filter	5388 (1-8)		X
		5390 (1-8)		X
		5563 (4-8)		X
		5613 (4)		X
		34748 (9)		X
		34749 (9)		X
75M11428	Selector Valve	5612 (5-7)		X
75M11149	Air Motor	6122 (8)	X	
		6390 (7)	X	
75M11558	Metering Valve	6391 (7)	X	
75M12157	Cylinder, Hydraulic	34825 (9)		X
		34827 (9)		X
75M12560	Rotary Actuator	34840 (9)	X	
		34845 (9)	X	
75M12665	Accumulator	6244 (9)	X	
		6245 (9)	X	
		6246 (9)	X	
		6247 (9)	X	
75M13255	Regulator	34964 (9)	X	

SPECIFICATION NUMBER	ITEM	FIND NUMBER LOCATION	CATEGORY	
			A	B
75M16990	Solenoid Valve	34755 (9)		X
		34758 (9)		X
		34759 (9)		X
		34761 (9)		X
75M21479	Orifice	5872 (4)	X	
		5873 (4)	X	
75M51383	Regulator	5459 (1-8)		X
		5559 (4-8)		X
		5666 (4-7)		X
		6200 (9)		X
75M51630	Check Valve	34939 (9)	X	
		34944 (9)	X	
		34954 (9)	X	
		34956 (9)	X	
		34960 (9)		X
		34963 (9)		X
		34972 (9)		X
		34974 (9)		X
		34981 (9)	X	
		34984 (9)	X	
75M51766	Pressure Switch	34699 (9)		X
		34724 (9)		X
76K00187	Solenoid Valve	34704 (9)		X
76K00188	Filter	34863 (9)		X
		34864 (9)		X
		34865 (9)		X
		34866 (9)		X
		34867 (9)		X
		34868 (9)		X
76K00189	Orifice	34762 (9)		X
		34765 (9)		X
		35730 (9)		X
		35731 (9)		X

SPECIFICATION NUMBER	ITEM	FIND NUMBER LOCATION	CATEGORY	
			A	B
76K00251	Valve, Deceleration	34839 (9)	X	
		34849 (9)		X
76K03230	Cylinder	34934 (9)		X
		34935 (9)		X
76K03578	Orifice	34951 (9)		X
		34971 (9)	X	
		34989 (9)	X	
76K03824	Cylinder, Pneumatic	34952 (9)	X	
76K03825	Cylinder, Pneumatic	34988 (9)	X	
B10425701	Solenoid Valve	34937 (9)	X	
		34938 (9)	X	
		34949 (9)		X
		34953 (9)		X
		34955 (9)		X
		34959 (9)	X	
		34961 (9)	X	
		34962 (9)	X	
		34969 (9)	X	
		34970 (9)	X	
		34973 (9)	X	
		34983 (9)		X
		34985 (9)		X
		34986 (9)		X
B10425928	Check Valve	34987 (9)		X
B10426693	Check Valve	34950 (9)	X	

SPECIFICATION NUMBER	ITEM	FIND NUMBER LOCATION	CATEGORY A	CATEGORY B
Vendor P/N 800262-19 Marotta	Check Valve	5866 (4) 5869 (4) 5972 (4) 5974 (4)	X X X X	
Vendor P/N 204002-19 Marotta	Check Valve	5863 (9) 6153 (6)	X X	
Vendor P/N MV583 Marotta	Solenoid Valve	11190 (6)	X	
Not Known	Orifice Plate	5594 (7)	X	
75M24511 75M24512 75M24513	Orifice Plate	29727 (6)	X	
		TOTALS	137	194

APPENDIX B

COMPONENT ANALYSIS SHEETS

COMPONENT ANALYSIS

COMPONENT Check Valve

SPECIFICATION NO. 75M05365 (-4, -6)

VENDOR James Pond Clark

VENDOR P/N (-4) 277 T1-8NN (-6) 277 T1-12NN.

FIND NUMBERS/CATEGORY A5418(1-8)/B, A5441(1-8)/A, A5484(4-8)/A, A5651(4-7)/B, A5680(4-7)/B, A6185(9)/B, A6226(9)/A, A6230(9)/B, A6252(9)/B, A6273(9)/B

FAILURE MODES
1) Leakage - System Malfunction
2) Stuck Open - System Malfunction.
3) Stuck Closed - System Malfunction

ANALYSIS These check valves are the James Pond Clark standard 200 series check valves as shown in the James Pond Clark Catalog. It is a poppet type check valve constructed of 303 SS material and Buna N seals. Cracking pressure required to open is .5 to 1 psi. The valve is required to have zero leakage up to maximum operating pressure. The check valve has a well guided, tapered poppet with a clean flow design such that normal flow paths of contaminant particles will flow through the valve without being trapped or causing damage to the seals. The James Pond Clark Engineering representative stated that these valves are used in commercial cleaned system without problems, as the poppet design is tapered to make it "self-cleaning". MMC has used many of these check valves in the Titan systems without any known contaminant problems.

ACTION Recommend the check valve not be considered for test.

COMPONENT ANALYSIS

COMPONENT	Solenoid Valve
SPECIFICATION NO.	75M06116
VENDOR	Marotta Valve Corp.
VENDOR P/N	225884 (MV74VE)
FIND NUMBERS/CATEGORY	A34701(9)/B
FAILURE MODES	De-energized - Can't check sys. press. transducer Energized - No system readout; constant charge Leakage - Possible erroneous readout

ANALYSIS

This valve for analysis purposes according to Marotta engineering is similar to 75M08825.

ACTION

Recommend that 75M08825 be tested.

COMPONENT ANALYSIS

COMPONENT Check Valve

SPECIFICATION NO. 75M06118

VENDOR James Pond Clark

VENDOR P/N HP279T1-8NN

FIND NUMBERS/CATEGORY A3470(9)/B, A34703(9)/B

FAILURE MODES Same as B75M05365 (Item 1)

ANALYSIS Same as B75M05365 (Item 1)

ACTION Recommend the check valve not be considered for test.

COMPONENT Deceleration Valve

SPECIFICATION NO. 75M06201-1 Modified to 75M21842-1

VENDOR Racine

VENDOR P/N

FIND NUMBERS/CATEGORY A5521 (1-8)/A

FAILURE MODES

Blocked - No Arm Retraction

Erratic - Loss of Arm Speed Control (Auto)

ANALYSIS

The deceleration valve is a composite of a relief valve, a sequence valve, a pressure compensator valve and a cam operated variable orifice spool. The sequence valve and pressure compensator valve are to be removed after test and retained in a parts kit. This leaves the valve as a mechanical variable orifice with a flow range of 60 to 120 gpm and a full flow relief valve. ECP 0258 provides for this modification.

Seal Material - Viton A

Leakage

External - None

Lubrication - Kel-F-90 Grease

Cleaning - Racine does their own cleaning of this component. The component is checked for cleanliness to NASA Specs by sampling the effluent after the functional test.

Tolerances - All moving parts have clearances from .0006 to .0011 of an inch.

The Racine Technical Representative felt this component would function with no problem in industrial level cleaned hydraulic fluid. Stability problems were given as the reason for modification of this valve.

The variable orifice spool is the only part in this valve which is chrome plated and the rest of the valve is made from hardened steel. The parts used in the valve have a rust preventitive on them and it is removed prior to assembly. Unless the valve is protected from moisture intrusion prior to installation there may be a corrosion problem.

This valve is not considered contamination sensitive due to the following reasons:

1. The tolerance on the variable orifice spool is fairly tight but the spool is operated by a mechanicam can which should overcome any sticking due to contamination.

2. Previous failure history of the valve.

3. Recommendation of the vendor.

4. Valve not considered to be a contamination generator.

ACTION

This valve is not recommended for test.

COMPONENT ANALYSIS

COMPONENT Pump

SPECIFICATION NO. 75M06350

VENDOR Commercial Stamping & Shearing Co.

VENDOR P/N P 15H 300 BEYR 10-16

FIND NUMBERS/CATEGORY A 5306(HCU 1, 2)/B

FAILURE MODES Inoperative - Possible hydraulic failure

ANALYSIS

The fixed-displacement, gear type, supercharger pump draws fluid from the reservoir through a 140 micron (nominal) filter and supplies the mainstage high pressure pump with 11 gpm at 30 psig. The excess fluid from the supercharger pump is diverted through a low pressure relief valve and back to the reservoir. The discharge fluid from the supercharger pump is filtered through a 10 micron (nominal) filter to protect the high pressure pump from contamination.

The gear type pump does not appear to be contamination sensitive and should be able to operate satisfactorily on a contamination level at least as dirty as the high pressure pump. The high pressure pump was designed to operate satisfactorily on fluid cleaned to NAS 1638 Class 9. The gear type pump does not appear to be a large contamination generator and any contamination critical to the system should be removed by the 10 micron (normal) filter just downstream from the pump.

ACTION

This fixed-displacement, supercharger pump is not considered contamination sensitive or a high contamination generator and is not recommended for test.

COMPONENT ANSLYSIS

COMPONENT Cylinder, Hydraulic

SPECIFICATION NO. 75M06506

VENDOR Pathon Mfg. Co.

VENDOR P/N C-11145

FIND NUMBERS/CATEGORY A5702(4-7)/A

FAILURE MODES Stuck No carrier withdrawal
Leakage Possible withdrawal malfunction

ANALYSIS -

Seal Material - Buna-N per MIL-P-25732, Viton A per MIL-P-25897, or Polyurethane, backup ring per MIL-R-8791

Leakage - GN_2 around barrel - none
Rod end 10 cc per 25 operating cycles, internal piston by-pass 5-25 cc/min

Hyd. around barrel - none
Rod end 1 drop per 25 operating cycles, internal piston by-pass = 5 cc/min

Lubrication - The spec calls out MIL-H-5606 for hydraulic cylinders and Kel-F-90 for pneumatic cylinders, but according to the Pathon Technical Representative it was going to be changed to some other lubricant. The lubricant may be Atlantic Refining Company #54 Lubricant. A problem with "O" ring spiraling on accumulators was evidently solved by using this lubricant.

Tolerances on cylinders between piston and barrel ranged from .0025 to .0095 in. on an 8 in. bore and .003 to .009 in. on a 3 in. bore.

The hydraulic cushion which is used on some cylinders does not appear to be contamination sensitive.

Leakage at the rod end seal would probably be the most common type failure once a cylinder is installed in the system. A metal wiper is used on the rod end to prevent contamination from entering the cylinder. Teflon or some other softer material would probably be more effective in keeping contamination out of the cylinder but temperature requirements prevents their use.

Most of the cylinders now or soon will have stainless barrels and rods and improved seals. This should reduce the problem of contamination generation and make cylinders less sensitive to contamination.

According to the Pathon Mfg. Technical Representative they clean their cylinders to an industrial level. They perform the functional and proof pressure test using hydraulic oil MIL-H-5606 and then send the cylinders with minimum seals to their cleaning vendor, TMC (Technical Micronic Control), to be disassembled, cleaned to NASA Specs., seals replaced, reassembled, and functional checked. The approximate cost for this cleaning was $200.00 for a 75-MO 7362 cylinder.

The hydraulic and pneumatic cylinders built by Pathon Mfg., Co. are not considered to be contamination sensitive. The contamination generation is not believed to be high due to the smooth finish requirements and improved seals used in cylinder construction, but testing may be required for verification.

Cleaning, assembly and test procedures or methods will be further reviewed to determine if the cylinders are meeting the reliability requirements without undue effort.

Pathon's Technical Representative said that hydraulic cylinders could stand more contamination than the pneumatic cylinders because hydraulic fluid lubricates the contaminants and allows them to "slide around" rather than causing wear which could happen in a dry pneumatic cylinder.

ACTION

This valve is not particularly contamination-sensitive, but does represent a broad category of components of the Service Arms. Recommend test.

COMPONENT Pump

SPECIFICATION NO. 75M06597

VENDOR Dennison Division, Abex Corp.

VENDOR P/N PV05-006-31R-062

FIND NUMBERS/CATEGORY G5309 (HCU-1,-2)/B

FAILURE MODES

Inoperate - Loss of Hydraulic Pressure

Erratic - Possible Hydraulic Failure

ANALYSIS

This is a piston type variable-displacement, pressure compensated pump capable of 9.5 gpm flow at 2750 psi. With no flow demand the press is 3000 ± 150 psi. The supply to the high pressure pump is received from a boost pump at 30 psi. Ten micron (nominal) filtration is used at the inlet to the high pressure pump and at the pump case drain. A differential pressure gage is used on the filter, which is at the high pressure inlet, to indicate when the filter is clogged or dirty and requires replacement of the filter element.

The Dennison Division Technical Representative was contacted and the following information was obtained:

1. Use clean oil. Ten micron filtration which is used on the suction side of the pump is completely adequate.

2. Change filters regularly.

3. Maximum level of contamination that the pump can stand without excessive wear is NAS 1638 Class 9. The test stands used by Dennison Division are required to meet NAS 1638 Class 8. The table below was given as the level of contamination the pump could stand and still function properly without excessive wear.

Size Range (Micron)	Number (Per 100 ml)
5-15	128,000
15-25	22,800
25-50	4,050
50-100	720
100 +	128

The pump is not considered contamination sensitive as long as the contamination level does not exceed NAS 1638 Class 9 and adequate filtration is used. Evaluation of the failure history of this pump shows that there were not any contamination problems.

ACTION

Recommend the pump (75M06597) not be considered for test.

COMPONENT ANALYSIS

COMPONENT	Check Valve
SPECIFICATION NO.	75M06604
VENDOR	Republic Mfg. Co.
VENDOR P/N	497-12Y-2
FIND NUMBERS/CATEGORY	A5314(HCU-1, -2)/B
FAILURE MODES	Open - Motorize hydraulic pump in back-up system - loss of hydraulic press Closed - No effect Leakage - Possible hydraulic malfunction

ANALYSIS

This is a standard Republic poppet type check valve and is used to prevent high pressure back flow into the HCU stage not being used. The body is aluminum alloy and the poppet is stainless steel, type 440. The seating surfaces are metal to metal, and the seals are Teflon and Buna-N. Leakage requirements are: external - none, internal - 1 drop per 2 minutes. There have not been any failures reported on this valve.

ACTION

This check valve is ruggedly made for high shook, continuous service in high velocity hydraulic systems. The check valve is not considered contaminant sensitive and is not recommended for test.

COMPONENT ANALYSIS

COMPONENT	Relief Valve (Hydraulic Check Valve)
SPECIFICATION NO.	75M06605
VENDOR	Republic Mfg. Co.
VENDOR P/N	446-16Y-30
FIND NUMBERS/CATEGORY	A5308(HCU-1, -2)/B
FAILURE MODES	Closed - Possible high boost pressure Open - Loss of hydraulic pressure Leakage - Possible hydraulic failure

ANALYSIS

This is a standard Republic poppet type check valve with a cracking pressure of 35 psi $\pm$ 6. The excess fluid from the low pressure boost pump is diverted through the relief valve and back to the reservoir. The body is aluminum alloy and the poppet is hardened stainless steel, type 440. The seating surfaces are metal to metal and seals used are teflon and Buna-N. Leakage requirements are: external - none, internal - 1 drop in 2 minutes. There are no reported failures on this relief valve.

ACTION

This relief valve (check valve) is ruggedly made for high shock, continuous service in high velocity hydraulic systems. The relief valve is not considered contaminent sensitive and is not recommended for test.

COMPONENT ANALYSIS

COMPONENT Filter

SPECIFICATION NO. 75M06606 (Rev. C)

VENDOR Fluid Dynamics

VENDOR P/N 002922

FIND NUMBERS/CATEGORY A5307(HCU-1, -2)/B

FAILURE MODES

Clogged - Loss of Hydraulic Supply

ANALYSIS

This filter is a Fluid Dynamics 10 micron nominal T-type filter with 304 SS element. The unit is cleaned to NASA specification by an outside cleaning facility. The element has 230 square inches of effective filter area with a specified flow capacity of 20 GPM. A Fluid Dynamics representative indicated that all units they supply are tested to verify bubble point, full flow, proof pressure, and leakage requirements. He also indicated that the same unit can be modified with a finer or coarser micron rated element, if required. It was indicated that the only problems to date with the subject filters were incorrect handling procedures by some of the outside cleaning facilities during cleaning operations. The absolute rating of this unit is 25 micron and has a 1500 psi differential collapse pressure. The Fluid Dynamics representative also stated he has seen some of these elements completely collapsed without allowing any contaminants to escape into the system.

ACTION

1) Recommend bubble point test on element after cleaning. Specification does not call out a bubble point test.
2) Investigate use of a finer micron rating element.
3) Investigate use of a ΔP indicator on the unit to provide indication when the element requires replacement.

COMPONENT ANALYSIS

COMPONENT	Filter
SPECIFICATION NO.	75M06607
VENDOR	Marvel
VENDOR P/N	M2449
FIND NUMBERS/CATEGORY	A5304 (HCU -1, -2)/B
FAILURE MODES	Clogged - Loss of hydraulic pressure

ANALYSIS

This filter is a 100 mesh (144 micron) sump type filter with a flow capacity of 10 GPM and filter area of 100 square inches. The material construction is 303 stainless steel with a monel wire mesh screen. The suction from the 30 psi low pressure pump will not collapse the filter. The filter is recleanable.

