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FINAL REPORT
THREE-PHASE PROGRAM
TO DEFINE REQUIREMENTS
FOR OPERATION OF FLUIDICS
ON COMPRESSOR BLEED AIR
(CONTRACT NO. N62269-74-C-0647)

76-411328

August 2, 1976

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Attention: Mr. Ed Schmitt/Code 30424

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A means of determining the ability of fluidics and filter systems to resist contamination when operating on gas turbine bleed air was required. A previous program determined the typical contaminants present in bleed air. This program determined the best approach to simulation and includes design and fabrication of a simulator which may be used to determine life and maintainability requirements for control elements and filters using compressor bleed air as the working fluid.

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AIRESEARCH MANUFACTURING COMPANY
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

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FOREWORD

This is the final report on a three-phase program conducted by AiResearch Manufacturing Company of Arizona, a Division of The Garrett Corporation, 402 South 36th Street, P.O. Box 5217, Phoenix, Arizona, 85010, under Contract No. N62269-74-C-0647, for the U.S. Naval Air Development Center (NADC), Warminister, Pennsylvania.

The report describes the various phases of the program conducted by AiResearch during the period from June 18, 1974, to March 26, 1976, and covers the investigation of numerous approaches to the design and development of a compressor bleed air simulator (CBAS) used in the final phases of the program to obtain data on fluidic system operation and to define filtration selection guidelines.

Supervision of this program at AiResearch was vested in Mr. David J. Schaffer, Sr. Project Engineer for Fluidic Systems, Pneumatic Systems Project. Mr. Trevor G. Sutton, Assistant Project Engineer, and Mr. Ray P. Martin, Development Engineer, were responsible for design and development portions of the program, and Mr. James A. Denneny, together with Mr. Sutton, was responsible for the final development and testing phase. Technical direction of this program for NADC was under Mr. Horace B. Welk, Jr. (30424) and Mr. Edward T. Schmidt (30424).

Publication of this report does not constitute approval by the Naval Air Development Center of the findings or conclusions presented herein.

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FINAL REPORT
THREE-PHASE PROGRAM TO DEFINE REQUIREMENTS FOR OPERATION OF FLUIDICS ON COMPRESSOR BLEED AIR
(CONTRACT NO. N62269-74-C-0647)

SECTION 1

INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

This is the final report on a three-phase program conducted by AiResearch Manufacturing Company of Arizona, a Division of The Garrett Corporation, to design, develop, and fabricate a compressor bleed air simulator (Phases I and II), then to utilize the compressor bleed air simulator (CBAS) to conduct contamination tests in order to establish filter requirements to protect fluidic circuits and reduce maintenance requirements (Phase III).

The information in this report is intended for presentation to the U. S. Navy, Naval Air Development Center, Warminister, Pennsylvania. The program was conducted under Contract No. N62269-74-C-0647. The Contract Data Requirements List item covered herein is identified as Sequence A003 (Final Report). The material in this report covers the progress accomplished during the period from program inception on June 18, 1974, to the termination date of March 26, 1976.

1.2 BACKGROUND AND OBJECTIVES

Until recently, compressor bleed air from gas turbine engines, which is used as a power source for fluidics and pneumatic controls in aircraft and ground power generating systems, has been a relatively unknown quantity with respect to particulate and fluid contaminants. Preliminary studies of problems associated with using compressor bleed air as the fluidic supply were conducted under Navy Contract N62269-73-C-0426. MIL-E-5007D defines contaminant levels at which pneumatic systems are tested when compressor bleed air is used as the power source. The objective of this program was to test fluidic circuits and filter systems, using the military specification as the basis for contaminant levels, and to establish filtration requirements for various applications.

Under the present program, a bleed air simulator was fabricated to provide the contamination levels of MIL-E-5007D. The simulator was then used to determine the ability of typical fluidic controls to operate at the above contamination levels and to determine the effectiveness of filtration systems. From this data, a decision may be made as to the filtration requirements for fluidic systems and maintenance scheduling requirements.

To achieve these objectives, the program was defined as a three-phase effort. The first phase consisted of the design, fabrication, and test of the solid contaminant injector which represents the most complex part of the simulator. During the second phase, the injector was incorporated into the complete simulator which was fabricated and tested. The third phase utilized the simulator to obtain data on fluidic system operation and to define filtration selection quidelines.

1.3 SUMMARY

Initially in Phase I, a review of available relevant material was conducted to provide background information and enable evaluation of the present state-of-the-art. From this, initial design and performance goals were established for the compressor bleed air simulator (CBAS). A variety of methods to introduce controlled particulate contamination into a pressurized airstream were conceived, investigated, refined, and evaluated. Based on preliminary tests and engineering judgement, a pressurized conveyor belt was selected as the best approach, and incorporated in the design of a particulate contaminant injector. The injector was fabricated and tested. Development tests demonstrated reasonable performance and provided information to assist in incorporation of the injector into the design of the CBAS.

Following establishment of the CBAS system schematic, the prototype CBAS design was completed. Component parts were selected or fabricated and assembled as a unit for development testing after numerous critical delays caused by late delivery and poor quality of several vendor-supplied items. As a result, the development test program for the CBAS system was compressed into the final 1-1/2 months of the 13-month program for Phases I and II. The complexities of control, calibration, and measurement encountered prevented achievement of the desired performance capabilities within the alloted contract time span. Although the CBAS was operable, and all problem areas were considered to be defined, some additional development was necessary to completely resolve such problems prior to starting the final phase (III) tests of this total program.

During the third phase of the program, final modifications of the particulate injector, air-water heat exchanger, and liquid contaminant injectors were completed. The remainder of Phase III activities involved the contamination testing of fluidic circuits and filtration systems. Initially, bleed air extraction probes were evaluated. Then different filter configurations were evaluated and fluidic circuits were life tested with contaminated bleed air both with and without filtration. In summary, the configuration capable of producing greatest service life appears to be a hooded trailing bleed air extraction probe in conjunction with a two-stage filter system. The first stage would consist of a cyclone separator, with a second stage depth media filter such as the Hydraulic Research unit described in this report.

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SECTION 2

COMPRESSOR BLEED AIR SIMULATOR (CBAS) DESIGN (PHASE I)

2.1 DATA AND TECHNOLOGY REVIEW AND EVALUATION

The documents listed in Table I were reviewed at the inception of this program. The information derived from these documents provided background and guidance during development of the various concepts discussed in Section 2.3, and the possible system approaches considered.

2.2 CBAS DESIGN AND PERFORMANCE OBJECTIVES

Based on an analysis of the data contained in the documents listed in Table I, particularly MIL-E-5007D and AiResearch Report 73-410307, in combination with practical, technical, and operating considerations, the initial CBAS design criteria and performance objectives were established. These objectives, as finally refined, are delineated on Table II. The specifications were selected to provide a unit, with the desired performance and employing available components, which is conveniently operable to test a wide range of fluidic and pneumatic equipment.

2.3 SOLID PARTICLE CONTAMINANT INJECTOR

The most formidable requirement for the simulator design was to provide an accurate and controllable means to inject particulate matter into a pressurized airstream. Accordingly, the initial effort of the simulator design program was concentrated on the design and development of the required particulate injector assembly.

2.3.1 Injector Design Considerations

The review of current technology provided the following possible general considerations for a contaminant injection system.

1. Main airstream flow rates may be either constant or variable. Due to the variability of fluidic circuit sizes and air consumption rates, constant flow with provisions for utilizing an adjustable portion of the main airstream flow should be included.

2. Control of contaminant injection rate with changes in main airstream flow rate could be manual or automatic. After considering relative complexity and expense, manual control was selected.

TABLE I

RELATED MATERIAL REVIEWED

Document	Title
MIL-E-5007D	General Specification for Turbojet and Turbofan Aircraft Engines
AiResearch Report 73-410307	Evaluation Program on Using Compressor Bleed Air as a Source of Pneumatic Power for Fluidic Circuits (Navy Contract N62269-73-C-0426)
HDL-TR-175-1	Contamination Effects in a Laminar Proportional Amplifier
L0242	Fluidic Reliability Program, Final Report
L0243	Investigation of the Effectiveness of Cyclone Separators on Fluidic Power Supplies
DAAG39-72-C-001 (Contract)	Thirteenth, Fifteenth, and Sixteenth Monthly Progress Reports
ARP749	Aircraft Engine Fuel Pump Endurance Test (Contaminated Fuel)
ANSI B93.28-1973	American National Standard Method for Calibration of Liquid Automatic Particle Counters Using "AC" Fine Test Dust

TABLE II

SIMULATOR DESIGN AND PERFORMANCE

Rated Airflow	120 lb per hour (26 scfm)
Discharge Pressure	10 to 200 psig
Discharge Temperature	Approx room temp to 288C (550F)
Contaminants Injected (at Rated Airflow)	
MIL-L-7808	3 ppm (0.00036 lb per hour)
NaCl (as 4 percent water solution)	0.2 ppm (0.000024 lb per hour)
H_2O	11.4 lb per hour maximum
AC Fine Test Dust	0.01752 lb per hour (8 grams per hour) (replaces the crushed quartz specified in MIL-E-5007D, Paragraph 4.6.2.2.5)

NOTES:

1. Separate and individual control of each contaminant is provided.
2. Contaminants are injected at approximately uniformly continuous rates.
3. Injection rates must be adjusted manually when test section airflow is changed.
4. Interval between recharging contaminants is eight hours.

3. Contaminant injection may be on a continuous or intermittent basis. Continuous, controllable injection is optimum.

4. Contaminant proportions can be defined in units of mass or volume. Units of mass were selected for all contaminants to provide uniformity of specification, to reduce confusion, and to agree with MIL-E-5007D.

5. Measurement of injected contaminants could be accomplished by particle count or gravimetric method on a continuous or sampling plan basis. A sampling plan could include: 1) checking after each reload of contaminant, 2) at fixed time intervals, and 3) when improper operation is suspected. In light of the basic requirements, a gravimetric sampling plan based on particle size was initially selected for normal operation. Frequency of sampling included all three of the possibilities during initial tests. Later testing proved this could not be achieved. Therefore, the final policy was to inject a known gravimetric quantity of contaminant into a known stream flow rate.

2.3.1.1 Injector Design Objectives - The design objectives for a particulate injector in the CBAS include:

1. Control of injection such that the rate is continuous.

2. Injection into an airstream that is at a pressure above ambient.

3. Uniform contaminant injection with respect to particle size distribution as a function of time.

2.3.1.2 Characteristics of Particulate Contaminants - Characteristics of particulate contaminants considered in the injector design included:

1. Larger particles settle quickly in liquids, and tend to migrate toward the bottom of a dry mix.

2. Smaller particles are readily blown or floated away from larger particles.

3. Smaller particles have a tendency to cling to surfaces.

4. Poor uniformity of particle size distribution with time can result from the injection method and separation/accumulation in the main airstream discharge line(s).

5. Any restriction in the main airstream discharge line tends to result in accumulation, packing, and shutoff of airflow.

6. The mix does not flow readily and tends to pack and plug.

7. Volume changes of at least 10 percent occur due to packing and settling from vibration.

8. Contaminant mix control must include properly specified constituents, controlled by weight, and batch agitation during injection to maintain constant proportions.

Contaminant problems encountered during preliminary design evaluation testing indicated that the original contaminant mix was not in accordance with the requirements of MIL-E-5007D. A subsequent evaluation revealed that the contaminant included particle sizes in excess of 500 micrometers (i. e., microns), and that these large particles clogged the orifices and nozzle of the test unit (White Model H, as discussed in a later paragraph). The maximum specified size for the bleed air simulator is 80 micrometers. Most of the characteristics noted in the preceding paragraph were based on tests utilizing the original contaminant.

A subsequent attempt was made to produce a contaminant mixture in accordance with MIL-E-5007D. This was tried by combining the correct proportion, by weight, of crushed quartz labeled 5, 5-10, 10-20, 20-40, and 40-80 micrometers. However, the resultant mixture appeared to contain far too many small-size particles. A microscopic exmaination of the constituent particle mixes revealed that they had not been properly classified. For example, the 40-80 micrometer crushed quartz did contain particles measuring between 40 and 80 micrometers; however, most of the particles were smaller than 40 micrometers.

A search for a source of off-the-shelf crushed quartz contaminant complying with MIL-E-5007D was not successful. Since developing the capability to prepare the proper mixture of contaminant was not within the scope of the program, a request was made to NADC to furnish the specified crushed quartz contaminant, or to permit the substitution of such contaminants as AC coarse air cleaner test dust (Arizona Road Dust) or AC fine test dust.

As no source of crushed quartz meeting the requirements of Paragraph 4.6.2.2.6 of MIL-E-5007D could be located, Naval Air Development Center approved the use of AC fine air cleaner test dust.

2.3.1.3 Injection Under Pressure - With regard to the injection of contaminants to a pressurized region, two possibilities existed:

1. The injection system could be pressurized to equal the line pressure.

2. Injection system pressure could exceed line pressure and the pressure difference could be utilized for injection.

2.3.1.4 Injection System Components - With the above information and factors in mind, a list of possible injection system components was derived. System components from this list were used in the concepts described in the following paragraphs. Table III is a partial list of the candidate components; many others were omitted on the basis of information previously discussed, or obvious unsuitability.

2.3.2 Injector System Approaches

Several injection system concepts evolved from the foregoing general considerations and are discussed in the following paragraphs. The original contaminant was used in the evaluation tests of these approaches.

2.3.2.1 Initial Systems Considered - Systems eliminated in the early evaluation stage included the following:

1. Mechanical Solid Particle Injector - The metering gear-type injector shown in Figure 1 was evaluated with respect to gear wear, wiper characteristics, and feed rate. In light of the low probability that the existing design could be improved to obtain desired performance and reliability characteristics, this approach was rejected.

2. Liquid-Carried Solid Particle Injectors - The Freon-carried solid particle injector shown in Figure 2 was studied in some detail. Water in place of Freon was considered as one improvement since no unspecified contaminants would be introduced. A mixture of water, oil, salt, and solid particles would offer advantages if proper mixing could be achieved. However, results of basic

TABLE III

CANDIDATE INJECTION SYSTEM COMPONENTS
(PARTIAL LIST)

Mixing Components
Tumbler
Paint Mixer
Vortex Injectors
Compacted Contaminant with Binder
Air Mixer

Feed Components
Vibrator Feed
Funnel
Hourglass
Atomizer
Slurry Pumps
Pinch Rollers
Balance Scale with Automatic Trip Mechanism
Flapper-Nozzle Weight Sensor
Solenoid Actuator
Encapsulated Strips
Bucket-Type Conveyor
Scrapers
Ejectors
Pipette Pickups
Magnetic Feeds
Worm Feeds (Stokers)
Aligning Holes
Pulse-Modulated Concentric Pinch Valves
Multiple Hole Injection Tubes

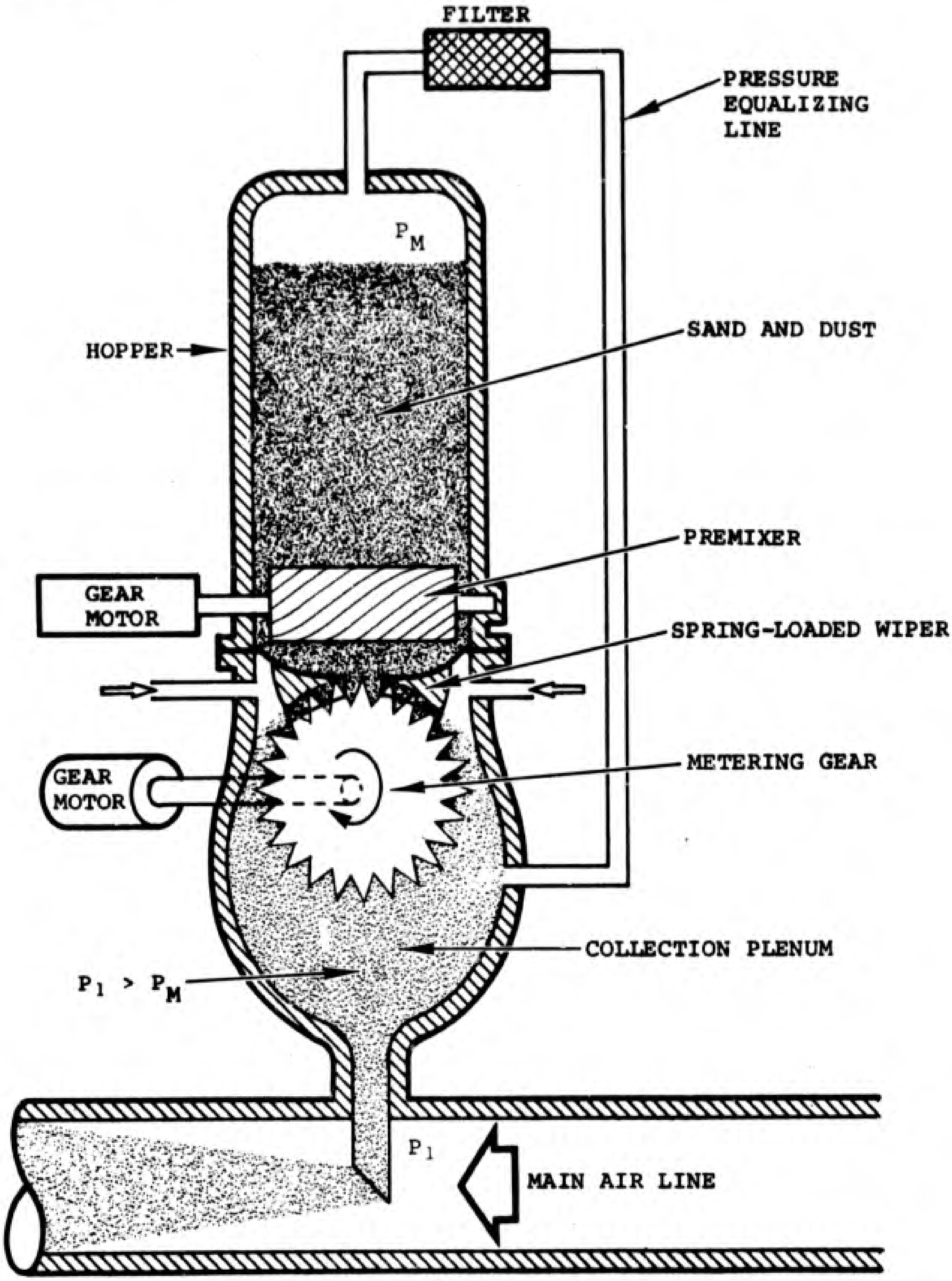


FIGURE 1

MECHANICAL SOLID PARTICLE INJECTOR

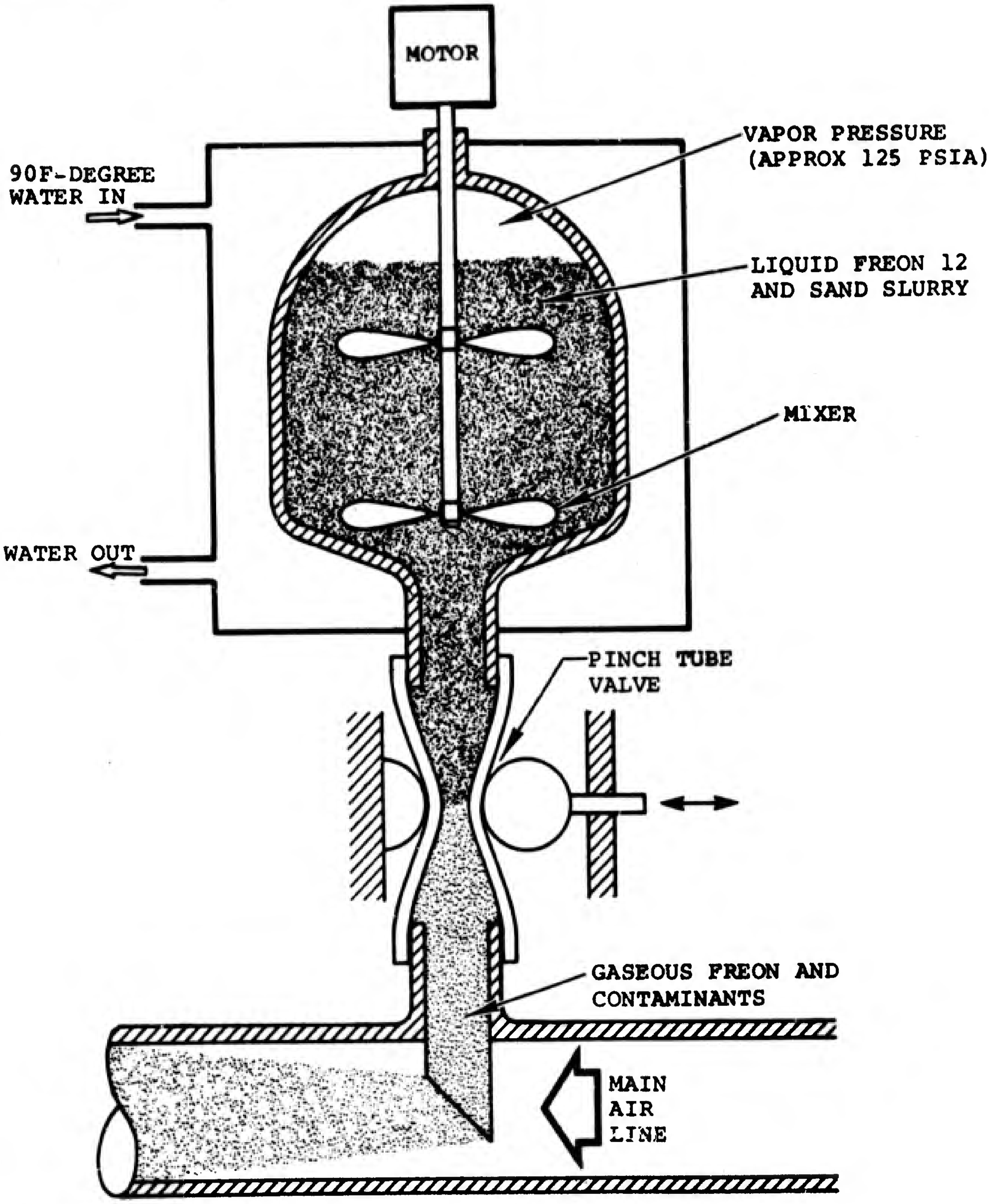


FIGURE 2

FREON-CARRIED SOLID PARTICLE INJECTOR

laboratory tests showed that a very wet slurry with severe agitation or superior particle suspension would be necessary for proper injection uniformity. Since this system approach did not appear to offer uniform injection with reasonable development effort, it was discarded in favor of more promising concepts.

Another slurry system was considered with a pump or pressurized-gas feed. Although mechanical and ultrasonic agitation methods were considered or tried, the possibility of maintaining adequate suspension and flow characteristics appeared to be quite low. In addition, calculations indicated that control restrictions of less than 0.005-inch diameter would be required as compared with unsatisfactory test results with restrictions larger than 0.025-inch diameter. In view of these problems, slurry systems were discarded.

3. Mercury Flotation Systems - Since the specific gravity of the solid contaminants is less than that of mercury, it appeared that the contaminant could be fed into the airstream from the top of a vertical tube by supplying mercury to the bottom. Unfortunately, basic tests of the configurations in Figure 3 showed that friction and packing of the particles prevented continuous lifting of the column. A flotation plug or cup was considered and rejected due to problems with jamming and abrasion between the cup and tube.

4. Fluidized-Bed Contaminant Dispenser - Evaluation of the dispenser described in Document L0242 (see Table I) was based on Documents L0242, L0243, and the 13th, 15th, and 16th progress reports under Contract DAAG39-72-C-001, and AiResearch experience with the specified contaminant. The results indicated an inability of the dispenser to correctly simulate the required injection uniformity with an apparent tendency to clog, shut off, or inject material in accumulated chunks. Accordingly, this dispenser was given no further consideration.

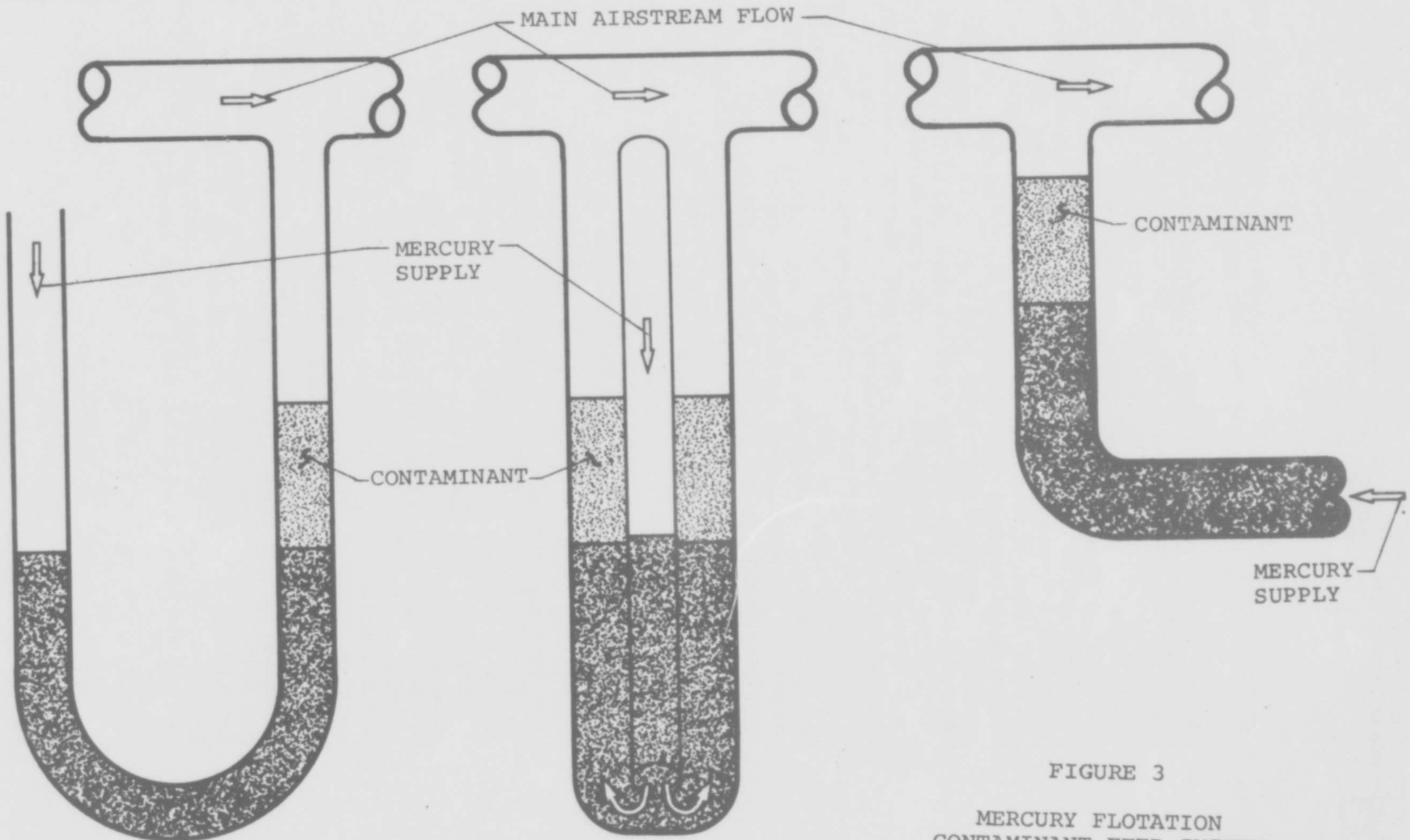


FIGURE 3

MERCURY FLOTATION
CONTAMINANT FEED SYSTEM

2.3.2.2 More Promising Systems - Individual features of the following more promising concepts apply to the various approaches.

1. Frozen Contaminant Injection System - Consideration of dry, premeasured portions of contaminant logically led to a basic concept of frozen samples of contaminant when feed systems were considered. The resulting system, shown in Figure 4, would utilize the contaminant mixed with water and frozen into a core or long cylinder in a rod-piston feed mechanism. The core cylinder would have to include a coolant passage and would probably be Teflon-coated. Basic laboratory tests of this approach showed that the larger contaminant particles would settle to the lower side of the core during freezing and that melting of the core end that projects into the airstream would probably be uneven. These conditions could lead to excessive wear and jamming of the core in the cylinder and unpredictable rates of injection. Development of the concept in the areas of core freezing techniques, improved melting zone configurations, and thermostatic control of the melting zone could prove effective in providing a reliable contaminant injector. However, in light of the development costs, difficulties inherent in freezing and handling the cores, equipment and operating complexities, and probable higher operating costs, this was not considered as the best design prospect.

2. Dry Contaminant Injection System - A dry contaminant injection system similar to the frozen contaminant system discussed above is shown in Figure 5. The approach is similar without the inherent thermal problems. However, the loose abrasive particles and mixed particle size create problems of wear, binding, and particle separation before injection. This was verified by basic testing which indicated that air pressure behind the piston and some sort of baffling at the injection point would be required. The air behind the piston aids in keeping the scraper seal free, and the baffling prevents main airstream flow from extracting all the loose contaminants from the cylinder at uncontrolled rates. Development of this system would include the following areas:

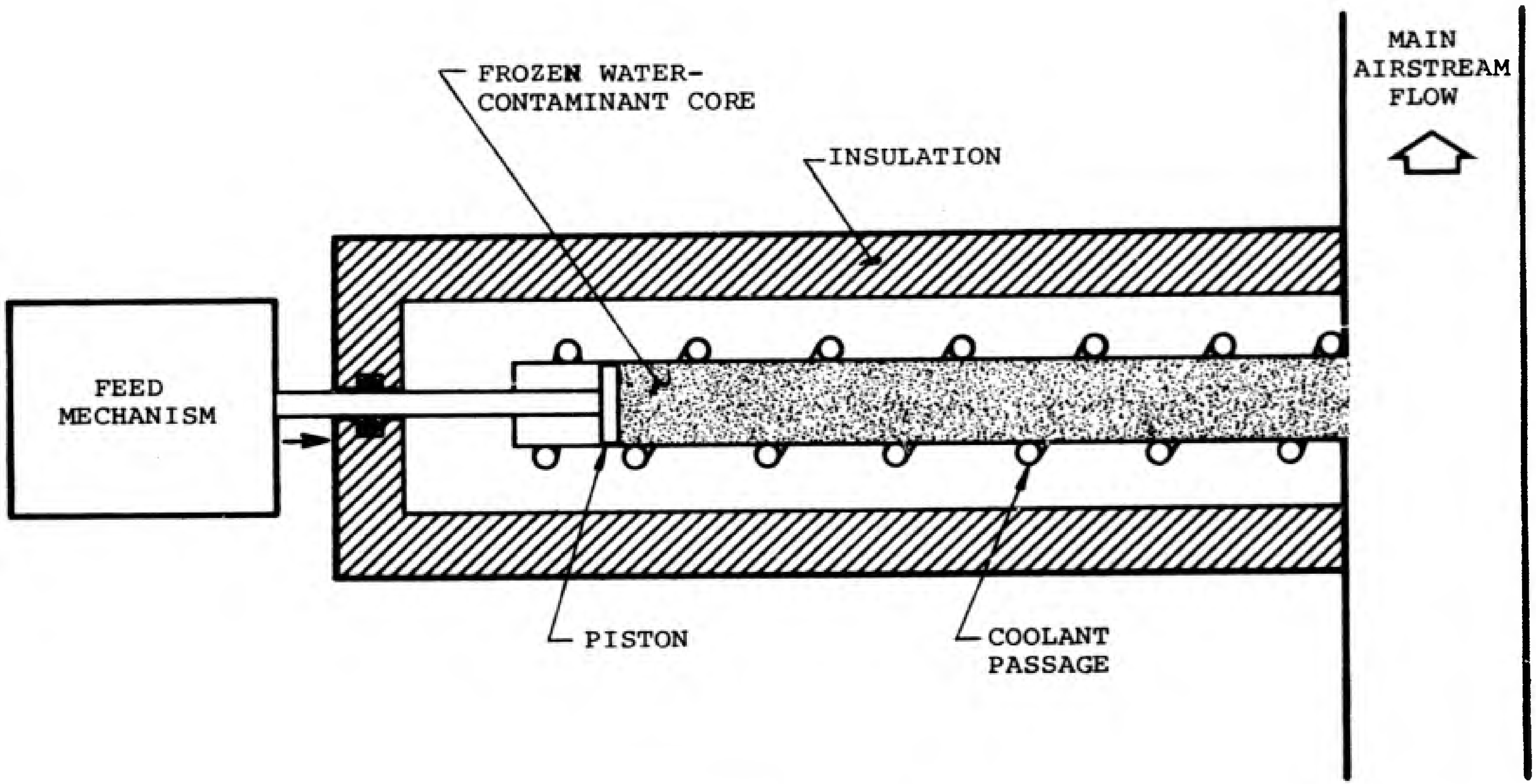


FIGURE 4

FROZEN CONTAMINANT
INJECTION SYSTEM

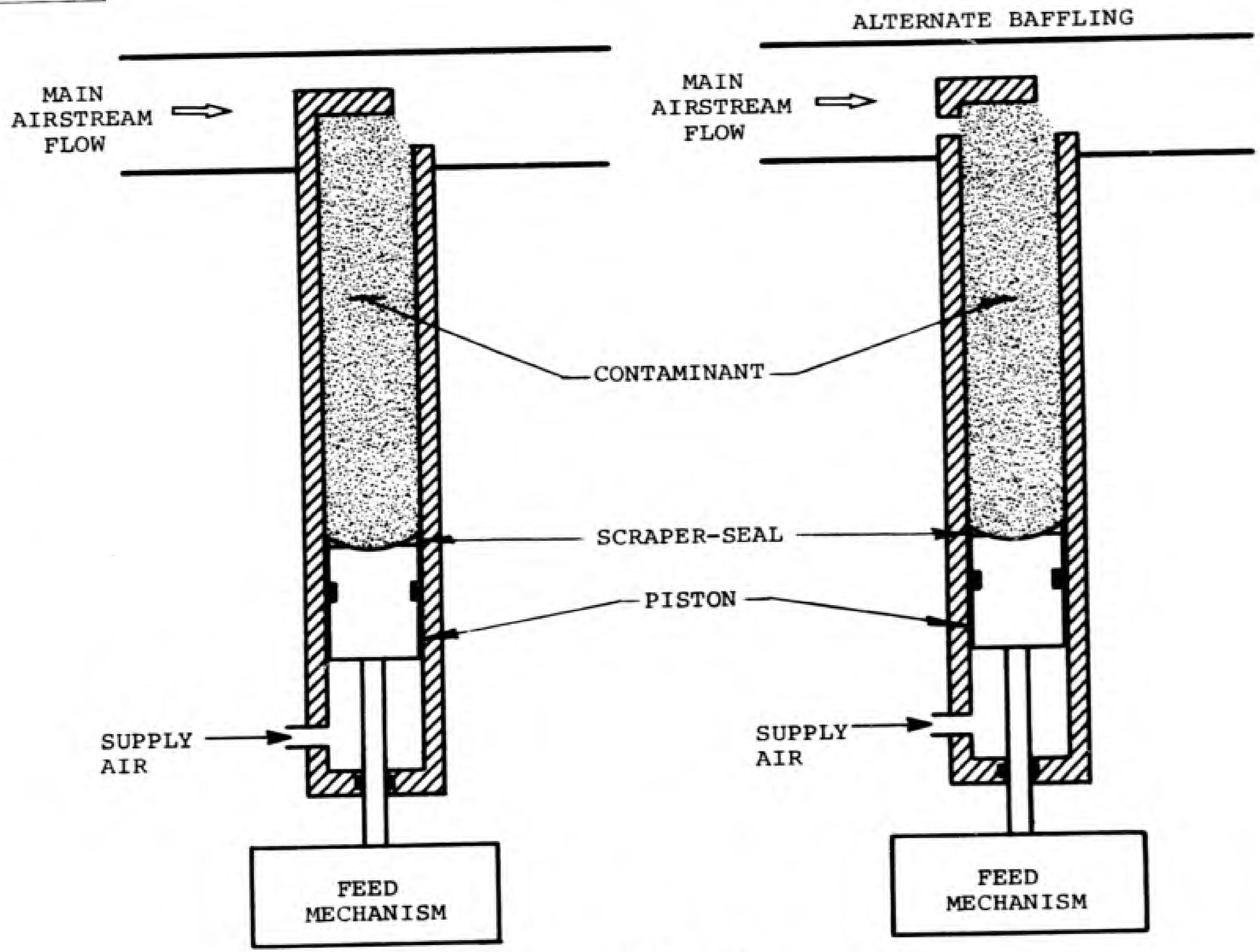


FIGURE 5

DRY CONTAMINANT
INJECTION SYSTEM

a. Matching of contaminant load size, feed rate, piston pressure, and scraper seal characteristics.

b. Refinement of the contaminant discharge configuration and projection into the main airstream.

c. Orientation of the main airstream duct (vertical appears to be advantageous for mixing purposes) and feed cylinder (vertical also appears to be advantageous). Satisfying these conflicting requirements would be difficult.

d. Possibility of the need for a cross airflow jet at the cylinder end to feed contaminant into the main airstream.

e. Valving to isolate the contaminant from the main airstream during recharging activity.

f. Determination of a suitable feed mechanism (motor-driven screw, pneumatic cylinder, rack and pinion, etc.).

Additionally, disposable or readily replaceable scraper seals, porous cylinder walls, and prepared contaminant refill cartridges might be necessary and would have to be evaluated.

In view of the considerable time and cost involved in this development program and because jamming still might be a problem, the dry injection system was not considered the best candidate for design. However, both this system and the frozen core approach were considered as backup concepts in the event that other systems proved to be unacceptable.

2.3.2.3 Final Candidate Systems - The final candidate injector systems were as described below.

1. Abrasive-Jet Machining Equipment - An S. S. White Industrial Abrasive Unit, Model H, was employed for fluidic element testing as shown in Document HDL-TR-175-1 (see Table I). Although this unit ordinarily uses a very small range of particle sizes for any normal application, the commercial/industrial status of the machine, with the attendant reliability, was considered as justification for evaluation

testing to determine its capabilities when using the dry contaminants of Table II. Information from the manufacturer indicated that satisfactory results could be obtained. Accordingly, a Model H abrasive unit was partially evaluated to develop special techniques and to determine its capability of utilizing the specified contaminant. Other manufacturers also provide equipment of this type which would perhaps be suitable for some applications.

2. <u>Pressurized Conveyor Belt System</u> - A satisfactory liquid-fuel tank contaminant feed system employs a conveyor belt driven at constant speed as utilized for contaminated fuel tests in accordance with ARP749 (see Table I). A modified concept of this approach to inject solid contaminant into an airstream is shown in Figure 6. As shown, the belt is located in a pressurized chamber with chamber pressure at least equal to main airstream pressure. Thus, it is relatively simple to transfer contaminant from the belt to the main airstream. The following factors were considered critical to evaluation and development of this type of system.

   a. Belt configuration (flat, grooved, ribbed, etc.).

   b. Belt material (elastomer, Teflon-coated, solid, foamed or fabric, etc.).

   c. Drive mechanism (electric or pneumatic motor, location, constant or variable speed, etc.).

   d. Contaminant charge (four- or eight-hour charge, dry or frozen, means of distribution on the belt, etc.).

   e. Pressurized chamber (means of accessibility for recharging contaminant).

   f. Means of contaminant pickup from the belt.

   g. Orientation of contaminant flow into the main airstream.

   h. Effect of pressure difference on transfer of the contaminant.