The purpose of this filter is to protect the low pressure boost pump from contamination and remove the large contaminant particles which would clog the 10 micron filter just downstream from the low pressure boost pump.

The chances of the filter becoming clogged are very remote because once the hydraulic fluid has been cleaned by recirculation, the contamination level in the reservoir should be low. Good maintenance policy, such as changing the filter at regular intervals and preventing contamination from entering the reservoir would help to insure the filter does not become clogged.

ACTION

The sump suction filter is considered adequate for the system and is not considered contaminant sensitive.

COMPONENT ANALYSIS

COMPONENT	Relief Valve
SPECIFICATION NO.	75M06660
VENDOR	Denison Division, Abex Corp.
VENDOR P/N	RIV 12-S45-S6
FIND NUMBERS/CATEGORY	A5316(HCU-1,-2)/B
FAILURE MODES	Open - Loss of Hydraulic Pressure Closed - No Effect Leakage - Possible Hydraulic Failure

ANALYSIS

The system relief valve is a variable pressure, spring loaded poppet-seat type valve. It has a flow capacity greater than the maximum flow of the main stage high pressure pump. The relief valve provides the system with a fluid unloading capability to prevent over pressure from the main stage pump during a malfunction of the pressure comepnsator.

Seal Material - Buna-N

Lubrication - Kel-F-90

Leakage Allowed
External - None
Internal - 100 cc/minute

Flow Capacity - 30 gpm

The Denison Technical Representative said they had no contamination problems with this valve and that it would operate properly in industrial cleaned hydraulic systems. He felt this valve was less sensitive to contamination than the mainstage pump, which is designed to operate on fluid cleaned to NAS 1638 Class 9. Failure analysis has revealed no failures due to contamination.

ACTION

This relief valve (75M06660) is not considered contamination sensitive and is not recommended for test.

COMPONENT ANALYSIS

COMPONENT Snubber

SPECIFICATION NO. 75M06706

VENDOR Operating & Maintenance Specialty Co.

VENDOR P/N 11316-2-1-F

FIND NUMBERS/CATEGORY A5341(HCU-1, -2)/B

FAILURE MODES

Blocked - No System Pressure Indication
Vented - Possible Erroneous Indication

ANALYSIS

Catalog information supplied on these specific snubbers stresses the point that these snubbers are designed to be "self-cleaning" to the point of operating in systems with dirt and pipe scale. The vendor states that the unit contains no filters, porous metal discs, rubber or plastic parts to replace or clean. The above specifications along with the use of these snubbers in low flow requirements systems indicate these parts will not be considered as a contaminant sensitive part in the system.

ACTION

Recommend the snubber not be considered for test.

COMPONENT ANALYSIS

COMPONENT Pressure Switch

SPECIFICATION NO. 75M07505

VENDOR Custom Components Switch

VENDOR P/N 603G-C9-7S

FIND NUMBERS/CATEGORY A5342(HCU-1, -2)/B

FAILURE MODES

Open - No System Pressure Indication
Closed - Constant Indication

ANALYSIS

This switch is actuated by a Belleville disc spring. The Belleville disc is the only portion of the unit contacted by the fluid media and there are no other moving parts. Therefore, this unit will not be considered as a contaminant sensitive part of the system.

ACTION

Recommend the pressure switch not be considered for test.

COMPONENT ANALYSIS

COMPONENT	Cylinder, Pneumatic
SPECIFICATION NO.	75M07725
VENDOR	Pathon Mfg. Co.
VENDOR P/N	C-11147
FIND NUMBERS/CATEGORY	A5894(2)/B
FAILURE MODES	Stuck - No. tray withdrawal Leakage - Possible withdrawal malfunction

ANALYSIS

The pneumatic withdrawal cylinder contains a cylinder body, two heads, a piston, a rod, seals, two adjustable cushions, and a wiper ring. The bore diameter is 2 inches, stroke 20 inches and rod diameter 1 inch.

This cylinder is similar to 75M06506-1 and reference is to be made to that analysis.

ACTION

This cylinder is not recommended for test.

COMPONENT ANALYSIS.

COMPONENT	Cylinder, Pneumatic
SPECIFICATION NO.	75M07998
VENDOR	Pathon Mfg. Co.
VENDOR P/N	
FIND NUMBERS/CATEGORY	A5811(6-7)/A
FAILURE MODES	Stuck - No tray withdrawal Leakage - Possible retraction malfunction

ANALYSIS

The pneumatic cylinder contains a cylinder body, piston, rod, seals and two end heads.

This cylinder is similar to 75M06506 and reference is to be made to that analysis.

ACTION

This cylinder is not recommended for test.

COMPONENT ANALYSIS

COMPONENT Filter (10 Micron Nominal)

SPECIFICATION NO. 75M08053 (Rev. E)

VENDOR Fluid Dynamics

VENDOR P/N FR1802

FIND NUMBERS/CATEGORY A5395(1-8)/B, A34747(9)/B

FAILURE MODES

Clogged - Loss of 3000 psi Hydraulic Supply

ANALYSIS

This filter is a Fluid Dynamics 10 micron nominal filter similar to 75M06606 (Item 10), the only difference being operating pressures, 3000 psi differential collapse pressure, 150 square inches of effective filter area and has 316 SS housing rather than aluminum housing. The element is the same 304 SS wire mesh with the same flow capacity of 20 GPM of hydraulic oil.

ACTION

1) Recommend bubble point test when elements are cleaned.
2) Consider smaller micron rating element.
3) Similar to 75M06606

COMPONENT ANALYSIS

COMPONENT	Cylinder, Pneumatic
SPECIFICATION NO.	75M08231
VENDOR	Pathon Mfg. Co.
VENDOR P/N	
FIND NUMBERS/CATEGORY	A5583(4-8)/A
FAILURE MODES	Stuck - No arm retraction Leakage - Possible retract malfunction

ANALYSIS

The hydraulic-pneumatic cylinder contains a cylinder body, piston, rod, seals, and two heads. The bore diameter is 7 inches, stroke 52 inches, and rod diameter 3.25 inches.

This cylinder is similar to 75M06506-1 and reference is to be made to that analysis.

ACTION

This cylinder is not recommended for test.

COMPONENT ANALYSIS

COMPONENT Pressure Switch

SPECIFICATION NO. 75M08323 (-2, -3, -4)

VENDOR Meletron Corp.

VENDOR P/N 372-95-252, 372-135-246, 372-215

FIND NUMBERS/CATEGORY A5432(1-9)/B, A5511(1-8)/B, A5533(4-8)/B, A5691(4-7)/B, A5767(6)/B, A5795(7)/B, A5852(4-8)/B, A5883(2)/B, A5908(2)/B, A5944(1)/B, A5991(4)/B, A6033(4)/B, A6072(8)/B, A6104(8)/B, A6132(8)/B, A6377(7)/B, A29741(6)/B

FAILURE MODES

Open - No Recharge Capability
Closed - Constant Recharge Attempt

ANALYSIS

This pressure switch is a bourdon tube actuated switch. As the only portion of this unit that will be contacted by the fluid media is the bourdon tube, there is no moving parts within the unit to be contaminant sensitive and, therefore, will not be considered as a contaminant sensitive part of the system.

ACTION

Recommend the pressure switch not be considered for test.

COMPONENT ANALYSIS

COMPONENT Check Valve

SPECIFICATION NO. 75M08325 (-1, -2, -3, -5, -6)

VENDOR James Pond Clark

VENDOR P/N 279T1-4NN, -6NN, -8NN, -12NN, -4WW

FIND NUMBERS/CATEGORY A5461(1-8)/B, A5561(4-8)/B, A5687(4-7)/B, A5710(6-7)/B, A5776(7)/A, A5823(4-6)/B, A5888(2)/B, A5917(2)/B, A5953(1)/B, A5978(4)/B, A6036(4)/A, A6045(4)/A, A6082(8)/A, A6092(8)/B, A6143(8)/A, A6387(7)/A, A6399(7)/B, A6419(7)/B, A29606(7)/A, A29607(7)/A, A29875(4-6)/A, A34802(9)/B.

FAILURE MODES Same as 75M05365 (Item 1)

ANALYSIS Same as 75M05365 (Item 1)

ACTION Recommend the check valve not be considered for test.

COMPONENT ANALYSIS

COMPONENT Check Valve

SPECIFICATION NO. 75M08326 (-1, -2)

VENDOR James Pond Clark

VENDOR P/N 279 T1-4NV, -6TB-1

FIND NUMBERS/CATEGORY A5782(7)/A, A29745(6)/A

FAILURE MODES Same as 75M05365 (Item 1)

ANALYSIS Same as B75M05365 (Item 1)

ACTION Recommend the check valve not be considered for test.

COMPONENT ANALYSIS

COMPONENT Snubber

SPECIFICATION NO. 75M08409

VENDOR Operating & Maintenance Specialty Co.

VENDOR P/N 11316-2-1-F and 75316-2-1-F

FIND NUMBERS/CATEGORY A5431(1-8)/B, A5510(1-8)/B, A55324-8/B, A5690(4-7)/B, A5763(7)/B, A5766(6)/B, A5849(4-7)/B, A5881(2)/B, A5907(2)/B, A5943(1)/B, A6031(4)/B, A6070(8)/B, A6102(8)/B, A6131(8)/B, A6379(7)/B, A29739(6)/B, A34693(9)/B, A34726(9)/B.

FAILURE MODES

Same as 75M06706

ANALYSIS

Same as 75M06706

ACTION

Recommend the snubber not be considered for the test.

COMPONENT ANALYSIS

COMPONENT	Metering Valve
SPECIFICATION NO.	75M08414 (-2, -3)
VENDOR	Robbins Aviation
VENDOR P/N	SSKG-375A-6C-768, SSKG-375A-8C-768
FIND NUMBERS/CATEGORY	A5924(2)/B, A5957(1)/A, A5478(1-8)/A A6251(9)/A
FAILURE MODES	Plugged - Possible retraction malfunction

ANALYSIS

Metering valve is a Robbins catalog standard metering valve described as follows:

Operating pressure vacuum to 6000 psi, safety factor 4:1, Cv = 0.90, zero external and internal leakage, orifice diameter 0.312 in., body material 303 stainless steel, Buna-N seals, approximately 6 turns to full open position. Robbins valves have been widely used in industrial type applications. They are not considered as a contaminant sensitive component for this analysis providing it is opened sufficiently to allow contaminants to pass through the valve. Open condition of the valve at time of this analysis has not been determined. Galling problem of threads has been attributed to improper choice of materials for bonnet and stem.

ACTION

This valve is always fully open or fully closed, and is not recommended for test.

COMPONENT ANALYSIS

COMPONENT	Relief Valve (Hydraulic and Pneumatic)
SPECIFICATION NO.	75M08415 (-1, -2, -3, -5H, -10H)
VENDOR	Anderson Greenwood
VENDOR P/N	28038 (-1, -2, -3, -5H etc.)
FIND NUMBERS/CATEGORY	A5476(1-8)/A, A5486(1-8)/A, A5727(1-7)/B, A5896(2)/B, A29693(3)/B, 29774(4-7)/B, A34665(9)/A, A34680(9)/A, A34753(9)/B, A34754(9)/B, A34797(9)/A
FAILURE MODES	Open - No arm retraction Closed - No effect Leakage - Possible retraction malfunction

ANALYSIS

The relief valve consists of a stainless steel body (303SS), teflon and buna-N seals and a Delrin seat. There have been 19 reported failures on this valve and many of the failures due to a Kel-F seat which was changed to Delrin by ECP0070. One failure was noted as being caused by a contaminant impinging on the seat.

ACTION

The relief valve is not considered contaminant sensitive and is not recommended for test.

COMPONENT ANALYSIS

COMPONENT Check Valve

SPECIFICATION NO. 75M08617 (-3)

VENDOR James Pond Clark

VENDOR P/N 559T1-8D-4

FIND NUMBERS/CATEGORY A5610(5-7)/B

FAILURE MODES Similar to Item 1 75M05365

ANALYSIS Valve design not considered to be contaminant sensitive. This item similar to 75M05365 (Item 1) and vendor representative classed this design as non-contaminant sensitive same as the 200 series type check valves.

ACTION Recommend the check valve not be considered for test.

COMPONENT ANALYSIS

COMPONENT	Accumulator
SPECIFICATION NO.	75M08814 (-2)
VENDOR	American Bosch Arma Corp.
VENDOR P/N	EHS 41-414
FIND NUMBERS/CATEGORY	A5468(1-8)/A, A5654(4-7)/B
FAILURE MODES	Stuck Piston - No hydraulic supply Leakage - Possible hydraulic failure

ANALYSIS

The accumulator contains a piston, cylinder, and two end caps, one for GN_2 input and the other for hydraulic fluid input. The GN_2 input forces the piston downward, exerting pressure against the hydraulic fluid. The piston moves up or down according to the pressure relationship between the hydraulic fluid and GN_2. Attached to the accumulator, at the GN_2 end, is a level switch which indicates the position of the piston, and when to recharge the hydraulic end.

Seal Material - Buna-N per MIL-P-25732 or equal

Lubrication - The Spec calls out Kel-f-90 grease or MIL-H-5606 hydraulic fluid. Atlantic Refining Co. #54 lubricant will be used and the Spec changed.

Leakage Allowed:
External - Bubble tight
Internal - 10 drops per 15 minutes (hyd)
5 cc per minute (GN_2)

Clearances - 3 to 6 thousandths between piston and barrel

Finish - 10-14 micron-inch RMS

According to the American Bosch Arma Corp. Technical Representative, their normal cleaning process was to mechanically brush the components using a soft bristled brush and flush using a compatible solvent. They perform the functional, leak, and proof pressure test on all assembled accumulators. The accumulators which are required to meet NASA cleaning specs are then sent to the cleaning vendor (ConTec or Wiley Lab) before being installed in the Service Arm System. The accumulators are disassembled and cleaned according to specification control drawing cleanliness requirements. Then they are reassembled using new seals, leak checked and functionally tested.

There have been several failures of accumulators after only a few cycles of operation and it was apparently due to the cleaning process used by the cleaning vendor. The main failures were due to O-ring spiraling, bore surface deterioration, and O-ring damage upon installation. There were several recommended changes to be made to the Specification Control Drawings according to NASA internal report number 5-6250-H-614 Dated 17 September 1968.

It was the opinion of the Bosch Technical Representative that the accumulators were being "cleaned to death". Changing the cleaning methods may well improve the overall system cleanliness and reliability, in addition to decreasing the accumulator failure rate.

An unsatisfactory condition report (KSC400720 dated 9-24-68) was just received and indicated an accumulator had O-ring damage and scored inner walls, which was evidently caused by an eccentric loading from the level switch to the piston. Also, upon replacement of the soft goods on all of the accumulators from mobile launcher 1, due to internal damage and leakage problems, an accumulator was found that had approximately 90 percent of the plating gone from inside the cylinder and the O-ring sealing surface was scored.

Due to the above analysis the accumulator is not considered contamination sensitive. Contamination generation may be a problem unless the recommendations in report 5-6250-H-614 are approved and solve the problem of cleaning the accumulators.

ACTION

Although not considered to be contamination-sensitive, failure history would indicate the need for test. This component also represents a major category of components on the Service Arms. Recommend this accumulator be considered for test.

COMPONENT ANALYSIS

COMPONENT	Backpressure Valve
SPECIFICATION NO.	75M08819-1
VENDOR	Rivett
VENDOR P/N	2276A
FIND NUMBERS/CATEGORY	A5502(1-8)/A, A 5503(1-8)/A, A34808(9)/A
FAILURE MODES	Closed - Arm will not retract Leakage - Possible soft hydraulic system

ANALYSIS

The backpressure valve consists of two bodies mounted on a subplate assembly. Each body contains an adjusting screw, spring, spool, and a seat. The valve maintains a constant backpressure in the hydraulic return line.

Seal Material - Buna-N per MIL-P-25732

Lubrication - MIL-H-5606 Hydraulic Fluid or Kel-F-90 Grease

Leakage - Internal - 5 cc/minute
External - None

Flow Capacity - 120 gpm at 60 spi pressure drop

Set Pressure - 80 ± 5 psi

The only moving part in this valve is the spool, which moves off the seat to allow fluid flow. The radial clearance between the spool and valve body is .003 to .006 of an inch. Failure due to the spool sticking open or closed is considered very unlikely. Also failure due to leakage caused by contamination is unlikely because the seat area is large and the seat is made of Buna-N, which is a good, soft sealing material.

One failure was reported on this valve, which indicated internal leakage was caused by deformation and contamination of the soft seat sealing surfaces. This type of failure is not considered critical to the system because the fluid lost would be replaced by the backpressure system and a positive pressure maintained. Also, the chances of this failure happening are rather remote.

ACTION

This backpressure valve is not considered contamination sensitive and is not recommended for test.

COMPONENT ANALYSIS

COMPONENT [illegible]

SPECIFICATION NO [illegible]

VENDOR [illegible]

VENDOR P/N [illegible]

FIND NUMBER/CATEGORY A5481(1-3)/A, A5482(1-3)/A, A[illegible]/A, A29676(1-2)/A, A34767(9)/A, A34768(9)/B, A34771(9)/A, A34774(9)/A, A34776(9)/A, A34780(9)/B, A34783(9)/B

FAILURE MODES
- Open - No Effect
- Closed - No arm retraction
- Leakage - Possible retraction malfunction

ANALYSIS - The pilot operated valve is a two-way, two-position valve which is externally operated by a hydraulic pilot which opens or closes [illegible]. A mechanical detent locks the valve in either of its [illegible] positions. The valve consists of an actuator assembly [illegible] rack which operates a ball valve.

[illegible] Buna-N per MIL-P-25732

Lubrication - Kel F90 grease

Leakage allowed - External - none
Internal - none

Critical Tolerances -

1. .070 in. orifice - which allows hyd fluid to actuate piston at a controlled rate.
2. .060 in between piston and bore of pilot valve.
3. Detent force of 35-40 in-lb to hold valve in its last energized position.
4. Displacement per stroke of piston 0.6 in^3

[illegible] does their own cleaning to MFSC Process 166D.

The Flodyne Representative said they had no contamination problems with this valve and that it would function properly if the system was considerably dirtier than present spec requirements.

Analysis of this component has found it to be considered not contamination sensitive. Below are some reasons:

1. Loose tolerances involved
2. Clean design of the ball valve
3. Low volume of flow in the pilot operated portion of the valve
4. Low contamination generation
5. Recommendation of the vendor
6. History of failures

<u>ACTION</u> - Testing of this valve is determined to be not necessary.

COMPONENT Pilot Operated Valve

SPECIFICATION NO. 75M08821

VENDOR Flodyne Controls

VENDOR P/N 15C150

FIND NUMBERS/CATEGORY A5513(1-8)/A

FAILURE MODES

#1 or #2	Deenergized	No Arm Retraction
#1 or #2	Energized	Possible Semi Extension Malfunction
#1 or #2	Open	Possible Extension Malfunction
#1 or #2	Closed	No Arm Retraction
#1 or #2	Leakage	Possible Retract Malfunction

ANALYSIS

The pilot operated valve is a two-way, two-position valve which is externally operated by solenoids. A detent mechanism locks the ball in the full open or closed position. The valve consists of solenoids, piston, rack and ball. The solenoid valves consist of a poppet and seat assembly. When the solenoid is energized the inlet is open to outlet and de-energized the inlet is blocked and the outlet is vented.

Seal Material - Buna-N per MIL-P-25732

Lubrication - Kel-F-90 Grease

Leakage Allowed

External - None
Internal - None

Cleaning - Flodyne does their own cleaning to MFSC-PROC-166D

Solenoid Valve Specs

Solenoid Pull - 25 lb
Spring Return - 8 lb
Solenoid Stroke - 0.005 in.
Orifice to Piston - 0.060 in.

Piston to bore clearance 0.060 in.
Displacement per Stroke 0.6 $in.^3$

The Flodyne Technical Representative said they had no contamination problem with this component. He said the solenoid valve portion of this component would be the most sensitive to contamination. An inlet filter is not used on the pneumatic solenoid valve used on this component, but Flodyne does use inlet filters on other solenoid valves which they build.

This valve is the same as the hydraulic pilot operated valve (P/N 15C160) except that this one has two solenoids. The valve is considered not to be contamination sensitive except for the solenoid portion. The flow through the solenoid in one cycle is very small and tends to reduce its contamination sensitivity. Further study will be conducted to determine if the solenoid portion should be considered for test.

ACTION

The solenoid is used in a low flow application. This valve is not recommended for test.

COMPONENT ANALYSIS

COMPONENT Pilot Operated Valve

SPECIFICATION NO. 75M08822(-1, -3)

VENDOR Kemp Aero Products

VENDOR P/N K 402016 (-1, -3)

FIND NUMBERS/CATEGORY A5537(4-8)/A

FAILURE MODES
Leakage - Possible premature retraction
Closed - No arm retraction
Open - No effect

ANALYSIS

The valve is a pilot operated valve supplied by Kemp Industries to meet the 75M08822 specification. The valve is operated by two solenoid valves, one to open the valve and the other to release the locking fingers which hold the valve and allow it to close by spring forces which allow pilot pressure to vent and the main poppet to close. The valve is designed for operating pressure of 3000 psig gaseous nitrogen with a flow factor of 2.0 SCFM/PSIA. The body material is 2024-T4 aluminum alloy (anodized) and trim materials also are 2024-T4 aluminum. Elastomers are Delvin or Buna-N (both shown in Kemp drawing). The valve has no failure history connected with contaminant problems. The valve will remain in its last energized position with a power loss to both solenoids. This valve contains no small orifices or exceptional tight tolerances as it is all standard "O" ring design with Kel-F 90 grease for lubrication. The pilot vent is screened for protection from external contaminants. Kemp representatives consider the valve is not contaminant sensitive and would prefer to supply the valve commercially clean such that they could clean and test the valve in their own facility. For this analysis, the valve is not considered to be contaminant sensitive and will not be considered a candidate for test.

ACTION

Recommend the valve not be considered for test.

COMPONENT ANALYSIS

COMPONENT	Solenoid Valve
SPECIFICATION NO.	75M08823
VENDOR	Marotta Valve Corp.
VENDOR P/N	806097-1 (510H-2A)
FIND NUMBERS/CATEGORY	A5417(1-8)/B, A5420(1-8)/B, A5460(1-8)/B, A5560(4-8)/B, A5578(4-8)/A, A5650(4-8)/B, A5707(6)/B, A5977(4)/B, A34814(9)/A, A34822(9)/B
FAILURE MODES	De-energized - No precharge, no retraction, system malfunction Energized - System malfunction. Leakage - Possible system malfunction

ANALYSIS

This valve is a Marotta solenoid valve, 2-way, 2 position, normally closed, with 1/2 inch male fittings. The valve is designed for 3000 psi gaseous nitrogen or hydraulic fluid operating pressure with a 0.20 inch ESEOD ($C_D = 0.6$). Response time is 75 milli-seconds maximum. Materials in the valve are 300 series stainless steel, nylon seat, and Buna-N seals, and Kel-F grease for lubrication. The operation of the valve is very similar to the 75M08825 except it is a two-way valve and is 1/2 inch tube size rather than 1/4 inch tube size. Therefore, this valve is also considered not to be contaminant sensitive but will be given further consideration as a test candidate. This valve is similar to valve used by Martin in gaseous nitrogen system cleaned to EPS50405 level C.

ACTION

Valve was used in tests to complete the system circuit.

COMPONENT ANALYSIS

COMPONENT: Solenoid Valve

SPECIFICATION NO.: 75M08824(-1, -2)

VENDOR: Marotta Valve Corp.

VENDOR P/N: 228154 -02, -05

FIND NUMBERS/CATEGORY: A5787(7)/B, A5837(4-7)/B, A5887(2)/B, A5914(2)/B, A5952(1)/B, A6023(4)/B, A6058(8)/B, A6090(8)/B, A6138(8)/B, A6400(7)/B, A29731(6)/B

FAILURE MODES:
De-energized - No bottle recharge
Energized - Constant recharge attempt
Leakage - Constant recharge attempt

ANALYSIS

This valve for analysis purposes according to Marotta engineering is similar to 75M08825. The valve is a two-way, two position, normally closed valve for use with 3000 psi gaseous nitrogen. The valve has a 0.11 inch ESEOD, 1/4 inch port. The remainder of the analysis will be the same as for 75M08825.

ACTION

This valve was used in tests to complete the system circuit.

COMPONENT ANALYSIS

COMPONENT	Solenoid Valve
SPECIFICATION NO.	75M08825(-2)
VENDOR	Marotta Valve Corp.
VENDOR P/N	225884(-02, -05)
FIND NUMBERS/CATEGORY	A5762(4-7)/B, A5792(4-7)/B, A5844(4-7)/B, A5879(2)/B, A5895(2)/A A5904(2)/B, A5940(1)/B, A5985(4)/B A6028(4)/B, A6066(8)/B A6099(8)/B A6128(8)/B, A6382(7)/B, A29736(6)/B
FAILURE MODES	De-energized - Can't check transducer Energized - No system readout, constant charge Leakage - Possible erroneous readout

ANALYSIS

This is a Marotta solenoid valve, 3 way, 2 position, 2 inlets and 1 outlet with 1 port (closest to solenoid) normally spring closed. The unit is designed for 3000 psi operating pressure with gaseous nitrogen and bubble tight leakage. The valve has aluminum body (anodized), 303 SS stem, nylon seat and Buna-N seals. The unit has 1/4 inch tube size male fittings. The stroke on the Marotta solenoid valves is approximately .020 inch. The valve is standard "O" ring type design with balanced poppet configuration. The valve has no small orifices or pilot ports, etc., which might become clogged from normal system contaminants. The valve for this analysis is considered not to be contaminant sensitive. Marotta project engineer indicated they feel their solenoid valves would operate satisfactorily under their commercial clean conditions which they estimate to approach the MSFC 164 specification level. These valves will be given further consideration as test candidates.

ACTION

Valve was used in test circuit.

COMPONENT ANALYSIS

COMPONENT	Solenoid Valve (Pilot Operated)
SPECIFICATION NO.	75M08826
VENDOR	Marotta-Valve Corp.
VENDOR P/N	227154 -2, -4
FIND NUMBERS/CATEGORY	A5663(4-8)/A, A6081(8)/A, A6113(8)/A, A6368(7)/A, A6405(7)/A
FAILURE MODES	De-energized - System Malfunction Leakage " " GN_2 Closed - " "

ANALYSIS

This valve is a Marotta three way, two position valve with two pilot valves. The pilot valves are solenoid valves, two way, two position, normally closed valves. The valve is designed for gaseous nitrogen or hydraulic fluid usage. Design operating pressure is 3000 psig inlet, atmospheric vent, and 600 to 1500 psig actuating port. The valve has 3/4 inch fittings with a 0.500 inch ESEOD. The valve materials are 300 series stainless steel, nylon seats, Buna-N seals and Dow Corning FS1281 lubrication. The valve has a screened port and check valve in actuation pressure inlet. There is an approximate .020 inch diameter port in the bleed side to the vent solenoid. This solenoid has been replaced with an orifice in the -4 configuration. Stroke on both poppets is approximately .100 inch. Although this valve is more complex with two solenoids, two main seats, etc., the valve is still considered by Marotta not to be contaminant sensitive and indicate they could operate the valve satisfactorily at their commercial clean level.

ACTION

This valve is not recommended for tests.

COMPONENT ANALYSIS

COMPONENT	Selenoid Valve (Pilot Operated)
SPECIFICATION NO.	75M08827
VENDOR	Marotta Valve Corp.
VENDOR P/N	227404-2
FIND NUMBERS/CATEGORY	A5730(4-7)/A
FAILURE MODES	De-energized - System Malfunction Energized - " " Leakage - " " Neutral Pos. - " " Normal Pos. - " "

ANALYSIS

For analysis purposes this valve is similar to 75M08826. This valve is a four-way, three position valve and contains two pilot valves, indicating switch, two stems, two poppet assemblies, two springs and a piston. The valve is designed for use with gaseous nitrogen and hydraulic fluid. Operating pressures of the valve are 750 psig low pressure inlet, 3000 psig high pressure inlet, and 600 to 1500 psig actuation pressure. The valve has 3/4 inch fittings and 0.500 inch ESEOD. Actuation port is 1/4 inch. Materials are 316 stainless steel body, 304 stainless steel poppet, nylon seats, and Buna-N seals. Kel-F 90 grease is used for lubrication. The actuation port contains a screen and a check valve same as the 75M08826 valve. The remainder of the analysis for this valve will be the same as for 75M08826.

ACTION

This valve is not recommended for test.

COMPONENT ANALYSIS

COMPONENT Regulator

SPECIFICATION NO. 75M08829

VENDOR Marotta Valve Corp.

VENDOR P/N 227464-J11

FIND NUMBERS/CATEGROY A5785(7)/B, A5835(4-7)/B, A5886(2)/B, A5913(2)/B, A5951(1)/B, A5956(1)/A, A6022(4)/B, A6057(8)/B, A6089(8)/B, A6136(8)/B, A6401(7)/B, A29730(6)/B, A34705(9)/B

FAILURE MODES

Closed - No Recharge; No Withdraw, Reconnect.
Erratic - Possible Low Charge

ANALYSIS

This Marotta hand operated regulator is for GN_2 usage. According to Moratta's representatives the design is similar to a unit used by MMC (MMC part No. PD4880124-109). The unit is assembled with fitting filters in the inlet, outlet, and vent ports. The most significant difference between the MMC unit and this unit is the MMC unit uses omniseals rather than "O" rings and has a large sensing piston for tighter accuracy requirements. There has been no failure history of these parts in the MMC level "C" clean system. Tolerances and clearances of the MMC and subject part are essentially the same according to Marotta's engineering representatives. This is not a high flow device as its normal use is to pressurize the dome of a higher flow dome regulator. The flow past the poppet and seat would be the critical area for contaminants to cause leakage problems which is protected against by use of the fitting filters described above. As these parts are required to perform with a certain accuracy in the system they will be considered as a possible test candidate to be tested during the new proposed cleanliness level test program.

ACTION

Recommend that this regulator be considered for test.

COMPONENT ANALYSIS

COMPONENT	Regulator
SPECIFICATION NO.	75M08830 (-1, -2)
VENDOR	Marotta Valve Corp.
VENDOR P/N	219004 (-B155, -J151)
FIND NUMBERS/CATEGORY	A5419(1-8)/B, A34734(9)/B
FAILURE MODES	Closed - Loss of hyd. sys. back pressure, standby hyd. press. Erratic- No effect. Could cause hold early in count; soft standby sys.

ANALYSIS

This regulator is similar to 75M08829 except for lower operating pressures. The 75M08829 was designed for 10,000 psi inlet and 3000 psi outlet. This regulator is designed for 3000 psi inlet and 0-150 psi out... with a factor of .05 SCFM/PSIA. The unit is designed for use with gaseous nitrogen or hydraulic fluid. Materials used in construction of the regulator are 2024-T4 aluminum body, 300 series stainless steel poppet, nylon seats and Buna-N seals. Kel-F 90 grease is used as lubricant. As these parts, like the 75M08829, are required to operate automatically with a certain accuracy, these parts will be considered as possible test candidates. Marotta engineering has indicated they can operate these regulators satisfactorily at their commercial clean level which approaches the MSFC 164 level. Martin has used similar regulators in ground pneumatic systems for a number of years with EPS 50405 level C cleaning with no contamination problems.

ACTION

Recommend that this valve be considered for test.

COMPONENT ANALYSIS

COMPONENT	Regulator
SPECIFICATION NO.	75M08831 (-2)
VENDOR	Marotta Valve Corp.
VENDOR P/N	230904(-11) RV78
FMEA NUMBERS/CATEGORY	A6075(8)/A, A6108(8)/A, A6373(7)/A, A6410(7)/A
FAILURE MODES	Closed - No withdrawal Erratic - Withdrawal malfunction

ANALYSIS

This regulator is a three way, spring referenced, preset pressure regulator. The regulator is designed for use with gaseous nitrogen. The unit is designed to maintain the outlet pressure either by flow from inlet to outlet to increase pressure or by flow from outlet to vent to reduce pressure to the preset pressure level within a certain accuracy. The unit is designed for an inlet pressure of 4500 psi maximum and an outlet pressure range of 50-190 psi. The valve has a flow factor of 0.5 scfm/psi. The inlet port is 3/8 inch and the outlet port is 1/2 inch. The unit does have a screen around the inlet port of the poppet to protect against contaminants (approx. 162 micron). As the unit is not subject to contaminant damage under normal operation, it is not considered contaminant sensitive. Marotta engineering imdicates the unit should work satisfactorily in their commercial clean condition. This regulator is a standard Marotta regulator design and similar to Martin part number PD48S0124-179.

ACTION

Recommend that this valve be considered for test.

COMPONENT ANALYSIS

COMPONENT	Automatic Shutoff Valve
SPECIFICATION NO.	75M08836(-1)
VENDOR	Marotta Valve Corp.
VENDOR P/N	232744-3 (FVA 12)
FIND NUMBERS/CATEGORY	A6374(7)/A, A6396(7)/A
FAILURE MODES	Closed - No effect Open - No withdrawal Leakage - Withdrawal malfunction

ANALYSIS

This valve is an automatic shutoff valve which operates with 4500 psi nitrogen gas. The valve remains open until pressure drop across valve increases to 40 psi. The materials are 303 CRES, nylon seat, Buna-N seals and Kel-F 90 grease for lubrication. The valve has 3/4 inch ports. As the valve is only for flow control and flow is such that particles should flow through valve easily, it is not considered as contaminant sensitive and will not be considered as a test candidate.