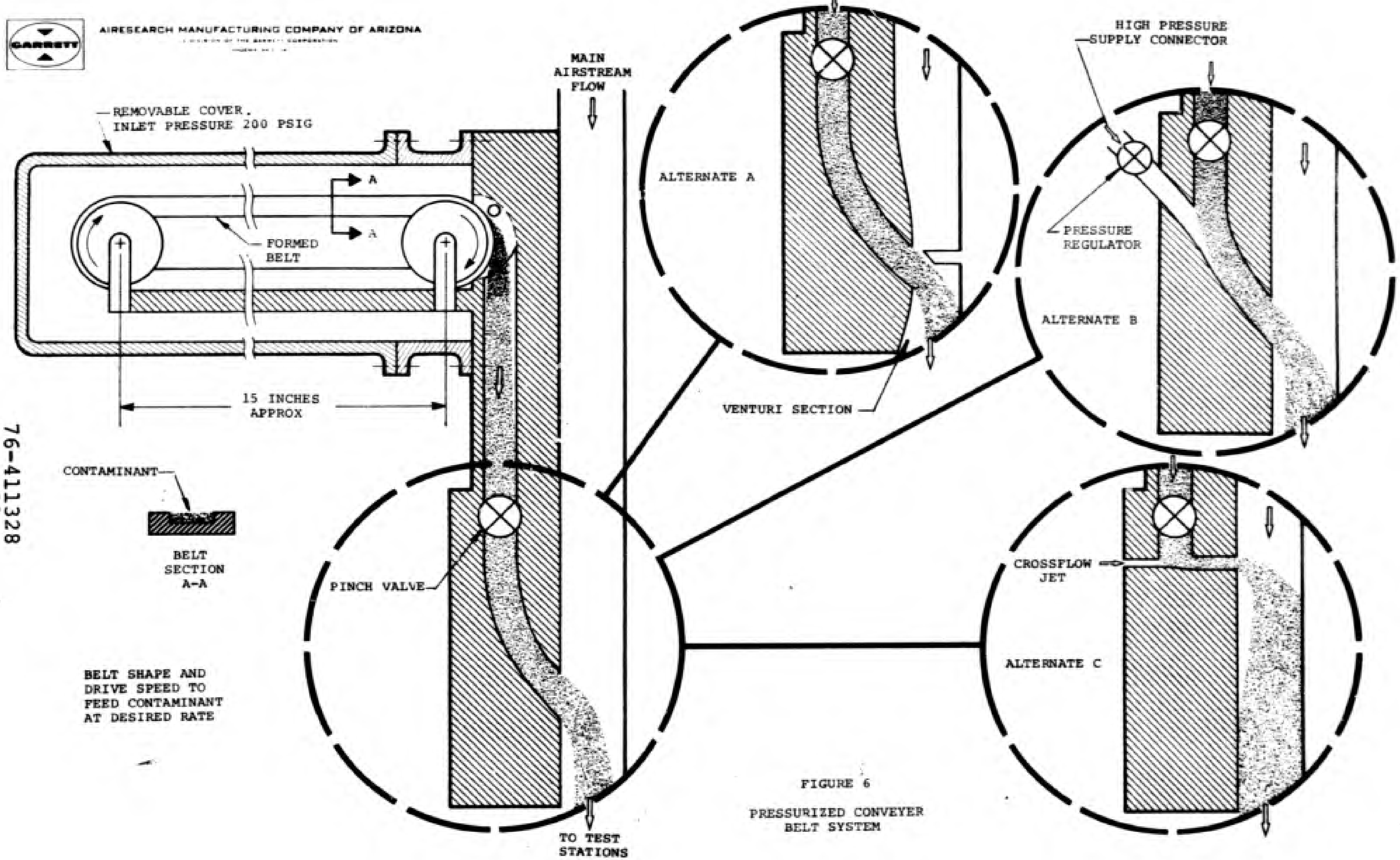


FIGURE 6

PRESSURIZED CONVEYER BELT SYSTEM

i. Use of a venturi, pressure regulator, or crossflow jet for delivery of the contaminant to the main airstream.

Since the previous use of this approach (for contaminated fuel tests) indicated success for fluidics testing, this design was considered very promising.

2.3.3 Injector Selection, Design, and Development

The review of the candidate injection systems led to selection of the Abrasive-Jet Machining Equipment and the Pressurized Conveyor Belt systems for further study and evaluation.

2.3.3.1 Abrasive Jet Machining Equipment - The satisfactory use of an S. S. White Industrial Abrasive Unit for fluidic element testing, as reported in Harry Diamond Laboratories Report HDL-TR-175-1, "Contamination Effects in a Laminar Proportional Amplifier", combined with the results of a preliminary evaluation of the potential of the equipment, indicated that this equipment might serve as a good basis for a solid particle contaminant injector. An S. S. White Industrial Abrasive Unit, Model H, was evaluated to determine suitability and potential for use in the CBAS. The evaluation was conducted almost exclusively with the initial sample of crushed quartz. The following conclusions were reached.

The unit probably could operate reasonably well with crushed quartz contaminant in accordance with MIL-E-5007D. However, this was not demonstrated. Even if the unit would function normally with the crushed quartz, it was felt that adjusting and providing the desired constant injection rate and maintaining the correct particle size distribution over a period of time would be difficult. In this regard, the unit appeared likely to deliver, for a short time, contaminant at a more steady and uniform flow rate than the pressurized conveyor belt system, but the rate probably would drift or be hard to maintain for a longer interval, such as an eight-hour shift.

The high particle velocities employed would cause more wear and require additional maintenance. Also, the unit would require modification to inject contaminant into a 200-psig line. The extent of the changes required were not determined. When a change in test section bleed air pressure is made, it probably would be necessary to adjust the unit setting and make a measurement to determine if the desired injector rate was achieved. Determining that the desired rate has been established is a demanding, time-consuming task.

In view of the foregoing, the abrasive-jet machine was selected as a back-up approach. If serious problems had occurred with the pressurized conveyor system, development of the Model H abrasive-jet machine approach would have been pursued. However, by the time use of AC fine air cleaner test dust was approved, it had become apparent that concentrating on the pressurized conveyor belt concept would be more productive. Accordingly, further evaluation of the Model H unit was discontinued.

2.3.3.2 Pressurized Conveyor Belt System - Consideration of the advantages, with less technical and practical problems anticipated, and preliminary tests with the original crushed quartz contaminant led to selection of the pressurized conveyor as the best probable concept. The expected relative insensitivity to the type of contaminant employed and to the main air stream pressure level, combined with the ability to deliver contaminant at an easily controlled uniform average rate, favored selection of the pressurized conveyor belt system. When initial design results and basic preliminary evaluation were promising, development of this injection system concept was emphasized.

A design layout of the pressurized conveyor belt system was made, refined, and reviewed to evaluate the possibilities and difficulties associated with this approach. The preliminary design layout effort revealed no insurmountable problems. The overall design appeared to be capable of compliance with all requirements. Therefore, it was decided to complete the detail design and fabricate a development unit for test.

The design subsequently conceived reflected all factors considered necessary to ensure the desired performance. The design permitted full evaluation of the performance of this conveyor belt approach to solid particle contaminant injection, and included features permitting adjustment and modification as required during evaluation. After testing, the unit was used in the complete compressor bleed air simulator. Some of the more significant features of the conveyor belt system are described in Section 2.4.

2.3.4 CBAS Design Considerations

When development of the particulate contaminant injection system was sufficient to demonstrate the soundness of the selected concept, the initial design of the compressor bleed air simulator (CBAS) was started. Selection of components was based on availability, adaptability, suitability, and overall system configuration. Several variations of the system schematic diagram were evaluated on the basis of preliminary laboratory tests, analyses, and engineering judgement. Necessary choices and decisions were made and finalized during the design layout effort.

The heater was a difficult problem. When the maximum amount of water is injected into the airstream, the heat required to vaporize the water and raise its temperature to over 550F (including a reasonable margin for heat loss between the heater and test section) is about equal to the heat required to raise the air temperature. Therefore, the original idea of spraying water into air, sufficiently hotter than 550F, exiting from the heater was not considered a feasible approach. Problems associated with assuring adequate heat transfer, control, packaging, and integration of a 20 kw (approximate) heater for a four pounds per minute airflow rate into the systems were studied.

The design airflow rate was reduced to two pounds per minute. This resulted from the lack of real need for higher airflows and the following advantages of a simulator with lower airflow capability.

- Smaller, lower cost components
- Lower initial cost simulator
- Lower operating cost
- Reduced energy consumption (approximately 50 percent)
- Simplified packaging and fabrication
- Increased simulator mobility
- Reduced water tank size (approximately 50 percent)
- More compact simulator
- Reduced exhaust noise levels
- Slightly improved injector performance

A maximum airflow rate capability of less than two pounds per minute would not be adequate for some tests and would create marginal injector control. Further, this would not produce significant size and cost benefits. Accordingly, the selected flow rate of two pounds per minute maximizes cost effectiveness without jeopardizing performance.

Commercially available units were selected to introduce oil and the salt water solution into the system. It was anticipated that modification of such units might be required to overcome corrosion problems. Initially, injection of salt mixed in the main water supply was considered. This idea was finally rejected since the introduction rates of water and salt could not be independently selected, and because it appeared likely that unknown and uncontrolled amounts of salt would deposit in, and possibly impair proper operation of, the heater, lines, and test section pressure regulator.

The final simulator layout drawing, L710403, is inserted at the back of this report. Various test sections with different interface configurations can be utilized easily. Additionally, all of the contaminant injectors can be recharged without interrupting high temperature airflow, and provisions are included for convenient instrumentation calibration.

2.4 CBAS DESCRIPTION AND OPERATION

2.4.1 Particulate Contaminant Injector

The conveyor belt (Item 14 on Sheet 1 of Layout Drawing L3288502, also included at the back of this report) is driven by a drive roller and powered by an electric motor (Item 16). The 115-vac motor is controlled, by varying the input frequency, from approximately 0.2 to 0.5 revolution per hour. At a design speed of 0.33 revolution per hour, the solid particle contaminant injector introduces the specified contaminant at the desired rate for an eight-hour operating period. The variable speed control, shown schematically in Figure 7, provides flexibility to meet other injection rate requirements, and can be readily adjusted and monitored to assure that the selected contaminant input rate is achieved.

The selected simple belt design works well and provisions have been included to permit easy, manual adjustment and rotation of the belt to facilitate loading and positioning of the contaminant. The conveyor belt is located and supported by the belt support (Item 4 on Sheet 1 of Drawing L3288502) and the bearing support (Item 5) which provide the rigid structural backbone of the unit. The body (Item 1) is made from plexiglass to permit visual observation of the injector during operation. The intermediate body (Item 2) is employed to permit easy assembly of the injector.

The bodies include passages to allow the contaminant to be dropped from the belt and be funneled into the fitting (Item 40) which connects via the tubing to the manifold (Item 47) where the contaminant enters the compressor bleed air line. When the cover (Item 3) is attached, the region surrounding the conveyor belt can be pressurized to a value slightly above the compressor bleed air line pressure. This permits introduction of the contaminant into the bleed air line at pressures up to 200 psig.

Several other features of the design ensure proper delivery of the contaminant into the main air stream. The wire rake (Item 10), the air knife (Item 8), and the scraper (Item 9) are all incorporated in the design to permit adjustment and evaluation of methods to assure that the contaminant is consistently removed from the belt and transported into the main air stream. The original design included features such as the "Y" and the adjustable tube to permit adjustment of the contaminant feed rate. Satisfactory operation was achieved

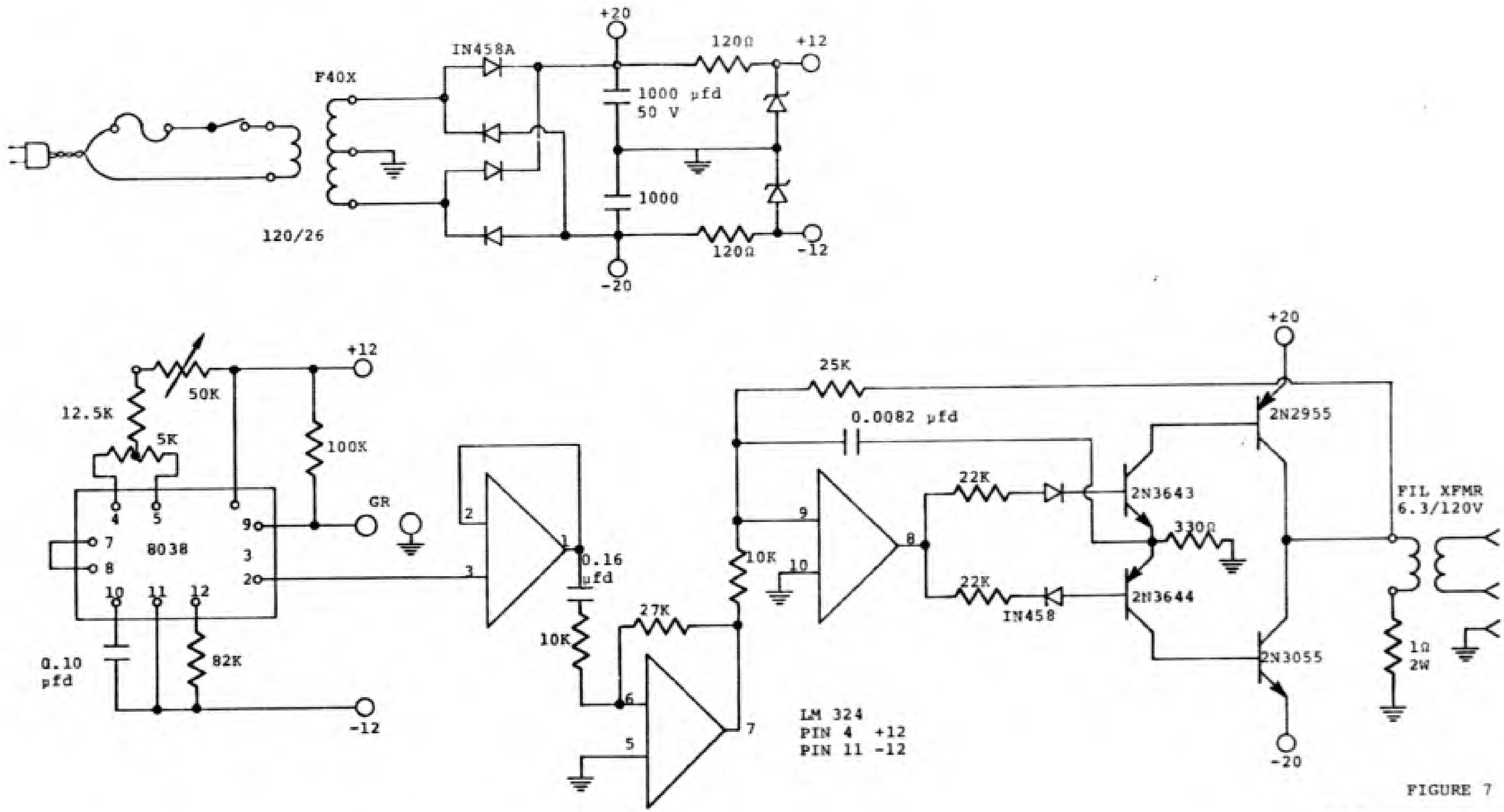


FIGURE 7

VARIABLE FREQUENCY MOTOR
SPEED CONTROL

with a more simple configuration; therefore, the final CBAS design does not require use of some of these development-oriented features. Regulation of the pressure difference between the pressurized conveyor belt region and the compressor bleed air line is controlled to help achieve the desired particulate feed rate.

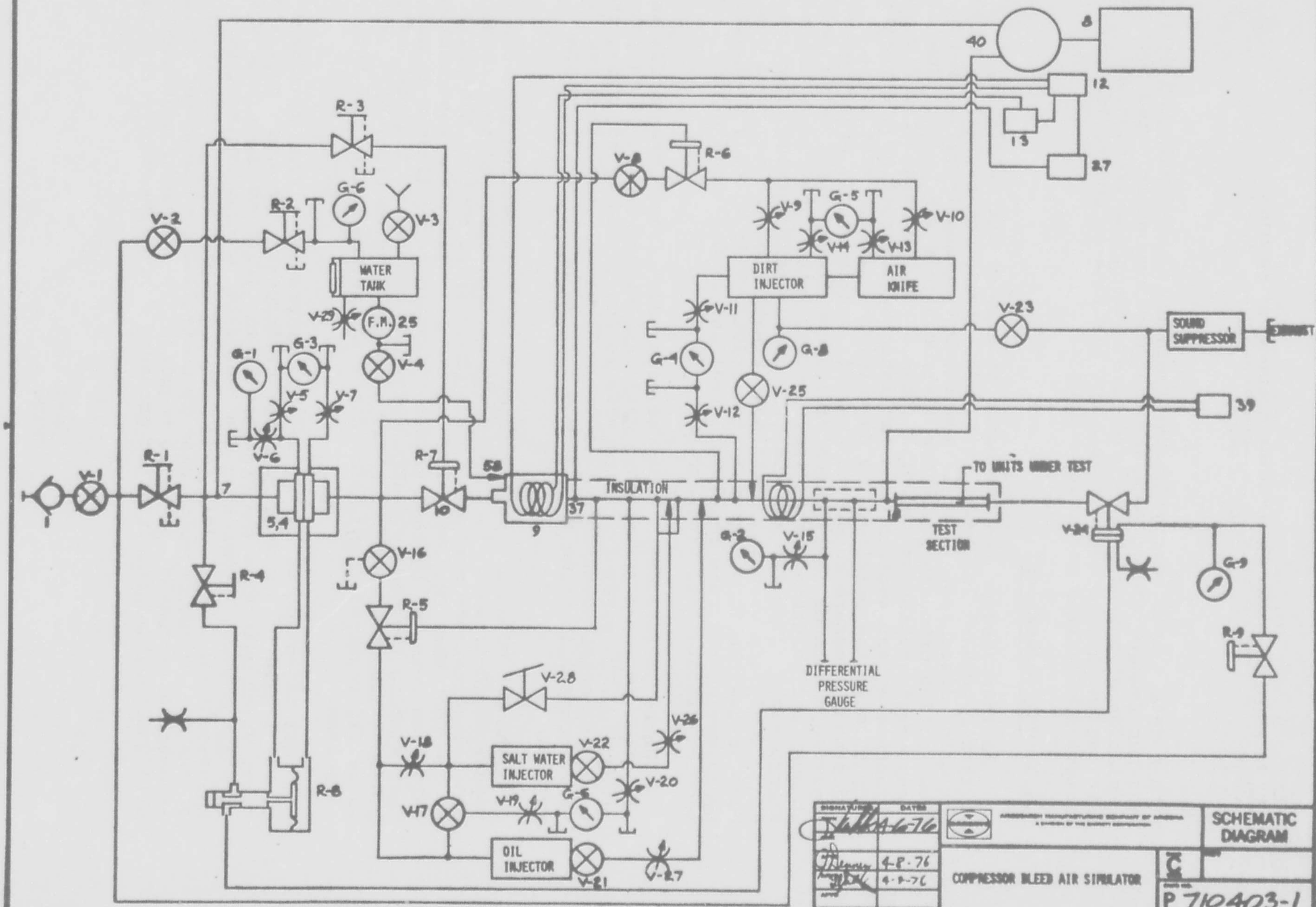
2.4.2 CBAS Operation

As indicated on the schematic diagram of the simulator, Schematic Diagram P710403-1 following this page, clean, dry air enters through the quick disconnect (Item 1) and the system supply valve (V-1). The flow section pressure regulator (R-1) controls air to the flow measurement section and orifice (Item 4) to 210 psig. The flow rate through the test section is established by controlling the pressure drop through the orifice. To do this, the airflow rate control adjustment pressure regulator (R-4) is set to supply pressure to pressure regulator (R-8) which causes the flow control valve (V-24) to open and maintain the desired airflow rate. The flow section thermocouple (Item 17) and the flow measurement section pressure gauge (G-1) are used to permit determination of the required pressure drop across the flow measurement section. This setting is controlled by adjusting the rate regulator (R-4) and is monitored by the flow section differential pressure gauge (G-3).

Water is introduced into the airstream through the nozzle assembly (Item 58), and the air and water are heated in the primary heater (Item 9). The water injection rate is controlled by adjusting the water injection pressure regulator (R-2) which pressurizes the water tank, controlling flow through the flow meter (Item 25) to the nozzle.

The hot moist air passes through the test section pressure regulator (R-1) which is adjusted by setting test section pressure control adjustment pressure regulator (R-3) to control the pressure in the test section. Pressure and temperature at the test section inlet are measured by test section pressure gauge (Item G-2) and test section thermocouple (Item 18). As air leaves the test section pressure regulator (R-7) and flows to the test section, oil, salt water (if required), and solid contaminants are introduced into the airstream.

Oil injection is controlled by the preset, fixed adjustment of the liquid contaminant injector differential pressure regulator (R-5) which maintains the pressure at the inlet to the oil injector at a fixed value higher than the test section pressure, and by adjustment of the oil drip feed rate. The pressure to the inlet of the salt water injector also is controlled by liquid contaminant injector differential pressure regulator (R-5) and by adjustment of liquid contaminant injector pressure control valve (V-18). Salt



SIGNATURES	DATES
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SCHEMATIC DIAGRAM

COMPRESSOR BLEED AIR SIMULATOR

C

P 710403-1

SHEET 1 OF 2

[redacted]

Item	Nomenclature
1	Quick Disconnect
V-1	Supply Valve
R-1	Flow Section Pressure Regulator
4.5	Flow Measurement Section and Orifice
G-1	Flow Section Pressure Gauge
G-3	Flow Section Differential Pressure Gauge
17	Flow Section Thermocouple
9	Primary Heater
R-7	Test Section Pressure Regulator
11	Secondary Heater
G-2	Test Section Pressure Gauge
18	Test Section Thermocouple
V-24	Test Section Flow Control Valve
R-4	Flow Rate Control Adjustment Pressure Regulator
R-8	Flow Control Valve Pressure Regulator
R-3	Flow Section Pressure Control Adjustment Pressure Regulator
V-2	Water Injector Pressurization Shutoff Valve
R-2	Water Injector Pressure Regulator
25	Flow Meter
58	Nozzle Assembly
V-3	Water Fill Valve
V-11	Gauge Isolation Valve
V-12	Gauge Isolation Valve
V-5	Gauge Isolation Valve
V-7	Gauge Isolation Valve
V-19	Gauge Isolation Valve
V-20	Gauge Isolation Valve
V-13	Gauge Isolation Valve
V-14	Gauge Isolation Valve
V-15	Gauge Isolation Valve
V-6	Gauge Isolation Valve
V-26	Salt Water Metering Valve
V-27	Oil Metering Valve

Item	Nomenclature
R-6	Solid Particle Injector Differential Pressure Regulator
V-9	Solid Particle Injector Cover Pressure Control Valve
V-10	Air Knife Pressure Control Valve
G-4	Solid Particle Injector Cover Differential Pressure Gauge
G-5	Air Knife Differential Pressure Gauge
V-25	Pinch Valve
V-23	Depressurizing Valve
R-5	Liquid Contaminant Injector Differential Pressure Regulator
V-18	Liquid Contaminant Injector Pressure Control Valve
V-17	Liquid Contaminant Injector Pressure Gauge Selector Valve
G-6	Differential Pressure Gauge
61	Dynamic Sampler
40	Thermocouple Selector Switch
8	Digital Temperature Indicator
13	Overheat Controller
27	Air Temperature Controller
12	Primary Heater Contactor
39	Secondary Heater Control
37	Air Temperature Thermocouple
V-21	Oil Injector Isolation Valve
V-22	Salt Water Injector Isolation Valve
V-16	Liquid Injector Depressurization Valve
V-14	Water Injector Isolation Valve
G-7	Water Injector Pressurization Gauge
V-8	Solid Particle Pressurization Shutoff Valve
V-28	Cooling Air Metering Valve
V-29	Water Tank Vent Valve

NOTE:

THIS ARTICLE IS FABRICATED, IDENTIFIED AND PROCURED AS PART NUMBER

SIGNATURES	DATES
DRF Hubb	4-6-76
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APP	4-8-76
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SCHEMATIC DIAGRAM

COMPRESSOR
BLEED AIR
SIMULATOR

AiResearch Manufacturing Company of Arizona
PHOENIX, ARIZONA
A division of THE GARRETT CORPORATION

DWG SIZE A

DWG NO. P 710403-1

SHEET 2 of 2

IDSM F 2001-8

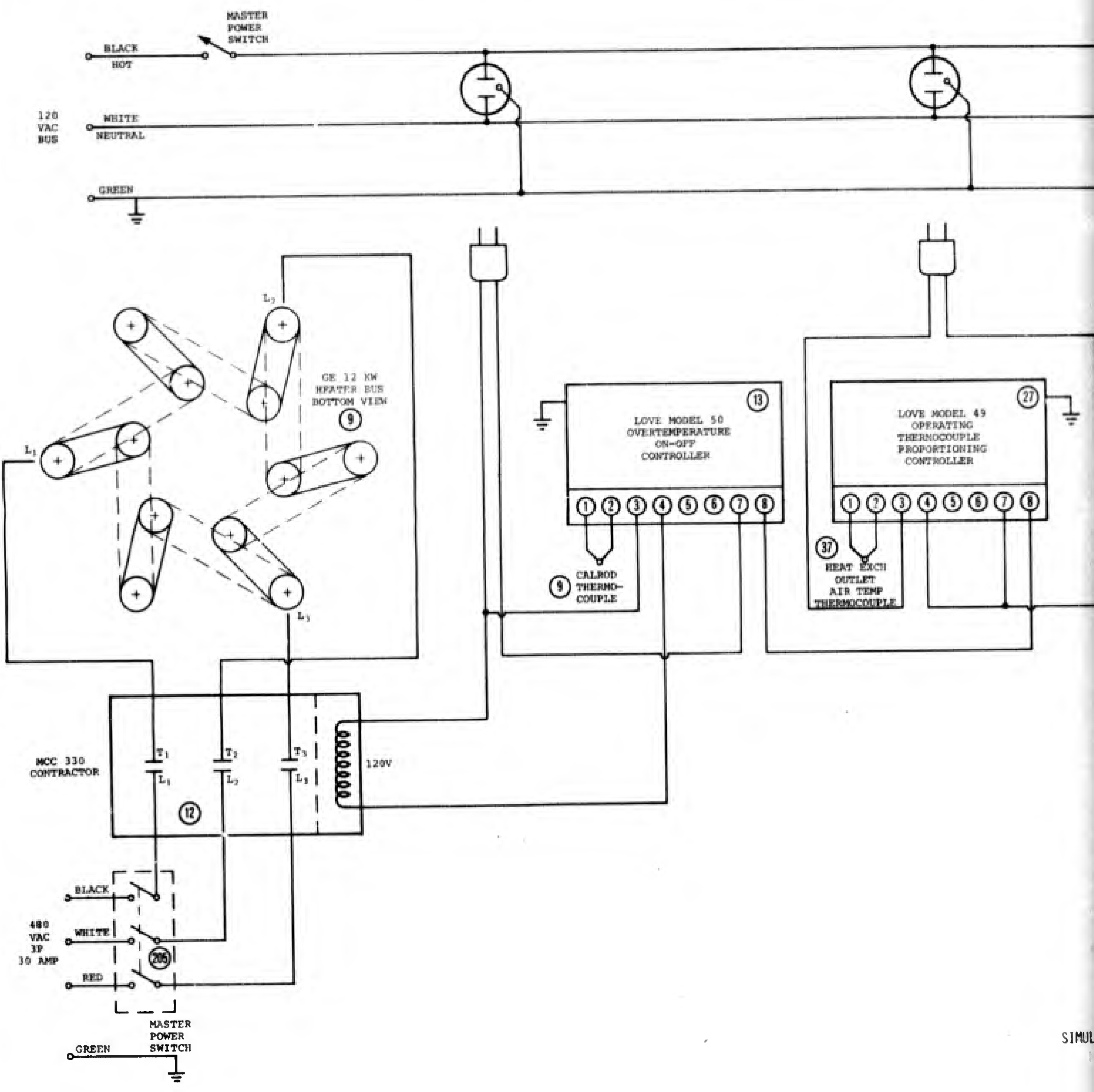
water drip feed rate adjustment provides the final control. Liquid contaminant injector pressure gauge selector valve (V-17) permits monitoring of the pressure differentials between the injector supply pressures and the mainstream pressure.

Operational control of the solid particle injector is accomplished by adjusting solid particle injector cover pressure control valve (V-9) and air knife pressure control valve (V-10). The fixed setting of solid particle injector differential pressure regulator (R-6) maintains the pressure at the inlet to the control valves (V-9 and V-10) at a higher level than mainstream pressure. By adjusting air knife pressure control valve (V-10), the desired positive pressure difference between the air knife and the cover of the dirt injector is set. This pressure difference is measured by air knife differential pressure gauge (G-5). Solid particle injector cover pressure control valve (V-9) is set to adjust the positive pressure differential between the dirt injector cover and the mainstream line pressure. This pressure difference is measured by solid particle injector cover differential pressure gauge (G-4). Adjustment of these pressure differences assures proper flow of the contaminant into the main airstream.

The system is designed so that hot airflow can be maintained through the test section during replenishment of the contaminants. (The design operating interval is eight hours.) This is provided by the isolation valves (V-21, V-22, and V-14) with the dirt injector cover depressurized through depressurizing valve (V-34).

An electrical schematic of the CBAS circuitry is included as Figure 8 to show the interconnections of the control and measurement devices.

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA



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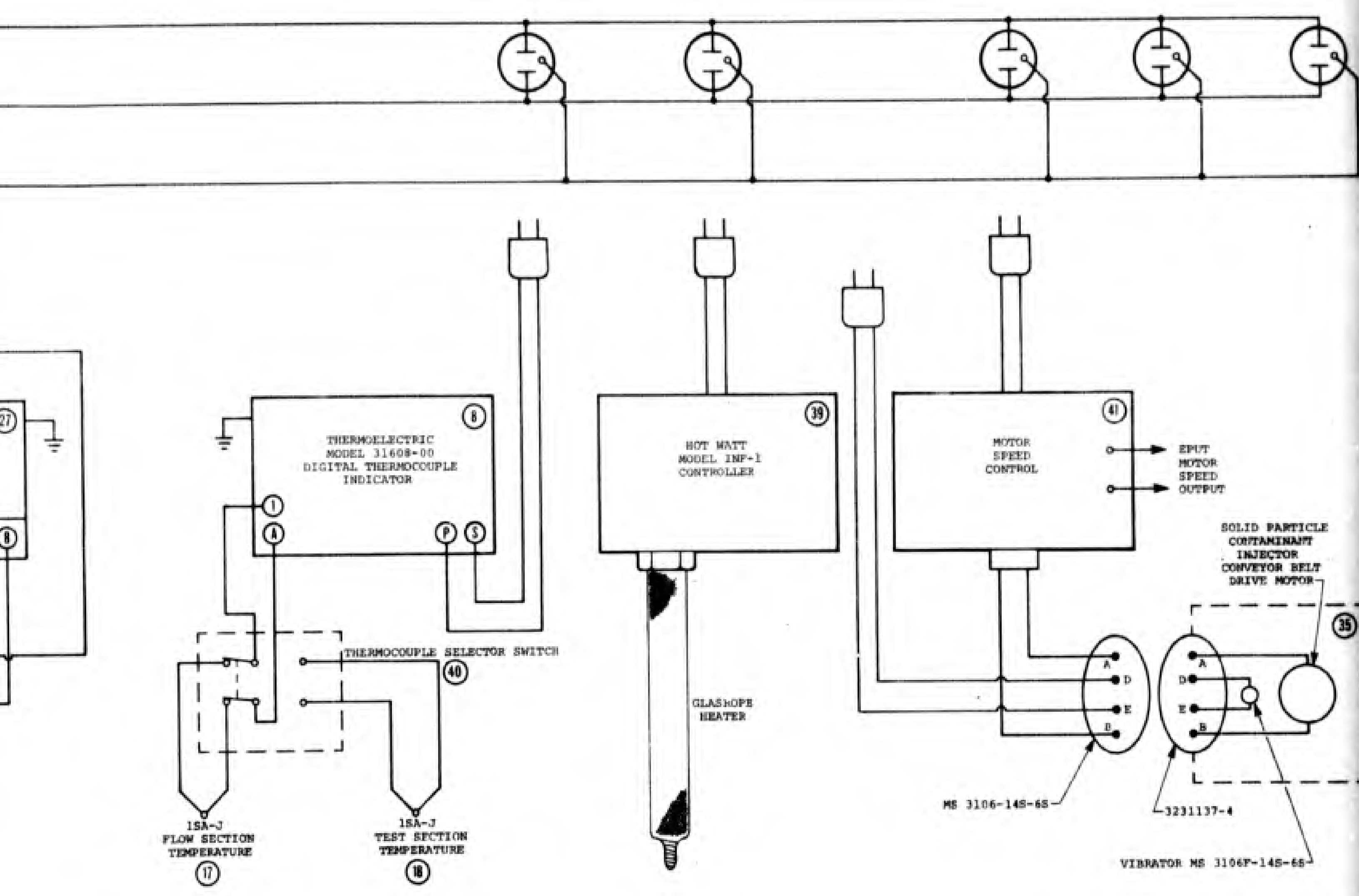

FIGURE 8

SIMULATOR WIRING DIAGRAM

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SECTION 3

CBAS DEVELOPMENT AND PERFORMANCE (PHASE II)

3.1 PARTICULATE INJECTOR DEVELOPMENT

Simple, basic exploratory tests, concentrating on the physical characteristics of the solid contaminant and basic hardware elements, were conducted during the period when various concepts were being considered. The results, combined with analytical evaluations, permitted selection of the most promising approaches. As noted in the preceding section, a Model H, S. S. White Industrial Abrasive Unit was tested briefly with the original crushed quartz contaminant; however, this testing was discontinued when it appeared that development of the pressurized conveyor belt concept would be more productive.

After a prototype conveyor injector was fabricated, assembled, mounted on a stand, and instrumented for development evaluation testing as shown in the photographs of Figures 9 and 10, a variable frequency speed control for the drive motor was fabricated and matched to the motor to provide a means of control of particulate injection. The conveyor belt operation was tested to demonstrate that drive speed was variable over the range of 0.25 to 0.60 revolution per hour. Testing covered a wide range of pressures with airflow rates of four and two pounds per minute. These tests 1) established the basic capabilities of the particulate injector system, 2) permitted observation of injector performance, 3) demonstrated suitability of the injector for integration into the CBAS, 4) provided installation and simulator component selection information, and 5) allowed initial development of operating methods.

Initial tests showed that solid contaminants could be injected at test section pressures from just above ambient to 200 psig with slightly erratic injection. However, results were encouraging since the injection rate was more stable than standard conveyor belt designs without wire rakes or air knives. This indicated that some redesign was necessary for the wire rake and air knife.

Testing with the revised wire rake and air knife (shown on Layout Drawing L3288502, Rev. A) demonstrated excellent performance and showed further major refinement to be unnecessary.