ACTION

Recommend this valve not be considered for test.

COMPONENT ANALYSIS

COMPONENT	Solenoid Valve
SPECIFICATION NO.	75M08839
VENDOR	ITT Aerospace Controls (Formerly General Controls)
VENDOR P/N	AV 14J1163
FIND NUMBERS/CATEGORY	A5439(1-8)/A
FAILURE MODES	#1 or #2 Deenergized - No Semi-Auto Retraction #1 or #2 Energized - No Semi-Auto Retraction Leakage - No Effect

ANALYSIS

The solenoid valve is a hydraulic, pilot operated, 4 way, 3 position cylinder lock valve. It contains 2 end caps, a retainer and piston assembly, spool assembly, two solenoids, seat and ball assembly and filter assembly. Upon energizing solenoid No. 1 or No. 2, hydraulic fluid flows through the ball and seat assembly to the piston assembly which causes the spool to shift and direct hydraulic pressure to Port No. 1 or No. 2. All ports are blocked when the solenoid is not energized.

Seal Material — Buna-N per MIL-P-25732 and MIL-P-5510

Leakage - External - Bubble tight
Internal - 5 cc per minute

Lubrication - Kel-F-90 grease

Clearances - Spool to sleeve clearance .00005 to .0001 of an inch based upon leakage allowance

Filter Assembly - 50 micron

The solenoid is protected against contamination in the ball and seat assembly by 50 micron filtration and the forces on the spool are sufficient to prevent sticking. There have been no reported failures due to contaminatination and only one failure due to internal leakage. This valve is very similar to the Sterer 75M08841 solenoid valve but the forces to operate the spool are much greater.

ACTION

This valve is not considered contaminant sensitive and is not recommended for test.

COMPONENT ANALYSIS

COMPONENT Solenoid Valve

SPECIFICATION NO. 75M08841 (-1, -3)

VENDOR Sterer Engineering Company

VENDOR P/N 26370-2 (37890 - new part per Sterer Eng Rep)

FIND NUMBERS/CATEGORY A5479(1-8)/A, A29677(1-2)/A
A34660(9)/A, A34661(9)/A, A34769(9)/A,
A34772(9)/A, A34779(9)/A, A34784(9)/A

FAILURE MODES		
	Stuck Straight	No arm retract
	Stuck crossed	No effect
	Leakage	Possible retract malfunction

ANALYSIS - The solenoid valve is a four-way, two-position, double solenoid, hydraulic selector valve. The solenoid contains a spool and sleeve assembly that is operated by energizing the solenoids The movemovement of the spool and sleeve assembly allows hydraulic fluid to flow through the ports. The valve has a mechanical latch which allows the valve to remain in its last energized position.

Seal Material Buna-N per MIL-P-25732 or equal

Lubrication - Kel-f-90 grease or MIL-H-5606 hydraulic fluid

Leakage allowed - External - No leakage
Internal - 10 cc per minute

Critical tolerances - Spool to sleeve clearance .00005 to .0001 of an inch based upon leakage allowance.

Solenoid Pull - 12 lb. (50% greater for new P/N)

Solenoid Travel - .065 of an inch

The Sterer Technical Representative said that 75M08841-1 (P/N26370-2) was changed to 75M08841-3 (P/N 37890). The basic change was in the switching mechanism and addition of a solenoid with approximately 50% greater pull. The Sterer Technical Representative also felt this valve was not contamination sensitive and similar spool type valves are used widely in aircraft systems which allow much more contamination than the NASA Specs. now imposed on this valve. He also said a statistical analysis as to this valve sticking or malfunctioning due to contamination would be enough to scare a person but that the valves do work.

Many reports have been written on servo valves, which have a spool, which have clearances as tight and tighter than this valve and in order to fail the spool by sticking the contamination levels had to be extremely high. Levels higher than NAS 1638 class 108, which is the dirtiest level in this spec, were required in order to cause the spool to stick. The contamination was actually so high that conventional methods could not be used for checking contamination levels. Time was a factor and spools would wear at much cleaner levels. Sticking was caused by silting of small particles which get in-between the spool and sleeve assembly.

This particular valve is used for supplying pilot pressure to the Flodyne pilot operated ball shut-off valve and the volume of flow is very low (approximately 6/10 of a cubic inch). This low flow will reduce the chances of the spool sticking due to silting if the oil contains high contamination levels.

ACTION

Vendor experience and very low flow does not indicate the need for tests.

COMPONENT ANALYSIS

COMPONENT	Check Valve
SPECIFICATION NO.	75M0?007
VENDOR	Republic Mfg. Co.
VENDOR P/N	458-32SS & 9-663-1
FIND NUMBERS/CATEGORY	A5475(1-8)/A, A5553(4-8)/A, A34698(9)/A, A34770(9)/A, A34773(9)/A, A34775(9)/B, A34777(9)/B, A34809(9)/A
FAILURE MODES	Open - No retraction Closed - No effect, possible extend malfunction, no arm extend or retract Leakage - Possible retract malfunction, extend malfunction

ANALYSIS

This is a standard Republic poppet type check valve, except for the grayloc fittings. The check valve has a 1 1/2 diameter and a flow capacity of 120 gpm at 28 psi pressure drop. The body is stainless steel, type 303, and the poppet is hardened stainless steel, type 440. The seating surfaces are metal to metal and seals used are Teflon and Buna-N. Leakage requirements are: external - zero and internal - 1 drop in 2 minutes. Two failures were reported on this check valve; both were external leakage and were not caused by contamination.

ACTION

This check valve is ruggedly made for high shock, continuous service in high velocity hydraulic systems. The check valve is not considered contaminant sensitive and is not recommended for test.

COMPONENT ANALYSIS

COMPONENT	Cylinder
SPECIFICATION NO.	75M09014
VENDOR	Pathon Mfg. Co.
VENDOR P/N	
FIND NUMBERS/CATEGORY	A6007(4)/A, A6018(4)/A
FAILURE MODES	Stuck - No LOX cylinder withdrawal Leakage - Possible withdrawal malfunction

ANALYSIS

The 75M09014 becomes the 76K00084 by replacement of u-cup seals with "o" ring seals.

The withdrawal cylinder contains a body cylinder, piston, rod, wiper ring, seals, two heads, and an adjustable cushion. The bore diameter is 3 inches and rod diameter 1.125 inches.

The cylinder is similar to 75M06506-1 and reference is to be made to that analysis.

ACTION

See 75M06505 for action analysis.

COMPONENT ANALYSIS

COMPONENT — Level Control Switch Assembly

SPECIFICATION NO. — 75M09283

VENDOR — Hayes Aircraft Corp.

VENDOR P/N

FIND NUMBERS/CATEGORY — A5470(1-8)/B, A6249(9)/B, A6250(9)/B, A6290(9)/B, A6292(9)/B

FAILURE MODES — Open - No accumulator recharge
Clogged - Constant recharge attempt
Leakage - Possible hydraulic malfunction

The level control switch assembly is a single pole, double-throw, mechanically operated switch assembly. The level switch contains a harness assembly with a switch, a piston which actuates the switch, a vent valve, and sintered restrictor. The level control switch indicates the position of the accumulator piston and activates the hydraulic charging solenoid valve to maintain the proper hydraulic level in the accumulator.

Lubrication - Dow Corning DC-55 Silicone Grease on packing and sliding surfaces.

Seal Material - Buna-N per MIL-P-25732

Leakage - External None

Stroke - 2.06 inches

The level switch has a sintered restrictor which regulates nitrogen to purge the switch and protect against explosion and fire hazards.

The only moving part of the level switch assembly exposed to the pneumatic/hydraulic system is the piston, which protrudes into the pneumatic end of the accumulator. There has been a failure of a level switch when it required 750 pounds to actuate, but it does not appear to have been caused by contamination.

ACTION

The level control switch is not considered to be contaminant sensitive and is not recommended for test.

COMPONENT ANALYSIS

COMPONENT	Solenoid Valve
SPECIFICATION NO.	75M09285
VENDOR	Marotta Valve Corp.
VENDOR P/N	806098 (MV 583H-2A)
FIND NUMBERS/CATEGORY	A5642(7)/A, A5809(7)/A, A5829(4-7)/A, A5860(4-7)/A, A5868(4)/A, A5871(4)/A, A5923(2)/A, A6040(4)/A, A6049(4)/A, A6053(4)/A, A6054(4)/A, A6147(8)/A, A6150(8)/A, A6413(4-7)/A, A6420(4-7)/A, A29753(6)/A, 11190(6)/A (by vendor P/N MV583)
FAILURE MODES	De-energized - No kickoff or no withdrawal Energized - Possible premature kickoff or withdrawal Leakage - Possible premature kickoff or withdrawal

ANALYSIS

This valve for analysis purposes according to Marotta engineering is similar to 75M08825. The valve is designed for use with 3000 psig gaseous nitrogen or hydraulic fluid. The valve is a three-way, two position, normally closed valve. Materials of construction are 300 series stainless steel with nylon seats. The valve has 1/2 inch ports with a 0.190 inch ESEOD. The remainder of this analysis will be considered the same as for 75M08825.

ACTION

Recommend that this valve configuration be considered for test.

COMPONENT ANALYSIS

COMPONENT Cylinder, Hydraulic

SPECIFICATION NO. 75M09362

VENDOR Pathon Mfg. Co.

VENDOR P/N C11152

FIND NUMBERS/CATEGORY A5492(1-8)/A, A5497(1-8)/A

FAILURE MODES

Stuck: Possible extend/retract malfunction
Leakage: Same as stuck

ANALYSIS

The hydraulic cylinder contains a cylinder body, piston, rod, seals, cartridge assembly, spare port plug assembly, needle and ball check assembly and two end heads. This cylinder has a bore diameter of 8 inches, rod diameter of 3.5 inches and stroke of 14.875 inches.

This cylinder is similar to 75M06506-1 and reference is to be made to that analysis.

ACTION

Refer to 75M06506.

COMPONENT ANALYSIS

COMPONENT	Regulator, Solenoid Operated
SPECIFICATION NO.	75M10090
VENDOR	Marotta Valve Corp.
VENDOR P/N	230864 (RV52CC)
FIND NUMBERS/CATEGORY	A5770(6)/A
FAILURE MODES	Closed - No tray withdrawal Open - Possible premature withdrawal Leakage - Possible premature withdrawal

ANALYSIS

This regulator is a dome referenced regulator with a pilot valve and a pilot regulator. The pilot valve is three way, two position, solenoid valve with indicator switch. The pilot regulator is pressure regulating valve with a downstream relief designed for dome loading. The dome is loaded through the pilot valve by the pilot regulator. The valve is designed for use with gaseous nitrogen. The operating pressure is 3000 psig. The ports are 3/4 inch with a flow factor of 1.6 SCFM/PSIA in to out and 2.4 SCFM/PSIA outlet to vent. The outlet of the pilot regulator has a .020 inch orifice, but the inlet to the pilot regulator has 28 x 500 mesh stainless steel screen to protect it. The sensing passage from the outlet to the piston has .060 inch orifice. The poppet is nylon coated which could be a contaminant generator if it could peel off. This is a very complex assembly although it is made up of more or less standard Marotta components.

ACTION

COMPONENT ANALYSIS

COMPONENT: Regulator

SPECIFICATION NO.: 75M10272

VENDOR: Hannifin Co. - Division of Parker Hannifin Co.

VENDOR P/N: R2550

FIND NUMBERS/CATEGORY: A5611(5-7)/B

FAILURE MODES: Closed - No cylinder actuation
Erratic - Possible platform malfunction

ANALYSIS

Regulator is a spring loaded diaphragm to reduce gaseous nitrogen supply pressure from 250 psi to an outlet pressure from 3-125 psi. The unit is designed for a proof pressure of 375 psi and a burst pressure of 625 psi. Materials used are corrosion resistant steel, Buna N seals, and Kel F 90 grease. Flow capacity of the unit is specified as 197 SCFM gaseous nitrogen at set pressure of 90 psi and flowing to atmosphere. The designed flow path is described by the vendor catalog as self cleaning as all flow is in a direction away from the seat. This regulator is not considered to be contaminant sensitive to normal gaseous nitrogen system usage.

ACTION

Recommend the regulator not be considered for test.

COMPONENT ANALYSIS

COMPONENT	Cylinder, Pneumatic
SPECIFICATION NO.	75M10807 (-1, -3)
VENDOR	Pathon Mfg. Co.
VENDOR P/N	B10481, B10480
FIND NUMBERS/CATEGORY	A5626(5-7)/B
FAILURE MODES	Stuck - Can't couple/uncouple vehicle Leakage - Possible coupling malfunction

ANALYSIS

The pneumatic cylinder contains a cylinder body, piston, rod, seals and two end heads. The bore diameter is 2.0 inches, rod diameter -- 1.0 inch and stroke 5.0 inches.

This cylinder is similar to 75M06506 and reference is to be made to that analysis.

ACTION

Refer to 75M06506.

COMPONENT ANALYSIS

COMPONENT Filter

SPECIFICATION NO. 75M10992 (Rev. C)

VENDOR Fluid Dynamics

VENDOR P/N (-1) FL1329-1 and (-2) FL1329-2

FIND NUMBERS/CATEGORY A5388(1-8)/B, A5390(1-8)/B, A5563(4-8)B, A5613(4)/B, A34748(9)/B, A34749(9)/B

FAILURE MODES

Clogged - Loss of 750 PSI GN_2 Supply

ANALYSIS

This filter is a Fluid Dynamics 10 micron nominal filter similar to 75M06606 (Item 10). The differences being it is an in-line type, 1200 psi differential collapse pressure, 150 square inches of effective filter area for the -2, and 45 square inches after the -1. This unit is used in gaseous nitrogen system rather than hydraulic oil. The -1 is a 1/2" line size and the -2 is a 3/4" line size. It has 316 SS housing with a 304 SS wire mesh element with teflon seals.

ACTION

1) Recommend bubble point test on element after cleaning.
2) Investigate using smaller micron rating elements. Elements of various micron ratings are available for use in this housing.

COMPONENT ANALYSIS

COMPONENT Air Motor

SPECIFICATION NO. 75M11149

VENDOR Gardner Denver

VENDOR P/N MR50C1

FIND NUMBERS/CATEGORY A6122(8)/A, A6390(7)/A

FAILURE MODES Inoperative - (stalled) - No LEM or service module carrier withdrawal

ANALYSIS

The air motor is a rotary vane motor with a 4-bladed rotor. The air motor is fully reversible with equal power in either direction.

Operating Pressure - 125 psi (GN_2)

Max. Output at 90 psi - 5.5 hp at 247 rpm

Lubrication - Kel-F-90 and SAE 30 motor oil

Cleaning - KSC-C-123, Level IV, Test Method A

There have not been any reported failures on this air motor. This type of air motor has widely been used in industrial applications and has performed well operating on industrial cleaned air systems. This air motor is not considered contaminant sensitive and any contamination generated would be vented through a check valve.

ACTION

It is recommended that the air motor not be considered for test.

COMPONENT ANALYSIS

COMPONENT: Selector Valve

SPECIFICATION NO. 75M11428

VENDOR Republic Mfg. Co.

VENDOR P/N N8042B-8AY2LCO

FIND NUMBERS/CATEGORY A5612(5-7)/B

FAILURE MODES
Straight - All cylinders will not extend
Crossed - All cylinders will not retract
Leakage - Possible platform malfunction

ANALYSIS

This is a 4-way, 2-position, manually operated selector valve. It is a Standard Republic Catalog design of their 8000 Series. The valve operates on GN_2 at 85-100 psi.

Seal Material - Buna-N per MIL-P-25732 or equal

Lubrication - Kel-F-90 Grease

Leakage:

Internal - None
External - 30 cc per minute at 2000 psi

Cleaning - Clean, protect and inspect to MSFC Spec A10M01671, Level IV, Test Method A, Certification required.

ACTION

This is a very simple and reliable selector valve and is not considered contaminant sensitive. It is recommended that this valve not be considered for test.

COMPONENT ANALYSIS

COMPONENT	Metering Valve
SPECIFICATION NO.	75M11558
VENDOR	Robbins Aviation
VENDOR P/N	C427A-16C-768
FIND NUMBERS/CATEGORY	A6391(7)/A
FAILURE MODES	Plugged - No LEM carrier withdrawal

ANALYSIS

This is a Robbins metering valve with similar design features as the 75M08414 metering valve.

ACTION

Investigation similar to action for 75M08414.

COMPONENT ANALYSIS

COMPONENT	Cylinder, Hydraulic
SPECIFICATION NO.	75M12157
VENDOR	Pathon Mfg. Co.
VENDOR P/N	
FIND NUMBERS/CATEGORY	A34825(9)/B, A34827(9)/B
FAILURE MODES	Stuck - Can't lock arm extended Leakage - Possible lock malfunction

ANALYSIS

The hydraulic cylinder contains a cylinder body, piston, rod, adjustable cushion, seals and two end heads. The bore diameter is 4 inches, rod diameter 1.75 inches and stroke 5 inches.

This cylinder is similar to 75M06506-1 and reference is to be made to that analysis.

ACTION

Refer to 75M06506.

COMPONENT ANALYSIS

COMPONENT	Rotary Actuator
SPECIFICATION NO.	75M12560-1
VENDOR	Flo-Tork Corporation
VENDOR P/N	
FIND NUMBERS/CATEGORY	34840(9)/A, 34845(9)/A
FAILURE MODES	Stuck - No arm retract/extend Leakage - Possible retract/extend malfunction

ANALYSIS

The actuator contains 4 head parts, a pinion, 2 pistons with integral pinion racks, 4 cylinder sleeves and a dual cylinder body. When hydraulic pressure is applied against the pistons, the pinion racks move in opposite directions. The teeth on the rack mesh with the pinion, turning the pinion either clockwise or counter-clockwise.

Seal Material - Buna-N

Lubrication - Mil-H-5606 Hydraulic Fluid

Leakage - Internal: .5cc/min. at 3000 psi (max.) Past actuating mechanism in locked position
External: 1 drop per 25 operating cycles

Cleaning - Complete assembly shall be flushed to contain contaminants not in excess of that specified in par. 2.6.0 of 10425040 or KSC-C-123 Level IV, Method A

The cylinder sleeve material is manganese bronze (SAE 43) and has a 16 RMS finish. The piston and pinion gear are made from hardened steel. The Flo-Tork technical representative said they just had refurbished several actuators, and there was some scoring of the cylinder walls but it was easily removed by polishing. Also, slight corrosion was found on the piston that was not submerged in hydraulic fluid. The bronze cylinder may be a contaminant generator because it is a relatively soft material and hard contaminant particles could score the cylinder finish. The problem of piston seizure is reduced by using the bronze cylinder which would tend to offset the bad effects of contamination generation.

ACTION

The problem of contamination generation is believed to be small -- especially due to the few cycles the actuator will see. Also, there are only a few components downstream from the actuator, and they are not regarded as being contamination sensitive. The actuator is not considered contamination sensitive and is not recommended for test.

COMPONENT ANALYSIS

COMPONENT	Accumulator
SPECIFICATION NO.	75M12665
VENDOR	American Bosch Arma Corp.
VENDOR P/N	EH5 41-591
FIND NUMBERS/CATEGORY	A6244(9)/A, A6245(9)/A, A6246(9)/A, A6247(9)/A
FAILURE MODES	Stuck Piston - No hydraulic supply Leakage - Possible hydraulic failure

ANALYSIS

The accumulator is similar to 75M08814 and reference is to be made to that analysis.

ACTION

Refer to 75M08814.

COMPONENT ANALYSIS

COMPONENT -	Regulator
SPECIFICATION NO.	75M13255
VENDOR	Marotta Valve Corp.
VENDOR P/N	226154(RV74A)
FIND NUMBERS/CATEGORY	A34964(9)/A
FAILURE MODES	Closed - Can't extend platform cylinder Erratic - Possible platform malfunction

ANALYSIS

Similar to Martin part no. PD48S0124-179 and to part no. 75M08831. For analysis of this part see analysis for 75M08831.

ACTION

This regulator is of the same configuration as 75M08831. Recommend that either of these valves be included in the tests.

COMPONENT ANALYSIS

COMPONENT — Solenoid Valve

SPECIFICATION NO. — 75M16990

VENDOR — Sterer Engineering & Mfg. Co.

VENDOR P/N — 32310

FIND NUMBERS/CATEGORY — A34755(9)/B, A34758(9)/B, A34759(9)/B, A34761(9)/B

FAILURE MODES

#1 deenergized - Can't unlock arm -extend cylinders
#2 deenergized - Can't lock arm-extend cylinders
#1 energized - Can't lock arm-extend cylinders
#2 energized - Can't unlock arm-extend cylinders
Leakage - Possible locking malfunction

ANALYSIS

The solenoid valve is a four-way, three-position double solenoid, hydraulic selector valve. The solenoid contains a spool and sleeve assembly that is operated by energizing the solenoids. The movement of the spool allows hydraulic fluid to flow through the ports. The valve is spring loaded so the spool returns to the center closed position when the valve is not energized.

This valve is the similar to 75M08841-3 and reference should be made to that analysis. The major difference is that this valve is a three position spring centered closed and 75M08841-3 is a 2 position valve mechanically latched in each position to protect against solenoid failure.

COMPONENT ANALYSIS

COMPONENT — Orifice, Flow Restricting

SPECIFICATION NO. — 75M21479

VENDOR — A. U. Stone Co. (AUSCO)

VENDOR P/N

FIND NUMBERS/CATEGORY — 5872(4)/A
5873(4)/A

FAILURE MODES — Clogged No LH_2 Line Secondary Withdrawal
No LOX Line Secondary Withdrawal

ANALYSIS

The orifice has a sharp edge diameter of .1406 inch (3570 micron) and GHe is the fluid media. The orifice acts as a secondary supply in case of a primary failure.

ACTION

Because of the size of the orifice, secondary function, and fluid media used, the orifice is not considered contaminant-sensitive and is not recommended for test.

COMPONENT ANALYSIS

COMPONENT - Regulator

SPECIFICATION NO. 75M51383

VENDOR Tescom

VENDOR P/N 26-1062-56-043, 26-1063-56-043

FIND NUMBERS/CATEGORY A5459(1-8)/B, A5559(4-8)/B, A5666(4-7)/B, A6200(9)/B

FAILURE MODES

Closed - No accumulator recharge.
Erratic - Possible low accumulator charge.

ANALYSIS

This regulator is a Tescom 1000 series hand operated regulator as described in the Tescom catalog. It is a spring loaded piston type constructed of 316 SS materials with Kel-F seats. The outlet pressure range is 50 to 6000 psig with inlet pressure to 10,000 psig. The unit assembly consists of a filter in the inlet portion constituted of bronze or stainless steel, which protects itself from partial contaminates in the flow stream. Tescom specifies in their catalog all regulators are cleaned for "gaseous oxygen service". Where special cleaning is required other than their own commercial, the parts are cleaned and tested by an approved outside facility. MMC has had very good service out of similar Tescom regulators in the Titan Systems. This part will not be considered as a contaminant sensitive item as it does have its own filter for added protection.

ACTION

Recommend the regulator not be considered for test.

COMPONENT ANALYSIS

COMPONENT	Vent Check Valve
SPECIFICATION NO.	75M51630
VENDOR	Marotta Valve Corp.
VENDOR P/N	232783-634
FIND NUMBERS/CATEGORY	A34939(9)/A, A34944(9)/A, A34954(9)/A, A34956(9)/A, A34960(9)/B, A34963(9)/B, A34972(9)/B, A34974(9)/B, A34981(9)/A A34984(9)/A
FAILURE MODES	Open - No effect. Closed - Lose mech. latch ability; can't extend, retract Leakage - No effect, APD malfunction

ANALYSIS

This check valve consists only of a modified fitting with vent holes drilled into the bottom of an "O" ring groove. Pressure can flow out by pushing "O" ring out but "O" ring prevents anything from flowing into the fitting. This part is not considered contaminant sensitive and will not be considered for test.

ACTION

Recommend this part not be considered for test.

COMPONENT ANALYSIS

COMPONENT	Pressure Switch
SPECIFICATION NO.	75M51766 (-2, -6)
VENDOR	Sigma-Netics Inc.
VENDOR P/N	704021(-2), (Hyd) 704026(6), (Pneu.)
FIND NUMBERS/CATEGORY	A34699(9)/B, A34724(9)/B
FAILURE MODES	Open - No Hyd Accumulator Recharge Closed - Constant Recharge Attempt

ANALYSIS

Pressure switch to control recharge of hydraulic accumulator. The switch is actuated by a piston which is moved by the pressure against a preset spring load. In addition to the piston seal, the switch is protected from the fluid media by a diaphragm (teflon or mylar). The -6 is set to deactivate at 2000 ± 20 psig and the -2 is set to deactivate at 50 psig. As these are a non flow device they are not considered as a contaminant sensitive component.

ACTION

Recommend the pressure switch not be considered for test.

COMPONENT ANALYSIS

COMPONENT	Solenoid Valve
SPECIFICATION NO.	76K00187
VENDOR	Marotta Valve Corp.
VENDOR P/N	MV509
FIND NUMBERS/CATEGORY	A34704(9)/B
FAILURE MODES	De-energized - No effect Energized - No accumulator pressurization Leakage - No effect

ANALYSIS

This valve for analysis purposes according to Marotta engineering is similar to 75M08825 and 75M08823. It is designed for 3000 psig nitrogen gas with 1/2" ports and 0.20 inch ESEOD. Materials are 300 series stainless steel, nylon seal and Buna-N seals. Remainder of the analysis will be same as for the 75M08825 valve.

ACTION

Refer to 75M08825.

COMPONENT ANALYSIS

COMPONENT	Filter, 200 Micron, In-Line
SPECIFICATION NO.	76K00188 (-1, -2)
VENDOR	Circle Seal Development Corp.
VENDOR P/N	4313G-200 CK, 4343G-200 CK
FIND NUMBERS/CATEGORY	A34863(9)/B, A34864(9)/B, A34865(9)/B, A34866(9)/B, A34867(9)/B, A34868(9)/B
FAILURE MODES	Clogged — No Semi-Auto Extend/Retract

ANALYSIS

This filter is a 200 micron rated in-line filter used in hydraulic system. Materials in contact with the fluid media are the 304 SS element, 303 or 304 SS body, and Buna N seals. The unit is designed for 3000 psig operating pressure, 4500 psig proof pressure, minimum collapse differential pressure of 3250 psi, flow capacity of 6.0 GPM with max pressure drop of 10 psid, bubble tight leakage, and has 25 square inches of effective filter area.

ACTION

Investigate use of smaller micron rating and also use of T-type filter to eliminate requirements to break into system to change element. 200 micron rating doesn't appear to be applicable to present cleanliness level requirements.

COMPONENT ANALYSIS

COMPONENT	Orifice, Flow Restricting (Hydraulic)
SPECIFICATION NO.	76K00189 (-1, -2)
VENDOR	A. U. Stone Co. (Ausco)
VENDOR P/N	
FIND NUMBERS/CATEGORY	A34762 (9)/B, A34765 (9) B, A35730 (9)/B, A35731 (9) B
FAILURE MODES	Clogged: No Auto Retract (For -2) No Semi-Auto Extend or Retract (For -1)

ANALYSIS

The -1 orifice has a .077 inch (1955 micron) sharp edge diameter and is used to control the rate arm 9 will extend or retract. The -1 orifice is protected by a 200 micron in-line filter on both sides. The -2 orifice has a .043 inch (1092 micron) sharp edge diameter. The orifice controls the rate which the pilot operated ball shut-off valve (75M08820) opens and closes. The volume of flow through the -2 orifice to open or close the ball shut-off valve is less than one cubic inch.

It is considered very unlikely that the -1 orifice would become clogged because of the 200 micron filter that is used in the system. The -2 orifice does not have a filter just upstream, but the volume of flow is very low which reduces chances of clogging.

ACTION

Both the -1 and -2 orifices are not considered contaminant sensitive; the -1 because of final filtration and -2 because of low v·lume of flow. It is recommended that the orifice (76K00189-1,-2) not b. considered for test.

COMPONENT ANALYSIS

COMPONENT Valve, Deceleration

SPECIFICATION NO. 76K00251 Make from 75M12561-1

VENDOR Racine Hydraulics

VENDOR P/N

FIND NUMBERS/CATEGORY A34839(9)/A, A34849(9)/B

FAILURE MODES Stuck - Can't retract arm
Erratic - Possible retract malfunction

ANALYSIS

Drawing defines rework of 75M12561-1 valve to new configuration. Drawing does not specify any test requirements. Valve similar to 75M06201-1 which was modified to 75M21842-1. The only difference between 76K00251 and 75M21842-1 is that 76K00251 has the relief valve blocked.

Refer to 75M06201-1 for analysis.

ACTION

Refer to 75M06201 for resultant action.

COMPONENT ANALYSIS

COMPONENT	Orifice, Flow Restricting
SPECIFICATION NO.	76K03578-1, -9, -12
VENDOR	A. U. Stone Co. (AUSCO)
VENDOR P/N	H92C-047, H92C-093, H92C-040
FIND NUMBERS/CATEGORY	34951 (9)/B, 34971(9)/A, 34989(9)/A
FAILURE MODES	Clogged: (1-) No platform extension on environmental chamber (-9) No adapter positioning device (APD) cylinder extension (-12) No APD cylinder control

ANALYSIS

The orifice sizes for the 3 dash numbers are; -1, .047 inch; -9, .093 inch; -12,.040 inch. The system is operated on GN_2 and the flow velocity is very high through the orifice and nesting of fibers, which would tend to clog the orifice, is very unlikely. Also pneumatic flow is bi-directional which will tend to prevent contamination from clogging an orifice. The volume flow rate is also low, which reduces the chances for contaminants to clog an orifice.

ACTION

Because of the orifice sizes, fluid media, bi-directional flow and low volume of flow the orifice is not considered contaminant sensitive and is not recommended for test.

COMPONENT ANALYSIS

COMPONENT Cylinder, Pneumatic

SPECIFICATION NO. 76K03824

VENDOR Miller Fluid Power

VENDOR P/N

FIND NUMBERS/CATEGORY A34952(9)/A

FAILURE MODES Stuck Piston - No platform cyl extend or retract
Leakage - Possible platform malfunction

ANALYSIS

The pneumatic platform extend/retract cylinder contains a cylinder body, 2 heads, a piston, a rod and a wiper ring. The bore diameter is 2.5 inches, stroke 80.0 inches and rod diameter 1.75 inches.

Seal Material - Buna N Per Mil-P-5315 or Mil-P-5516

Lubrication - Type Kel-F-10 or DC 55 (Dow Corning)

Leakage - 5 SCIM Max. (internal)

Cleaning - KSC-C-123 Level VI, Test Method 4, certification required

The cylinder uses HYCAR piston cups and HYCAR rod seals. The piston rod is hardened to 50-54 Rockwell "C" and chrome plated. The cylinder has a Teflon piston rod dirt wiper and corrosion resistant surfaces. The operating pressure for the cylinder is 750 PSI.

ACTION

The pneumatic cylinder is not considered contaminant sensitive or a contaminant generator and is not recommended for test.

COMPONENT ANALYSIS

COMPONENT Cylinder, Pneumatic

SPECIFICATION NO. 76K03825

VENDOR Lionel Pacific, Inc., Aero-Space Div.

VENDOR P/N

FIND NUMBERS/CATEGORY A34988(9)/A

FAILURE MODES Stuck Piston - No Adapter Positioning Device (APD) extend or retract
Leakage - Possible APD malfunction

ANALYSIS

The pneumatic APD extend/retract cylinder contains a cylinder body, 2 heads, a piston, a rod and a rod wiper. The bore diameter is 2.5 inches, stroke - 21.5 inches and rod diameter is 1 inch.

Seal Material - Buna-N per Mil-P-5315 or Mil-P-5516

Lubrication - Type Kel-F-10 or DC 55

Leakage - 5 SCIM Max. (internal)

Cleaning - KSC-C-123 Level VI, Test Method A, certification required

The cylinder heads are made from 2024-T6 aluminum and the cylinder body, piston and rod are 17-4PH CRES Per AMS 5643, COND H.

ACTION

The cylinder is not considered contaminant sensitive or a contaminant generator and is not recommended for test.

COMPONENT ANALYSIS

COMPONENT Solenoid Valve

SPECIFICATION NO. 10425701

VENDOR Marotta Valve Corp.

VENDOR P/N 229604(MV123K)

FIND NUMBERS/CATEGORY A34937(9)/A, A34938(9)/A, A34949(9)/B, A34953(9)/B, A34955(9)/B, A34959(9)/A, A34961(9)/A, A34962(9)/A, A34969(9)/A, A34970(9)/A, A34973(9)/A, A34983(9)/B, A34985(9)/B, A34986(9)/B

FAILURE MODES

De-energized - No cylinder retract or extend
Energized - No cylinder retract or extend
Leakage - Possible malfunction

ANALYSIS

This valve is a 3-way, 2 position solenoid valve similar to 75M08825 except the ports are 3/8" size and the body is 316 stainless steel. Designed for 3000 psig nitrogen gas with a .189 inch ESEOD. The remainder of the analysis will be considered the same as for 75M08825.

ACTION

See 75M08825 for resultant action.

COMPONENT ANALYSIS

COMPONENT Check Valve

SPECIFICATION NO. 10425928

VENDOR James Pond Clark

VENDOR P/N P279T1-4TT

FIND NUMBERS/CATEGORY A34987(9)/B

FAILURE MODES Same as 75M05365 (Item 1)

ANALYSIS Same as 75M05365 (Item 1)

ACTION Recommend the check valve not be considered for test.

COMPONENT ANALYSIS

COMPONENT Check Valve

SPECIFICATION NO. 10426693

VENDOR James Pond Clark

VENDOR P/N P279T1-4TT

FIND NUMBERS/CATEGORY 34950(9)/A

FAILURE MODES Same as 75M05365 (Item 1)

ANALYSIS Same as 75M05365 (Item 1)

ACTION Recommend valve not be considered for test.