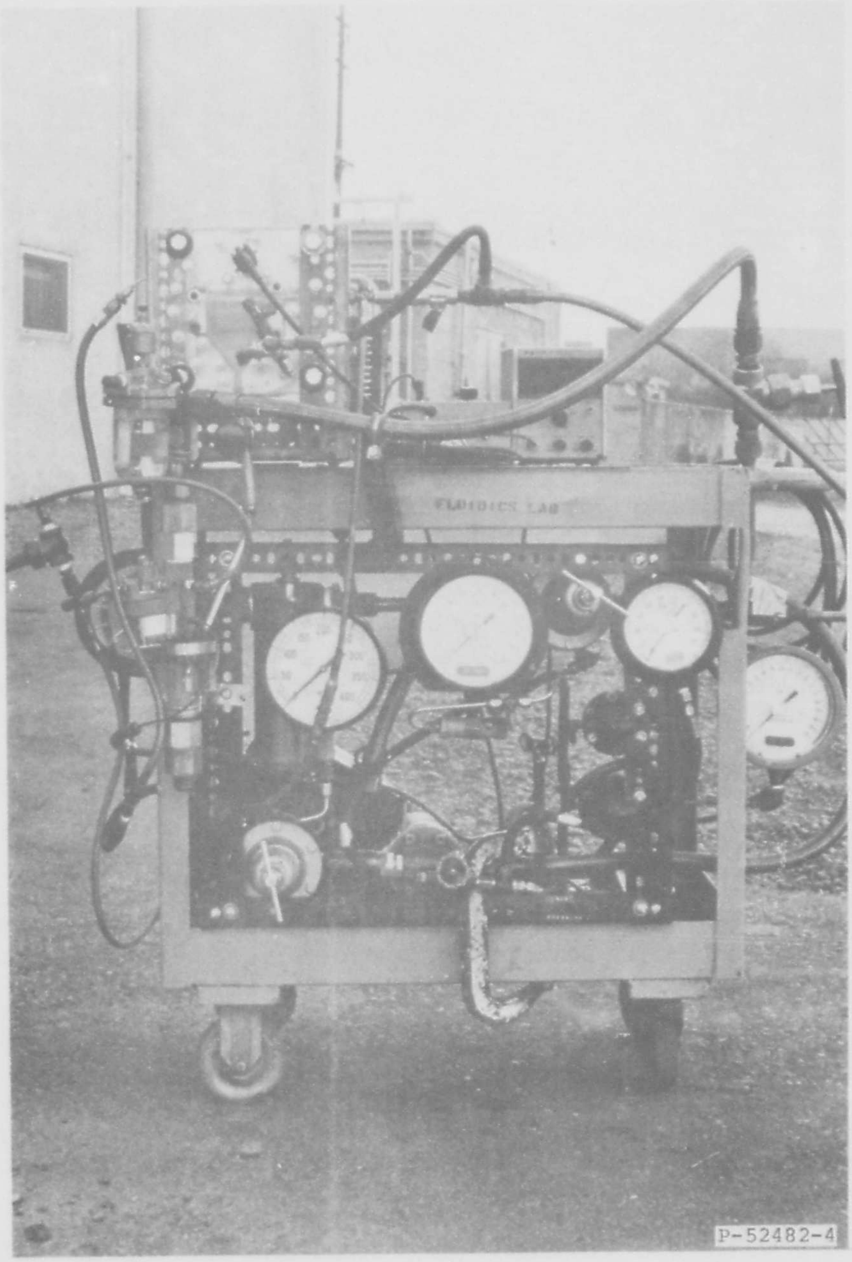


FIGURE 9

INJECTOR INSTALLED IN THE
DEVELOPMENT TEST STAND

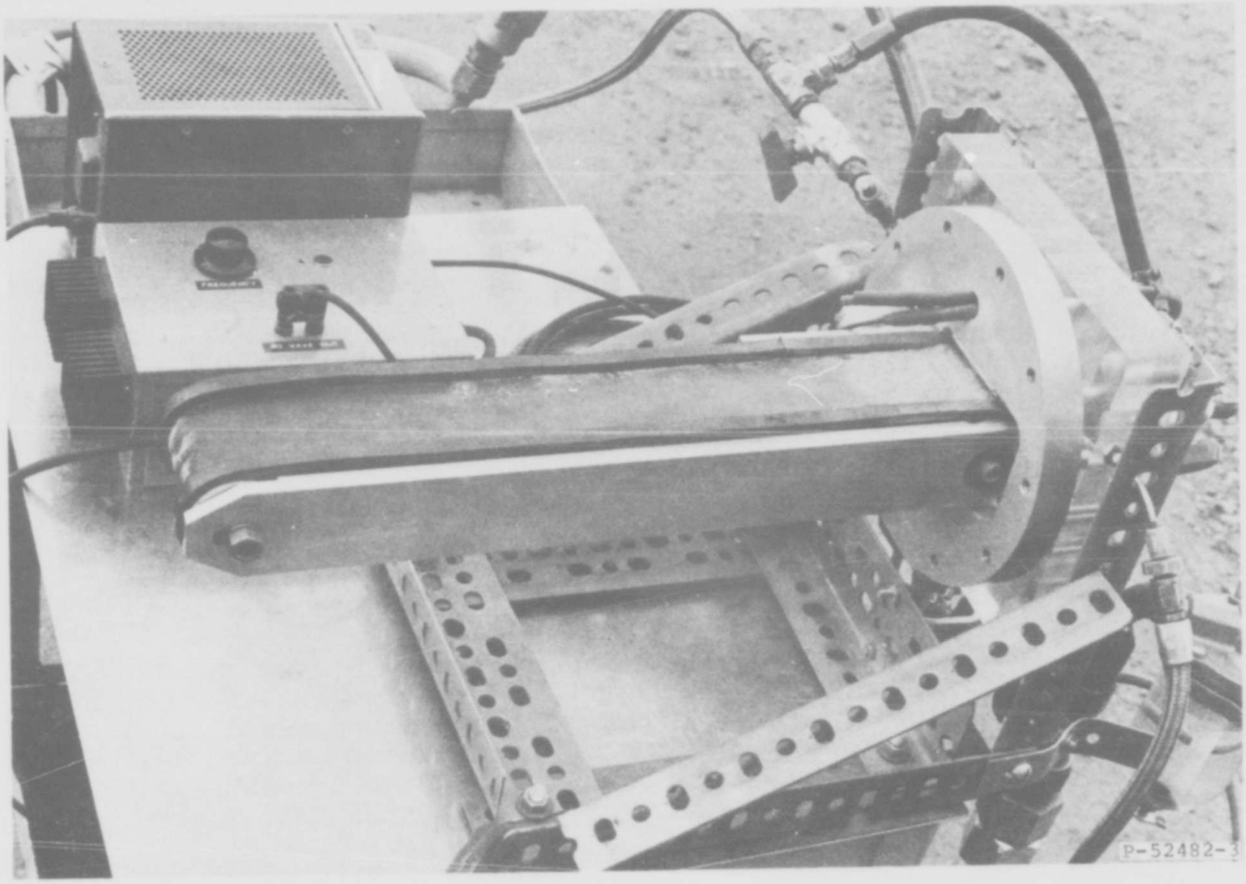


FIGURE 10

INJECTOR INSTALLED IN THE
DEVELOPMENT TEST STAND

3.2 CBAS DEVELOPMENT

Testing of the injector also included developing preliminary operating procedures, establishing auxiliary equipment requirements, and exploring simulator systems approaches and component choices, upon which the CBAS design was predicated. The CBAS development program was delayed considerably by late delivery of certain purchased items and the necessity of returning some to the vendors for correction of deficiencies. During the assembly of the complete simulator system, including installation of the tubing and electrical circuitry, several changes in design were made to avoid interferences, improve maintainability and access, and permit incorporation and evaluation of probable later modifications with minimum difficulty.

Development testing of the CBAS included system tests, component interaction tests, and individual component performance tests. In addition to the usual functional problems inherent in the development of any system as complex as the CBAS, calibration of the simulator presented a substantial challenge because of two significant factors which had definite influence on the development test program.

1. Accurate measurement of the contaminant levels at the test section is extremely difficult.

2. Because the CBAS was designed to operate over a wide range of test section temperature, pressure, air velocity, and air contamination level conditions, the measurement problems were compounded due to the variety and number of tests required to completely evaluate, demonstrate, and calibrate the CBAS system.

Considerable difficulties were experienced with off-the-shelf commercial components due to the unusual application, and hardware quality defects or limitations, which caused delays, malfunctions or undesirable operation, as discussed in the following paragraphs.

The water injection subsystem required several modifications. With reference to Schematic Diagram P710403-1, the water injector nozzle assembly (58) was moved to the top of the heater (9) so that the water would be vaporized and carried out of the heater. The original location, in the coolest section of the heater, and the low air velocity in the heater resulted in water puddling in the bottom of the heater. In addition, an inline filter was added to ensure that the injector nozzle would not be clogged by contaminants in the water system. Even with the noted changes, operation of this water injection subassembly was expected to require critical calibration adjustments to assure water vaporization and avoid flooding and improper system performance.

The initial airflow control subsystem, assembled from available parts, had a flow capacity far in excess of the nominal two pound per minute requirement of the CBAS. This required significant modifications in the test section flow control (V-24) and pressure regulating (R-8) valves to reduce the sensitivity of flow gain versus valve opening in order to provide better throttling and control. The original test section pressure regulator (R-7) and flow section pressure control adjustment pressure regulator (R-3) also had to be replaced to improve control of the test section pressures up to 200 psig.

Since improper CBAS operation could result in reverse flow through the oil, water, and salt water injectors, check valves were incorporated but proved impractical, since the pressure loss due to the check valves resulted in a marginal pressure available to the injectors.

Development testing of the CBAS system also resulted in several improvements in the particulate injector subsystem. A deflector plate directs airflow from the cover region and across the top of the conveyor belt to ensure delivery of the contaminant. A modified scraper configuration reduces the tendency to collect deposits of contaminant on the belt. The initial belt design consisted of a loop of rubber with a rim on each side, all bonded together with rubber cement. This proved unsatisfactory due to delamination of the rims. A one-piece injection molded rubber belt, shown in Figure 15 on Page 45, resolved these difficulties.

Because the salt water injector was an off-the-shelf unit designed for use with lubricating oil, some clogging and corrosion problems were encountered. The clogging can be minimized by periodic cleaning and flushing procedures which also minimize the corrosion problem. However, if corrosion becomes a major problem, it will be necessary to replace this injector with one fabricated from corrosion resistant materials.

3.3 CBAS CALIBRATION TESTS

3.3.1 Salt Water Injection Subsystem

Testing of the salt water injection subsystem was initially accomplished by setting a known drip rate of concentrated salt solution from the injector into the airstream. The resultant salt concentration in the mainstream airflow was then measured by passing a sample of the airflow through a water bath and utilizing an ion detector to determine the parts per million salt concentrate collected in the water bath sample. Discrepancies were found between the total salt injected and the resultant airflow salt level, which were due, principally, to salt buildup in the tubes and the inability to very accurately measure and control the salt concentration in the injected water. The concentration of salt must, therefore, be decreased to enable higher drip rates to be used to increase the accuracy of reading, and also incidentally decrease the salt buildup.

3.3.2 Oil Injection Subsystem

Oil was introduced at various drip rates and mainstream air temperatures. The original tests utilized the AiResearch Mobile Emissions Analyzer Van, which is normally employed in determination of the constituents in the exhaust gas of production and development gas turbine engines manufactured by AiResearch. Provision is made to determine the quantities of CO, CO_2, NO_X, and unburned hydrocarbon (HC) present. The analysis techniques and accuracy levels were in accordance with specifications established by the Environmental Protection Agency. For the tests being reported, heated sample lines were run from the dynamic sampler to the analyzer van. Isokinetic sampling was not possible since the van could not accept the flow rate required.

The sensitivity to the oil aerosol appeared to be poor, particularly at lower temperatures, and contamination of the measurement system with lubricating oil was considered possible. Hydrocarbon content was indicated as parts per million by volume, propane equivalent.

Poor correlation was shown between calculated oil introduction rates, visual observation of lubricator operation, inspection of the test section, and the observed relationship between variations in indicated contamination level and changes in the oil introduction rate adjustments; therefore, a different measurement technique appeared necessary.

Accordingly, the sampled air was passed through a coil of 3/8-inch OD tubing immersed in an alcohol-dry ice bath. Chemical analysis of the resultant freeze-out sample revealed that 37.7 milligrams of oil were collected during a test period of 1-1/2 hours, during which the average drip rate was 146 drops per minute. Based upon these results, the specified 3 ppm of oil contamination in the test section air should be easily attained. Additional calibration points, to more fully establish the relationship between lubricator drip rate and oil introduction, were determined using this freeze-out test method.

3.3.3 Water Injection Subsystem

During initial operation of the water injection system, it became apparent that all of the water was not vaporizing. If vaporization is complete, the humidity can be determined by measurement of the water flowing through the flowmeter (25), since the airflow is known. After all system modifications were completed, a correlation check was run using a form of wet bulb-dry bulb temperature measurement methods to verify the water injection system performance and calibration before Phase III.

3.3.4 Particulate Contaminant Injection Subsystem

The introduction of the solid contaminant was readily controlled. A sample of contaminant was weighed and then uniformly distributed on the conveyor belt between the calibration marks. A counter was connected and the particulate speed control adjusted (for normal use) to 60 cycles per second. Except for a very light coating of low micron particles on the belt and on the pressurized interior of the particulate injector, all contaminant enters the mainstream airflow. Particulate injection was essentially uniform and continuous. The average contamination rate is determined by dividing the charge weight of particulate by the total airflow during the test period.

SECTION 4

FINAL CBAS DEVELOPMENT AND DETERMINATION OF FLUIDIC FILTRATION SELECTION GUIDELINES (PHASE III)

4.1 FINAL CBAS DEVELOPMENT

Because of the calibration problems, relative to measurement of contaminant levels, discovered during performance testing of the prototype CBAS, a corrective action program was promptly implemented simultaneously with initiation of Phase III activities. It was concluded that reliable contaminant level measurement in the test section was not practical, due to the state-of-the-art and available equipment. Therefore, modifications to several injector systems were made in order to measure input levels for each constituent at the point of injection. This was accomplished in the following manner:

- <u>Oil and Salt Water Injection Subsystems</u> - The photograph of Figure 11 depicts the modified liquid injection systems. Each system consists of a transparent liquid level reservoir, a micro-precision flow metering valve and an injector tube. A 0.5 percent NaCl solution is used in the salt water tube. Analytical calculations and physical calibrations were made to establish correlation between reservoir liquid level change and gravimetric flow rates of oil and salt solution. Actual simulator test runs verified that specified amounts of each contaminant were being injected into the main airstream. The photographs of Figures 12 and 13 show the front and rear views of the modified CBAS.

- <u>Water Injection Subsystem</u> - Complete vaporization of water was accomplished as shown on the attached schematic diagram of Figure 14. A CRES 347 sheet metal can was attached to the resistance heating elements. An injector nozzle was installed in order to spray water into the can and onto the elements. Stainless steel wool was packed into the annular area between the can and heat exchanger wall. The test section pressure regulator was installed upstream of the heat exchanger to reduce the heat power required to produce complete vaporization. A water drain valve was installed in the bottom of the heat exchanger to permit monitoring of the vaporization process. This provided counter-flow airflow through the heat exchanger to facilitate the vaporization process.

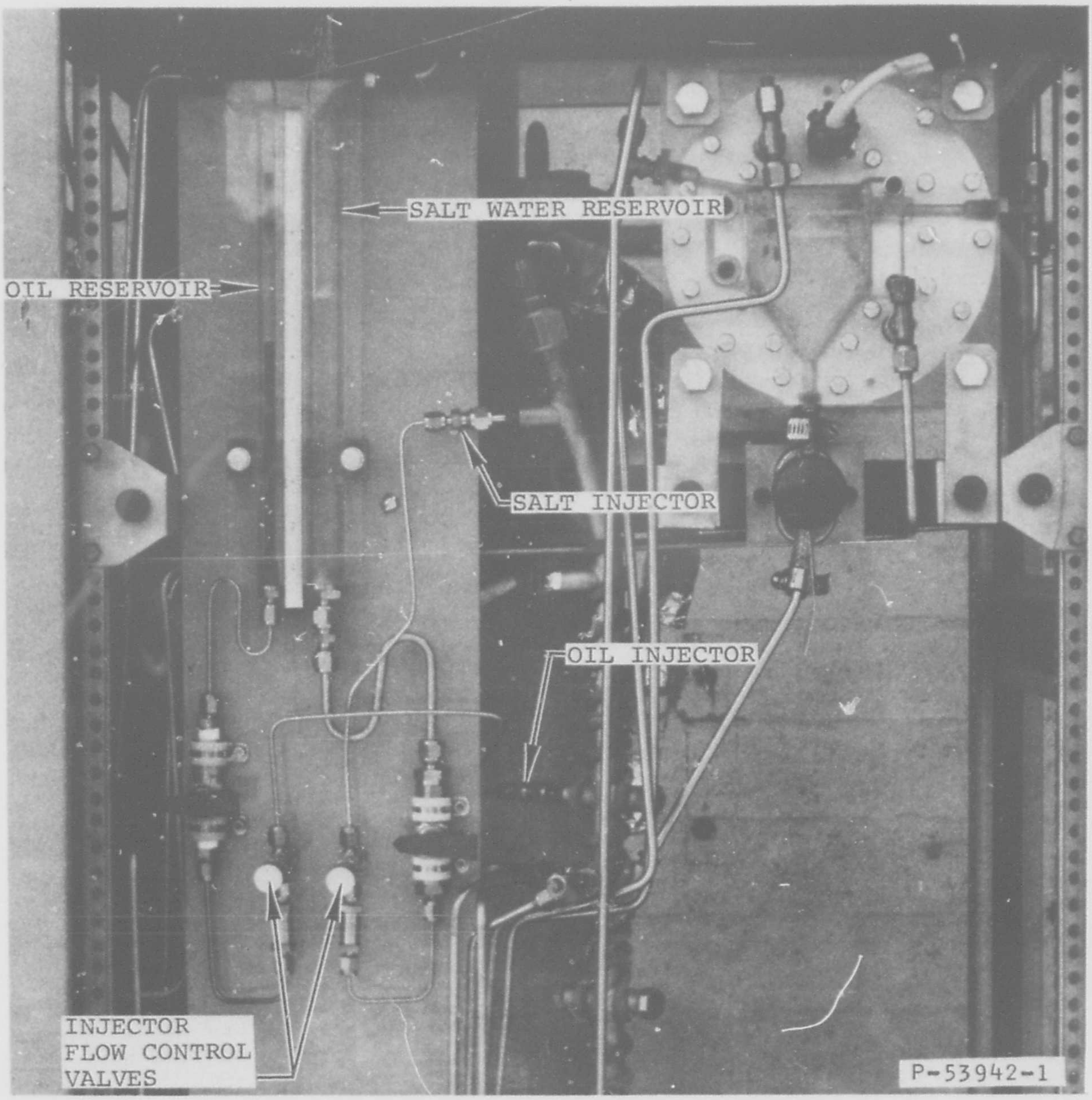


FIGURE 11

MODIFIED LIQUID INJECTORS
IN CBAS

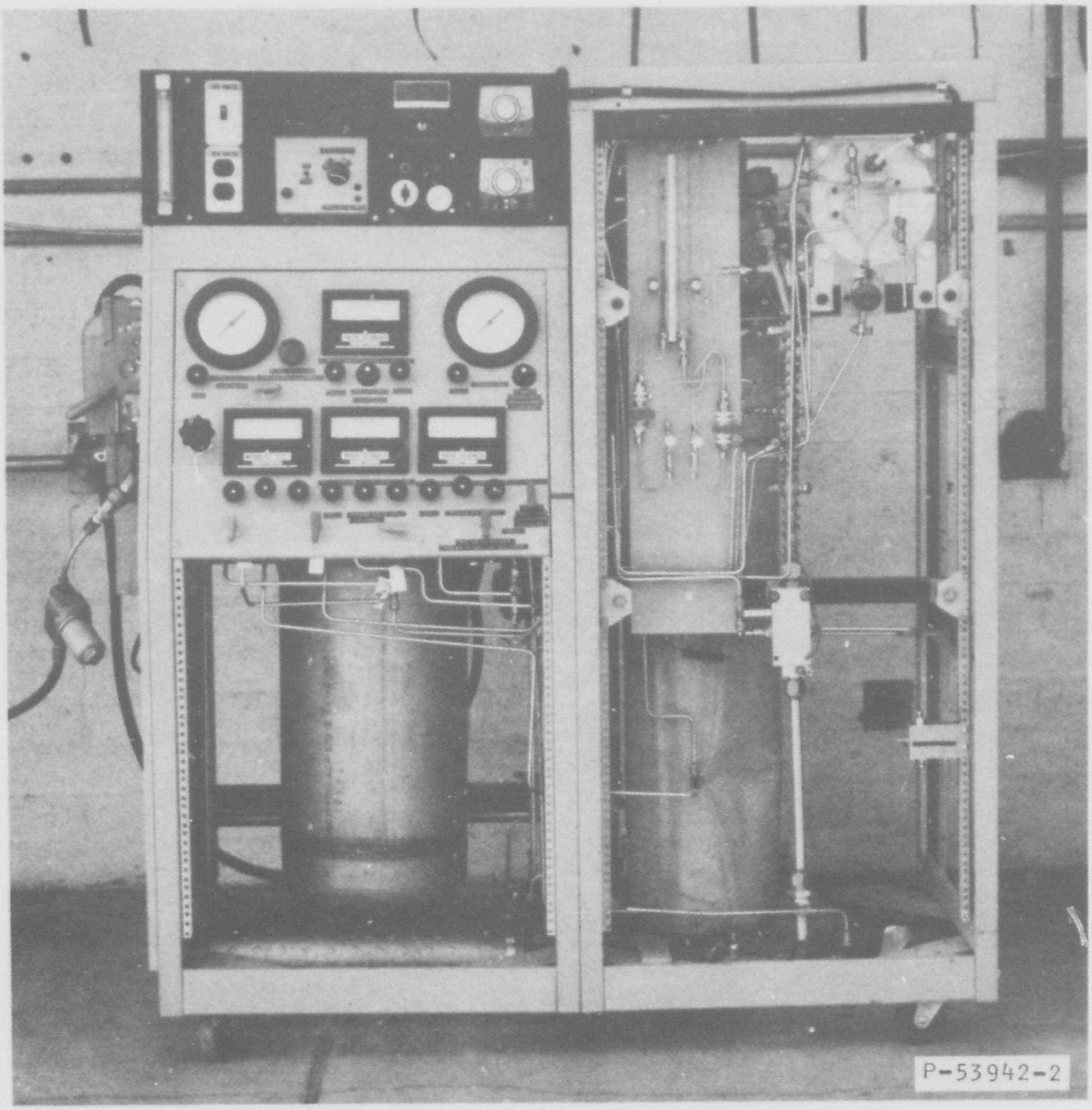


FIGURE 12

FRONT VIEW OF MODIFIED CBAS

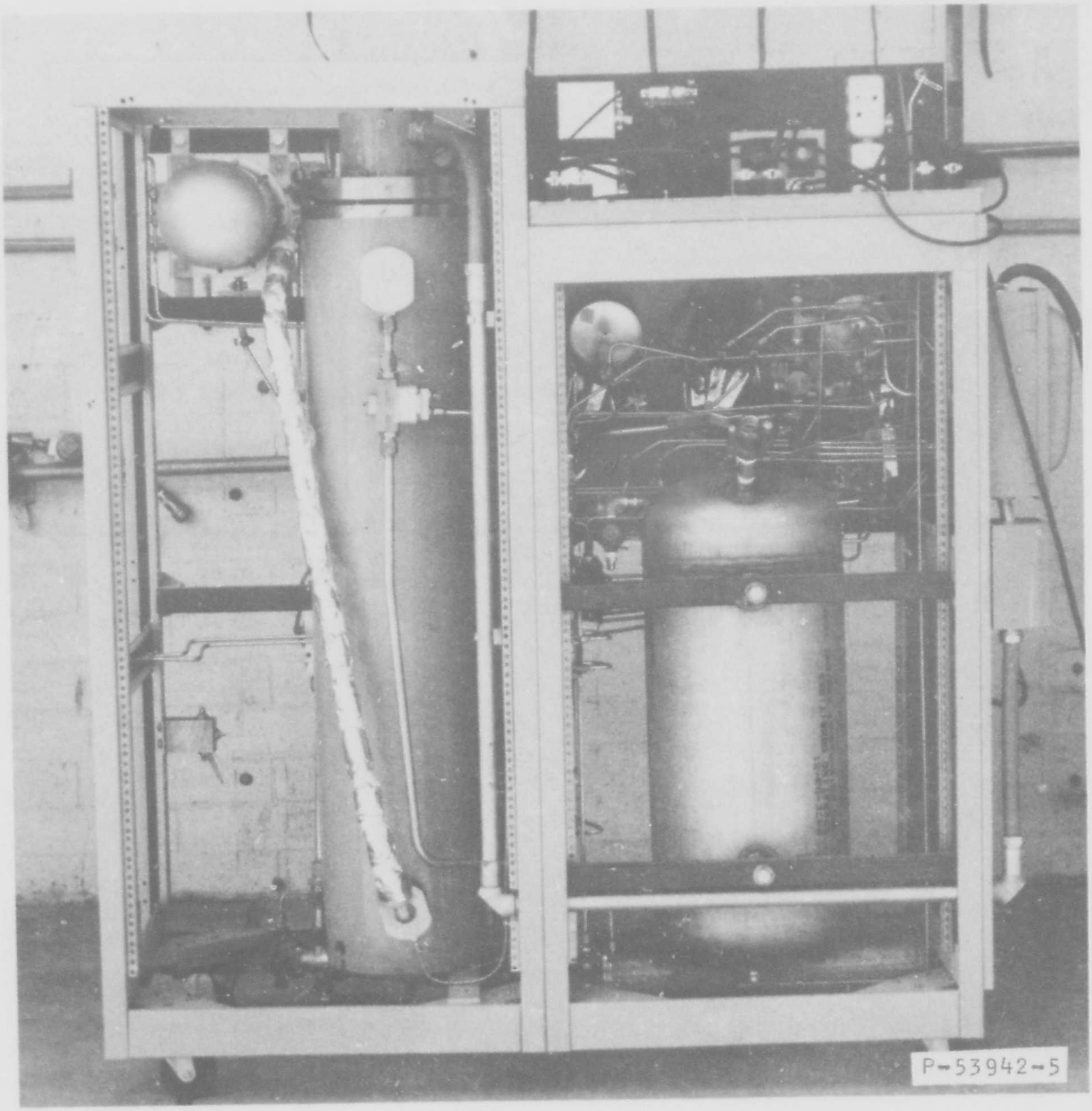


FIGURE 13

REAR VIEW OF MODIFIED CBAS

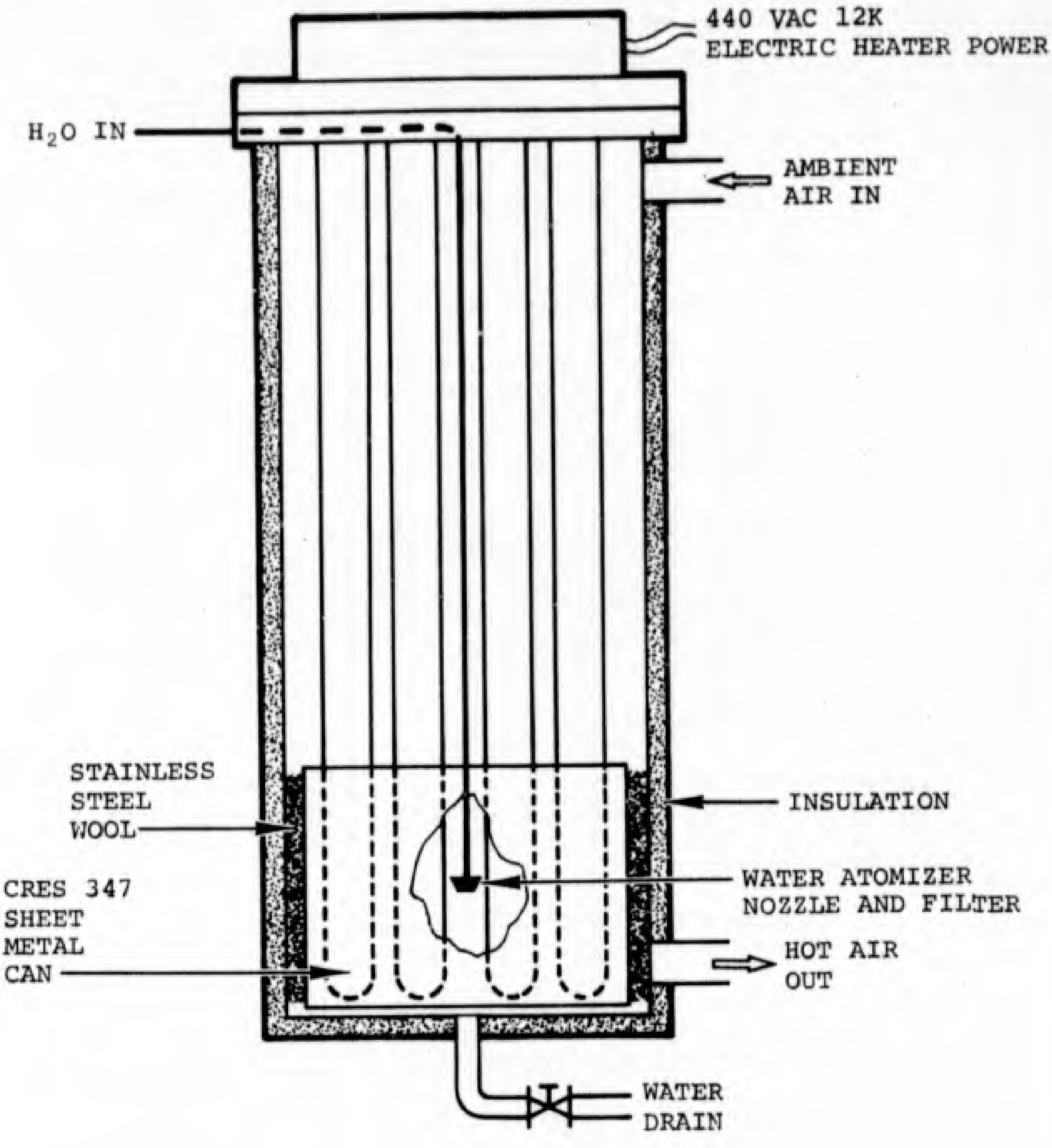


FIGURE 14

MODIFIED WATER/AIR HEAT EXCHANGER

Subsequent calibration runs indicated that, during a four-hour period with 500F discharge air temperature, water injected at the maximum flow rate of 86 cc per min was completely vaporized. No evidence of liquid was present at the drain valve throughout the test.

- <u>Particulate Contaminant Injection Subsystem</u> - During initial performance tests, it was noted that AC fine dust would pack behind the injector rake and, during four-hour runs, up to 60 percent of the AC fine dust would clog and not feed into the air stream. This problem was accentuated by the increased humidity present during recent testing. The photograph of Figure 15 shows the modifications made to the rake system to assure uniform flow of the AC fine dust into the air stream.

  The rake is cantilever-supported by an electric vibrator. The vibration energy transmitted to the rake tines enables the dust to flow through rather than clog the rake. A four-hour test run demonstrated the effectiveness of this modification.

4.2 PHASE III GENERAL TEST PLAN

The overall objective of the test program was an initial effort to maximize fluidic circuit life when operating on simulated compressor bleed air. The major dependent variables which could influence the outcome include:

a. The concentration and nature of contaminants in the bleed air.

b. Compressor bleed port characteristics. What type(s) of extraction or sensing tubes will minimize entrained contaminants in bleed air?

c. Filter system performance. Filter system efficiency and dirt holding capacity are important considerations. In general, the greater the efficiency of a surface type or depth media filter, the larger the filter size becomes for a given life requirement.

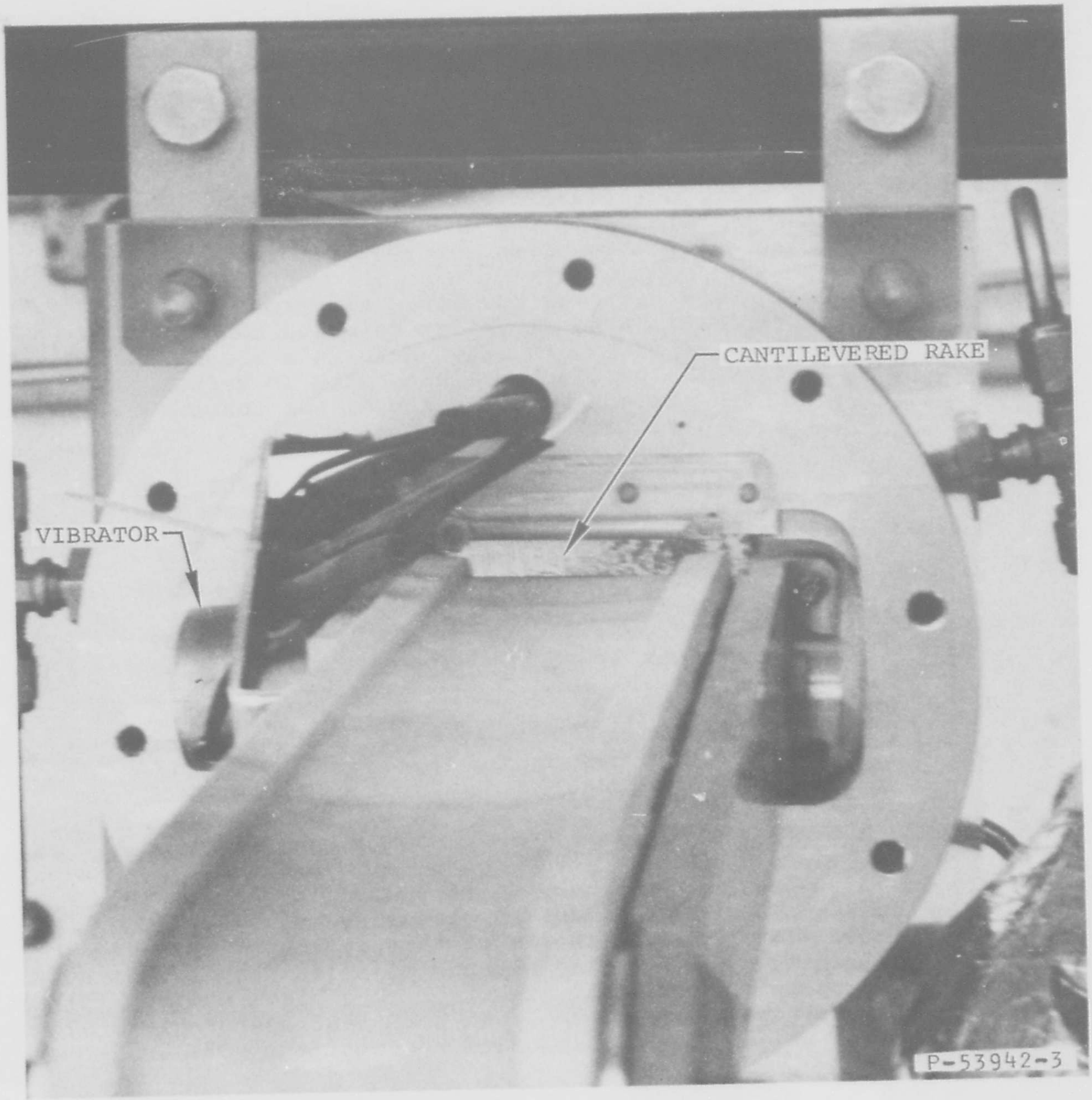


FIGURE 15

MODIFIED RAKE ASSEMBLY OF
CBAS CONTAMINANT INJECTOR

A general test plan was outlined to accomplish the objectives of Phase III (i.e., conduct contamination tests, and establish filter requirements to protect fluidic circuits and reduce maintenance requirements). The Phase III program included the following tasks:

<u>Task 1</u> - Conduct literature and vendor field research to establish state-of-the-art filter media for aerospace fluidic applications. This task terminated in the selection of candidate filters for the subsequent test program.

<u>Task 2</u> - Design and test various bleed air probe configurations to establish relative tendencies to pick up contaminants in a bleed airstream. Review experience with ID versus OD bleed air extraction ports on gas turbine compressors.

<u>Task 3</u> - Service-life test several candidate filter systems on the bleed air simulator to establish filtration effectiveness. Each filter was loaded into a production fluidic circuit and circuit performance was monitored. Fluidic circuit laminations were unbonded to enable frequent circuit inspection. Also, filter ΔP was continuously monitored to establish maintenance requirements.

<u>Task 4</u> - Reduce and normalize test data in order to rate effectiveness of various filter media. Publish final test report.

4.3 FILTER MEDIA SURVEY (TASK 1)

The majority of the aerospace filter companies contacted responded to the problem statement by proposing multiple-stage filter systems. Their justification of this approach was based upon the desirability of removing a range of solid particle sizes along with hydrocarbon aerosols. In order to achieve optimum filter service life, multiple stages are sized such that each individual stage handles a uniformly proportionate share of the total contaminant load.

One approach consisted of a first stage mechanical or aerodynamic device to remove the coarser constituents. The second stage consisted of a fine mechanical filter to assure that the third stage, which coalesces the aerosols, did not plug prematurely with dirt particles.

Following the survey, AiResearch procured commercially available representative samples of several concepts to establish a relationship between filter system configuration and fluidic circuit service life, as described under Task 3.

4.4 BLEED AIR PROBE CONTAMINATION TESTS (TASK 2)

Tests of a variety of bleed air duct extraction probes were conducted utilizing the probe assembly shown in the photograph of Figure 16. A 3/4-inch tube was used which produced test duct velocities of 80 feet per second. This velocity approximates the low end of gas turbine compressor discharge velocities at maximum power conditions. Engine compressor discharge velocities vary approximately from 107 to 215 feet per second at maximum power. When test probe area blockage in the test duct is considered, it is possible to conclude through analysis that test duct velocities are representative of engine conditions.

Four different test probe configurations were evaluated: a static probe; a total probe (probe with sensing orifice oriented upstream to measure total pressure); a trailing probe (probe with sensing orifice oriented downstream); and a hooded trailing probe. These probes are illustrated in Figure 17. The test duct assembly is shown in Figure 16 with probes installed.

The DC-10 aircraft thrust reverser system features a fluidic controller for regulation of air motor speed and torque. During the course of the DC-10 program development, test data was collected by General Electric which substantiated a subsequent reconfiguration of bleed air extraction from sixteenth-stage OD to sixteenth-stage ID bleed extraction. On a gravimetric basis, the OD bleed air contamination level per pound of air extracted was 850 times that of exhausted ID bleed. As a result, ID bleed extraction was selected. The inertial effects tend to carry the bulk of solid contaminants to the OD port.

In the initial test, four probes were tested: a static probe, a total probe, a trailing probe, and a hooded trailing probe. Each probe assembly was loaded to 0.2 lb per min airflow at 60 psig and room temperature. This flow rate was thought to reflect a typical sophisticated fluidic control system. This flow rate was used to evaluate bleed ports and filter systems initially. The fluidic circuit used in the final test phase of the program required a 0.040 lb per min airflow at 40 psig. Discharge air from each probe was collected individually on a separate Millipore filter paper. The air temperature was then raised to 320F in the test section and the A. C. fine dust solid contamination, oil, salt water, and water constituents were all injected in accordance with the prescribed test stand operating levels (Reference, Section 2.2, Table II). The relative probe locations for each run are depicted by the sketches in Figure 17, and some of the actual probe configurations are shown in Figure 18.