COMPONENT ANALYSIS

COMPONENT	Check Valve
SPECIFICATION NO.	--
VENDOR	Marotta Valve Corp.
VENDOR P/N	800262-19(CVM 508)
FIND NUMBERS/CATEGORY	A5972(4)/A
FAILURE MODES	Closed - No LH_2 Cyl. withdrawal Open - No effect Leakage - No effect

ANALYSIS

This check valve is poppet design check valve similar to check valves of same design used by Martin. The poppet is well guided and the flow path is such that any particles should tend to flow right on through the valve. This item is not considered to be a contaminant sensitive part and will not be considered for test.

ACTION

Recommend this part not be considered for test.

COMPONENT ANALYSIS

COMPONENT	Check Valve
SPECIFICATION NO.	---
VENDOR	Marotta Valve Corp.
VENDOR P/N	204002-19(CVM-8)
FIND NUMBERS/CATEGORY	A5863(8)/A, A6153(6)/A
FAILURE MODES	Closed - No secondary system withdrawal, valve actuation Open - No effect Leakage - No effect

ANALYSIS

Poppet type check valve similar to Marotta part number 800262. Not considered to be a contaminant sensitive part and will not be considered for test.

ACTION

Recommend this part not be considered for test.

COMPONENT ANALYSIS

COMPONENT	Solenoid Valve
SPECIFICATION NO.	--
VENDOR	Marotta Valve Corp.
VENDOR P/N	MV583
FIND NUMBERS/CATEGORY	11190(6)/A
FAILURE MODES	De-energized - No effect Energized - No effect Leakage - Possible premature withdrawal

ANALYSIS

This valve for analysis purposes according to Marotta engineering is similar to 75M08823. MV583 is the same model series as the 75M08823 which is MV583-H2A.

ACTION

See 75M08823 for resultant action.

COMPONENT ANALYSIS

COMPONENT Orifice, Flow Restricting

SPECIFICATION NO. Not Known

VENDOR A. U. Stone Co. (AUSCO)

VENDOR P/N

FIND NUMBERS/CATEGORY 5594 (7)/A

FAILURE MODES Clogged No hydraulic withdrawal

ANALYSIS

The orifice has a sharp edge diameter of .45 inch (11,430 micron) and is used to control the rate of hydraulic withdrawal.

ACTION

The orifice is too large to be considered contaminant sensitive and is not recommended for test.

APPENDIX C

BIBLIOGRAPHY WITH ABSTRACTS

1. Abshire, R. W.: "Technical Considerations in Designing a Hydraulic System for the SST." SAE Conference Proceedings: Aerospace Fluid Power Systems and Equipment Conference. pp 57-62, Los Angeles, California, May 18-20, 1965. 650341.

This paper discusses the high reliability required for commercial, supersonic aircraft hydraulic systems. Contamination control influences design considerations to the extent that the systems are designed to eliminate any chance of introducing foreign contaminants after equipment installation. In this design the fluid is filtered upon introduction to the system at all fluid filling points. Fluids were selected for their resistance to creating contaminants through chemical reaction with system components.

2. Anthony, H. V., et al.: "Contamination Sensors," AEC/NASA Symposium on Contamination Control, September 1967.

This paper presents in detail a discussion of various particle counting devices such as in-place counters and automatic counters, as well as sampling techniques, including isokinetic, Wyle wedge, etc. Cryogenic liquids, ordinary gases, and liquid fuel and oxidizers are included in the discussion, both for purity analysis and particulate analysis. Recommendations are made for the best techniques to be used for the various fluids.

3. "Atlas 'E' Overhead Doors Design Validation and Product Improvement Study." Contract AF04(647)-863. Bechtel Corporation, Vernon, California, January 1962. AD 828734.

Extremely heavy contamination was discovered in overhead door hydraulic systems. Doors became inoperable or tended to settle down when left in open position. Pumps were found to be clogged and valves were sticking and leaking. The hydraulic systems had never undergone any contamination control whatsoever. Initial contamination had evidently been high and when water base fluid had been replaced by petroleum base fluid, water became an additional serious contaminant. The suggested remedy was to flush out contaminated fluid, add filtering processes, and replace malfunctioning components. Estimated cost of repairing damage to doors caused by malfunctioning hydraulic system and repairing the hydraulic system itself totaled $596,000.

4. Bose, R. E.: "The Effect of Cavitation on Particulate Contamination Generation." Oklahoma State University, Doctorate Thesis, 1966.

This paper describes an experimental program conducted to determine the effectiveness of the cavitation phenomenon in producing particulate contamination. The fluid used was distilled water, and several different materials were investigated to determine which offered the best resistance to the process. Materials were 1100-I'8 aluminum, 2024-T351 aluminum, free-cutting brass, Monel, 304 stainless steel, and Electrolytic Tough-pitch copper.

It was found that large quantities of particulate could be generated by this process, with sizes ranging to 280 microns. The largest particles were generated from the softer aluminum and copper materials. The largest size generated from the Monel and stainless specimens was approximately 40 microns; however, these harder materials generated much larger quantities of the smaller-sized particles. A correlation was established between particle cutoff size and Brinell hardness number. Empirical relations are promulgated for particle size distribution versus strain energy of various materials.

5. Brittain, R. C.: "Titan II: Retractable Work Platform Hydraulic Systems (HS-2) Test Program." Parsons Company, Los Angeles, California, 6 February 1963. AD 828725.

This report gives a detailed description of tests run on a Titan II retractable work platform hydraulic system. Contamination specifications are outlined. The procedures used to ensure that the hydraulic system met specifications are detailed. Data used to determine contamination levels before and after flushing is presented...After approximately ninety cycles, the contamination level of the system stabilized. The system contamination limit as specified is as shown for 100 ml at any sampling point:

Particle Size	26 thru 50	51 thru 100	101 thru 200	201 thru 500	500 thru 1000	>1000
Maximum Count	1050	250	70	20	3	0

Fiber Length	100 thru 1000	1001 thru 2000	>2000
Maximum Count	25	5	0

6. Connelly, R. F. and Gatzek, L. E.: "Deteriorative Effects of Both Usage and Long Term Storage on Aircraft and Missile Hydraulic Fluids." Journal of Engineering for Industry, May 1963; ASME Transactions, Paper 62-AV-13.

This paper presents a comparison of MIL-H-5606 and MIL-H-6083 hydraulic fluids with respect to particle agglomeration, chemical precipitation, crystal growth, and extraction of elastomer components. In 5606 fluid, particles tend to agglomerate, then decompose when disturbed, and reprecipitate during inactive periods. The corrosion additive in 6083 fluid is very effective in breaking up and preventing further particle growth. Vibration, either mechanical or sonic, increases the rate of particle growth. The Silting Index is used to measure this phenomenon; the following test results are presented:

Storage Period	Silting Index
MIL-H-5606	
2 days	0.004
9 days	0.010
2 months	0.016
5 months	0.160
10 months	2.960
12 months	4.000
24 months	∞
MIL-H-6083	
2 hours	0.002
42 months	0.035
64 months	0.098

Also, 5606 fluid tends to react chemically with storage containers, particularly in the presence of significant amounts of moisture.

Crystal growth as large as 5 x 150 microns has been observed in 5606 fluid; these melt at about 350 °F. Constituents of elastomers can be extracted by hydraulic fluids; these are mostly in the 25-micron range.

7. Connelly, R. F.: "Relationships between Contamination and System Failure." American Association for Contamination Control, Fifth Annual Meeting, March 1966. AFRPL-TR-67-290.

This author maintains that so-called contamination failures in the vast majority of cases result in loss of performance rather than catastrophy. The long-term effect is wear resulting from silting. Effects of metallic particle silting is more severe than nonmetallic; fibers are particularly troublesome because they tend to "nest" and thus increase silting tendencies, and because they do not settle out as readily as metallic particles. MIL-H-5606 fluid with acrylic viscosity improvers appears quite prone to silting over a long term of activity. Homogenizing improves this tendency, but is transient in nature. Fluids not containing these improvers have endured more than five years with no change in silting index.

The major recommendation is made that contamination levels not be selected solely on the basis of blueprint clearances, because this results in the imposition of unrealistically low limits. Experimental evidence relative to the system effects should be obtained, including consideration of fluid composition, particle size, and contamination concentration. The statical nature of the contamination sample must be remembered when setting size limits.

8. Deane, T. N.: "Hydraulic Fluid Particle Growth Halted." SAE Journal, Volume 69, No. 3, March 1961.

The subject of particle growth in MIL-H-5606 hydraulic oil is discussed in this paper. The cause is pinpointed as agglomeration of very small particles (less than 5 micron), the adhesion being provided by the additive viscosity improver, methacrylate. The following conclusions are stated:

1) The mechanism is one of large particles being formed from small ones;

2) Vibration accelerates the rate of growth by increasing the force with which the particles strike each other and therefore the probability of their sticking together;

3) The precipitate has been redispersed by agitation, the oil refiltered and repackaged, then after further storage the precipitate has reformed;

4) Precipitate does not form in oils that contain rust preventative agents, or in oils that do not contain methacrylate viscosity improvers (such as MIL-H-6083).

It is also stated that the rate of growth is proportional to the square of the concentration of particles. Thus, if by filtering, the particle count is reduced by a factor of 10, then the growth rate will drop by a factor of 100.

9. Deane, T. N.: "The Effect of Contamination on Fluids and the Effect of the Ingredients of the Fluids on Contamination." SAE Conference Proceedings: Aerospace Fluid Power Systems and Equipment Conference, Los Angeles, California, May 18-20, 1965. 650352.

This paper discusses contaminant effects on hydraulic fluid functions. Contaminants lower temperature at which fluid oxidizes. Submicronic contaminants agglomerate to form 25 to 200 micron particles. The rust preventative in MIL-H-6083 prevents agglomeration by neutralizing electrolytic properties of fluid. Moisture causes oxidation and thus speeds wear. Moisture combines with anti-wear agent to plug filters. Water creates acid in some fluids which causes chemical reactions. It is considered worthwhile to permanently remove all contaminants from hydraulic fluid regardless of size or substance.

10. "Decontamination of Hydraulic Fluids and Dynamic Hose Study." Oklahoma State University Technical Report SEG-TR-64-74, January 1965. AD 612907.

This report discusses a new means of upgrading the decontamination capabilities in USAF ground support equipment, a device known as the hydroclone. This is a centrifugal separating device which is used in place of a conventional filter. To evaluate the performance of the device in hydraulic systems, a field test program was undertaken. Field studies were conducted at Edwards AFB, California, and Tinker AFB, Oklahoma. Particle counts were obtained by a HIAC automatic particle counter; microscopic examinations were made to determine the types of contaminant present. Five hundred-milliliter samples were used. The following results were obtained:

Gravimetric Analysis (mg/l) -

Sample No.	Upstream of Hydroclone	Downstream
1 (Edwards)	31.6	10.6
2 (Edwards)	33.9	10.9

Sample No.	Upstream of Hydroclone	Downstream
3 (Edwards)	15.2	12.5
4 (Edwards)	11.7	11.2
5 (Edwards)	8.6	8.6
6 (Edwards)	12.3	11.2
7 (Edwards)	7.9	11.0
8 (Edwards)	10.2	10.2
9 (Tinker)	32.8	24.5
10 (Tinker)	33.0	20.5
11 (Tinker)	12.5	13.1
12 (Tinker)	12.1	13.5
13 (Tinker)	11.8	10.0
14 (Tinker)	10.6	7.7
15 (Tinker)	10.7	14.0

Particle Counts -

Micron Size	Quantity
6 (Tinker)	3523
11 (Tinker)	1117
15 (Tinker)	103
20 (Tinker)	47
6 (Edwards)	1591
11 (Edwards)	194
15 (Edwards)	52
20 (Edwards)	16

The particulate was analyzed as iron, bronze, paper, plastic, cotton, carbon, and aluminum. Maximum size encountered was 600 microns. The report concludes that the hydroclone is as efficient as normal filtration techniques, with the added advantage that it does not load up and require changeout.

In addition, cleaning of high pressure rubber and teflon-lined hoses was evaluated by dynamic pressure pulsation. It was found that, compared to normal flushing techniques, the dynamically cleaned hose would generate far fewer and smaller particles during operational service.

11. Dwyer, J. L.: Contamination Analysis and Control. Reinhold Publishing Corporation, New York, 1966.

This book discusses the analysis and control of contamination in aerosols, gases, and liquids. The main points are aerosol sampling and inspection; particle sampling of cylinder gases; errors in probe sampling; liquid dispersions, suspensions, and emulsions; particle counters; methods of quantitative and qualitative sample analysis; contaminants on surfaces; clean rooms; and component cleaning. It is a general survey and state of the art for theoretical as well as practical means of contamination analysis and control.

12. "Effect of Contamination on Fluid System Components: Bulletin A50." Aircraft Porous Media, Inc., Glen Cove, Long Island, New York. Pall Corporation, 1966.

This paper abstracts and discusses ten articles that were selected after a thorough search of available information concerning contamination, wear, life, and performance of fluid systems. Filtration below five microns absolute appears to improve most hydraulic systems. In no instance observed did finer filtration degrade component performance. Finer filtration improves valve wear, component life, system operation, and hydraulic fluid performance and stability. Silting of submicronic particles can be reduced significantly by filtration with three-micron absolute filters.

13. "Effect of Contamination on Fluid System Components: Supplement 1 to Bulletin A50." Aircraft Porous Media, Inc., Glen Cove, Long Island, New York. Pall Corporation, 1967.

This paper abstracts and discusses six articles which are intended to supplement those covered in Bulletin A50. Further evidence is presented to favor the use of submicronic filtration. Wear is reduced in piston rings and valve lifters when oil is filtered to eliminate submicronic contaminants. Tests show that contaminants severely increase damage in cavitational zones. Elimination of particulates of the five- to ten-micron range increase pump and servo valve life and reduce the frequency of hydraulic system cleaning.

14. Farri , John A.: "The Meaning of Fluid Filter Ratings." FSR #25, Aircraft Porous Media, Inc., April 1, 1965.

This company bulletin is a comprehensive, readable discussion of nearly every aspect of filters that should be considered by any design engineer having a need to specify filtration equipment. The importance of adequate filtration to prevent wear and subsequent leakage of valves is pointed out with reference to work performed by General Electric. Wear versus contamination of aircraft piston pumps is discussed with reference to Grumman work. Experience of ultrafine filtration

in commercial aircraft hydraulic systems is tabulated. A review of existing military filter specifications is given; interestingly enough, no such specification exists for pneumatic applications. All aspects of filter design are discussed in detail, including nomenclature, efficiency, and rating measurement techniques, bubble point tests, pore size versus ratings, limitations and interpretations of ratings, fiber removal, dirt capacity, cleaning techniques, collapse pressure, media migration, and flow fatigue.

15. Farris, John A.: "New Approach to Selecting Fluid System Filtration." Bulletin FSR-39, Pall Corporation, Glen Cove, Long Island, New York.

This report discusses the various considerations that should be given to selecting proper filters for hydraulic systems. Descriptions are given of typical contamination failures. Types of filtration media are discussed for various applications. Recommendations of filter types are made, considering fluid life, additive removal, filter location, bypass valves, flow, pressure, and service interval with respect to area and dirt capacity. Dual element, 3-micron absolute filtration is advised. The optimum filter arrangement is to use relatively coarse (25 micron) filters in the pressure line ahead of each critical component to prevent catastrophic failures, and an ultrafine filter in the return line to minimize wear by preventing recirculation or buildup of ultrafine particles generated by components.

16. Fitch, E. C.: "Fluid Contamination Project: Study in the Field of Fluid Contamination." Report No. 6. Oklahoma State University, Stillwater, Oklahoma. August 1963. AD 422550.

This report describes the use of the HIAC automatic particle counter in determining contamination levels in fluids. Despite the expense, the author was pleased with the results and simplicity of the data obtained using the HIAC counter. Test filters were cleaned ten times with one of two solvents. After three or four cleanings the contamination level no longer showed a steady decrease but, instead, became erratic. After ten cleanings with one fluid, an additional cleaning with the other solvent repeatedly showed that one solvent was better at removing some type of contaminant in the filters than was the other solvent.

Distillation of the solvents proved a satisfactory method of reclaiming the solvents. It was indicated that care is required in the distillation process because under certain contamination conditions localized heating caused contaminants to be carried with distillate.

17. "Fluid Filters: Media and Contamination." Bendix Filter Division, Publication No. BFD 168, not dated.

This informative booklet describes all conceivable aspects of the use of filters in hydraulic systems. No data are presented, but extensive discussions are given on types of filters, filter characteristics, filter cleaning and drying techniques, analysis procedures, clean room facilities, packaging techniques and materials, and considerations for writing filter specifications. All of this general information would be quite instructional to any person working hydraulic system cleanliness problems.

18. Gayle, J. B. and Romine, J. O.: "Studies on the Reliability of Particulate Contamination Analyses." George C. Marshall Space Flight Center. MPT-P&VE-M-62-5. March 6, 1962.