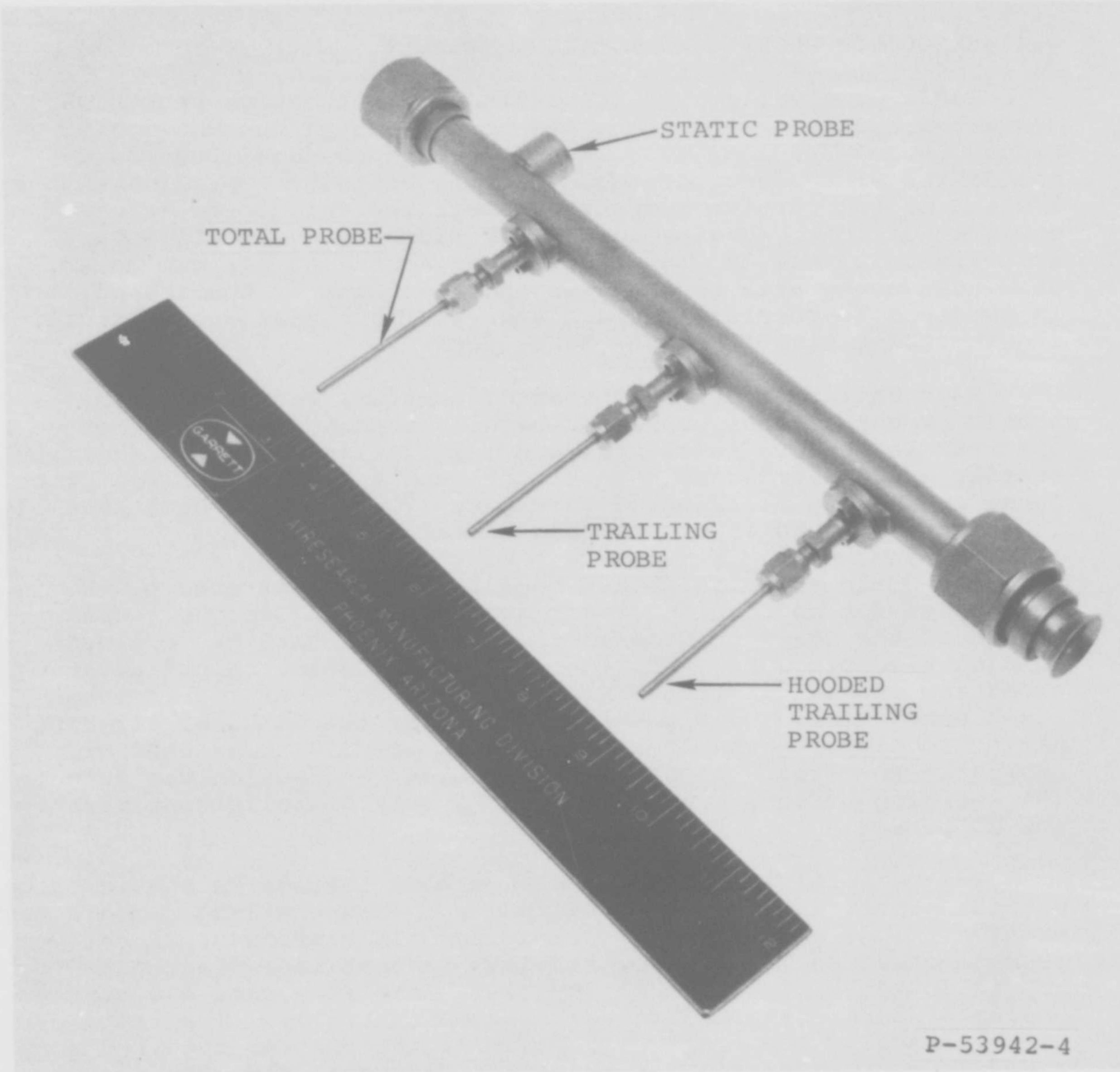
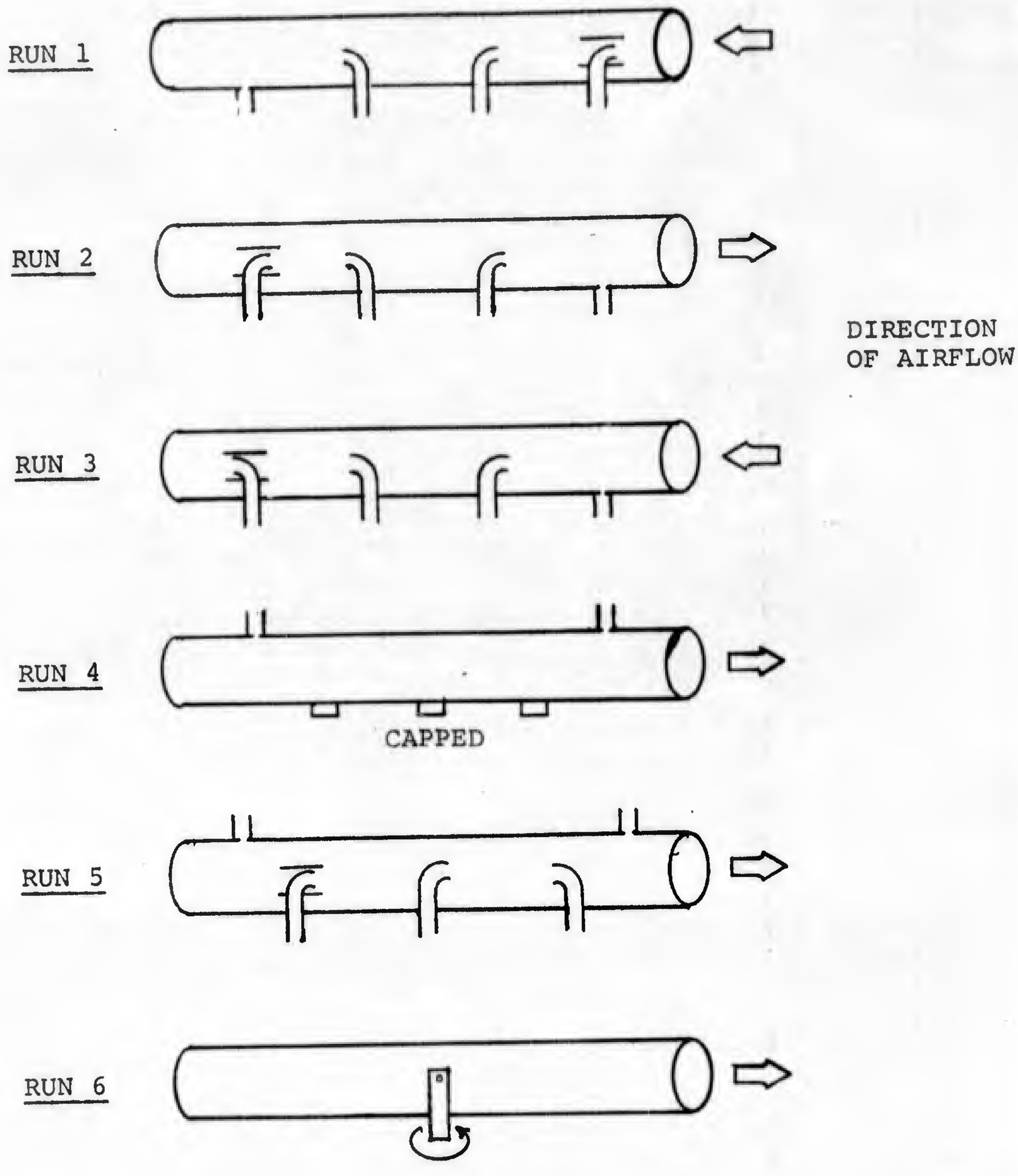


FIGURE 16

TEST PROBE ASSEMBLY



PROBE ROTATED 90, 120, 150, AND 180 DEGREES TO AIRFLOW

FIGURE 17

ORIENTATION OF TEST PROBES

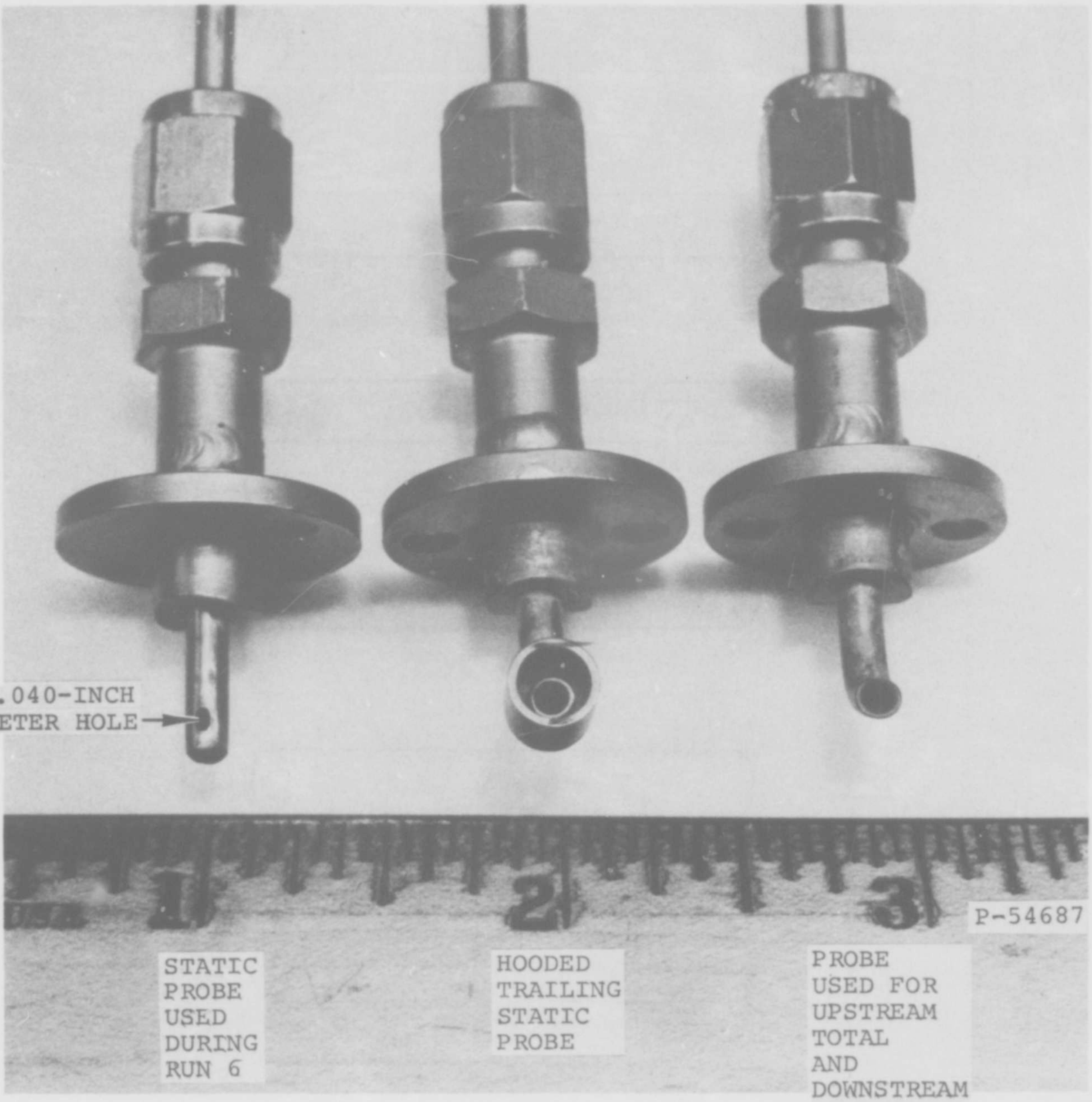


FIGURE 18

TEST PROBES USED FOR CONTAMINATED
BLEED AIR EXTRACTION TESTS

This test condition was maintained for eight hours. At the end of the run, the filter papers were weighed to establish tare levels. It is interesting to note that initial tests indicate the following relative probe rankings based on gravimetric measurement of dirt collected. The static probe sample was arbitrarily normalized at 1.0, and other probes reflect relative amounts of dirt collected:

	First Test	Second Test	Third Test
Static Probe	1.0	1.0	1.0
Total Probe	0.58	0.75	1.02
Trailing Probe	0.15	0.26	0.37
Hooded Trailing Probe	(No Data)	0.15	0.31

During the first run, the test section was inadvertently installed backward. The second run was a retest. The tabulated results from Runs 2 and 3 indicate that an upstream object such as another probe can produce dynamic disturbances which affect the amount of entrained contamination. Note particularly the data inversion between Runs 2 and 3. Accordingly, two additional tests were devised to investigate this phenomenon. The test probe was modified to add a static probe port downstream of the hooded trailing probe. This was done because the location of the static probe was changed from the upstream to the downstream location during Runs 2 and 3.

The objective of Runs 4 and 5 was to establish whether the presence of the probes in the duct influenced the amount of dirt collected at the downstream static port due to fluid disturbance. Run 4 was made with all probes removed, and demonstrated nearly identical contaminant collections at both static ports. During Run 5, the probes were reinstalled. All five ports were adjusted to a flow rate of 0.2 lb per min at 60 psig and 300F, and a four-hour, full contaminant run was performed. The contaminants extracted from both the upstream and downstream static probes were collected. Results indicated that the downstream static port collected 2.62 times as much dirt as the upstream static port. A complete data tabulation for the first five test runs, showing both gravimetric and normalized data, is presented in Table IV.

This data would appear to support the following conclusions:

(a) Installation of a hooded trailing probe should yield the least amount of extracted contamination. This fact was also borne out during icing tests of probes for air supply to a gas turbine engine fluidic fuel control.

TABLE IV

BLEED AIR EXTRACTION PROBE
TEST RESULTS

	Run 1	Run 2	Run 3	Run 4	Run 5
1. Total Probe					
Gravimetric	0.0432	0.4854	0.5277	No Data	No Data
Normalized	0.58	0.75	1.02		
2. Upstream Static					
Gravimetric	No Data	No Data	0.5179	0.3776	0.2649
Normalized			1.0		
3. Downstream Static					
Gravimetric	0.1598	0.6448	No Data	0.3821	0.6938
Normalized	1.0	1.0			
4. Trailing Probe					
Gravimetric	0.0242	0.1667	0.1904	No Data	No Data
Normalized	0.15	0.26	0.37		
5. Hooded Trailing					
Gravimetric	No Data	0.0970	0.1613	No Data	No Data
Normalized		0.15	0.31		

NOTE: Test probe position in test section is shown in diagram form in Figure 17.

(b) Location of a static port in the wall of a duct can be critical, as evidenced by Runs 4 and 5. Velocity disturbances can produce dynamic pressures at the port as evidenced by the downstream port data. These dynamic conditions can have a very significant impact on quantity of extracted contaminant.

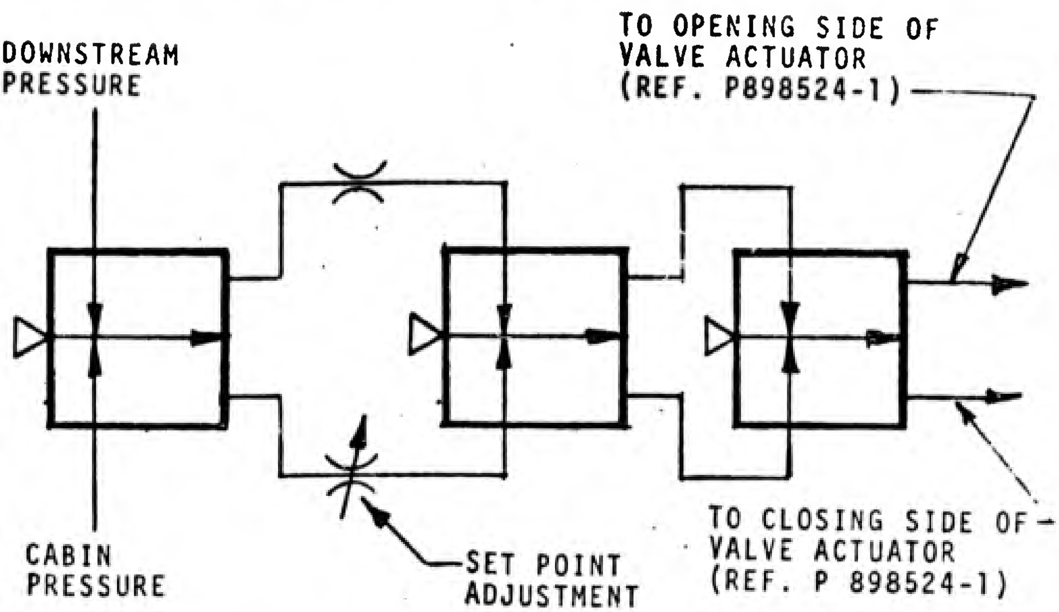
Following these test runs, one final test (Test Run 6) was conducted. During this test, a 0.125-inch diameter tube with a 0.040-inch diameter hole was located in the duct so that the hole could be rotated through 90 degrees from the static position to the trailing position. All other probes were removed. Test probe flow was adjusted to 0.1 lb per min and duct conditions were the same as for Runs 1 through 5.b The data indicated the following:

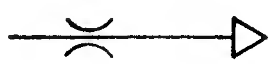
	Dirt Extracted in Four Hours grams	Normalized to Static Position
Static Position	0.170	1.0
Mid-Position Between Static and Trailing	0.075	0.44
Trailing	0.038	0.22

This data further supports the use of the trailing probe configuration. As this probe is rotated from the static position toward the trailing position, a significant reduction in contaminants is observed.

4.5 FLUIDIC CIRCUIT AND FILTER SYSTEMS SERVICE LIFE TESTS (TASK 3)

The fluidic circuit of the S-3A ram air ventilation valve was selected for the service life portions of the test. The circuit consists of a three-stage gain block, shown in Schematic P710254-1 on the following page and the photograph of Figure 19. The amplifier was tested in a loose laminant configuration, enabling element inspection at the end of the test program. Amplifier gain and null shift were evaluated periodically.



VALVE SUPPLY PRESSURE  = FLUIDIC SUPPLY PRESSURE

Description:

This fluidic system acts in conjunction with a valve to maintain downstream pressure a fixed amount above cabin pressure.

FOR ASSEMBLY SEE 3150017

NOTE:

THIS ARTICLE IS FABRICATED, IDENTIFIED AND PROCURED AS PART NUMBER

SIGNATURES	DATES
DRF T. Myflund	7-8-70
CHK	
APP W. [illegible]	7-15-70
APP D. J. Schiff	7-22-70
APP	
PAT DEPT.	

SCHEMATIC DIAGRAM

FLUIDIC CONTROL SYSTEM

AiResearch Manufacturing Company of Arizona
PHOENIX, ARIZONA
A division of THE GARRETT CORPORATION

DWG SIZE A | DWG NO. P 710254-1

SHEET 1 OF 1

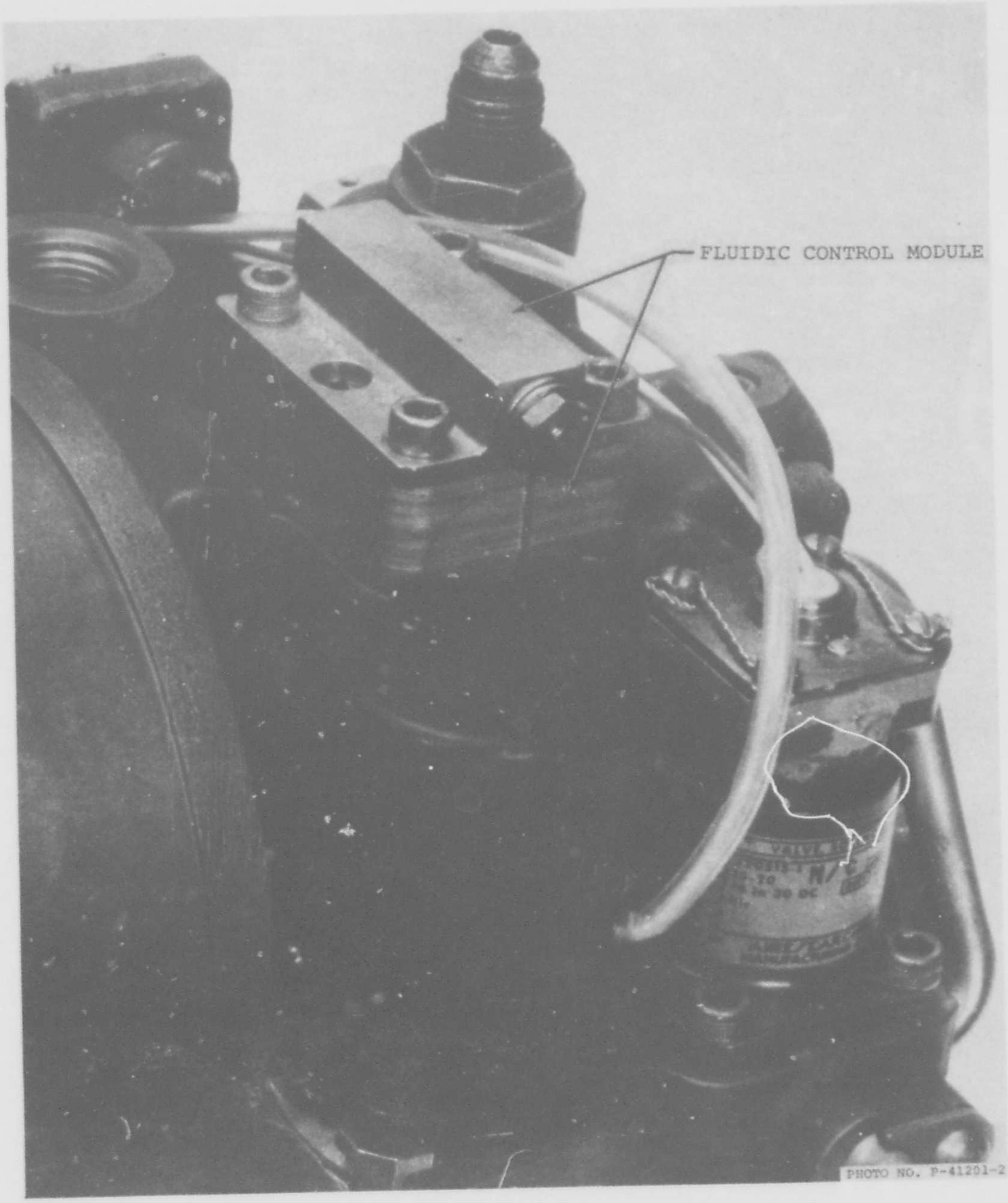


FIGURE 19

S-3A RAM AIR
VENTILATION VALVE
(AIRESEARCH PART 898524-1-1)

4.5.1 Baseline Fluidic Circuit Tests Without Filtration

Four fluidic circuits were installed in the test setup, two of which are shown in the photographs of Figures 20 and 21 and the schematic diagram of Figure 22, without the filter for these baseline tests. The objective of this test was to obtain baseline performance criteria for each circuit without filtration for an extended period of time by monitoring performance with simulated contaminated bleed airflow. A typical recorder trace of this test is included as Figure 23. In all four test stations, the addition of moisture caused an immediate reduction in gain and saturation levels as indicated in Figure 23. The fluidic circuit used throughout this test program is depicted schematically in Figure 22. An assembly drawing of the laminations with individual lamination position numbers in the stack (1, 2, 3, etc., numbered from base to top) is shown in Figure 24. Since all laminations were unbonded 300 Series CRES elements, the circuit was easily disassembled for inspections.

Four separate test runs were conducted. The circuit air supply inlet conditions for the test section were 40 ±1 psig with a temperature range of 275 to 300F. The flow rate of the three-stage fluidic amplifier gain block was 0.040 lb per min. The measured temperature at each circuit vent port was in the range of 150 to 175F with the ambient temperature of the stack at room temperature. With the exception of the initial calibration, flow rate was not recorded during subsequent contamination test runs with the fluidic circuit.

During the first run, all contaminants were added at specified CBAS contaminant levels (see Table II herein) per MIL-E-5007D as tabulated below.

Contaminant	Amount
MIL-L-7808 Oil	3 ppm
NaCl	0.2 ppm
H_2O	0.0950 lb per hr H_2O per lb per hr airflow
AC Fine Dust	7.9 grams per hr in (0.01752 lb per hr) 120 lb per hr airflow

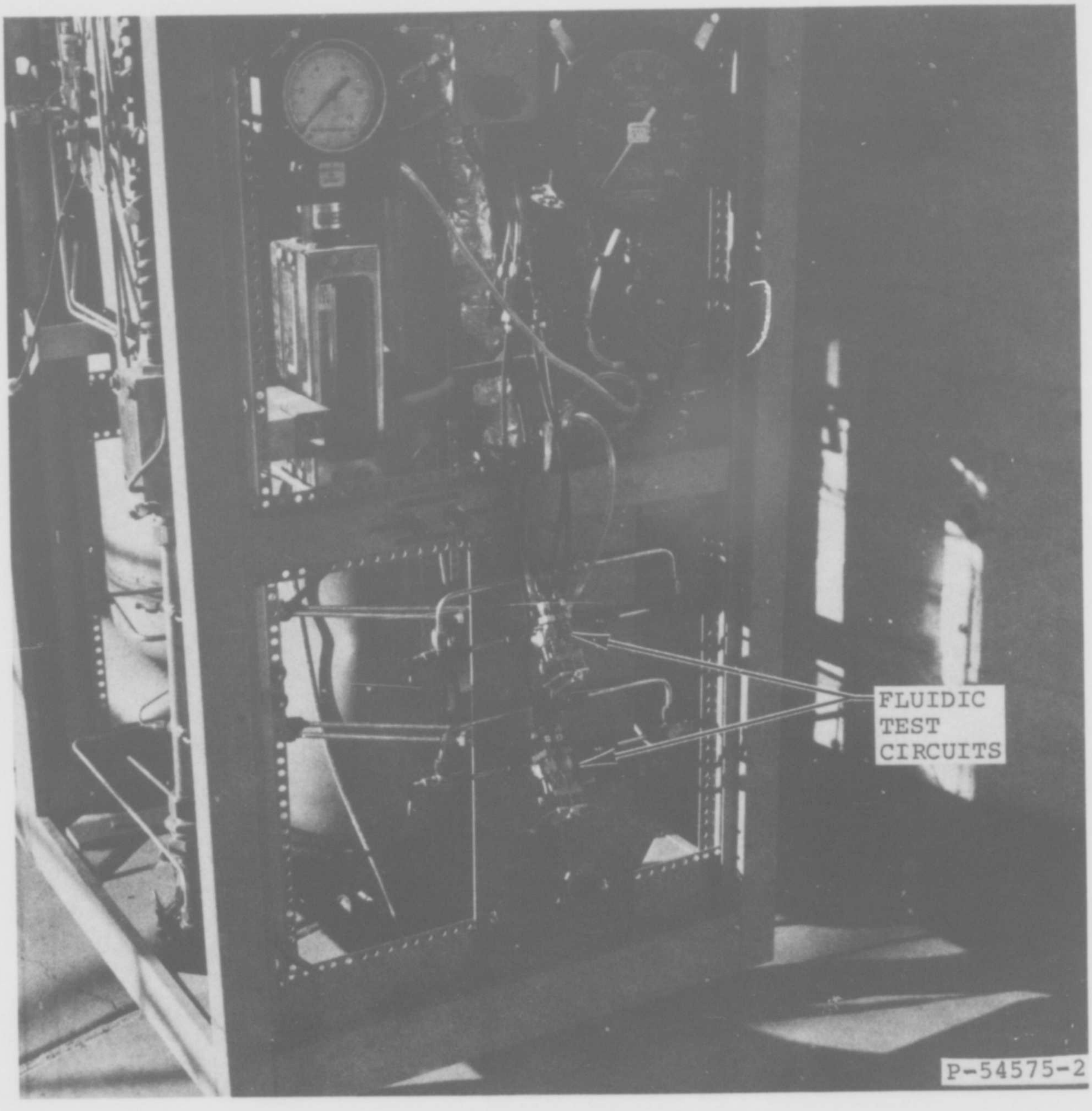


FIGURE 20

FLUIDIC TEST CIRCUIT
INSTALLATION IN CBAS

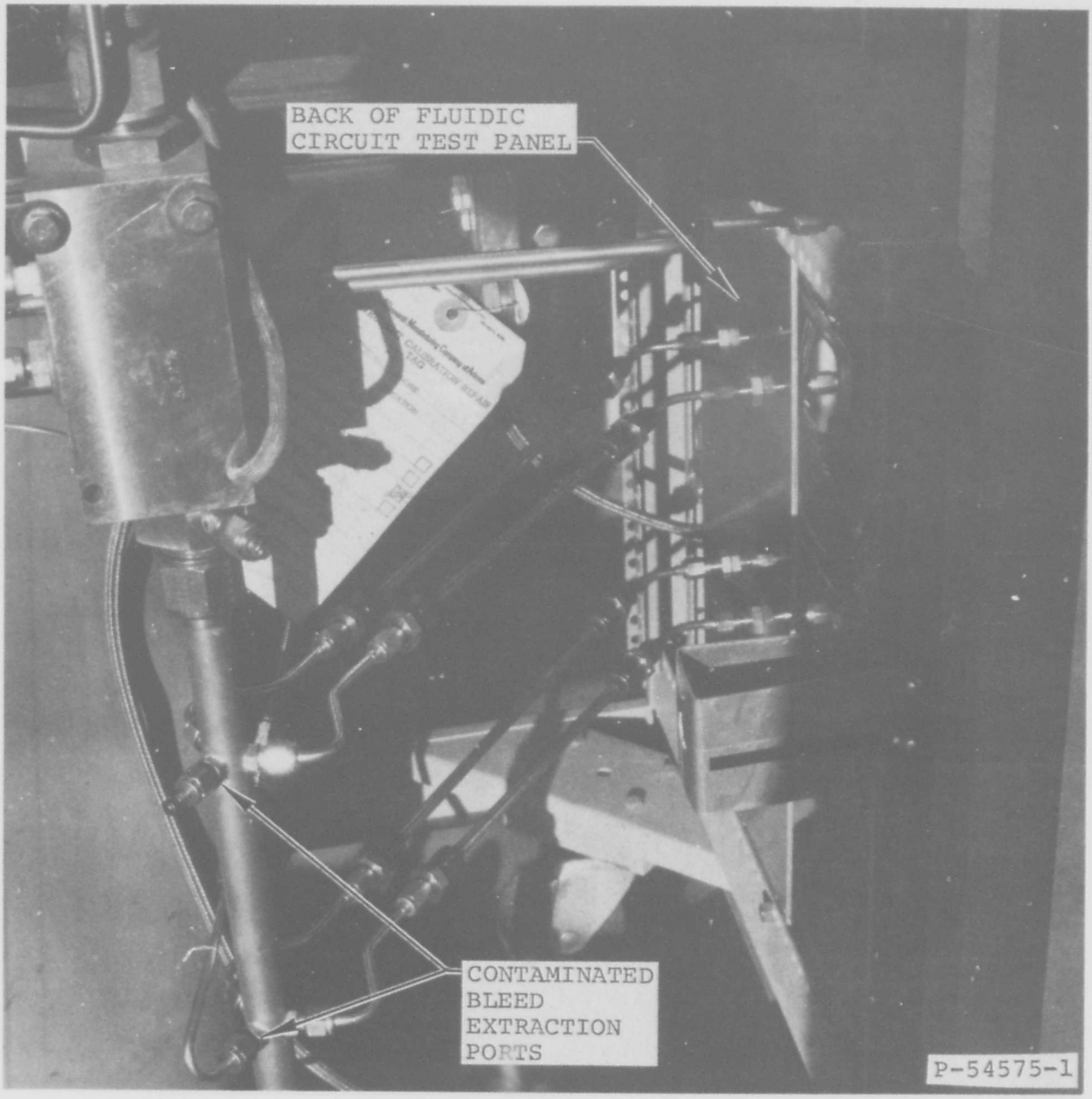


FIGURE 21

BLEED EXTRACTION PORTS IN CBAS TEST SETUP
FOR FLUIDIC CIRCUIT TESTS

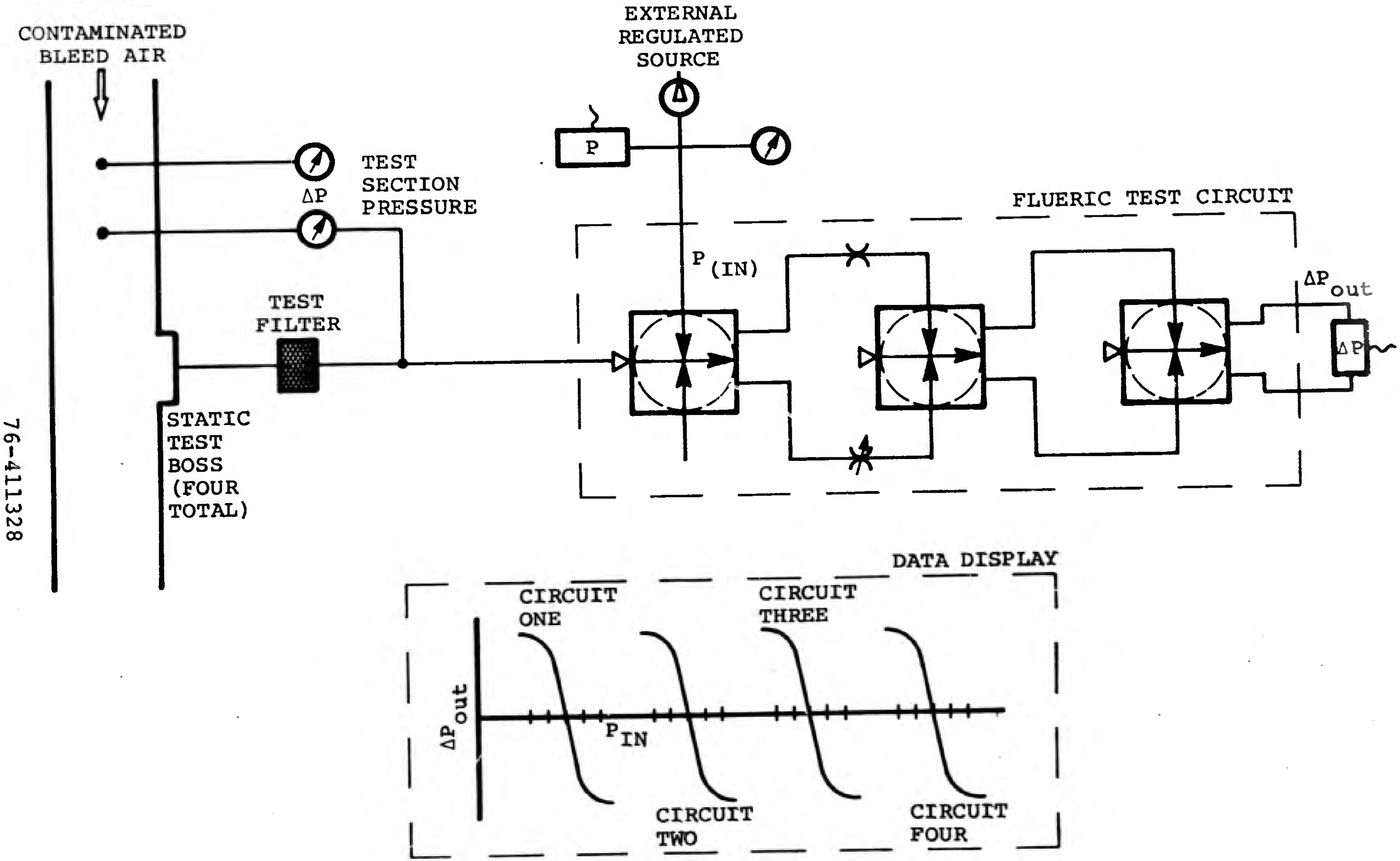


FIGURE 22

TEST SETUP SCHEMATIC DIAGRAM
FLUIDIC CIRCUIT AND FILTER CONTAMINATION

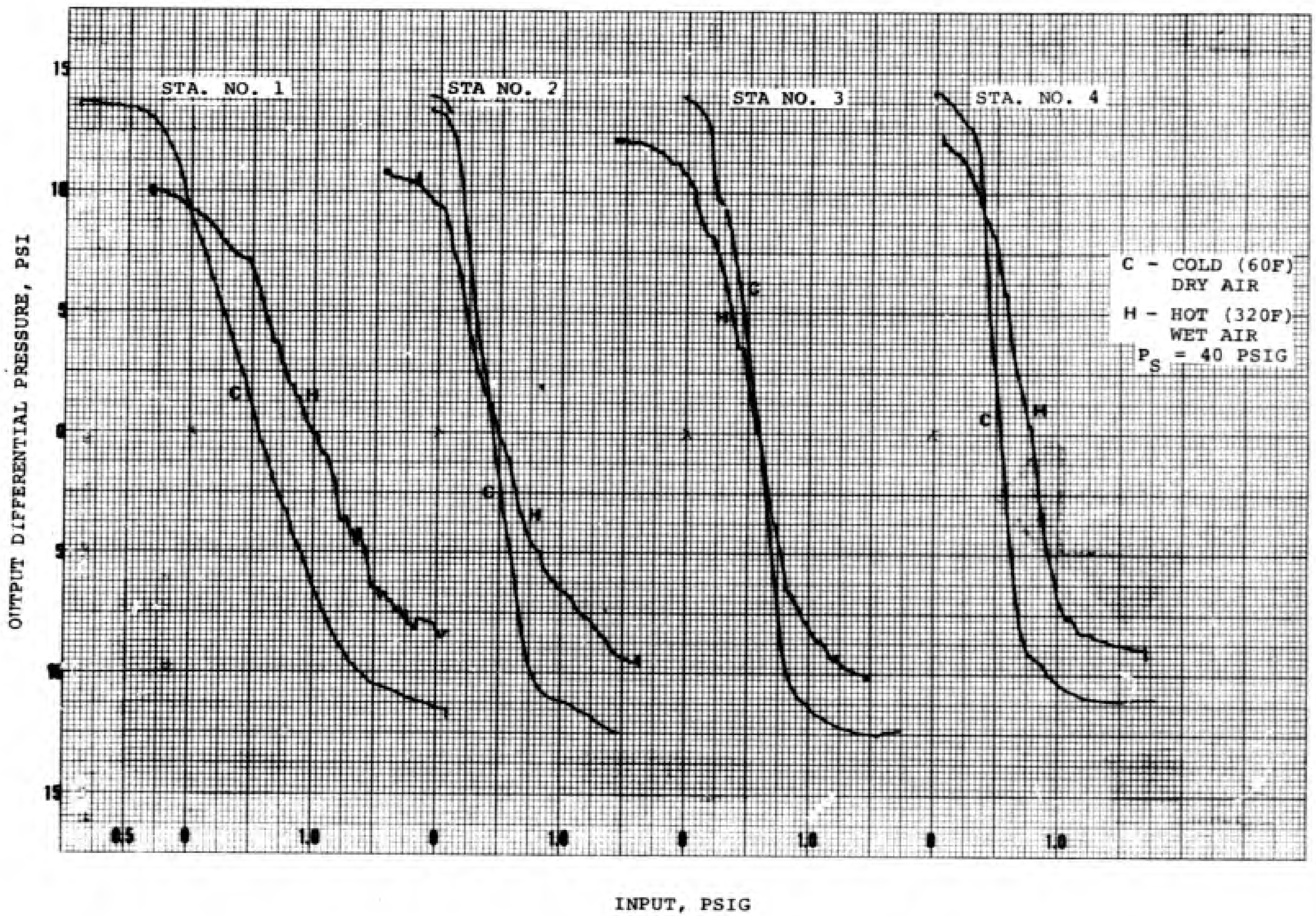


FIGURE 23

TEST DATA
PRIOR TO CONTAMINATION

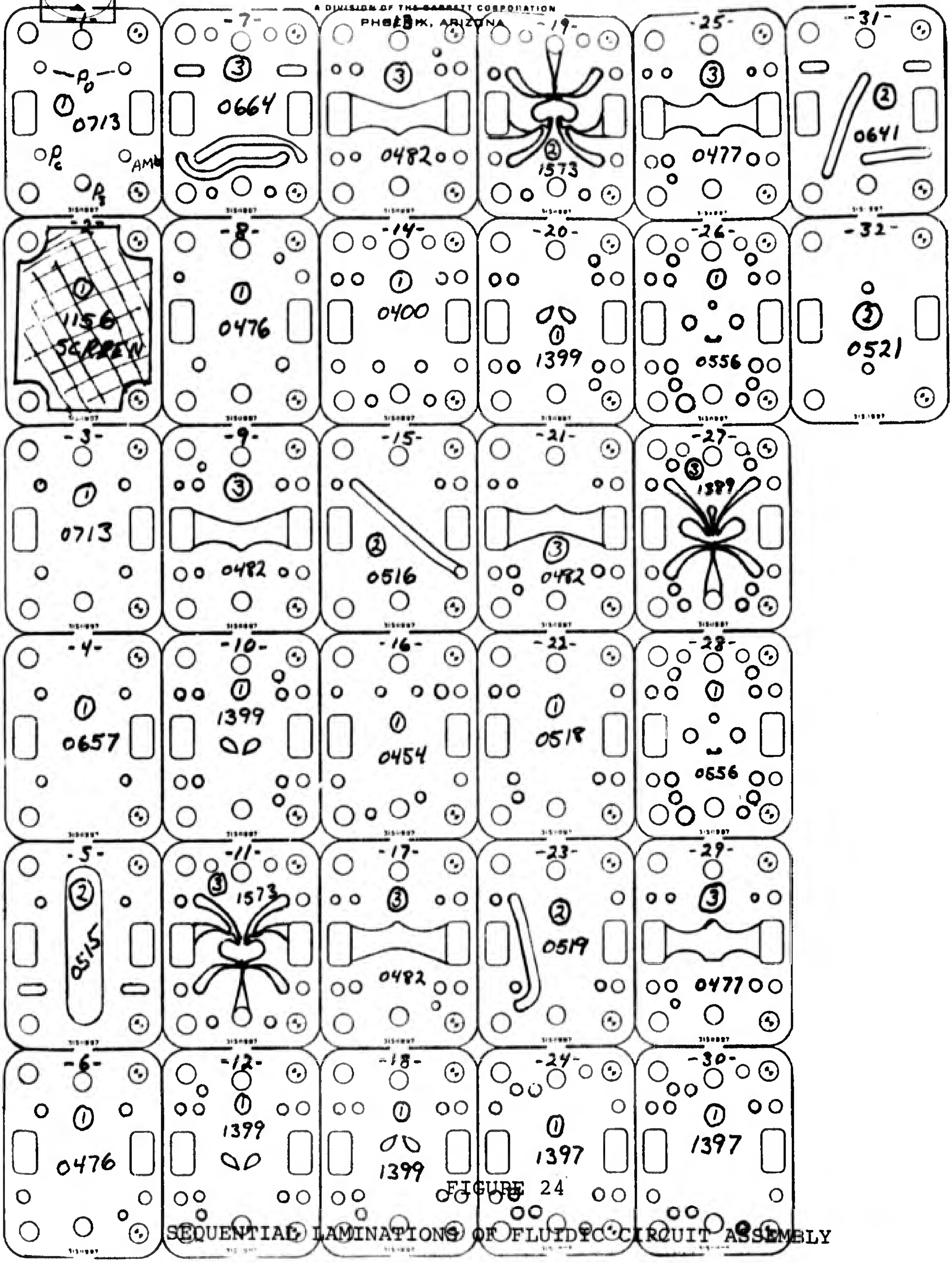


FIGURE 24

SEQUENTIAL LAMINATIONS OF FLUIDIC CIRCUIT ASSEMBLY

This first test run was terminated after one hour since three of the four circuits exhibited gross null shift, loss of gain, and extreme noise, as shown on traces of Figures 25 and 26. Following a drying period of 90 minutes with 70F dry airflow, three of the four circuits were restored to the point of exhibiting normal performance, as shown in Figure 27. As a result, modifications to the setup to prevent condensation in the circuit were ordered. Disassembly of the fourth circuit (Station 1) revealed extensive contamination as depicted in Figures 28 through 32. Subsequent disassembly of the other three circuits revealed varying degrees of contamination, all extreme and detrimental.