There are many factors that can influence the reliability of the results of a contamination analysis of a specific system. Examples are given where wide variations in particulate contamination count are experienced due to the operation or nonoperation of a valve. Generally, if a valve is opened and closed during contamination sampling, the particle count is greatly increased over that obtained when the valve is not operated.

The reproducibility of a particle count is affected by the operator. Different operators will vary in their determination of the particle count for the same sample to a greater degree than the same operator will vary in several determinations with the same sample. Reproducibility improves with a greater number of particles in a sample. The primary conclusion is that variations in the sampling method have a much greater effect on reproducibility than variations associated with particle count determination.

19. Hocutt, M. G.: "Establishing Hydraulic System Operational Contamination Limits," SAE Conference Proceedings: Aerospace Fluid Power Systems and Equipment Conference, Los Angeles, California, May 18-20, 1965. 650333.

Hydraulic system contamination limits must be established such that they prevent significant degradation of system performance and yet are practical enough to command system cleanup when exceeded. The case history of the YJ93-GE-3 is presented as an example of how contamination levels are generated for a hydraulic system.

Through extensive testing it was determined that the system would continue to operate with some degradation of performance but without failure at contamination levels in excess of class 12. The hydraulic function that degraded was the control servo valves; therefore, the system contamination levels would have to be limited so that the servo valves could function satisfactorily. It was determined that a class 12 level of contamination produced a 4.3 pound spool silting force to move the valve from null. The physical characteristics of the valve were a 0.375-inch spool diameter with a hardness equivalent to R_c 70 or greater and a 0.0006-inch diametrical clearance between spool and sleeve. A valve silting force greater than 3.5 pounds caused unsatisfactory control performance; therefore a contamination level of class 8 which would maintain the valve silting force below 3.5 pounds was selected for the system.

In order to eliminate high levels of particle counts experienced during the first few hours of testing due to built-in contamination, all subsystems were cleaned by flushing to a class 6 level of contamination, and auxiliary 3-micron absolute filtration was added during initial system running hours.

Contamination Classes per NAS 1638

Control Class	5 to 15	15 to 25	25 to 50	50 to 100	100
6	16,000	2,850	506	90	16
8	64,000	11,400	2,025	360	64
12	1,024,000	182,400	32,400	5,760	1,024

All filters used were stainless steel wire mesh with high temperature and high pressure drop capability. The auxiliary filter had a 3-micron absolute element backed up by a 15-micron absolute element. The main dirt generators of the system were the 12 actuators and 14-piston hydraulic pump. These dirt generators, however, contributed very little of the metallic wear contaminants.

The operating contamination level sustained by the J93 hydraulic system is equivalent to or possibly one class lower than that of aircraft hydraulic systems according to SAE report 749D.

Important conclusions were:

1) "The use of 3-micron absolute auxiliary filtration in addition to the normal system filtration lowers the contamination level approximately 3 classes.

2) "The use of subsystem flushing prior to system assembly plus ultrafine auxiliary filtration of part of the system flow during initial hours of engine running have proven very successful in eliminating high initial operating contamination levels and the wide variation in contamination levels during the life of the system.

3) "Servo valve spool silting forces, with all other parameters remaining constant, vary in direct proportion to the level of contamination."

20. Hollinger, R. H. and Donis, J. N.: "Contamination Tolerance of Aircraft Hydraulic Pumps." Franklin Institute Research Laboratories, Philadelphia, Pennsylvania, March 1967. AD 814826.

This report presents a very comprehensive analysis of the effects of particulate density, size, and hardness on wear in hydraulic pumps. Three methods of measuring contamination level were used to supplement one another; they were silting index, HIAC counter and gravimetric analysis. Cotton linters, jeweler's rouge, iron filings, and AC fine test dust were generally used as the contaminants in controlled proportions. Careful dimensional analysis was run on the contaminants and pump components after each 50-hour and 1000-hour test. The conclusion reached was that some contaminants are more harmful than others and those proven to be harmful should be removed.

21. Hollinger, R. H., et al.: "Evaluation of Wear and Contamination Generation of Hydraulic Components." Franklin Institute Research Laboratories, Report F-B2116, NASA Accession No. X66-14859, February 1965.

This report covers investigations into the capability of sampling valves to give representative hydraulic samples; contamination generation and malfunction susceptibility of H-1 engine hydraulic system pumps; and an evaluation of the S-IV hydraulic system under known conditions of fluid contamination.

FRC and Maledco were compared, using AC coarse test dust and collecting 100 ml samples. A great amount of tabular data is presented; it was concluded that the Maledco valve gave slightly better agreement between line and sample. However, the FRC valve had advantages in size, weight, and ease of installation. The Wyle wedge is not recommended for use in hydraulic sampling.

Vickers and Kellogg hydraulic pumps were compared for contaminate generation. Again, great amounts of tabular data are presented. The Kellogg pump appeared to show more variance, but no significant difference in amounts was found. For particles over 100 micron in size, case drain analysis indicated quantities as high as 178% of the input fluid level. After an initial wear-in period of about 8 hours, there was no significant change in leakage flow rates. Bronze cylinder blocks contributed more particulate than did ductile iron.

Systems were cleaned initially to SAE/ASTM Level 1 or better; contamination in the form of AC coarse test dust was then added in controlled amounts to achieve higher ASTM levels. Samples were counted per ARP-598. For the pumps, a maximum safe level of ASTM Level 2 is recommended if leakage is not to become excessive in reasonable operating times. Levels 3-4 caused noticeable degradation in system performance and Levels 5-6 caused unacceptable performance.

22. Howell, G. W.: "A Bibliography of Aerospace Valve and Fluid Component Technology." TRW Systems, Redondo Beach, California, December 1965. AD 485305.

This document contains a list of 3502 articles that are pertinent to fluid component technology. Included is an introduction, alphabetical source list, numerical source list, and a descriptive cross-reference list. Several references are pertinent to contamination control.

23. Howell, G. W. and Weathers, T. M.: "Aerospace Fluid Component Designer's Handbook." TRW Systems, Redondo Beach, California, March 1967. AD 809183.

Filtration and contamination are two sections in this rather extensive design handbook. Pneumatic and hydraulic filters of several types are rated and compared for a number of operational environments. Types of contamination are discussed and classified, such as internally generated metallic contaminants and external dust contaminants. Effects of hydraulic system contaminants are outlined. Industrial cleanliness requirements are presented for components and fluids as well as a guide for selection of cleaning agents. It is recommended that materials, uncontrollable contamination, fluids, and tolerances be given particular consideration when designing fluid systems.

24. Huggett, H. L.: "Servo Valve Internal Leakage as Affected by Contamination." SAE Conference Proceedings: Aerospace Fluid Power Systems and Equipment Conference, Los Angeles, California, May 18-20, 1965. 650334.

Servo valves were extensively tested using field launcher fluid and new fluid. Records were kept of viscosity and leakage rates of the fluids during the testing periods. After about four hours the fluid viscosities were similar but the leakage rate increase of the more highly contaminated fluids stabilized at 2.8 times that of the less highly contaminated fluids. The conclusion was that controlled-fluid contamination level increased the useful life of servo valve assemblies by 277%.

25. Kinney, W. L., Schumann, E. P., and Weiss, P. A.: "Hydraulic Servo Control Valves, Part VI - Research on Electrohydraulic Servo Valves Dealing with Oil Contamination, Life and Reliability, Nuclear Radiation and Valve Testing." Cook Research Laboratories, Skokie, Illinois, November 1958. AD 211733.

This report discusses problems encountered by aircraft companies in the field of hydraulic components. A comparative chart of maximum allowable contamination levels is shown for five companies. These contamination levels were established by each company on the ground that they worked consistently and could be maintained at not too great an expense. The maximum particle size allowed by any of the five companies is 300 microns.

Failures due to contamination at temperatures above 160°F are much more prevalent than those for systems whose operating temperature is below 160°F. Paper filters tend to disintegrate at temperatures above 200°F. General design considerations are discussed which if employed result in a less contamination-sensitive system.

A test procedure is presented and the acceleration of wear or contamination generation due to the addition of particle contaminants is discussed. Testers must be careful that they are actually testing components rather than filters; many component failures were due to filter clogging rather than general system contamination level.

26. Kinney, W. L., Schumann, E. P., and Weiss, P. A.: "Hydraulic Servo Control Valves, Part 7 - Design for Improved Reliability, Tolerable Oil Contamination Level Standards, and Nuclear Reactor Irradiation Test Results." Cook Research Laboratories, Skokie, Illinois, November 1958. AD 231657, WADC TR 55-29 Part 7.

This report is a continuation of Part 6, which has been previously abstracted. Only the chapter on oil contamination is pertinent to this program. An experimental analysis of various hydraulic oils was obtained from selected aircraft at Wright-Patterson and Bergstrom AFB. Using this data along with the results of servo valve tests reported in Part 6, an upper limit for the contamination allowable in aircraft hydraulic system samples is presented.

The results of the field survey were as follows:

Source	≤ 10 μ	10 to 20 μ	20 to 40 μ	≥ 40 μ
F-100	434,921	21,352	20,058	1,391
F-101	Not Countable	3,103	489	139
F-102	Not Countable	6,850	1,500	435
F-104	Not Countable	107,565	1,950	505
F-105	Not Countable	3,333	789	179
F-101	12,292,950	100,114	13,200	2,050
F-101	822,819	86,052	33,865	6,050
F-101	1,628,385	7,300	5,950	505
F-101	728,490	84,348	29,842	4,500
F-101	1,483,358	61,344	11,100	3,300
F-101	1,427,717	231,318	120,984	13,550
Cook Stand #1	Not Countable	49,927	1,175	77
Cook Stand #2	Not Countable	60,279	700	70

The following is the recommended maximum contamination level for aircraft servo valve applications, based on a 100 ml sample:

$\leq 10\ \mu$	10 to $20\ \mu$	20 to $40\ \mu$	$\geq 40\ \mu$
Unlimited	15,000	3000	80

In arriving at this specification, criteria of other valve users in the field were also considered but found to be much more conservative than the results of this analysis justify. They feel that the majority of the contamination is either airborne dust, or is generated by the system pump.

Several general recommendations pertaining to contamination test techniques are also presented. Reference is made to Part 6 for a more complete description.

Note: The above recommended level is revised in a further section of this report, Part 8.

27. Kinney, W. L.; Schumann, E. P., and Weiss, P. A.; "Hydraulic Servo Control Valves, Part 8 - Investigations of Oil Contamination Effects and Nuclear Radiation Testing." Cook Research Laboratories, Skokie, Illinois. October 1962. AD 464061. WADC TR 55-29, Part 8.

This report contains a wealth of information from various users of hydraulic servo valves concerning the cleanliness of oil from actual installations, the cleanliness specifications from various companies, and test results of new valves tested with actual field fluid. As a result of these investigations, the criteria recommended by the authors in Part 7 of this report is revised herein to considerably looser limits. The revised recommendation is as follows, based on a 100 ml sample:

$<5\mu$	$5-15\mu$	$15-25\mu$	$25-50\mu$	$50-100\mu$	$>100\mu$
Unlimited	25,000	3,000	1,000	200	150

As part of the above investigation, a questionaire was sent to more than 20 servo valve users, and many of those who responded included their own company cleanliness specifications for fluid used in servo systems. The information thus obtained is shown in the following Table I. Note: All dimensions refer to the largest particle dimension except for North American which uses the smallest particle dimension.

Also as part of the investigation, field samples of hydraulic oil were taken from 31 different aircraft, missiles, and test stands, all of which were in a fully operational condition. The results of this sampling program are shown in Table II.

The third effort reported on herein involved testing four new, different servo valves with oil that was obtained from operational field sites. Test duration ranged as high as 40 hours. None of the four valves demonstrated any aspect of failure during these tests. The contamination count is shown in Table III.

Table I Fluid Contamination Specifications

Organization	Systems	Maximum Number of Particles/100 ml					Other Controls
Boeing	Test Stands Missiles in Field	No Limit No Limit					Weight, 0.3 mg/100 ml Weight, 0.5 mg/100 ml
Hughes	New Oil	Average of four largest particles, 50μ None >150μ					A "Time to Filter" specification
North American	All	10-20μ 2,875	20-40μ 1,375	40-80μ 350	80-100μ 100	>100μ 0	None
Martin Marietta		10-25μ	25-40μ	>40μ			
	Vanguard	2,150	400	270			13 Fibers
	Mace	4,500	700	450			20 Fibers
ABMA	All	10-25μ 2,150	25-50μ 530	50-100μ 60	>100μ 0		10 Fibers
SAE Panel Recommendation	General Hydraulics Systems	5-15μ 50,000	15-25μ 20,000	25-50μ 5,000	50-100μ 500	>100μ 250	None
Lockheed	Ground Support Equipment Flight Control Systems	3,500 10,000	1,250 2,500	250 500	25 50	3 10	None None
Westinghouse	All	5,000					None
BuWeps	Missile Fluid Specifications	10,000	4,000	1,000	100	53	None
Air Force	Rev. MIL-H-5606B	20,000	9,000	2,500	150	1	A "Time to Filter" specification

Table II Contamination of Field Hydraulic Systems

Fluid	Weapon System	Hydraulic Circuit	Particles/100 ml Fluid				
			5-15µ	15-25µ	25-50µ	50-100µ	>100µ
MIL-H-5606	TM-76 Mace	Power Pack 24 into Missile	33,800	1,640	788	108	124
		24 from Missile	3,930	726	112	22	0
		Power Pack 13 Recycled	2,520	740	524	38	28
		25	2,756	3,160	1,104	204	254
		26	3,200	1,560	434	132	34
		27	9,980	3,520	708	134	124
		29	13,200	1,980	854	62	108
		39	4,360	998	244	58	80
	GAM-77 Hound Dog	Power Pack S2-3A	11,400	732	518	132	116
	IM-99 Bomarc	Missile 57-2733	32,500	4,590	3,600	312	152
		Hydraulic Bench No. 4	1,190	272	182	82	52
	F-100D	Flight Control System	8,800	2,170	392	80	46
	F-101	A/C 541 506 Primary System	39,800	2,570	184	20	34
		Utility System	203,000	25,700	2,880	434	168
		A/C 541 499 Utility System	3,800	1,526	824	182	152
		A/C 56 329 Utility System	1,700	606	306	56	28
	F-102	Hydraulic Cart	5,660	1,260	768	[illegible]	160
		A/C 7795	31,600	9,220	2,520	842	466
	F-104	A/C 929 System 1	182,000	5,520	188	25	22
		System 2	69,500	3,700	604	28	28
		A/C 860 System 1	33,800	838	196	32	14
		System 2	3,080	1,280	430	106	38
		A/C 850 System 2	1,800	408	216	58	6
	New Oil	Esso	2,590	682	314	32	66
		Standard of California	9,290	2,540	474	136	76
		Shell	7,620	2,280	154	18	46
MIL-H-8446	B-58	Hydraulic Cart	76,100	632	80	20	64
		A/C 81014	65,800	1,560	236	28	80
	New Oil	Drum	26,900	2,380	1,060	60	190
		Gallon Can	2,570	700	334	60	72
Hughes Specification 20-1124	GAR, Falcon	No. 1	2,530	1,040	306	160	170
		No. 2	2,090	338	228	162	172

Table III Contamination Levels During Laboratory Tests

Fluid	Source	Conditions of Test	Test Time	Particles/100 ml Fluid				
				5-15μ	15-25μ	25-50μ	50-100μ	>100μ
MIL-H-5606	TM-76 Mace Power Pack	Moog 942 150 psi 115°F	5 min	17,600	2,160	180	140	166
			12 hr	9,450	3,850	704	222	84
			24 hr	7,690	4,370	728	342	146
			40 hr	5,250	1,890	1,290	360	180
MIL-H-5606	IM-99 Bomarc Test Stand	Cadillac FC-10 3000 psi 150°F	5 min	112,000	21,600	246	42	46
			12 hr	28,000	2,200	--	--	--
			24 hr	20,200	8,760	4,580	--	--
			40 hr	148,000	99,800	78,800	3,650	166
MIL-H-5606	F-102 Hydraulic Cart	Atchley 3000 psi 150°F	5 min	32,200	4,300	306	164	36
			12 hr	14,200	2,220	86	--	--
			24 hr	22,500	3,700	--	--	--
			40 hr	6,570	1,550	460	72	64
MIL-H-8446	B-58 Hydraulic Cart	Hydraulic Reservoir 2000 psi 160°F	5 min	8,180	2,760	580	210	140
			12 hr	5,650	1,930	806	246	280
			24 hr	4,150	1,140	424	114	204
			40 hr	2,410	1,400	234	96	110

28. Kirnbauer, Erwin A.: "A Method of Determining the Degree of Contamination of Sampling Valves." Aircraft Porous Media, Inc. APM-FSR-9B

This paper was written as a proposed ARP for the SAE. It presents detailed test procedures for determining the amount of contamination that is contributed to a fluid sample by the sampling valve itself, under low pressure conditions. Contaminants generated while mounting the valve into the system, that which is built into the valve itself during manufacture, and that generated by valve operation are the major sources considered.