Because of results of the first run, a second run using new circuits was initiated. The test setup was modified to shorten lines between the CBAS test section and the test circuits in an attempt to reduce water condensation effects within the test circuits. However, at the end of 60 minutes of testing, three of four circuits had failed completely, and were still inoperative after 60 minutes of drying. The results of circuit teardown showed failure modes similar to Run 1 as shown by the photographs of Figures 33, 34, and 35.

The results of the first two runs indicated a maximum circuit life of 60 minutes when exposed to all contaminants without filter protection.

The third test run was conducted using dirt only, with the liquid contaminants (oil, water, and salt solution) omitted. The fourth test run duplicated Run 3 to check data consistency. The test results for Run 3 are summarized on Figures 36 through 39 and photographs of the circuit components are included in Figures 40 to 44. The results of Run 4 are summarized on Figures 45 through 48. In general, the data indicates a gradual shift in null and loss of gain with time. Eventually, total failure of a circuit occurs suddenly, as indicated by a drastic null shift and essentially zero gain. In most cases, such sudden failure occurred between 10 and 20 hours of running time with dry dirt only. As previously noted, a maximum life of 60 minutes resulted with all contaminants on line and no protective filtration system used. Of particular interest is the dirt pattern displayed on the amplifier vent in Figure 40, which clearly reveals the tendency for contamination to accumulate in low velocity regions such as leg vent cavities adjacent to the main vent channels. The corresponding amplifier is shown in Figure 41 for additional evidence. This information will be most helpful in future amplifier designs.

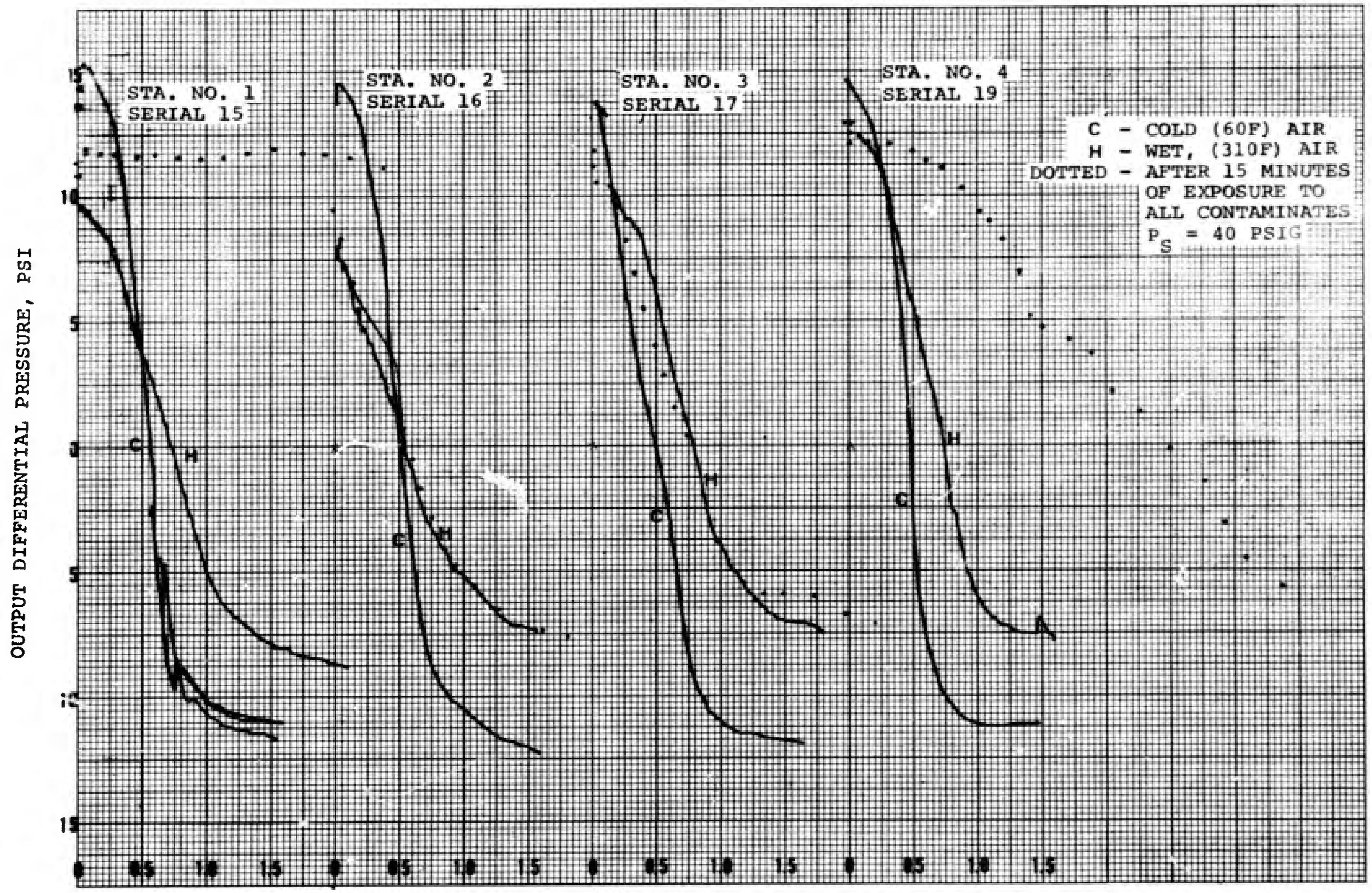


FIGURE 25

TEST DATA
AFTER 15 MINUTES OF CONTAMINATED AIRFLOW

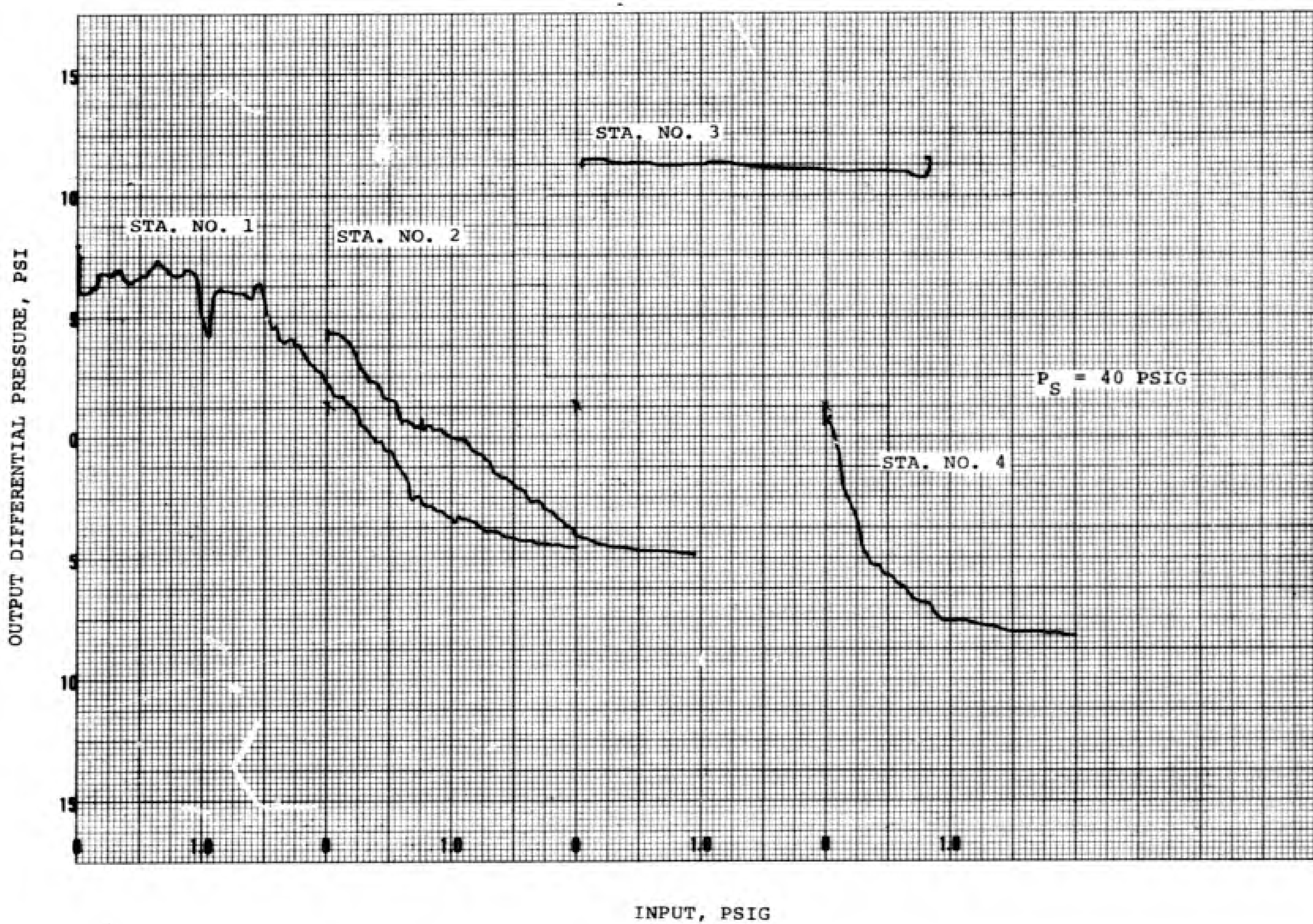


FIGURE 26

TEST DATA
AFTER 60 MINUTES OF CONTAMINATED AIRFLOW

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION

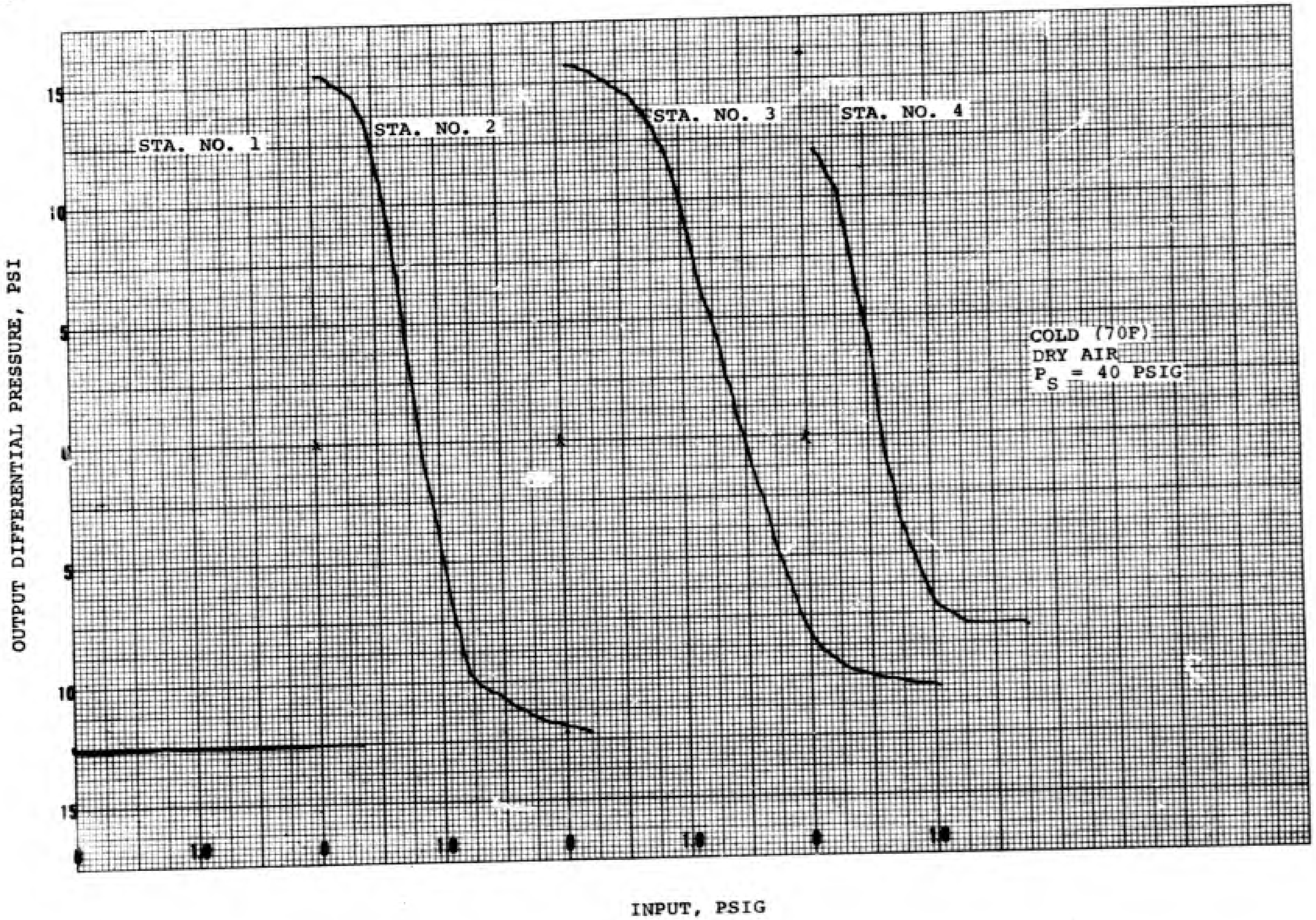


FIGURE 27

TEST DATA
90 MINUTES AFTER CONTAMINATION STOPPED

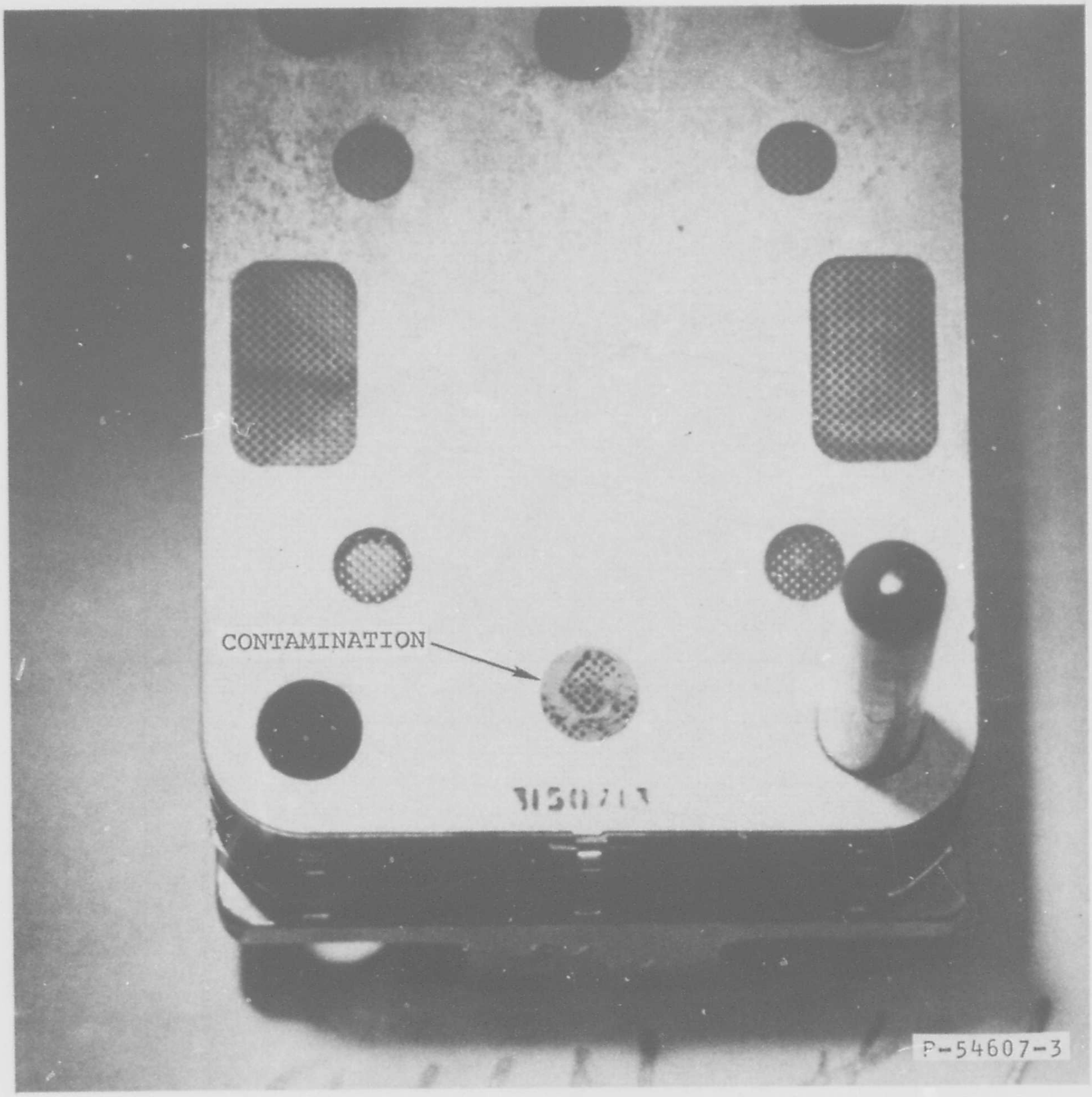


FIGURE 28

UNFILTERED BLEED AIR TEST
BUILDUP OF DIRT IN SUPPLY SCREEN
RUN 1, STATION 1, LAMINATION 2

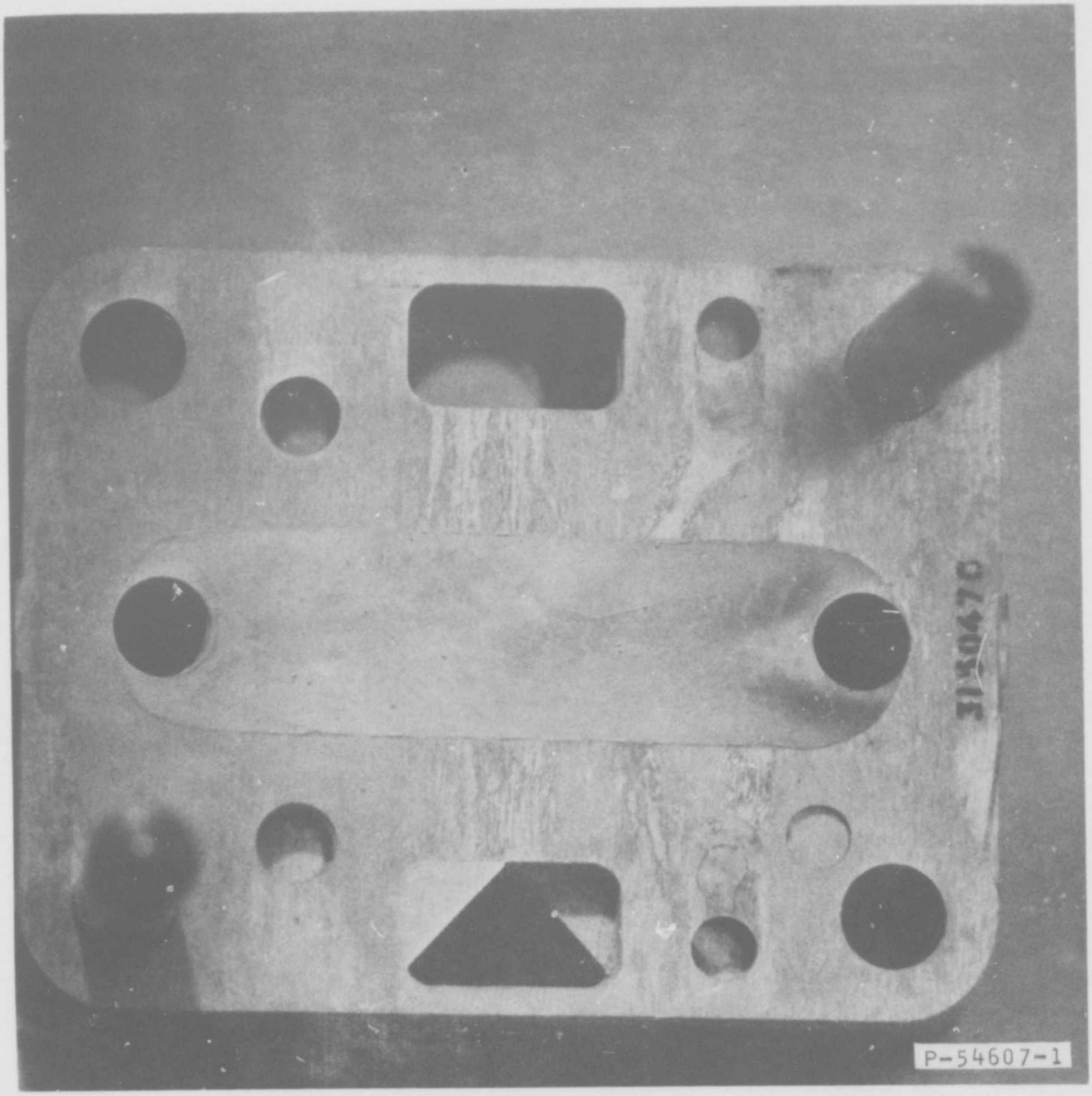


FIGURE 29

UNFILTERED BLEED AIR TEST
CONTAMINATION BUILDUP IN SUPPLY TRANSFER
RUN 1, STATION 1, LAMINATION 6

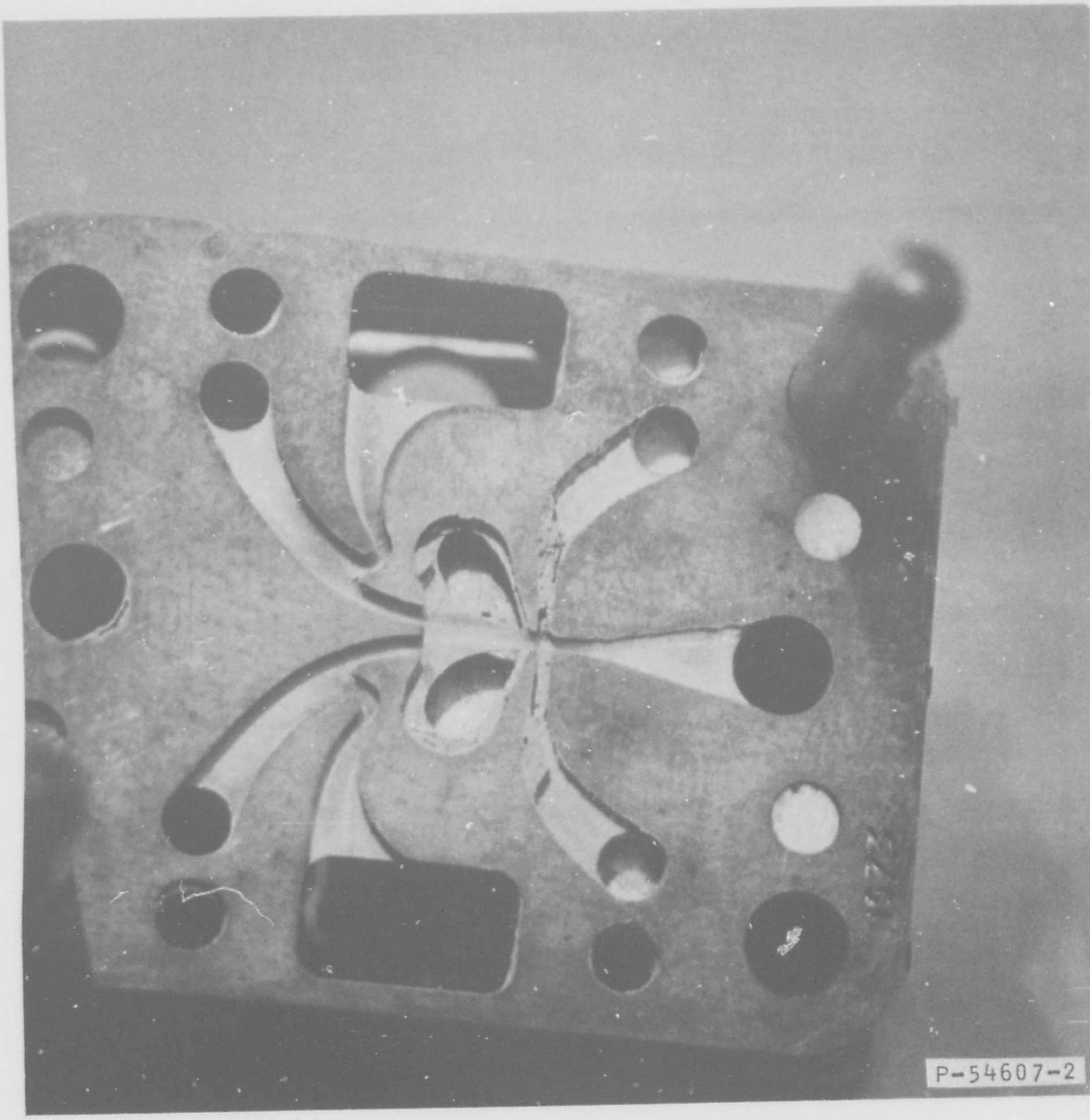


FIGURE 30

UNFILTERED BLEED AIR TEST
CONTAMINATED CONTROL PORTS
FIRST STAGE AMPLIFIER
RUN 1, STATION 1, LAMINATION 11

FIGURE 31

UNFILTERED BLEED AIR TEST
DIRT BUILDUP IN
FIRST STAGE EXHAUST REGION
RUN 1, STATION 1, LAMINATION 12

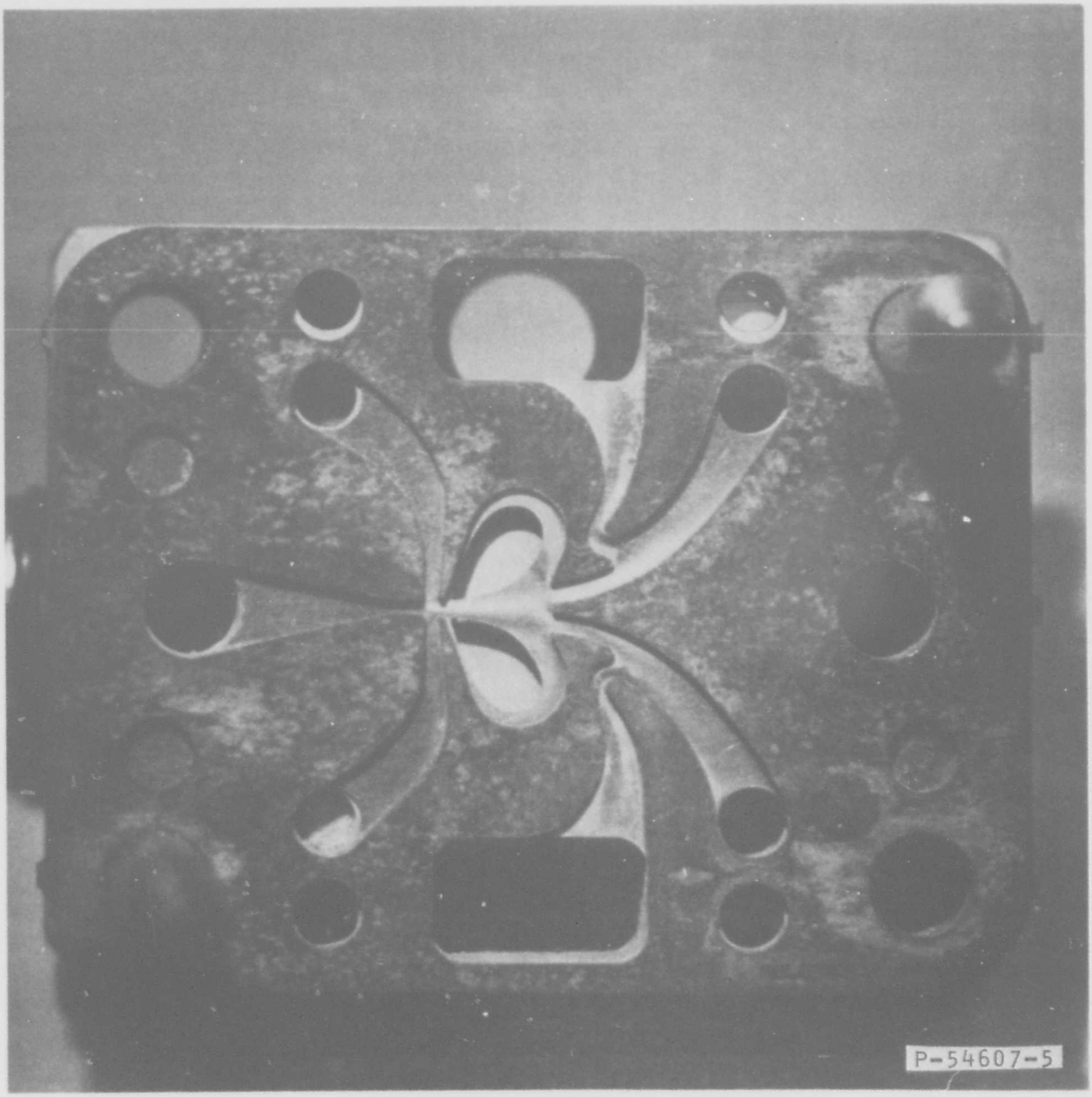


FIGURE 32

UNFILTERED BLEED AIR
PHOTO SHOWING LACK OF DIRT IN
SECOND STAGE AMPLIFIER
RUN 1, STATION 1, LAMINATION 19

FIGURE 33

UNFILTERED BLEED AIR
PARTIAL BLOCKING OF
THIRD STAGE VENT
RUN 2, STATION 1, LAMINATION 27

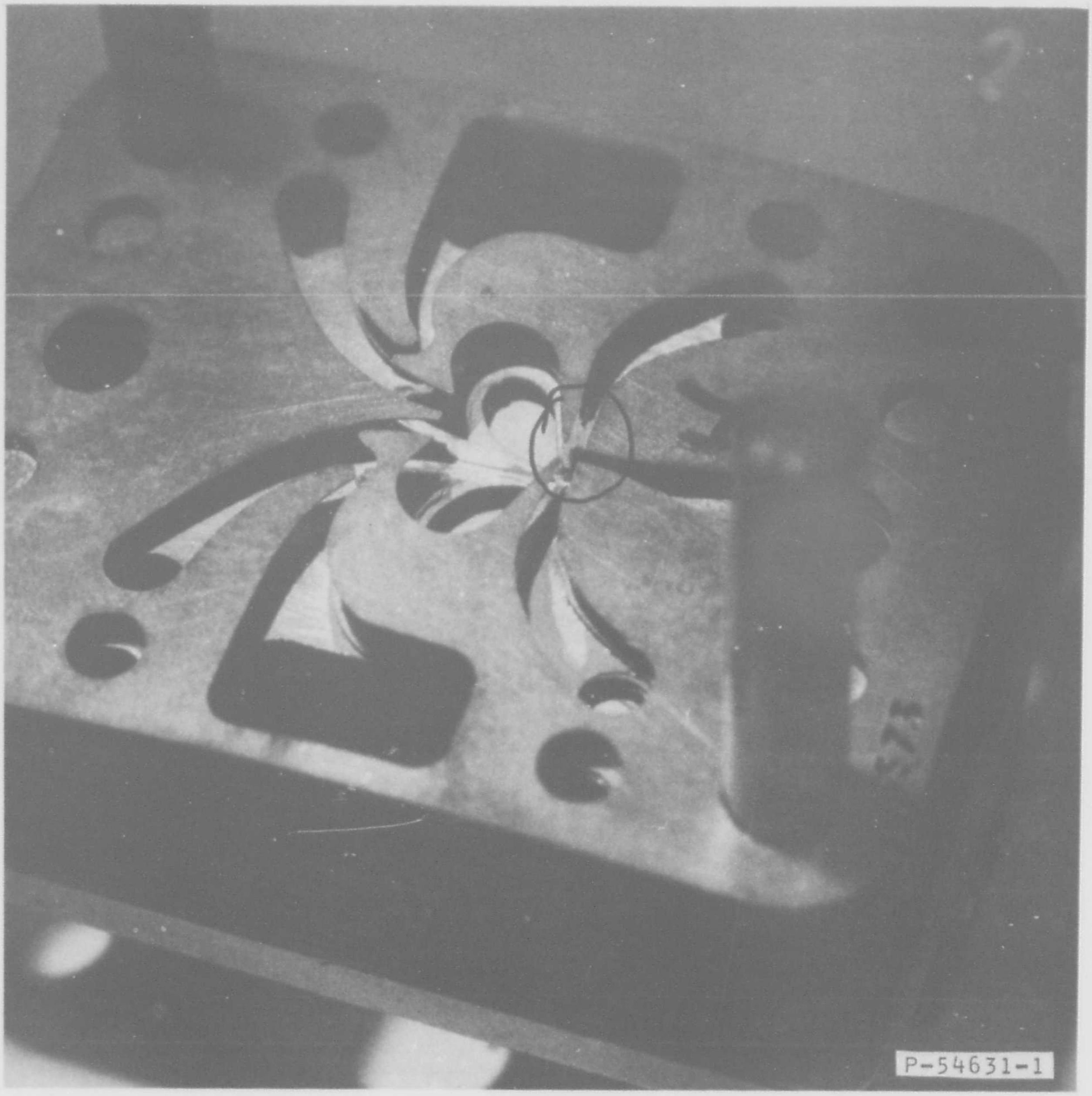


FIGURE 34

UNFILTERED BLEED AIR
PLUGGED CONTROL PORT
RUN 2, STATION 3, LAMINATION 11

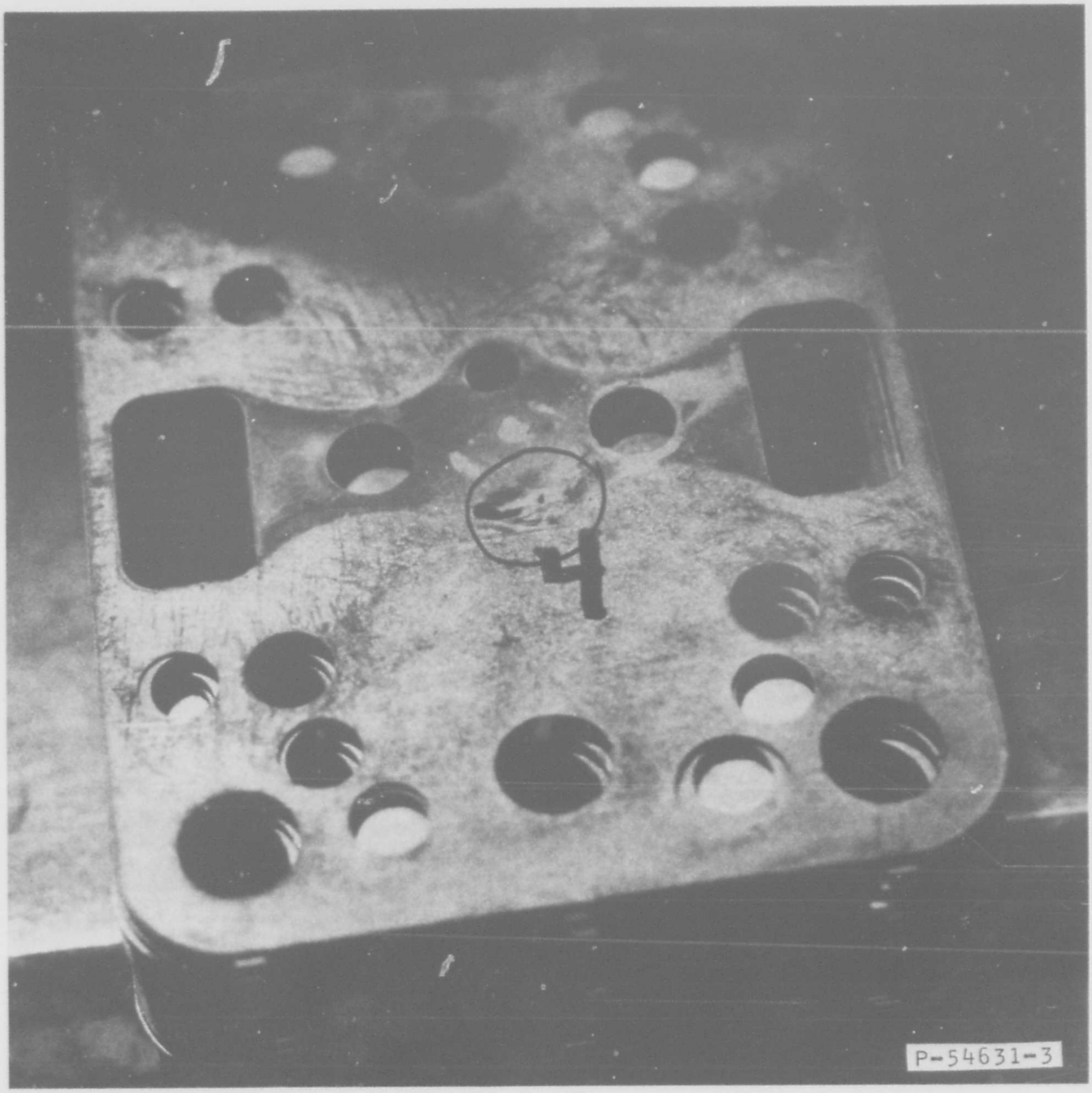


FIGURE 35

UNFILTERED BLEED AIR
PARTIALLY BLOCKED VENT
VIEWED FROM EXHAUST SIDE
RUN 2, STATION 4, LAMINATION 26

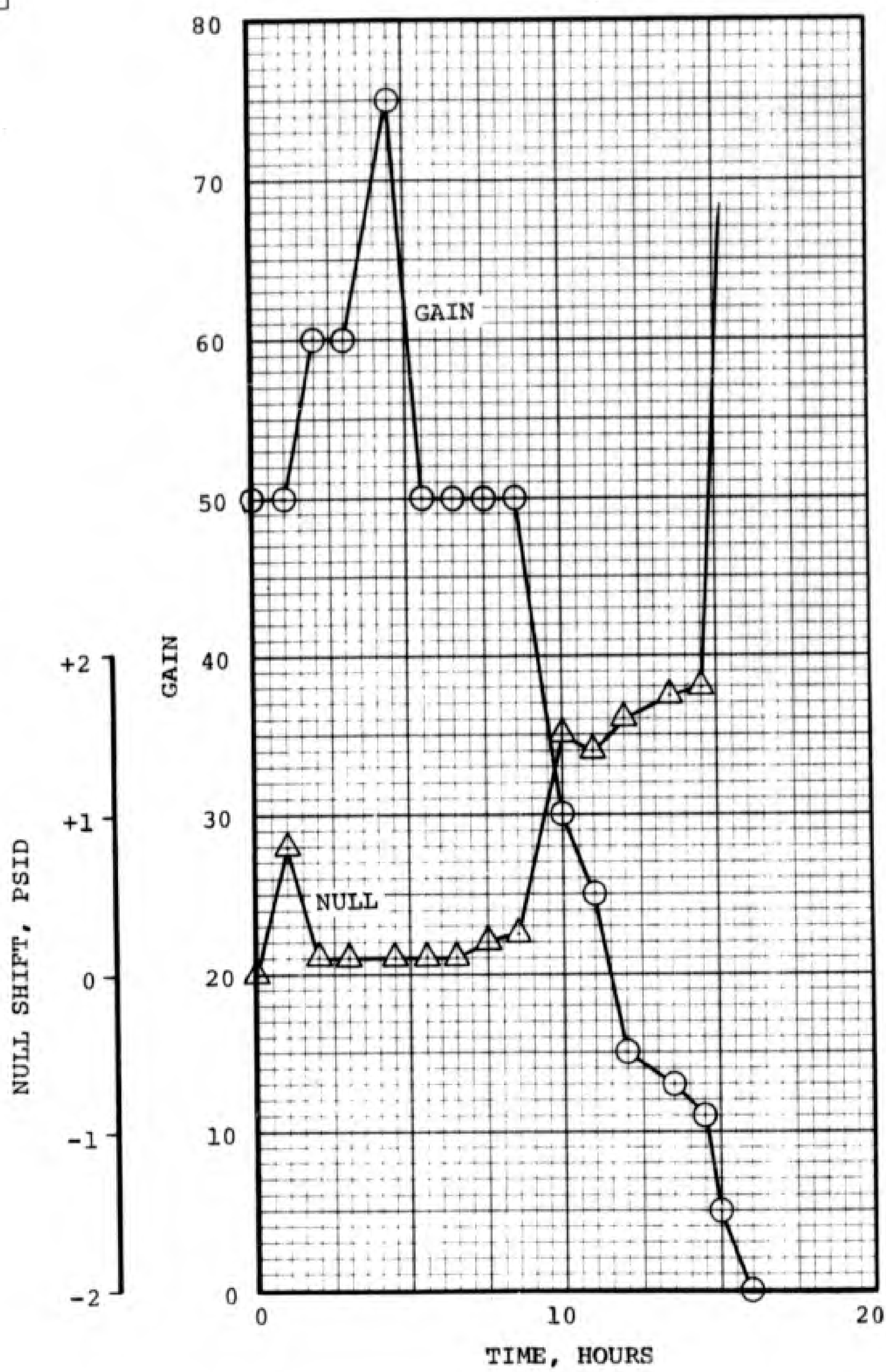


FIGURE 36

RUN THREE SUMMARY
CIRCUIT STATION 1

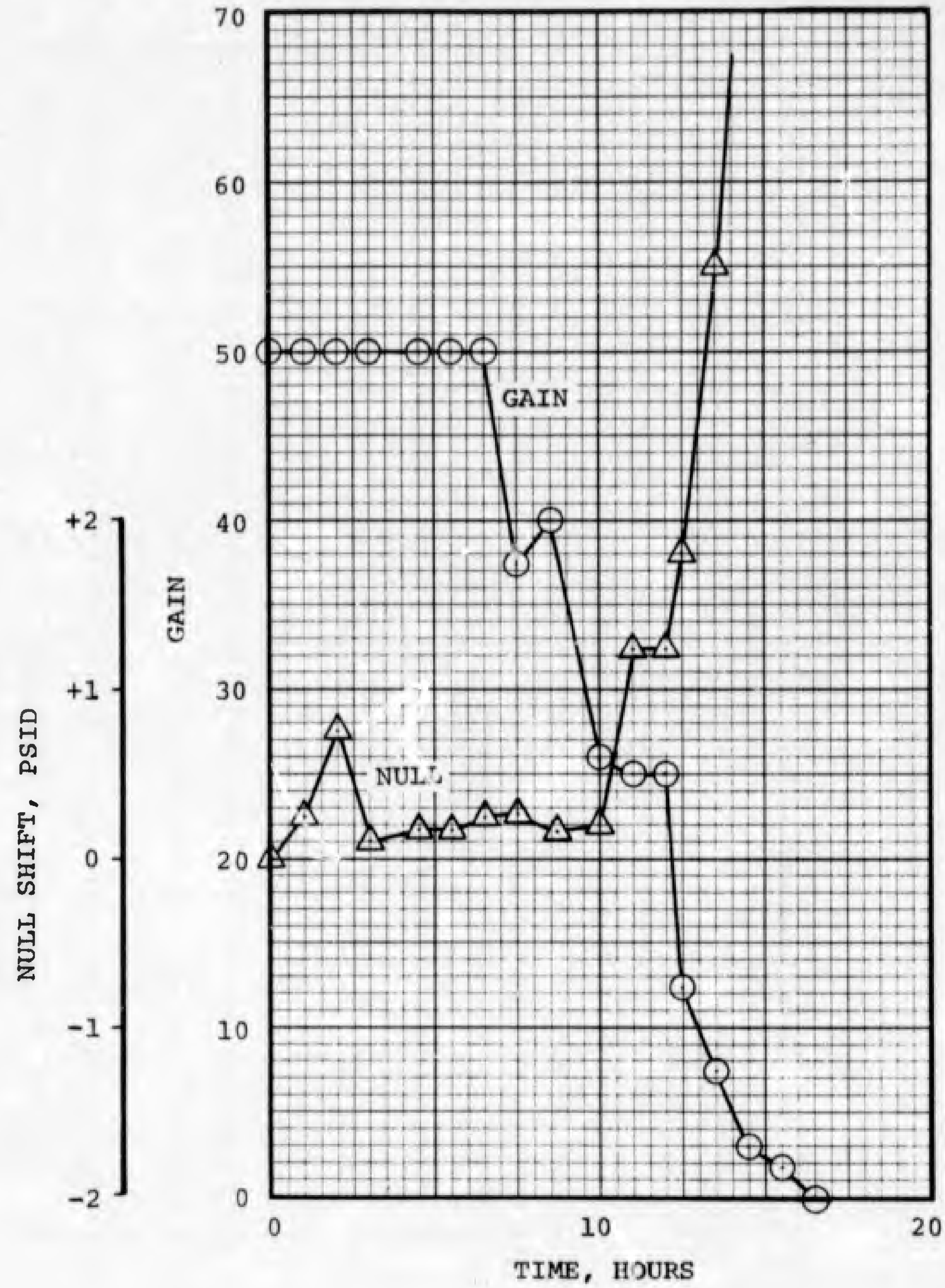


FIGURE 37

RUN THREE SUMMARY
CIRCUIT STATION 2

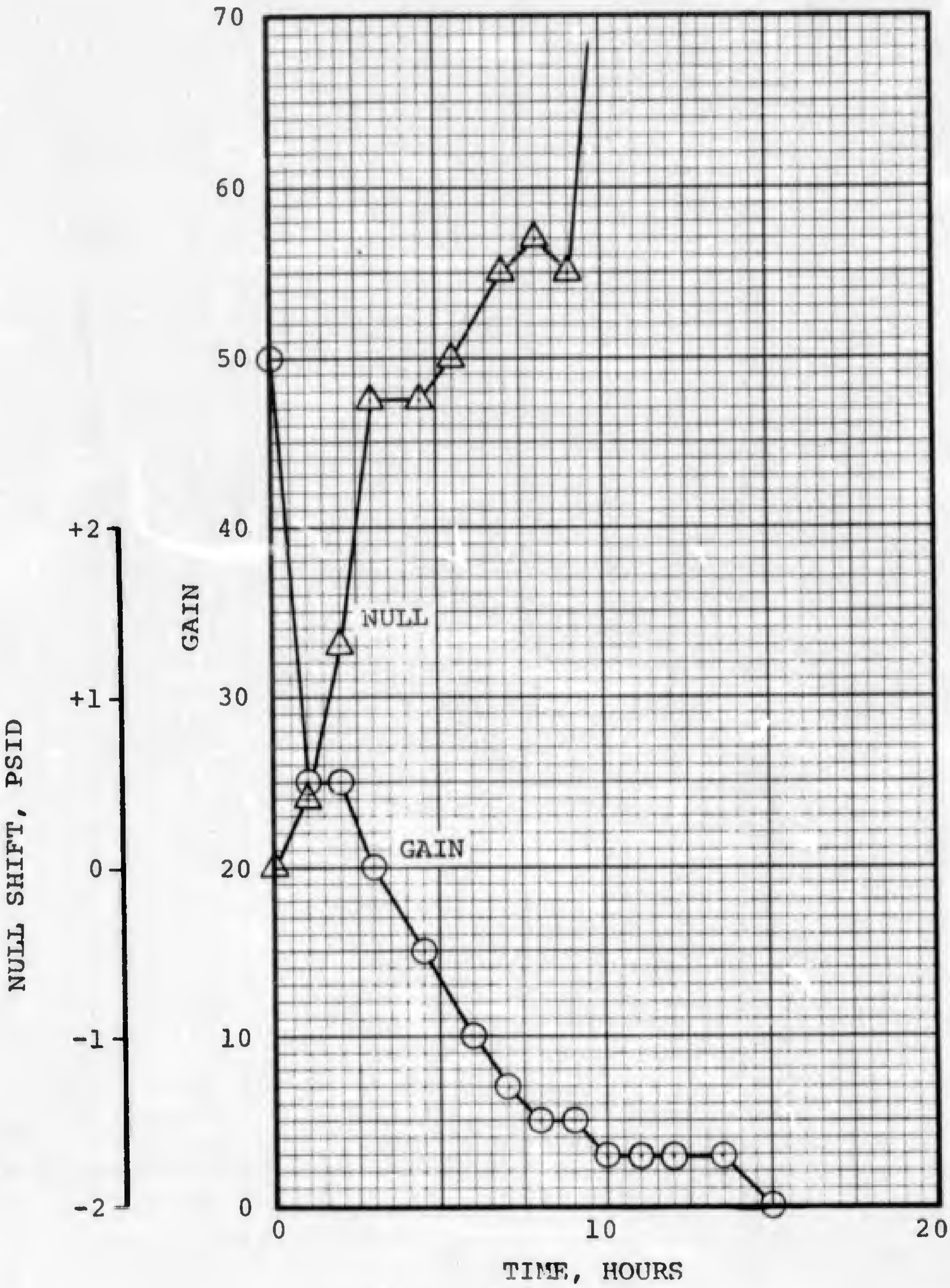


FIGURE 38

RUN THREE SUMMARY
CIRCUIT STATION 3

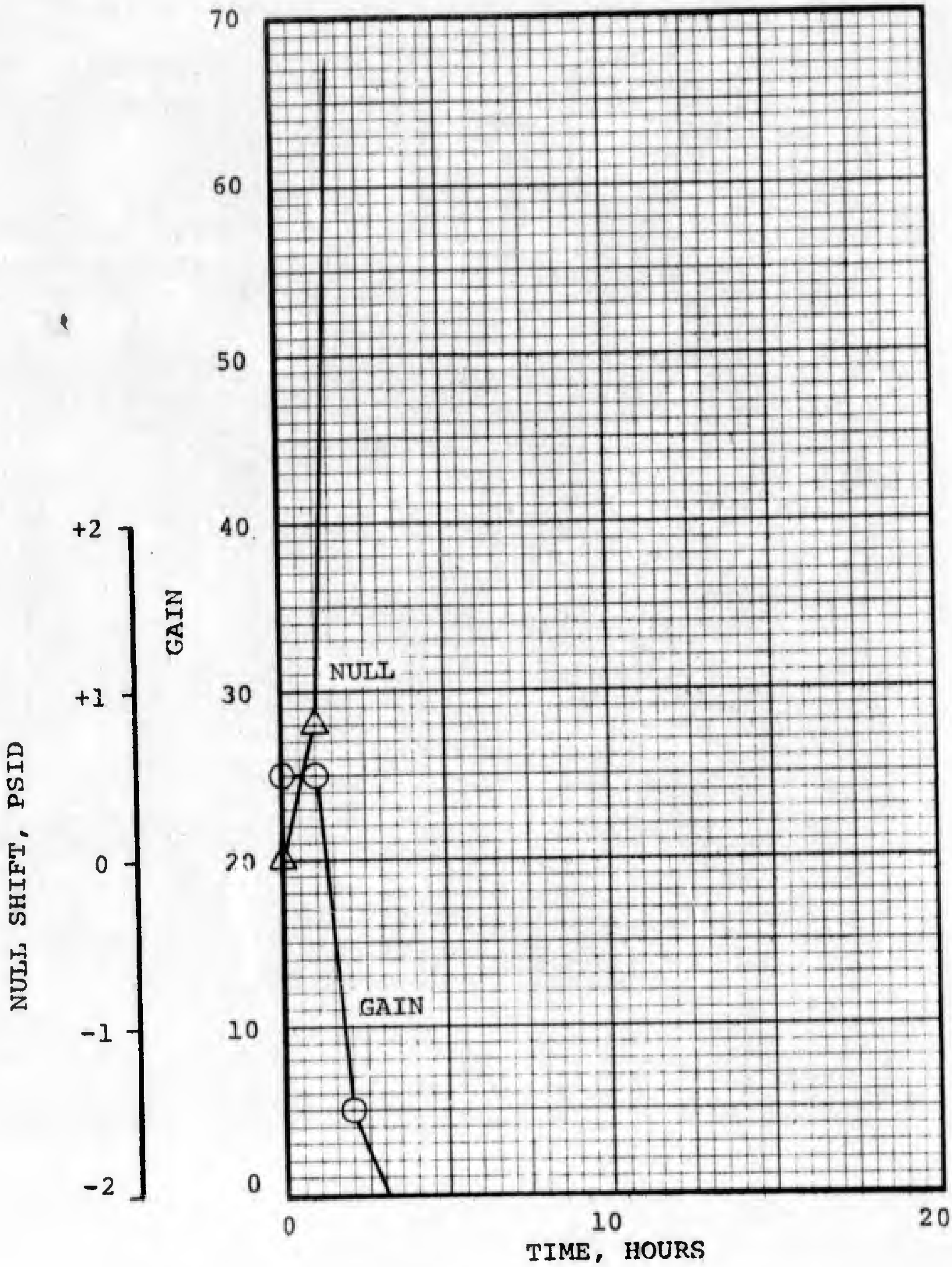


FIGURE 39

RUN THREE SUMMARY
CIRCUIT STATION 4

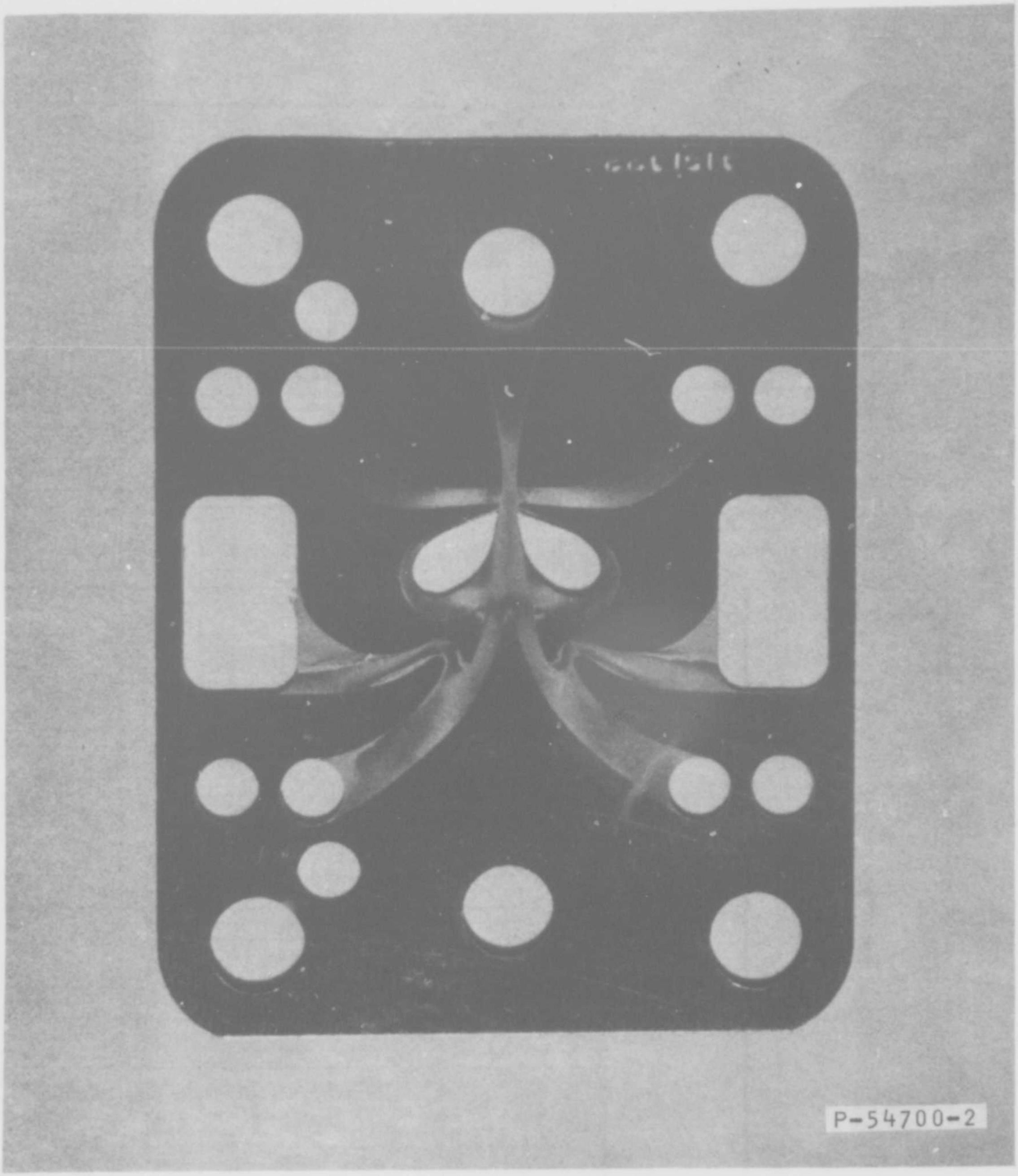


FIGURE 40

UNFILTERED BLEED AIR TEST
DIRT PATTERNS ON VENT PLATE
DEPICT FLOW PATTERNS THROUGH AMPLIFIER

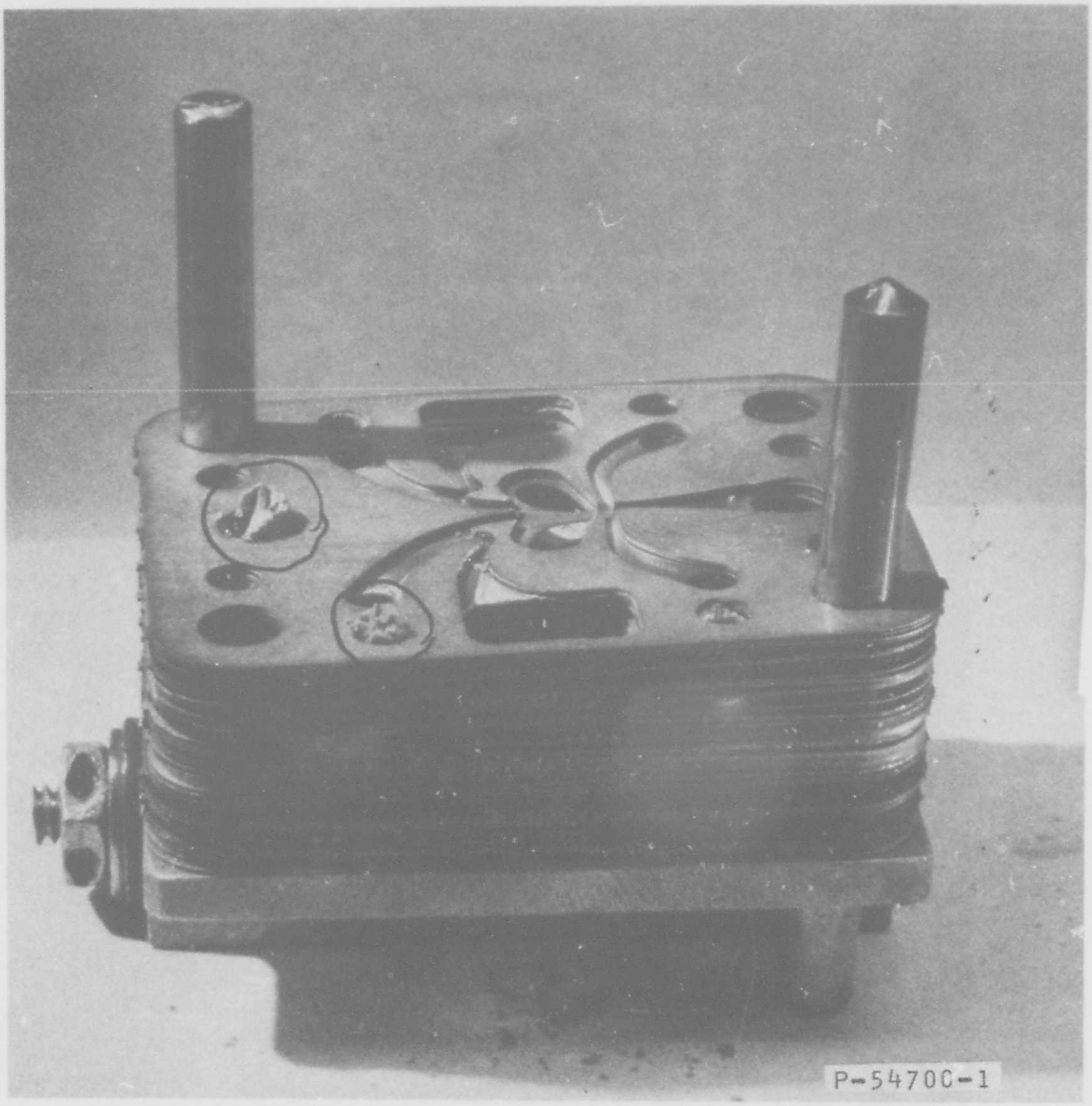


FIGURE 41

UNFILTERED BLEED AIR TEST
BLOCKED SIGNAL PORTS
RUN 3, STATION 1, LAMINATION 11

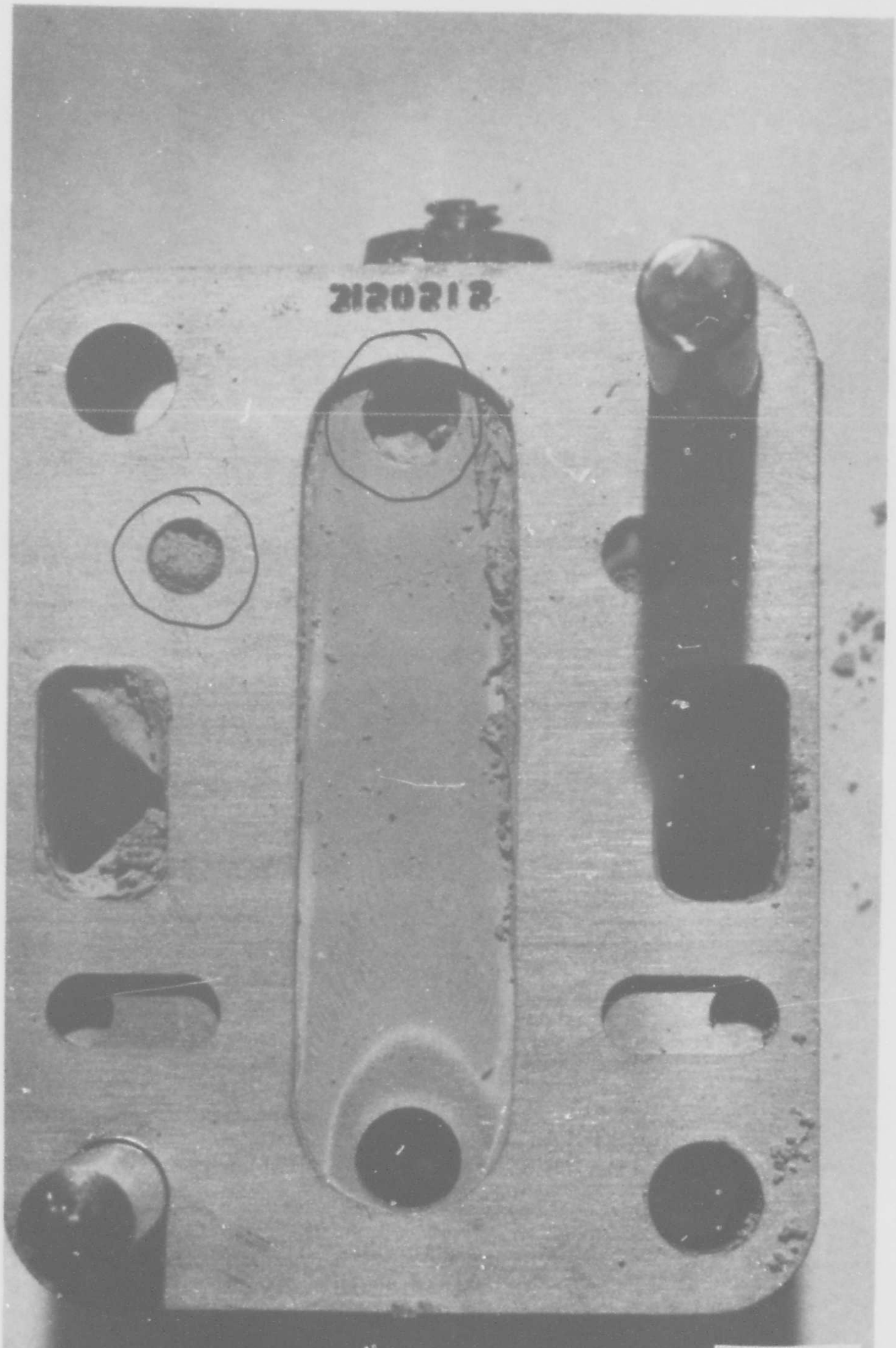


FIGURE 42

UNFILTERED BLEED AIR TEST
BLOCKED SUPPLY AND SUPPLY TRANSFER
RUN 3, STATION 1, LAMINATION 5

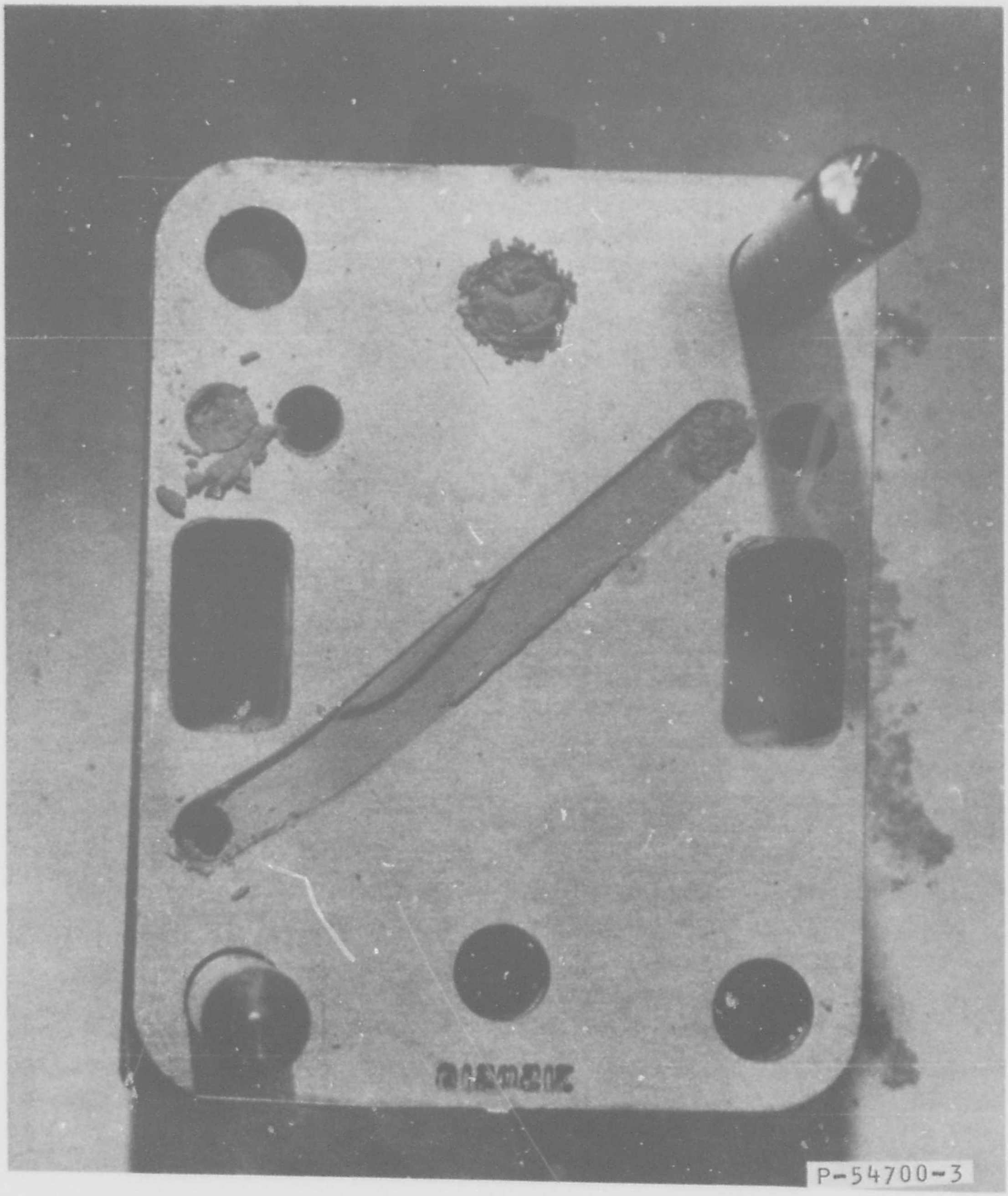


FIGURE 43

UNFILTERED BLEED AIR TEST
DIRT PATTERNS IN TRANSFER
RUN 3, STATION 1, LAMINATION 15

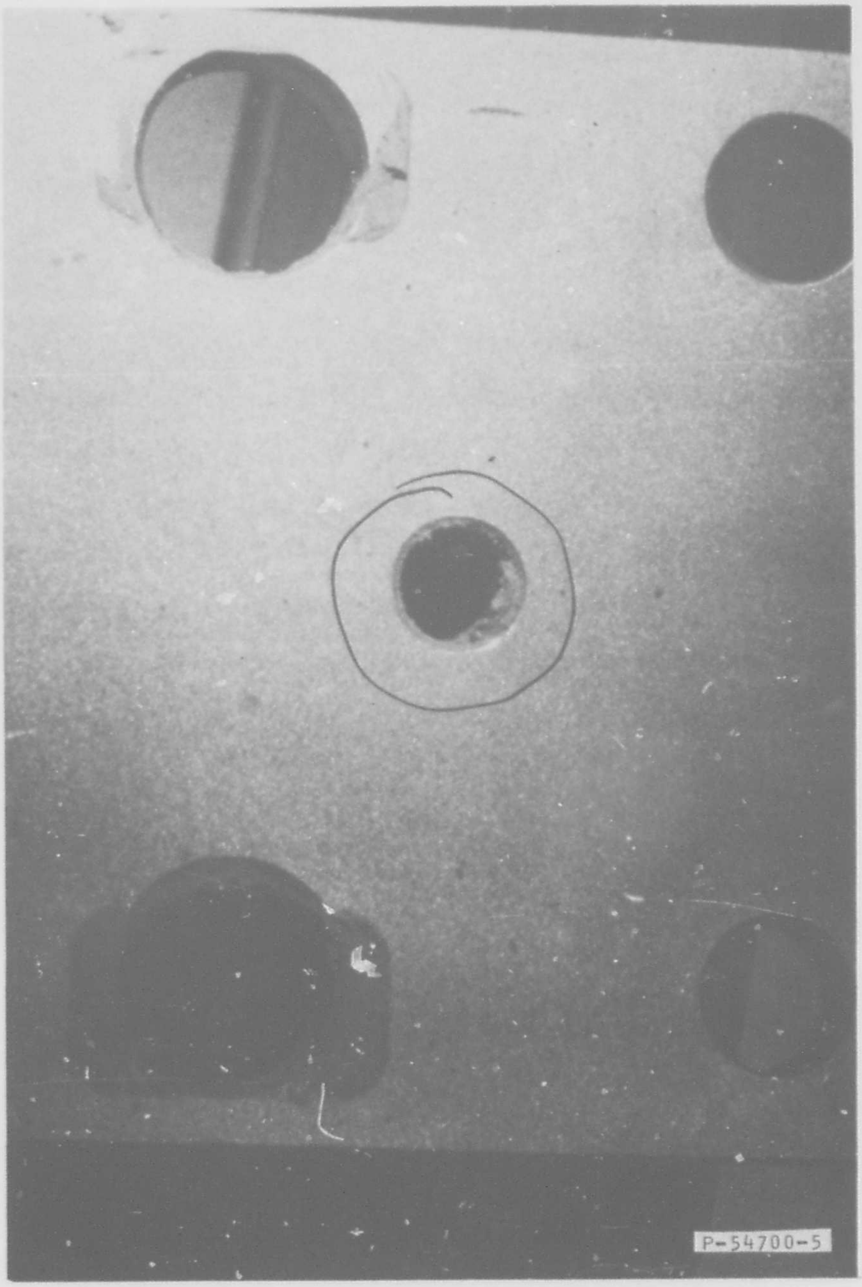


FIGURE 44

UNFILTERED BLEED AIR TEST
DIRT IN NEEDLE VALVE
ADJUSTMENT COVER
RUN 3, STATION 1, COVER

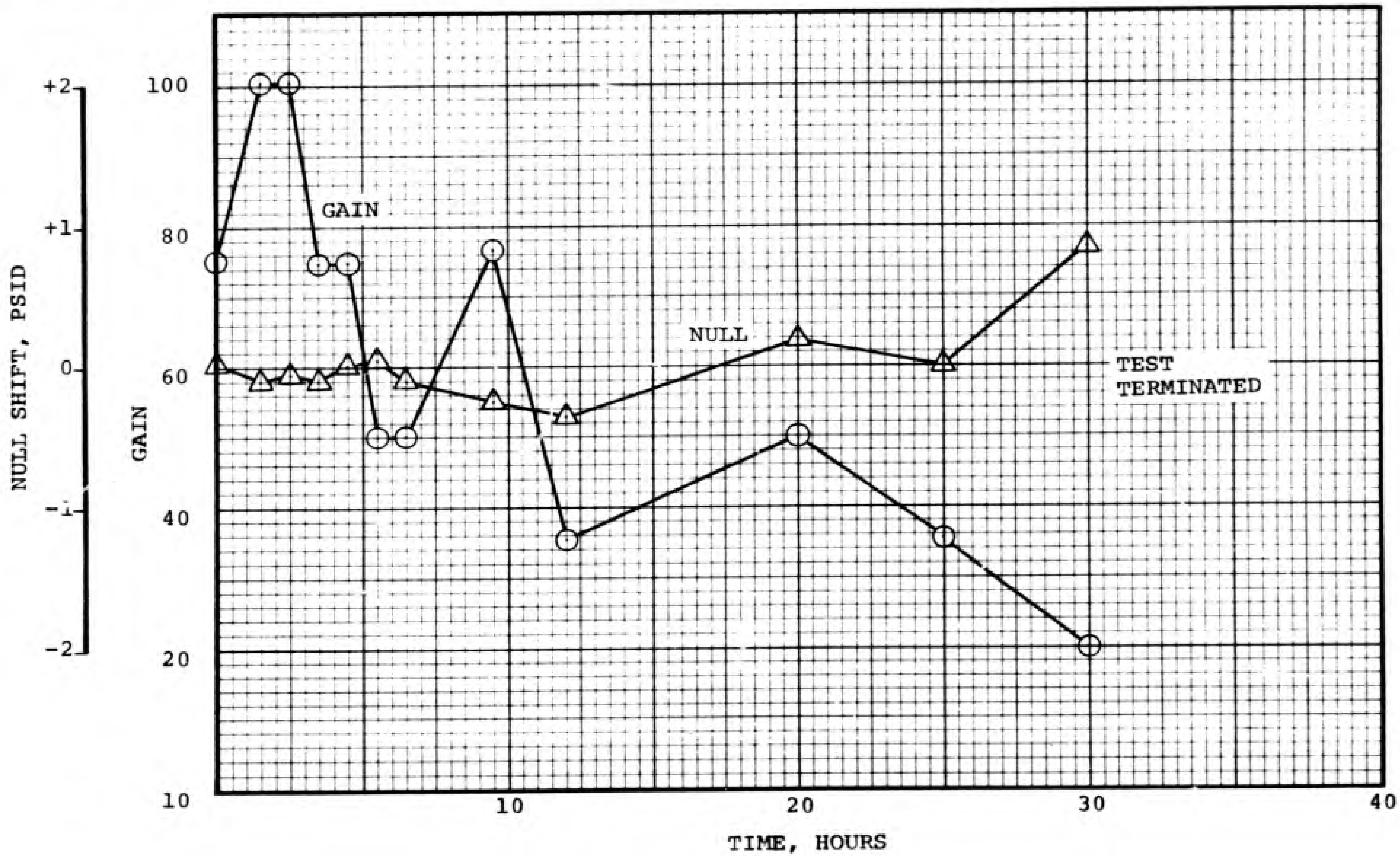


FIGURE 45

RUN FOUR SUMMARY
CIRCUIT STATION 1

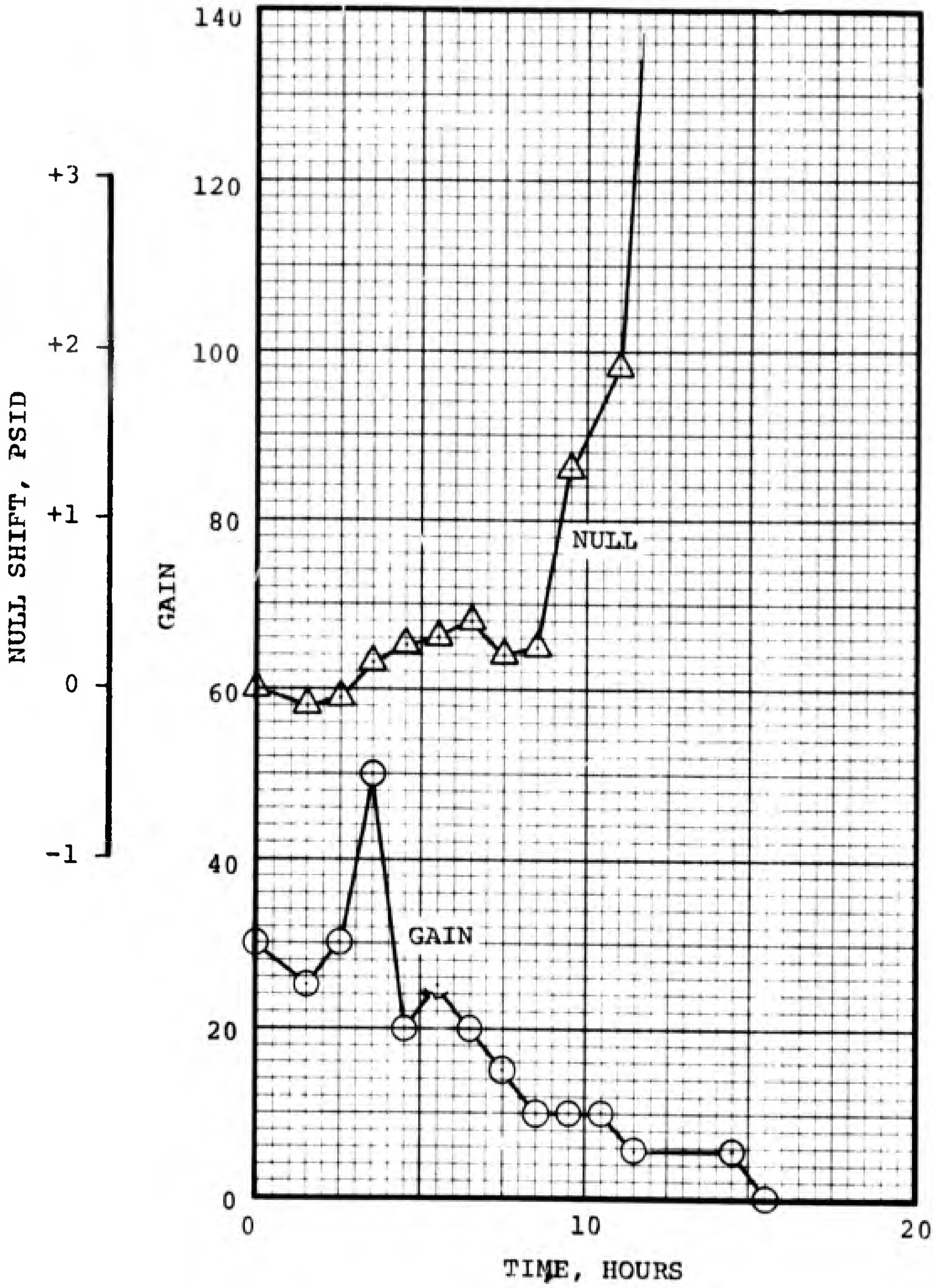


FIGURE 46

RUN FOUR SUMMARY
CIRCUIT STATION 2

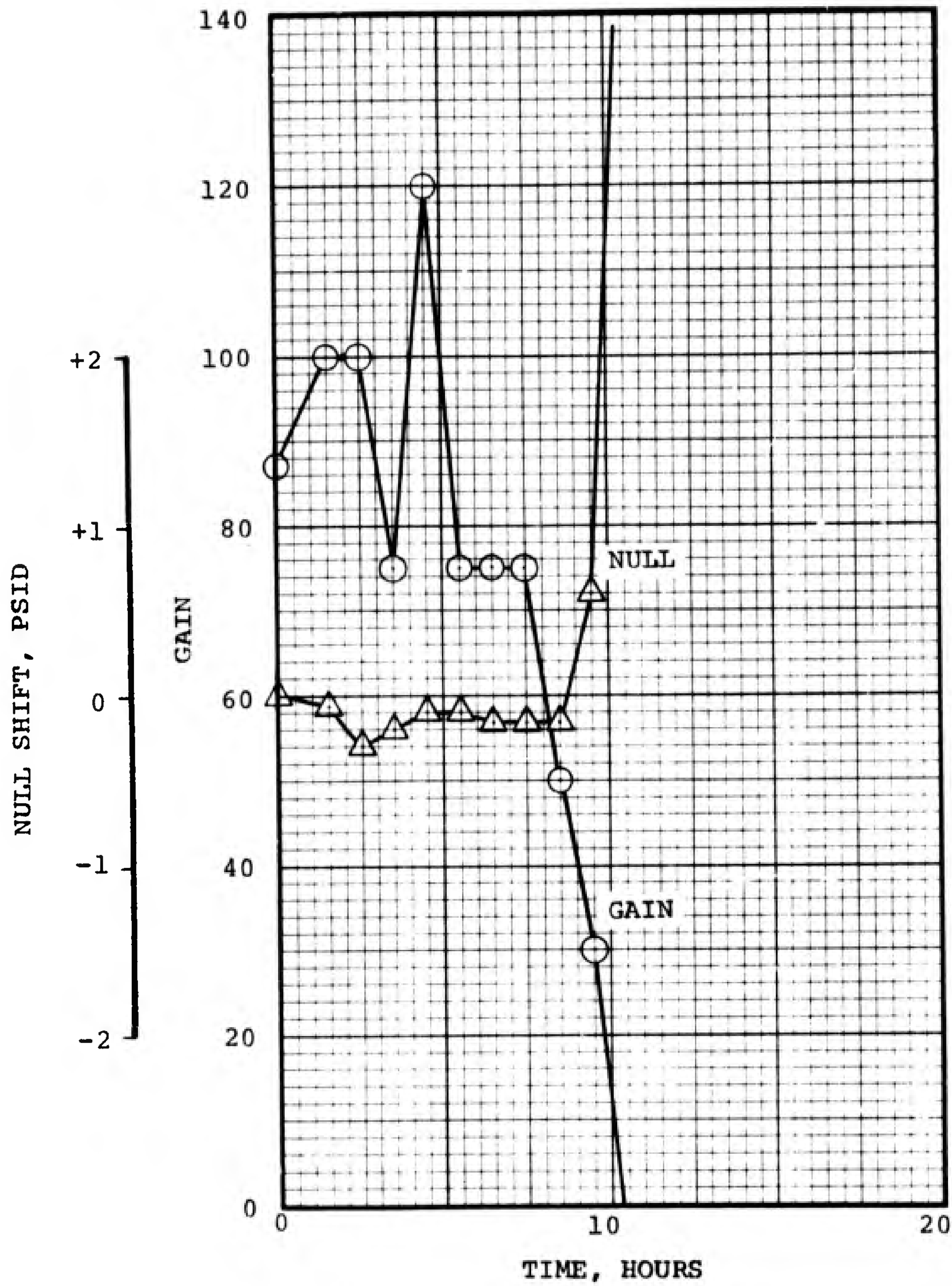


FIGURE 47

RUN FOUR SUMMARY
CIRCUIT STATION 3

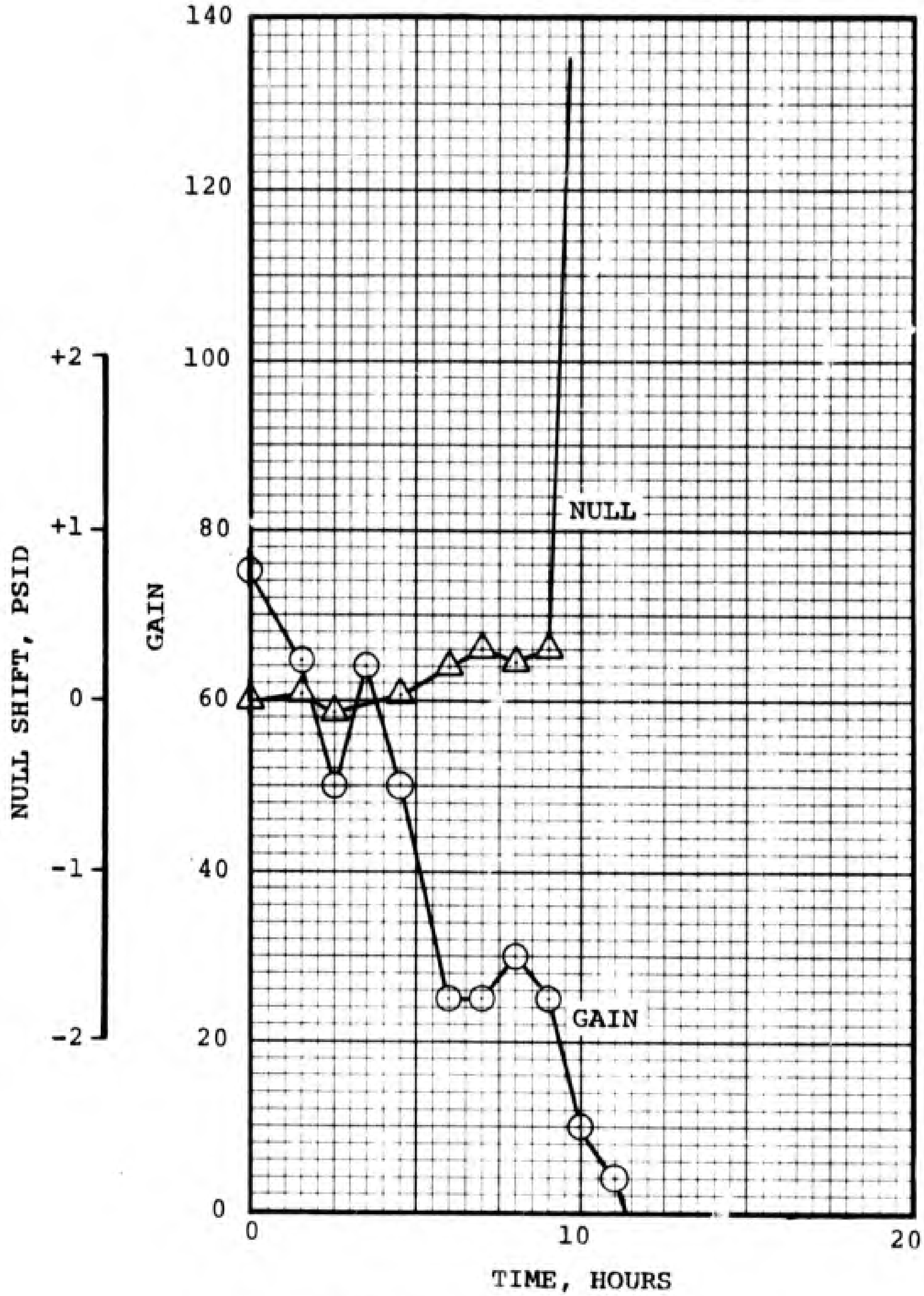


FIGURE 48

RUN FOUR SUMMARY
CIRCUIT STATION 4

4.5.2 Filter Efficiency Tests

The second phase of the test program consisted of subjecting several different filter configurations to efficiency tests, the objective being to determine on a gravimetric basis the percentage of dirt each filter would retain. To accomplish this, the clean filter was weighed, tested with contaminated airflow, and then weighed again. The setup utilized for these tests is shown schematically in Figure 49. The Millipore screen, used to trap downstream contamination, was also dried and weighed before and after each test. The tare weight of the filter represents the contaminant (dirt) trapped by the filter, and the tare weight of the Millipore screen represents the amount of dirt passed by the filter. The efficiency is calculated as follows:

$$\text{Percent Efficiency} = \frac{\text{weight of dirt trapped by filter}}{\text{weight of dirt trapped by both test filter and Millipore screen}}$$

In some tests, a water-filled impingement tube was utilized in lieu of a Millipore filter to catch particles passed by the test filter. The photograph of Figure 50 shows this technique. The impingment tube has the advantage of maintaining a consistent low level of backpressure on the test filter, thus eliminating the effects of flow variation. When this technique was employed, the dirty water was filtered through a Millipore paper filter, which was weighed before and after to ascertain the weight of contaminant retained. For several tests, the AiResearch Mobile Exhaust Analyzer Van was used to sniff the test section discharge and the discharge of each test filter, to establish a relative figure of merit for hydrocarbon removal.

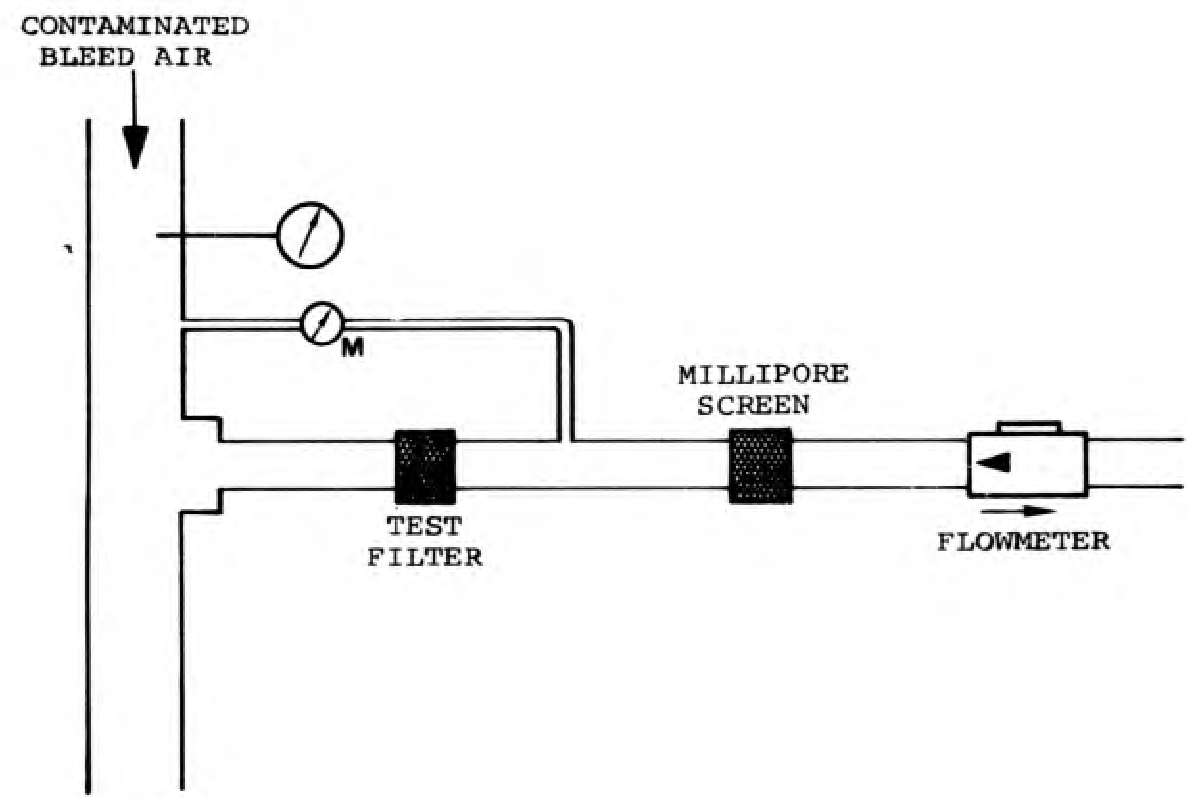


FIGURE 49

TEST SETUP SCHEMATIC DIAGRAM
FILTER EFFICIENCY AND CAPACITY TEST

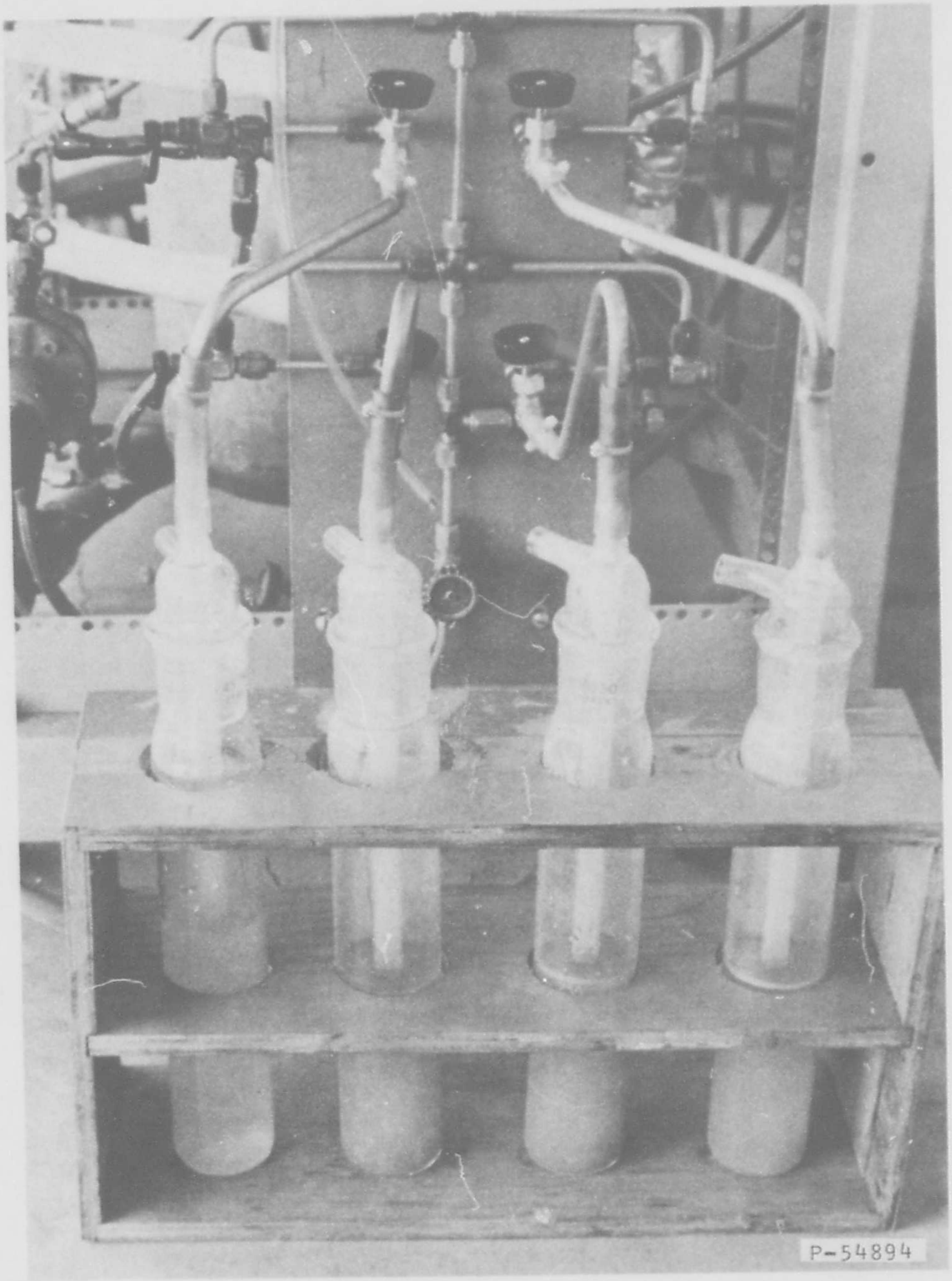


FIGURE 50

VIEW OF WATER-FILLED IMPINGER TUBES
USED FOR COLLECTING CONTAMINANTS AT
TEST FILTER DISCHARGE PORT

Several test filter configurations were evaluated during this stage of the program, and included:

1. AiResearch Filter Element, Part 111790 - This element is packaged in a housing, Part 663282. This is a three-square-inch area, depth media element. Several different element ratings were tested.

Element Part No.	Micron Rating
111790-1	5
111790-2	10
111790-3	20
111790-4	40
111790-7	74

2. Fluid Conditioning Products, Inc., Filter Part 9377-4052 - This is a filter system featuring two 10-micron filters packaged back-to-back (in series). Each element has a working surface area of 2.6 square inches and is of silver-brazed, sintered bronze construction. Rated flow is 3.5 scfm with a 3.0 psi pressure loss.

3. Hydraulic Research, Filter Part 11-11852 - This is a multi-layer element with a surface area of 30 square inches. The filter rating is 15 microns absolute.