Two appendixes are included which present the results of tests conducted by APM on two different types of sampling valves: 1) ABMA Drawing No. 8941098 (Dr. #198-59) (Benton Needle Valve P/N 2000); and 2) Fluid Regulator Corporation Bleeder Valve P/N FRC7665-01. The results of both tests indicate that very little contaminate was generated by mounting the valves. The "built-in" contamination of the Fluid Regulator Corporation valves was negligible. However, the Benton did generate during opening and closing; the contaminate was 60 to 65% metallic and was of the following levels:

Size	Particle Count
5-25μ	50,000
25-50μ	750
50-100μ	100
100μ plus fibers	40

29. Longyear, D. M., Jr., Blatter, A., and Porter, D.: "Concepts to Extend Servosystem Life and Minimize Performance Degradation." SAE Conference Proceedings: Aerospace Systems and Equipment Conference, Los Angeles, California, May 18-20, 1965. 650316.

This paper discusses design considerations that may reduce requirements for filtration to control contamination in hydraulic systems. Principal wear in servo valves is due to cavitation and erosion. A means of reducing wear and contaminant generation is the use of better materials. A comparison study was run on materials selected for characteristics of machineability, stability, strength, and hardness. Wear can be considerably reduced by the use of tungsten-carbide servo valves that are virtually insensitive to normal hydraulic system contamination.

30. McKenzie, G. W.: "Operation and Maintenance Requirements for SST Hydraulic Systems." SAE Conference Proceedings: Aerospace Fluid Power Systems and Equipment Conference, Los Angeles, California, May 18-20. 650343.

This paper discusses the minimum filter requirements recommended for the SST hydraulic systems. For this system it was recommended that all return fluid should be filtered through dual filter assemblies comprising a 3-micron absolute primary element with bypass to a 15-micron absolute secondary filter with no bypass. All other system filters should be at least 15-micron absolute with no bypass. This paper also discusses desirable properties of a hydraulic fluid to be developed for SST with primary consideration placed on fire resistance properties.

31. MIL-STD-1246A. 18 August 1967. Department of Defense, Washington, D. C. 20301.

This specification describes DOD contamination control levels. This revision varies from the revision dated 27 May 1966 by allowing a greater number of particles above a given size for the same cleanliness level. Small particles for any level are controlled by listing a maximum weight of nonvolatile residue for each 100 milliliters of fluid. Examples of cleanliness levels with particles greater than a given size are listed below:

Cleanliness Level	Particle Size (Microns)	Allowable Quantity of Particles	Nonvolatile Residue Ranges
10	5	3	A. Less than 1.0 mg
100	15	280	B. 1.0 to 2.0 mg
	25	75	C. 2.0 to 3.0 mg
	50	11	D. 3.0 to 4.0 mg
	100	1	E. 4.0 to 5.0 mg
500	50	11,000	F. 5.0 to 7.0 mg
	100	950	G. 7.0 to 10.0 mg
	250	25	H. 10.0 to 15.0 mg
	500	1	J. 15.0 to 25.0 mg
1,000	250	1,000	
	500	45	
	750	7	
	1000	1	

32. Neiland, V. R.: "Contamination Effects and Controls in Saturn Launch Vehicle Hydraulic Systems." AEC/NASA Symposium on Contamination Control: Current and Advanced Concepts in Instrumentation and Automation. Albuquerque, New Mexico, September 12-14, 1967.

Contamination in hydraulic systems can be much more effectively dealt with when its sources and effects are understood. The contamination level of a closed system can be considerably reduced by the operation of some of its components prior to assembly since the contaminant generation level is reduced after a relatively short break-in period.

Plots are given of experimental data on critical clearances in some hydraulic system components, and the time required for component malfunction due to silting versus contamination level. Examples are given of system filter failures due to resonance; excessive resonance may be prevented by proper support of filter elements. Vibration and contamination levels for Saturn hydraulic components are given as well as contamination specification limits.

33. Parker, James W.: "Hydraulic System Contamination." Ground Support Equipment, Volume 4, No. 6 January 1963. AD 485305.

This article was extracted from Air Force Report ASN TN 61-143. Fifteen operational aircraft and two ground-servicing units at Wright Patterson Air Force Base, Ohio, were surveyed for contamination in hydraulic systems. Large quantities of contamination were found; in the over-100-micron range, as many as 5100 particles were counted in the sample. The major problem source is identified as transfer of fluid from shipping containers and poor treatment of ground test equipment. The complete results of contamination levels found during this survey are presented in the tabulation.

Contaminants in Operational Aircraft Hydraulic Systems

A/C Type	5-10 Micron	10-25 Micron	25-50 Micron	50-100 Micron	100 Micron	Remarks	Weight (mg/100 ml)
F-105	53,840	28,160	13,480	5,410	1,730	After Flush	
F-105	12,140	5,170	3,070	520	370	After Flush	
MJ-2A	79,970	36,720	20,150	9,380	4,240	After Flush.	
F-105	31,161	12,261	5,860	1,870	1,260	Before Operation	
F-105	39,220	19,620	12,870	6,060	1,820	Before Operation	
MJ-2A	101,330	47,150	24,380	8,340	3,590	Before Operation.	
KC-135	2,750	1,050	1,440	1,430	2,620	1 oz fluid	
KC-135	13,460	920	720	720	340		
KC-135	10,510	1,530	630	180	160		
B-58	0	--	--	--	--	--	0.2
B-58	--	--	--	--	--	--	1.8
TB-58	48,900	3,200	1,600	800	18	--	8.2
TB-58	--	--	--	--	200	50	2.8
B-52G	--	---	--	--	--	--	6.8
B-52G	--	--	--	--	5,100	--	8.3
F-105	--	33,050	15,840	2,290	1,180	Accident.	A/C
B-58	87,000	34,200	6,800	300	10	3	5.2

34. Piccone, M.: "Control of Contamination in Rocket Booster Hydraulic Systems." SAE Conference Proceedings: Aerospace Fluid Power Systems and Equipment Conference, Los Angeles, California, May 18-20, 1965. 650345.

This paper provides a comprehensive discussion on the importance of contamination control in hydraulic systems, types of contaminants, means of system contamination, sizes of particle contaminants, specifications for hydraulic fluid cleanliness, effects of vibration and flushing on cleaning systems and components, methods of contamination control, comparison of automatic to light microscope contaminant counting methods, and a comparison of some automatic particle counters. General coverage is given to many aspects of contamination control in hydraulic systems and is liberally sprinkled with experience on actual systems.

35. Pino, M. A. and Furby, N. W.: "New Considerations in Hydraulic Fluid Testing." SAE Conference Proceedings: Aerospace Fluid Power Systems and Equipment Conference, Los Angeles, California, May 18-20, 1965. 650329.

This paper discusses the requirements imposed by specifications on aviation hydraulic fluids as being unjustified in view of actual conditions to be met in application.

In principle, the author agrees that revisions to MIL-H-5606 hydraulic fluid were beneficial but disagrees with the criteria of (essentially) a zero particle count in excess of 100 microns. This paper presents the problems inherent in transferring fluid from containers to the using system without introducing contamination and recommends that all fluid be passed through a filtration cart prior to filling the hydraulic system. White room conditions are required to package hydraulic oil to this specification with a high rejection rate and attendant costs.

The author further points out that MIL-H-5606 specifications are in excess of major airframe manufacturers specifications whose limits have been shown to be perfectly adequate for broad use. The table compares the specifications (A, B, and C) used by major airframe manufacturers in relation to MIL-H-5606.

Examples of Particulate Contamination Requirements

Application A*		Application B	
Particle Size Range	Number (Maximum)	Particle Size Range	Number (Maximum)
5-10	16,000	5-14	10,000
10-20	4,800	15-24	4,000
20-40	1,200	25-49	1,000
40-80	240	50-99	100
80-160	16	100-299	50
>160	4	>300	3

*Same as Class 3, ARTC-28

Examples of Particulate
Contamination Requirements
(concluded)

	Application C	MIL-H-5606A Exhibit A	MIL-H-5606B
Particle Size Range	Number (Maximum)	Number (Maximum)	Number‡ (Maximum)
5-15	2,500	20,000	2,500
15-25	1,500	9,000	1,000
25-50	150	2,500	250
51-100	20	150	25
>100	5	0†	0†

†One less than number of samples counted.

‡Filter rate and total weight of insolubles requirements also.

The author also points out that superclean fluids are not superior to normal specification fluids (such as example C in the tabulation) in terms of oxidation stability and recommends a requirement of 3 or 4 particles in the largest size counted instead of a zero particle count criteria. The results would be (1) lower fluid costs, (2) increased sources of supply, (3) better fluid availability, (4) fluid quality functionally equal to present fluids. Nitrogen blanketing that has become accepted practice is also discussed.

36. "Precision Cleaning Methods and Cleanliness Requirements for Parts and Assemblies of Apollo Fluid Systems." North American Aviation, Inc., Downey, California, 19 July 1965. MA0610-017.

This specification details cleaning and contamination control requirements used for the Apollo program. Filters as fine as 0.45-micron are required for analysis of a fluid contamination level. The cleanliness requirements used are shown in the tabulation on page C-28.

Level	Particle Size (microns)	Allowable Quantity (per 100 ml)	Maximum Nonvolatile Residue (mg) (per 100 ml fluid)
1	50-75	100	1 mg
	75-100	10	
	Above 100	0	
2	50-100	100	1 mg
	100-175	10	
	Above 175	0	
3	160-200	5	No requirement
	200-250	1	
	Above 250	0	
4	175-700 (particles and fibers)	6	2 mg
	Above 700 (particles)	0	
	700-1500 (fibers)	1	
	Above 1500 (fibers)	0	

37. Reid, Stanley F.: "How Lockheed Keeps Contaminates Out of Hydraulic Systems During the Manufacture of Large Cargo Aircraft." Contamination Control, Volume V, No. 8, August 1966.

This article presents a comprehensive description of the program that Lockheed/Georgia has instituted to ensure cleanliness of hydraulic systems on the C-5A cargo aircraft. In-plant fabrication of tubing and hose assemblies is conducted by normal processes, but all subsequent operations are conducted under controlled cleanliness conditions. Special cleaning and capping equipment has been designed. Control of the fluid itself is considered vital. All test equipment is certified. Cleanliness clauses are a part of all vendor procurement. Educational and training programs have been instituted for the personnel involved. Sampling is accomplished by the "bomb" and visual counting method, but "in-place" techniques and automatic sampling equipment are being evaluated.

38. Robinson, N. F.: "Fluid Contamination Survey of 143 Naval Aircraft Hydraulic Systems," Douglas Aircraft Company, Inc., Long Beach, California, 13 March 1968. AD 402711.

This report describes the fluid sampling and analysis of 143 naval aircraft. Emphasis is placed on contamination level and type and number of filters employed in each system. The conclusion reached is that it is not unreasonable to expect the existing fluid system to be able to sustain a maximum contamination level of class 5 with minor modifications, and that newly designed systems should be able to maintain a maximum contamination level of class 4. The means of attaining these higher cleanliness levels are proper filtration and the use of components that have been broken in (passed initial high contaminant generating stage). The contamination classes recommended are the tentative SAE, ASTM, and AIA hydraulic-fluid standard contamination levels as shown:

Size Range (microns)	Maximum Particle Count Class 4	Maximum Particle Count Class 5
5-10	32,000	87,000
10-25	10,700	21,400
25-50	1,510	3,130
50-100	2[illegible]	430
>100	21	41

39. "SSFL Sampling Instructions." Rocketdyne Division, North American Rockwell Corporation. FL 11-5-1072. 1 May 1965.

This specification establishes sampling methods and practices for use in testing fluids for contamination at Santa Susana Field Laboratories. The sampling methods for dynamic and static sampling are given in an explicit step by step manner to ensure that there is as little deviation in analysis due to sampling variation as is possible.

40. Stechmeyer, J. P.: "Construction of a Controlled Environmental Area Utilizing Commercial Construction Materials." SAE Conference Proceedings: Aerospace Fluid Power Systems and Equiprent Conference, Los Angeles, California, May 18-20, 1965. 650344.

This paper discusses constructing and maintaining a clean room for assembly, test, and inspection of critical components. Considerations are made for cost, upkeep, and assembly time. Floor, wall, and ceiling materials are considered for appearance and function. Air conditioning and housekeeping must be checked and maintained uniformly throughout the operation of the clean room. Personnel clothing must be kept clean and in good repair. Equipment must be selected for cleanliness of operation and ease of maintenance. Every element must be considered to reduce expense and obtain required cleanliness level.

41. Tollier, G. F., Lewellen, J. W., and Standke, H.: Survey of Contamination in Rocket Propulsion Fluid Systems. Rocketdyne Division, North American Rockwell Corporation, Conoga Park, California. AFRPL-TR-67-290. AD 829701.

This paper discusses fluid contamination. The primary interest is to demonstrate the many diverse aspects of contamination with which industry is now faced. Physical characteristics of particulate and chemical contaminants are described as well as their potential detremental effect in fluid systems. A general survey of contamination level control exercised by various corporations indicates a need for a much clearer definition of contamination problems and solutions. A bibliography of articles and assorted specifications outlines present knowledge and concern for contamination analysis. An extensive number of graphs and tables give an indication of data available for consideration in the design and maintenance of fluid systems.

42. Van Loon, J. K.: "Silting Index - What It Is, How to Find It, What It Tells." Hydraulics and Pneumatics, Vol. 17, No. 3, March 1964.

This article presents a derivation of the mathematics involved in the Silting Index and describes the test technique involved. Basically, the index is a measure of the time required to pass a specific volume of hydraulic fluid, under a specific pressure, through a 0.8 micron filter. The higher the index, the greater the tendency of the fluid to silt. It can predict failure rates of high tolerance servo valves. The detailed test procedure is given in ARP-788 of the SAE.

43. Van Loon, J. K.: "Value Engineering of Contamination Control." SAE Conference Proceedings: Aerospace Fluid Power Systems and Equipment Conference, May 18-20, 1965. 650331.

Contamination control is mandatory for good component reliability. In order to keep reliability high and cost low, the customer and supplier should review their contamination controls and specifications to ensure that they are adequate but not too severe. Care must be taken that the component is not contaminated due to reliability testing at system installation. The F-111 flight control servo actuator development is used to demonstrate the successful application of Value Engineering to Contamination Control. This is a case of a "contamination control program designed for a specific component or system. . . to eliminate the GOLD PLATE from the product." It mentions that either MIL-H-5606B or MIL-H-6083 hydraulic fluid is used in testing, with a final flush of MIL-H-6083. The particle specification used for the F-111 components is presented below.

Micron Range	Over 1000	Fibers 500-1000	100-500	50-100	25-50	15-25	5-15
Component							
Number of Particles Allowable	0	5	11	55	1,000	4,000	20,000

44. Wheeler, H. L., Jr.: Fluid Filters: Media and Contamination. Bendix Filter Division, Bendix Aviation Corporation. Publication No. BFD 168. 1960

To control the level of contamination in hydraulic systems, a variety of filter types or combinations of types may be selected. Each hydraulic component generates its own type of contamination and is also sensitive to a certain range of contaminant sizes. The two primary filter types are surface filter (single-membrane element) and depth filter; each has advantages and disadvantages that should be considered when selecting filters for a specific system. The surface filter is more easily adaptable to "absolute" particle size filtration while the depth filter has a greater contaminant holding capacity. Clean room facilities are necessary in filter production to reduce migration effectively.

Particle counting in the range smaller than 10 microns is extremely unreliable with optical techniques because the particle sizes are approaching the wavelength of light.

45. Wiley, John W.: "Hydraulic Fluid Contamination." Aerospace Maintenance Safety, Vol. 19(2), February 1964.

This author maintains that the keys to maintaining clean aircraft hydraulic systems are (1) strict filter maintenance both in the aircraft and in ground servicing units, (2) prefiltering fluid added to reservoirs, and (3) knowledgeable servicing and maintenance techniques. Certain system functions deserve particular attention; for example, plugged filters may have gone into the bypass mode and passed contamination on down into the system. Special attention should also be given to maintaining cleanliness of air reservoirs on test stands, since contamination here can be passed on into the hydraulic fluid. Paper elements should not be used in high-velocity systems because the impact of a larger particle may perforate the fiber. Pressure surges can put a filter into momentary bypass. When a system is flushed and sampled, the sampling operation should be repeated after an engine run or test flight since engine vibration and system operation will often loosen particles that will show up in the filters.

Convair Cleanliness Specification 13.07H and 13.17C are presented; the requirements are as follows:

Maximum Particle Size, μ:	0-10	10-25	25-50	50-100	100-200
Maximum Quantity Allowable:	None	9000	900	90	9

One fiber allowed, 40μ maximum diameter
Sample volume is 100 ml

Also in this paper, recommended particle counts are presented which are believed adequate to prevent silting of servo valves:

Maximum Particle Size, μ:	5-14	15-24	25-59	50-100	>100
Maximum Quantity Allowable:	150,000	17,000	7,000	1,000	100

Sample volume is 100 ml