4. Balston Filter, Part 95A, With a Part 050-11BH Microfiber Element - This element is a high efficiency coalescing element for removing solid particles down to 0.6 micron and for coalescing and removing liquid droplets to below 0.1 micron size. Surface area is 5.0 square inches.

5. Koby Filter, "Senior" Model - This is an activated charcoal and cellulose fiber pad filter with an absolute rating of 0.5 micron. Surface area of the cellulose pad is 7.0 square inches.

6. Cyclone Separator - Designed by McDonnell Douglas Astronautics Company for the Department of the Army, Harry Diamond Laboratories, under Contract No. DAAG39-73-C-0100. This unit was loaned to AiResearch for this program. The cyclone separator

was sized for an inlet pressure of 3.5 psig with a pressure drop of 0.5 psig at an airflow rate of 3.0 scfm (0.225 lb per min). The separator was intended to collect all particles greater than 5 microns and 50 percent of those particles with diameters of one micron. McDonnell Douglas reported this unit to be highly effective in protecting fluidic systems from contaminated engine bleed gases (air) and recommended applications where this device functioned as a prefilter upstream of a conventional barrier filter. Actual flow versus pressure loss at supply pressure levels from 20 to 40 psig were performed at AiResearch to verify performance, as shown in Figure 51.

4.5.2.1 <u>AiResearch Filter Elements Evaluation</u> - The first filter test (Run 5) was conducted on AiResearch filter elements with ratings of 5, 10, 20, and 40 microns (μ), using airflow at 40 psig and 300F contaminated with dry dirt only. The airflow rate was established at 0.2 pound per minute (2.66 scfm) through each test filter. The results of this test, which was of 5.5 hours duration, indicated the following efficiencies:

Filter Element μ	Efficiency percent
5	82
10	83
20	80
40	58

This test was rerun (Run 6) to check for repeatability of results, except that the 74μ element was substituted for the 20μ unit. The results of Run 6, with a duration of six hours, provided the following:

Filter Element μ	Efficiency percent
5	96
10	81
40	76
74	65

During both runs, the pressure losses across both the 5μ and 10μ elements were in the range of 10 to 13 psi. Also, the flow rate

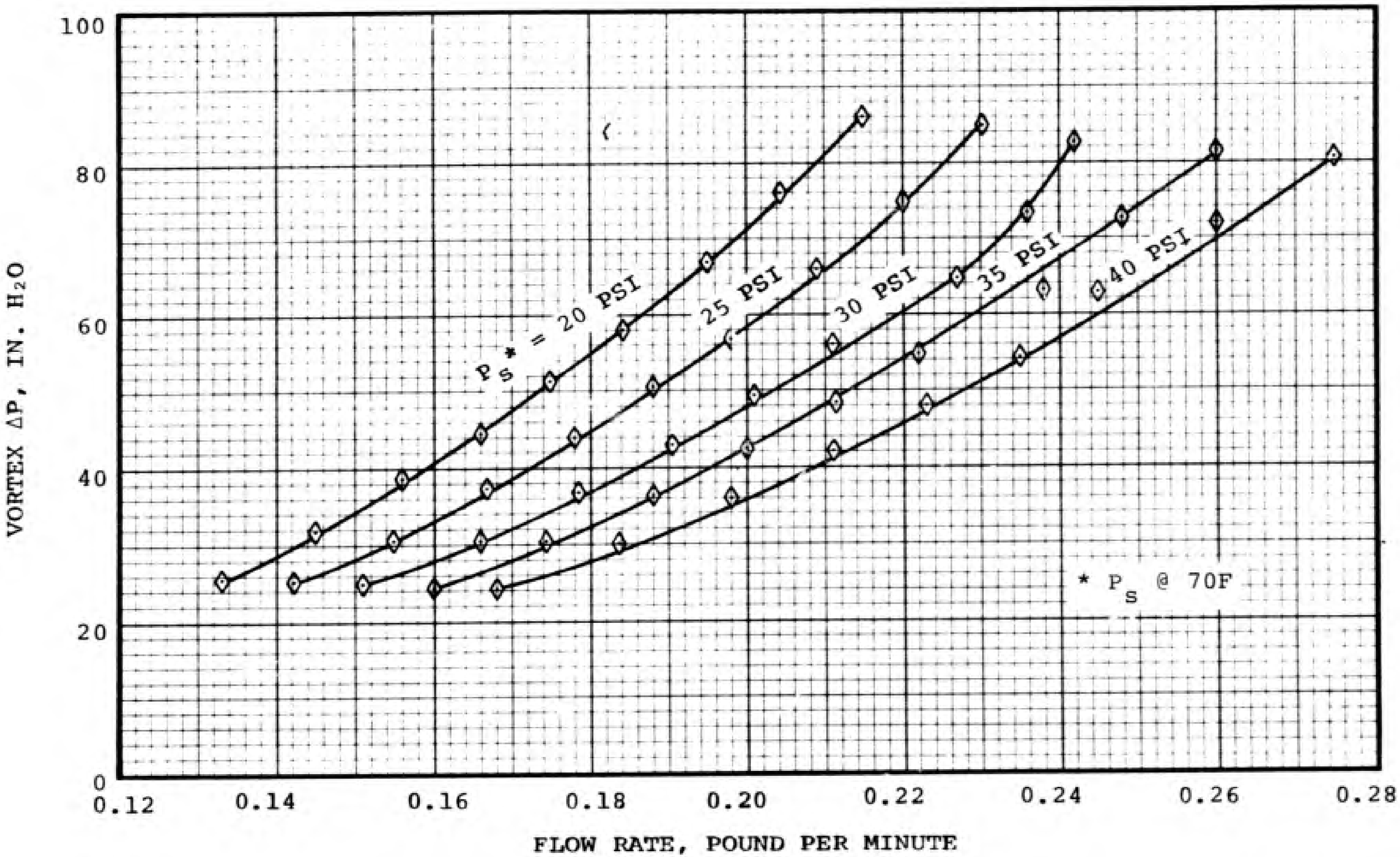


FIGURE 51

PRESSURE LOSS VERSUS AIRFLOW
CYCLONE SEPARATOR

across these elements gradually reduced as dirt buildup increased on the downstream Millipore filter. All test filters were bubble-point tested to verify specified ratings.

Run 7 duplicated Run 6 except that impinger tubes were substituted for the Millipore sampler to maintain constant backpressure as shown in Figure 50. The results of this six-hour test were as follows:

Filter Element μ	Efficiency percent
5	98
10	81
40	79
74	65

The final test of the AiResearch filter elements was a six-hour test (Run 8) with all liquid contaminants added along with the particulate matter (dirt). The results of this test indicated efficiencies as tabulated below.

Filter Element μ	Efficiency percent
5	96
10	80
40	85
74	73

The results of this series of tests indicated that, for filters of this design, selection of the 40μ or 74μ elements would be advantageous for two reasons. First, the relatively good filtration efficiency, despite the fact that the particle size distribution of the A.C. fine test dust was skewed toward the small particle size by the specified distribution.

Micron	Percent by Weight
0 to 5	39 ±2
5 to 10	18 ±3
10 to 20	16 ±3
20 to 40	18 ±3
40 to 80	9 ±3

Second, both the 5μ and 10μ elements had relatively short service lives. In general, the measured pressure loss across the 40μ and 74μ elements was in the range of 1 to 3 psid, whereas the corresponding loss across the 5μ and 10μ elements was in the 10 to 16 psi range. From this data, it may be concluded that this type of filter, with only three square inches of surface area, would require a pre-filter stage for longer life in heavy duty cycle applications.

4.5.2.2 Commercial Filter Evaluation - Four different commercially available filter configurations (Koby, Fluid Conditioning Products, Balston, and Hydraulic Research) were subjected to comparative contamination testing. Run 9 was a 14-hour test with inlet conditions of 40 psig and 300F and airflow of 0.2 lb per min through each filter with all contaminants introduced. The test filters are shown before the test in the photographs of Figures 52 and 53. Figure 54 is a photograph of the Koby filter, and Figures 55 and 56 show the Balston element, following this test. Results of this 14-hour test were as follows:

Filter	Efficiency percent	Pressure Drop psi
1. Fluid Conditioning Products	99	5.9
2. Koby	*	11.0
3. Balston	90	2.1
4. Hydraulic Research	99.84	5.5

* No efficiency data was available on the Koby elements during this run since outgassing caused a net weight decrease.

During this test, it was noted that water was dripping from the Millipore sampler downstream of the Balston filter for the final 13.5 hours of this 14-hour test due, apparently, to the coalescer becoming saturated early in the test run.

The pressure drop fell from 5.0 to 2.1 psi across the Balston filter while the flow rate fell from 0.2 to 0.033 ppm. This would indicate water saturation of the downstream Millipore sampling paper. Thus, while the Balston element indicated 90 percent efficiency in trapping solids, it failed to coalesce entrained water vapor during Run 9. Also, the Koby filter indicated a 0.7 percent net weight decrease during Run 9. It was suspected that outgassing of the paper media may have occurred. Also, because of the problems in measuring a weight change of 4.6 gram for a filter weighing 649 grams, it was decided to retest the Balston and Koby filters during Run 10.

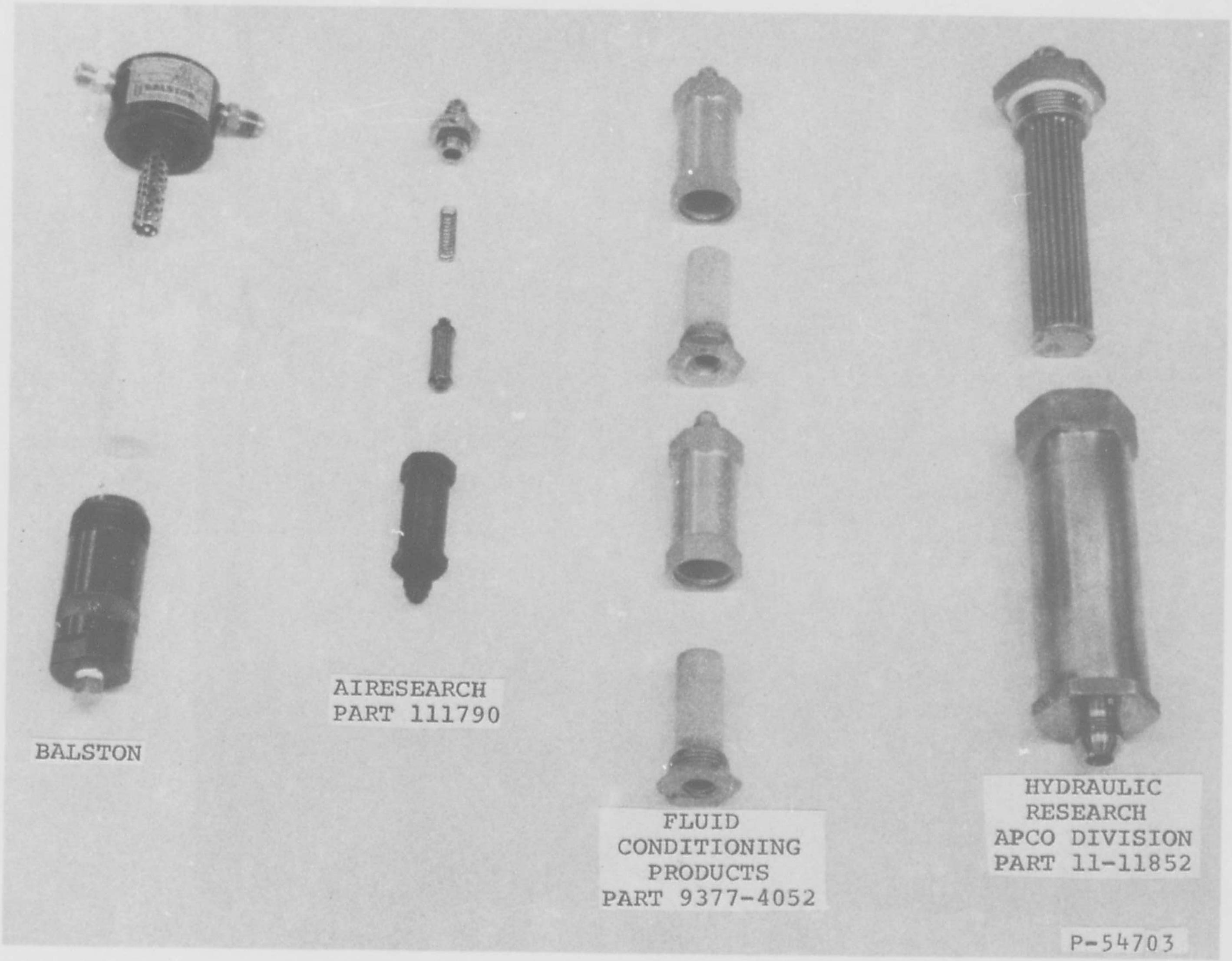


FIGURE 52

VIEW OF SEVERAL TEST FILTERS

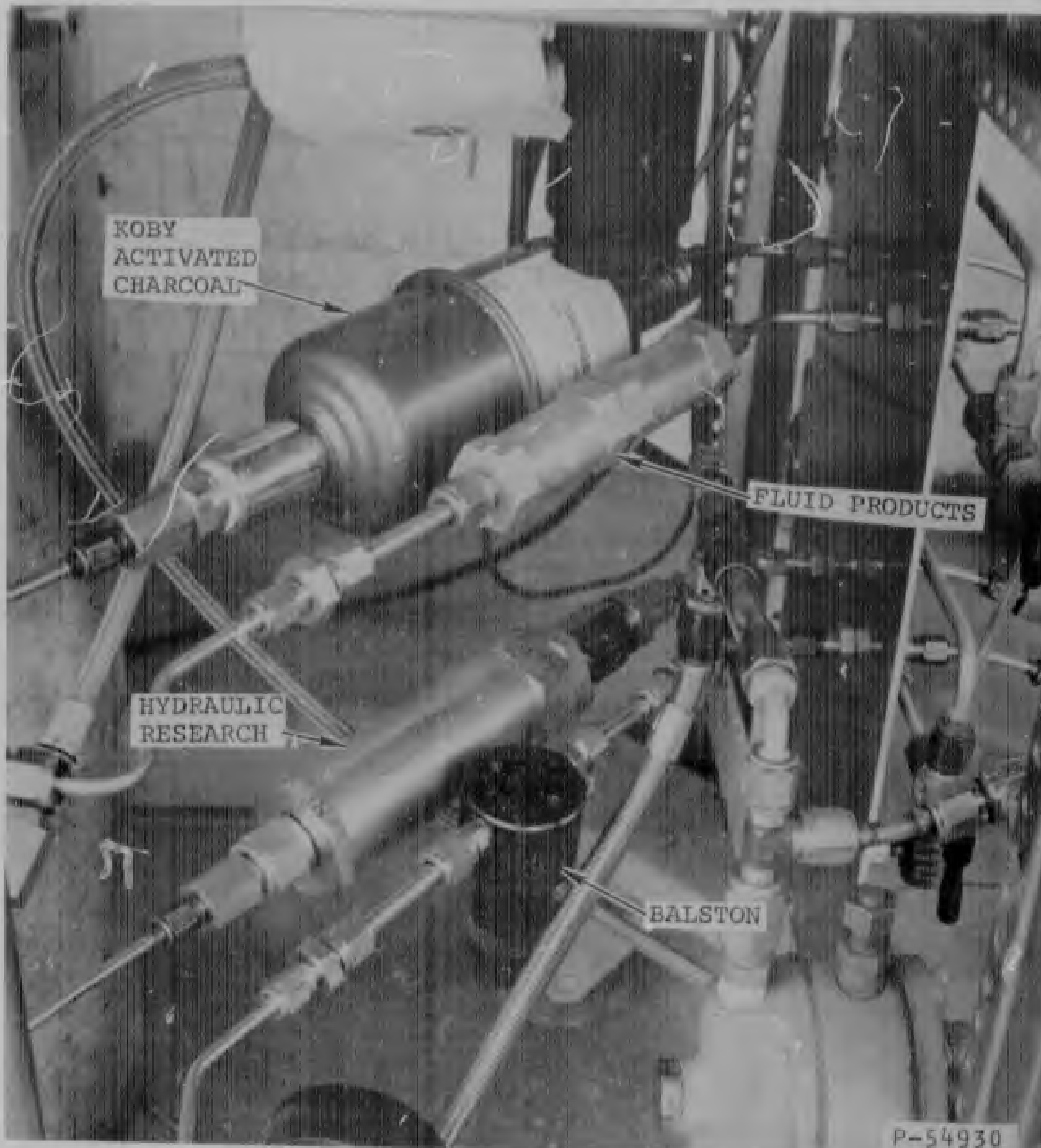


FIGURE 53

VIEW OF FOUR TEST FILTERS
INSTALLED IN TEST SETUP

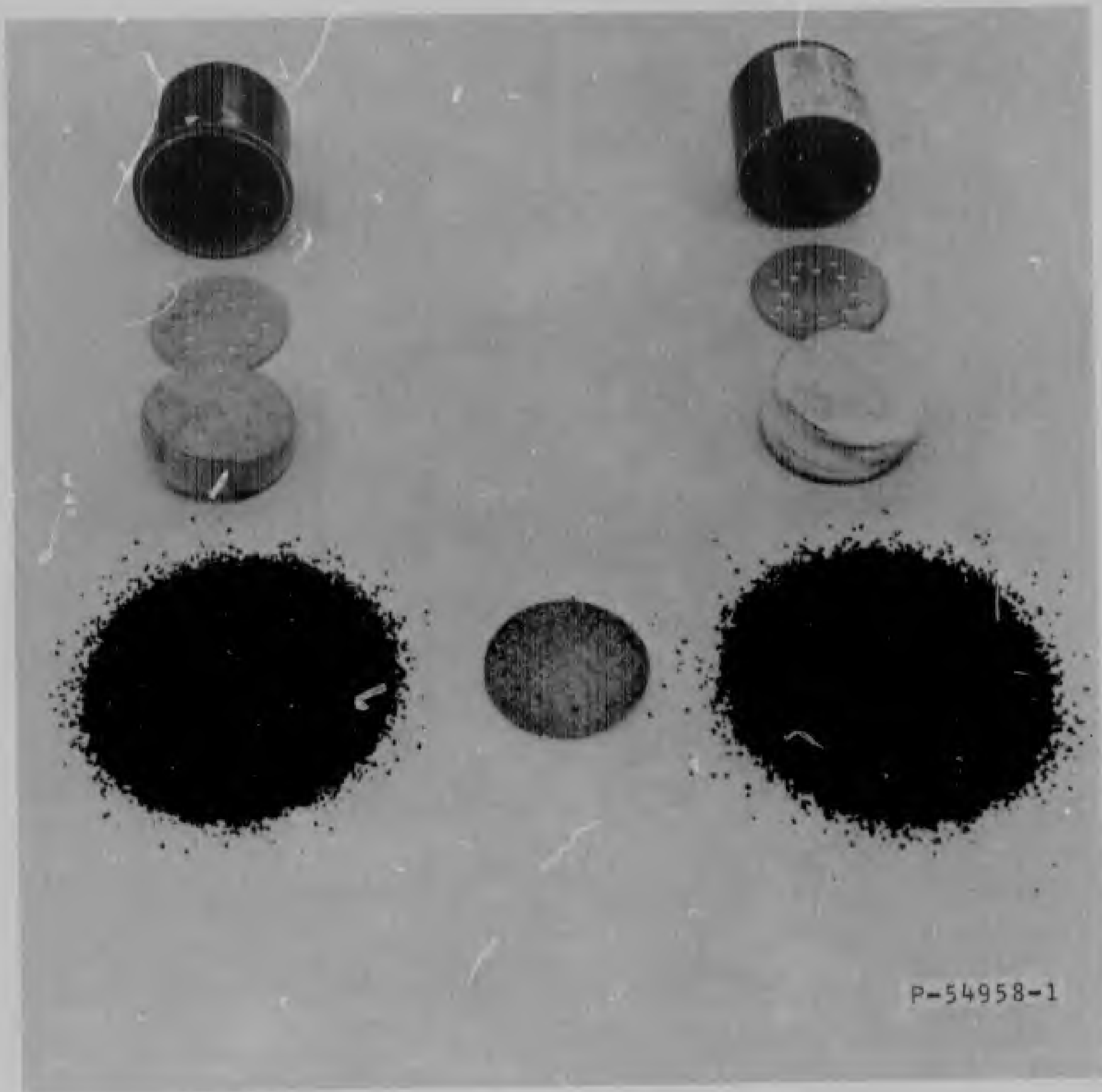


FIGURE 54

CUTAWAY VIEW OF KOBY ACTIVATED CHARCOAL FILTER SHOWING DIRT COLLECTED ON INPUT FILTER DISC STACKS

FIGURE 55

VIEW OF BALSTON COALESCER
ELEMENT AFTER TEST

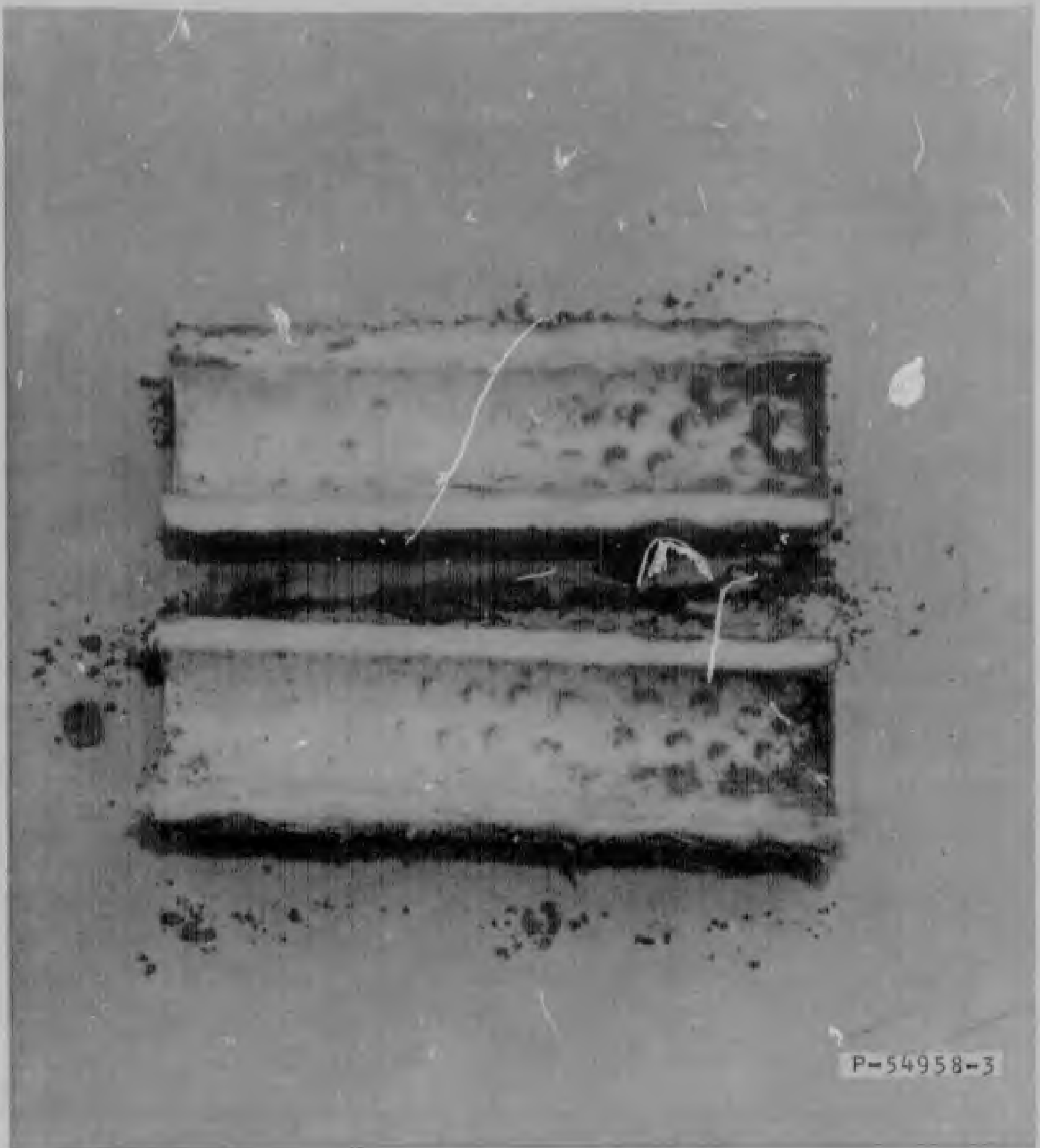


FIGURE 56

CUTAWAY VIEW OF BALSTON
ELEMENT SHOWING DIRT
MIGRATION THROUGH ELEMENT
(NOTE SUPPORT TUBE PATTERN)

During Run 10, the cyclone separator, depicted assembled and disassembled in the photographs of Figures 57 and 58, was tested for a period of 9.5 hours with all contaminants. The Koby and Balston filters were also retested on this run. At the 9.5-hour point, both the Koby and Balston filters exhibited a pressure drop exceeding the 16 psid range of the gauge. The test was terminated at this point as both elements were loaded. Also, during this run, the AiResearch Mobile Emission Analyzer Van sampled the discharge of the Koby, Balston, and cyclone separator filters, as well as the main test section, to measure hydrocarbon levels. To determine cyclone separator efficiency, the scavenge port was vented to a Millipore sampler. The results of this test are shown below.

Filter	Efficiency percent	Pressure Drop psi	Hydrocarbons* ppm
1. Cyclone Separator	91	1.1	1.8
2. Balston	99	>16	2.5
3. Koby	99.7	>16	1.2

* Test section hydrocarbon level at CBAS muffler discharge was 6.0 ppm. These readings were taken by the Mobile Emission Analyzer Van.

The next run (Run 11) was conducted with only the cyclone separator in the test section and with the scavenge port closed so that scavenged contaminants were collected in the integral collection chamber. The filter efficiency after 19.5 hours of contamination testing was 85 percent, which is lower than the 91 percent efficiency recorded with the collection chamber vented.

The tentative conclusions formulated from the foregoing series of test runs were as follows.

(1) The cyclone separator with scavenge port open is a highly efficient prefilter with limitless capacity which should greatly extend the life of secondary stages with no required maintenance.

(2) The activated charcoal (Koby) and coalescer (Balston) filter elements were highly efficient at removing solid particles, but have limited service life due to surface area and liquid handling capacity.

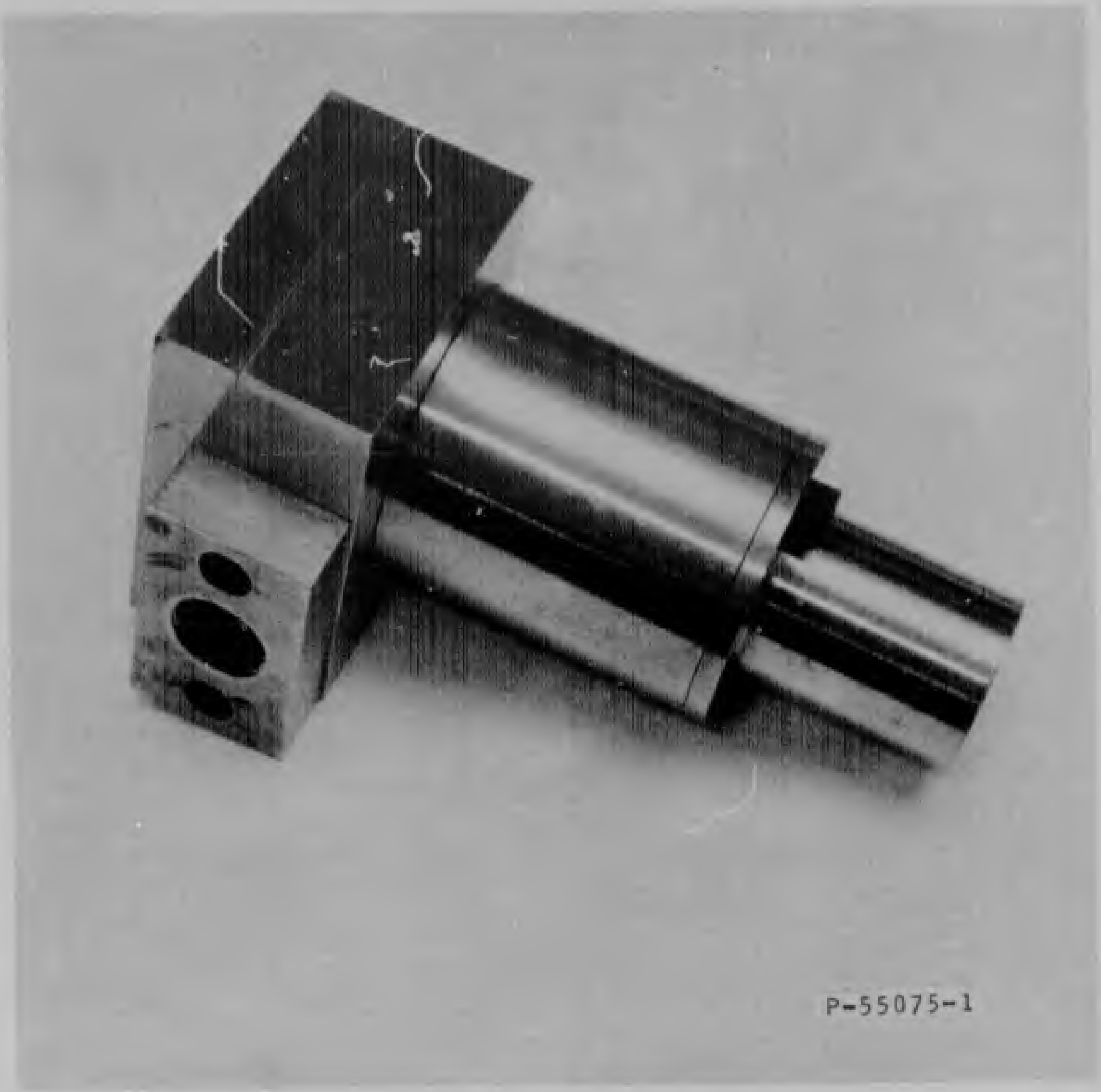


FIGURE 57

PHOTO OF CYCLONE SEPARATOR
ASSEMBLED

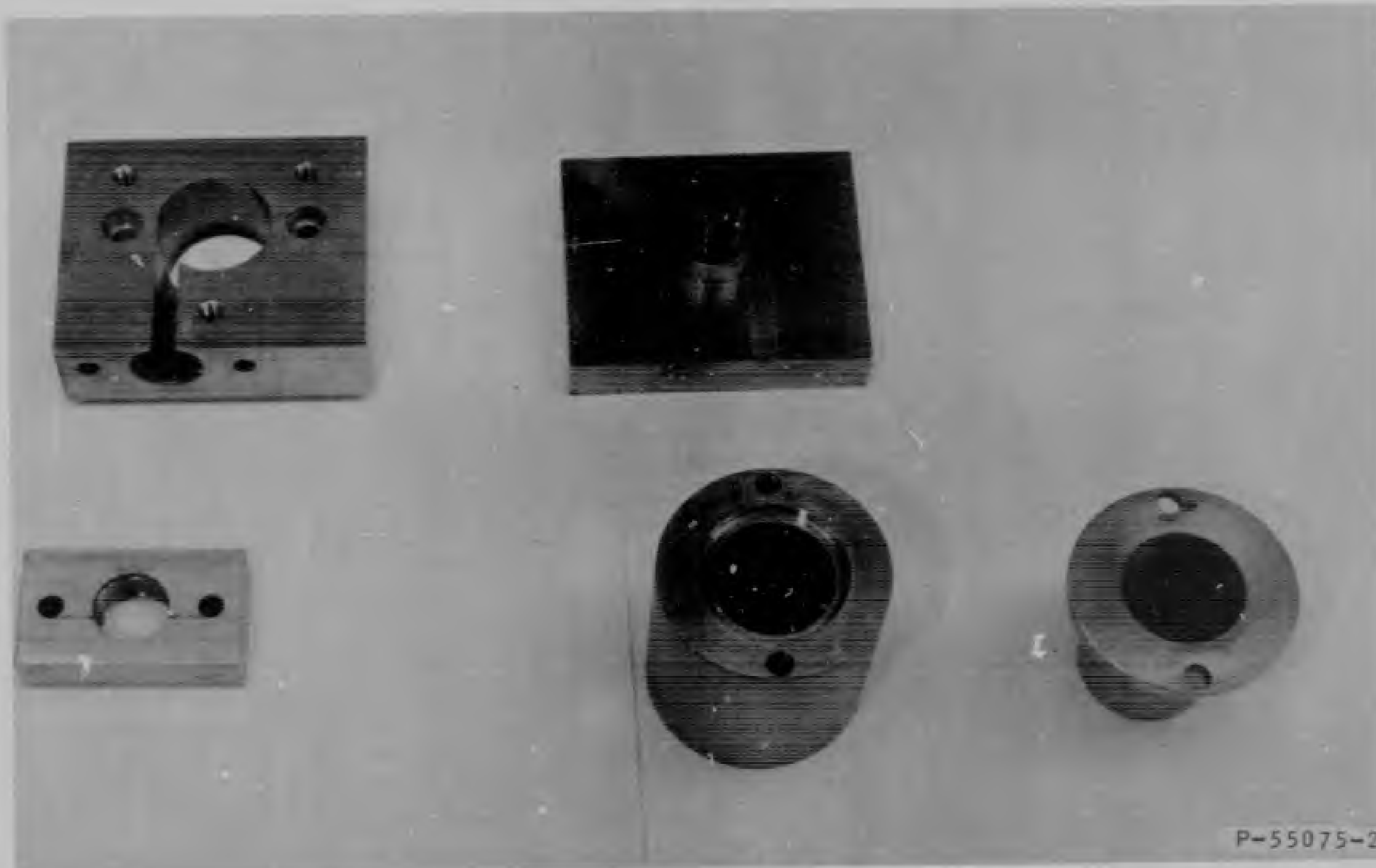


FIGURE 58

PHOTO OF CYCLONE SEPARATOR
DISASSEMBLED

(3) The multi-stage element Hydraulic Research filter is highly efficient in filtering solids. This design coupled with the cyclone separator prefilter should be very efficient with long life potential. More life studies should be performed to determine the effect of surface area on filter life when used with the cyclone separator.

(4) The two-stage sintered bronze filter from Fluid Conditioning Products was highly efficient in solid particle removal. This configuration, however, appears open to question since,

a. Sintered bronze bead filters have been known to cause media migration in hydraulic installations, and

b. The arrangement of two elements in series appears questionable as regards optimizing holding capacity or service life, package size, and efficiency, particularly, since the multi-stage element in the Hydraulic Research unit appears to accomplish this concept in a single element. Servicing the design with two stages in series would require cleaning or replacing both elements.

4.5.3 Service Life Tests

For the service life tests, the fluidic circuits were installed on the CBAS as shown in the photograph of Figure 59 and the test filters were installed in the setup as depicted in the photograph of Figure 60. As shown, the Hydraulic Research filter was installed in the line to Station 1, the cyclone separator with the AiResearch 10m filter in series was in the line to Station 2, and the AiResearch 74m filter was used in the line upstream of Station 3.

4.5.3.1 Test Run 12 - During this test, Stations 1 and 3 accumulated 18 hours of contaminated airflow operation without removal. Station 2 also accumulated 18 hours of run time, but the filtration system was removed and cleaned twice during the course of the test. The first removal occurred after the first four hours to inspect for suspected foreign matter which may have been inadvertently admitted to the system during the test setup installation. However, inspection revealed that this filter combination, which had been expected to provide a long operating life for the circuit, had failed after only four hours. The test recordings of Figures 61 and 62 show performance at the start and after four hours of Run 12. At this time, both the fluidic circuit and the filter system from Station 2 were cleaned before continuing the test.

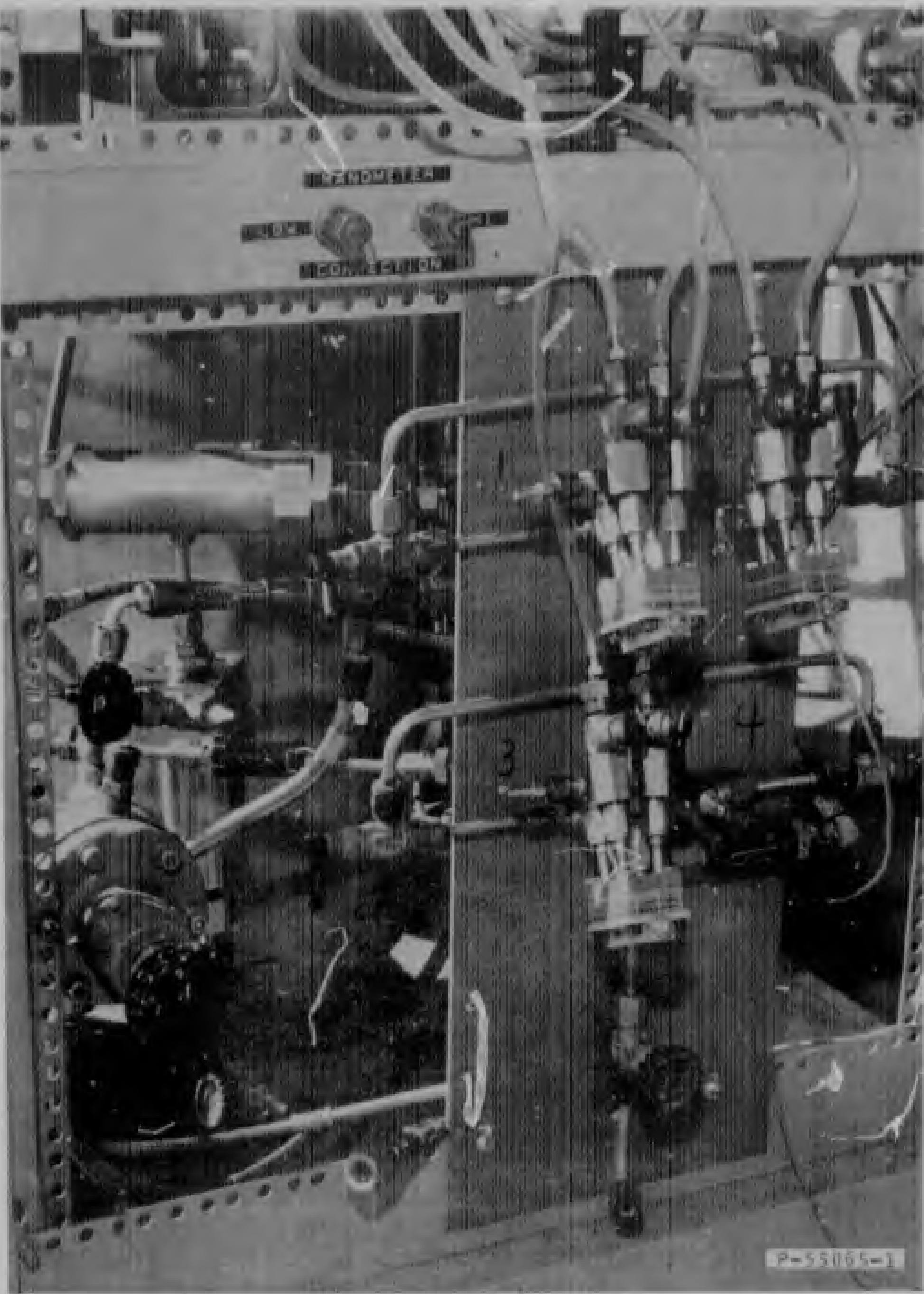


FIGURE 59

SERVICE LIFE TESTS
CIRCUIT TEST SETUP

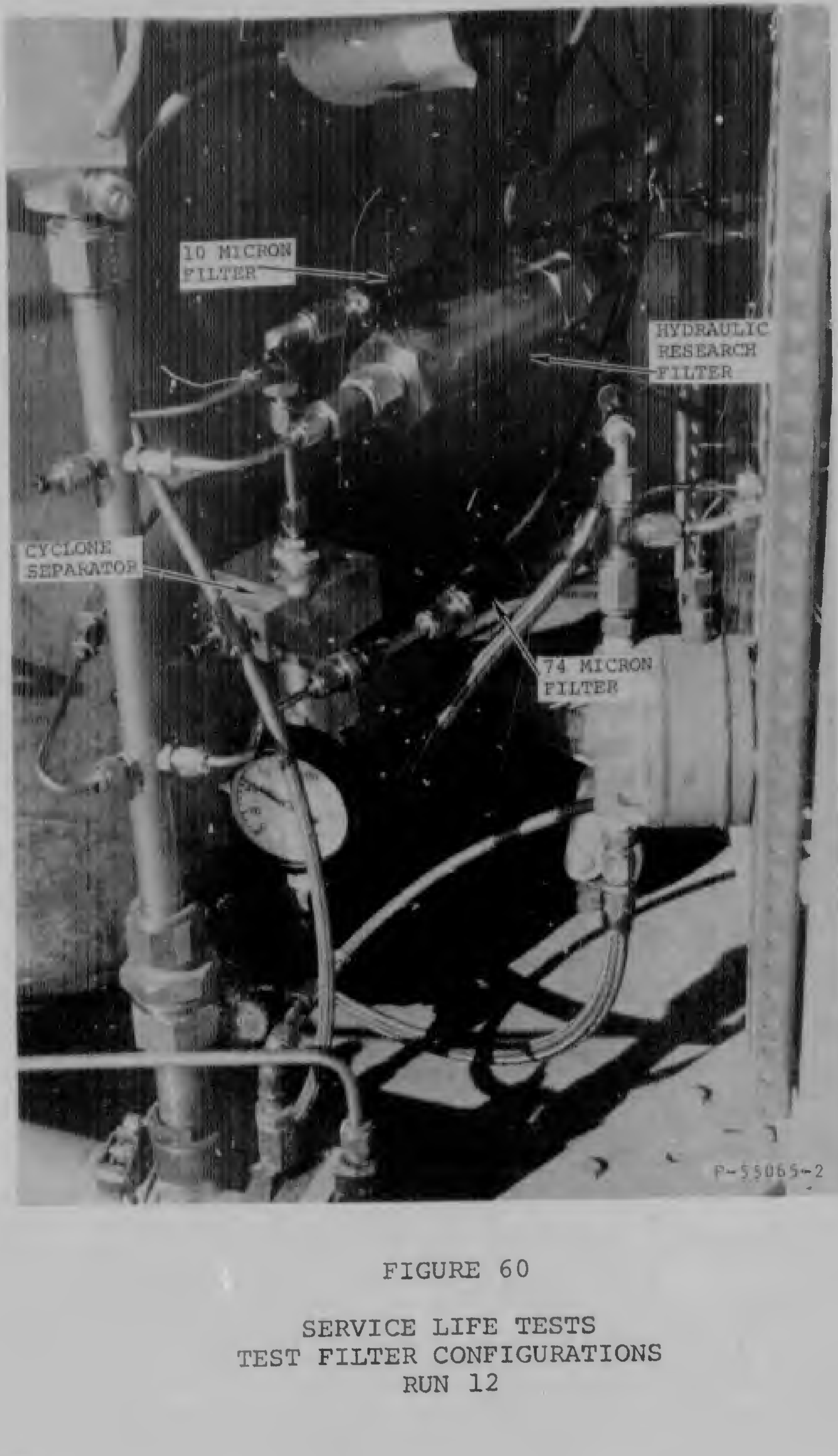


FIGURE 60

SERVICE LIFE TESTS
TEST FILTER CONFIGURATIONS
RUN 12

MP-54078

HEWLETT-PACKARD/MOSELEY DIVISION
9270-1006
FOR USE ON AUTOGRAF RECORDERS
10 UNITS/DIVISION

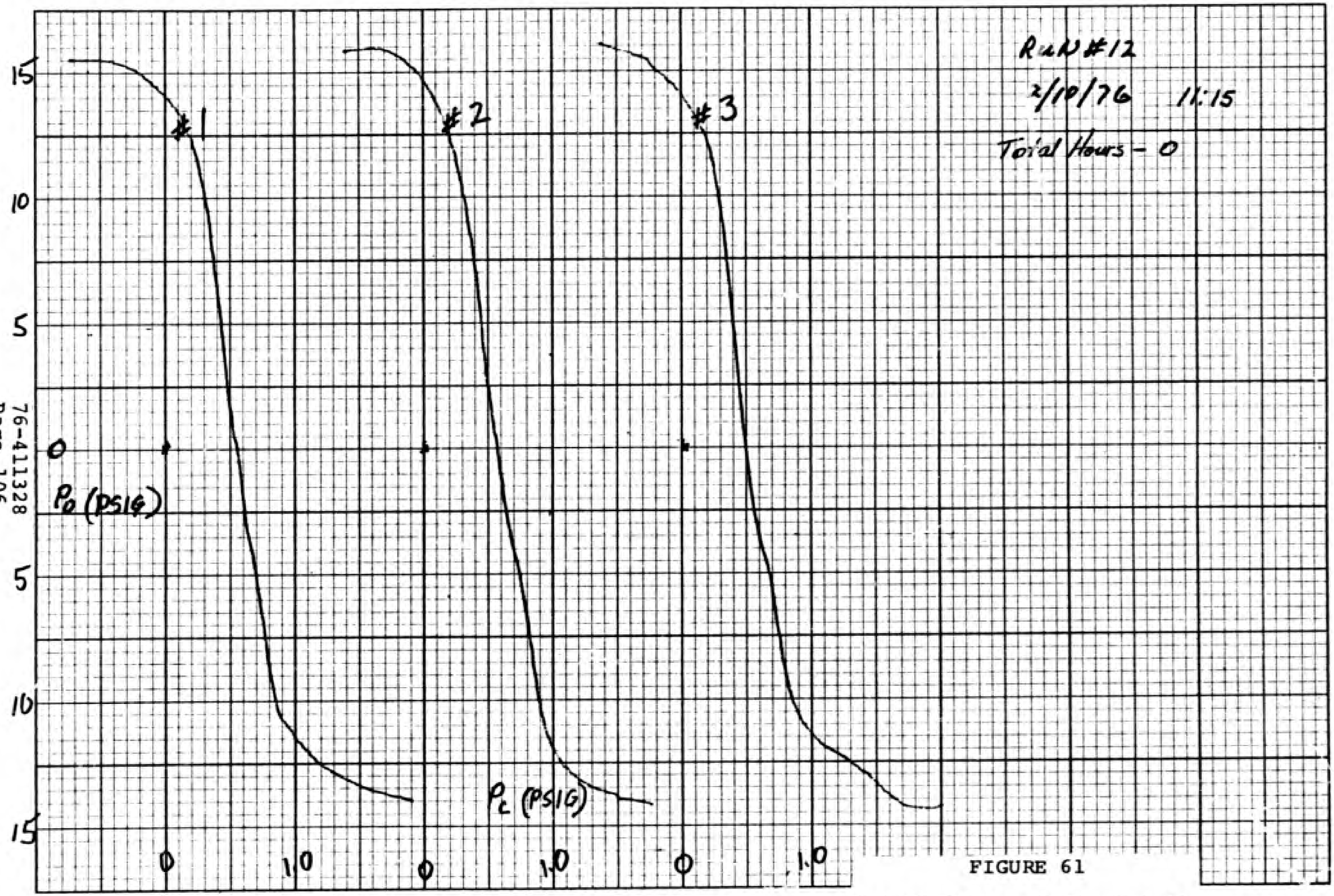


FIGURE 61

RECORDING 1 - START RUN 12

HEWLETT-PACKARD/MOSELEY DIVISION
9270-1006
FOR USE ON AUTOGRAF RECORDERS
10 UNITS/DIVISION

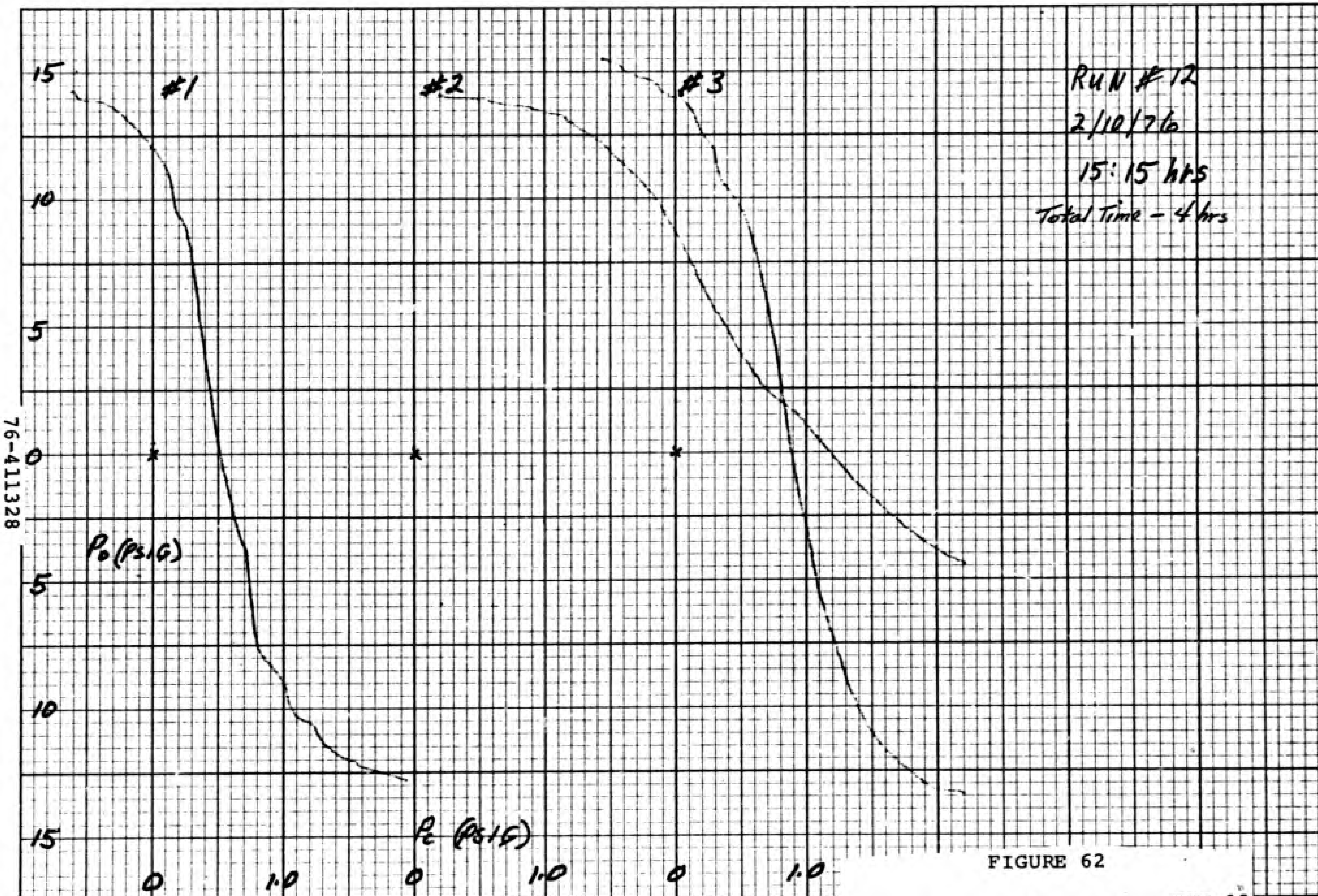


FIGURE 62

RECORDING 2 - FOUR HOURS RUN 12

Within one hour after continuation of this test, the circuit on Station 2 indicated a degradation in performance. At this point, it was suspected that condensation was taking place inside the circuit since the stack temperature for maintaining the water in the vapor state was marginal. In an effort to remedy this suspected problem, a crude ambient box was placed over the circuits in an attempt to maintain a higher temperature in the stacks. With this improvisation, the stack temperature did increase by 27 degrees, but the circuit performance did not improve. At the end of three hours after continuing the run, the circuit of Station 2 had ceased to function, as shown by Figure 63; so it again was removed, inspected, and cleaned along with the filter system.

In an attempt to determine the cause of the rapid failures on Station 2, the test run was continued for a 7-hour period during which dirt was the only contaminate introduced. The Station 2 circuit exhibited good performance throughout this period. At this point, Stations 1 and 3 had accumulated 14 hours of contaminated air testing. The No. 1 circuit performance was still acceptable, but the No. 3 circuit exhibited a considerable null shift (P_C = 0.5 to 1.6 psi).

For the final four-hour portion of this run, oil and salt water were introduced along with the dirt, but without additional water. Once again the No. 2 circuit failed rapidly after three hours of exposure to the noted conditions, as shown in Figure 64.

Following completion of Run 12, all circuits and filter systems were removed from the CBAS setup, carefully examined and compared, photographed, and then cleaned.

4.5.3.1.1 Observations of Contamination in Circuits (Run 12) - During the first disassembly inspection of Circuit 2 after a four-hour run time, the inlet screen appeared to be approximately 20 percent blocked, but no other blockage was apparent in the circuit. The path of the power jet was defined by a deposit of oily dirt along the entire length of the vent plate, with the heaviest deposit in the interaction region of the first-stage amplifier. The amplifiers in the second and third stages were somewhat cleaner and, except for the supply transfer, there was virtually no contaminant accumulation in transfer passages, control ports, or output ports. During the second teardown, observations were essentially identical to those above.

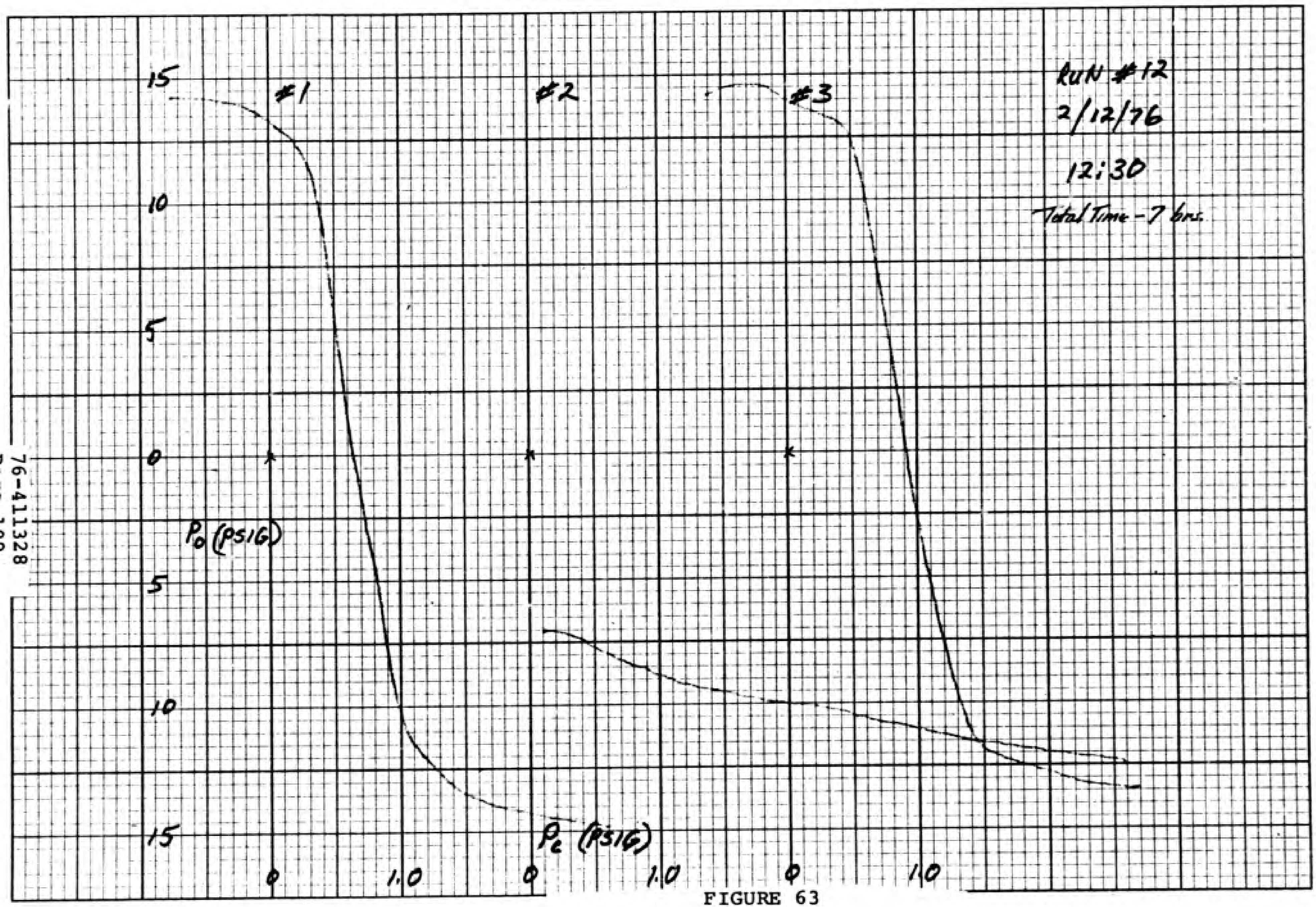


FIGURE 63

RECORDING 3 - SEVEN HOURS RUN 12

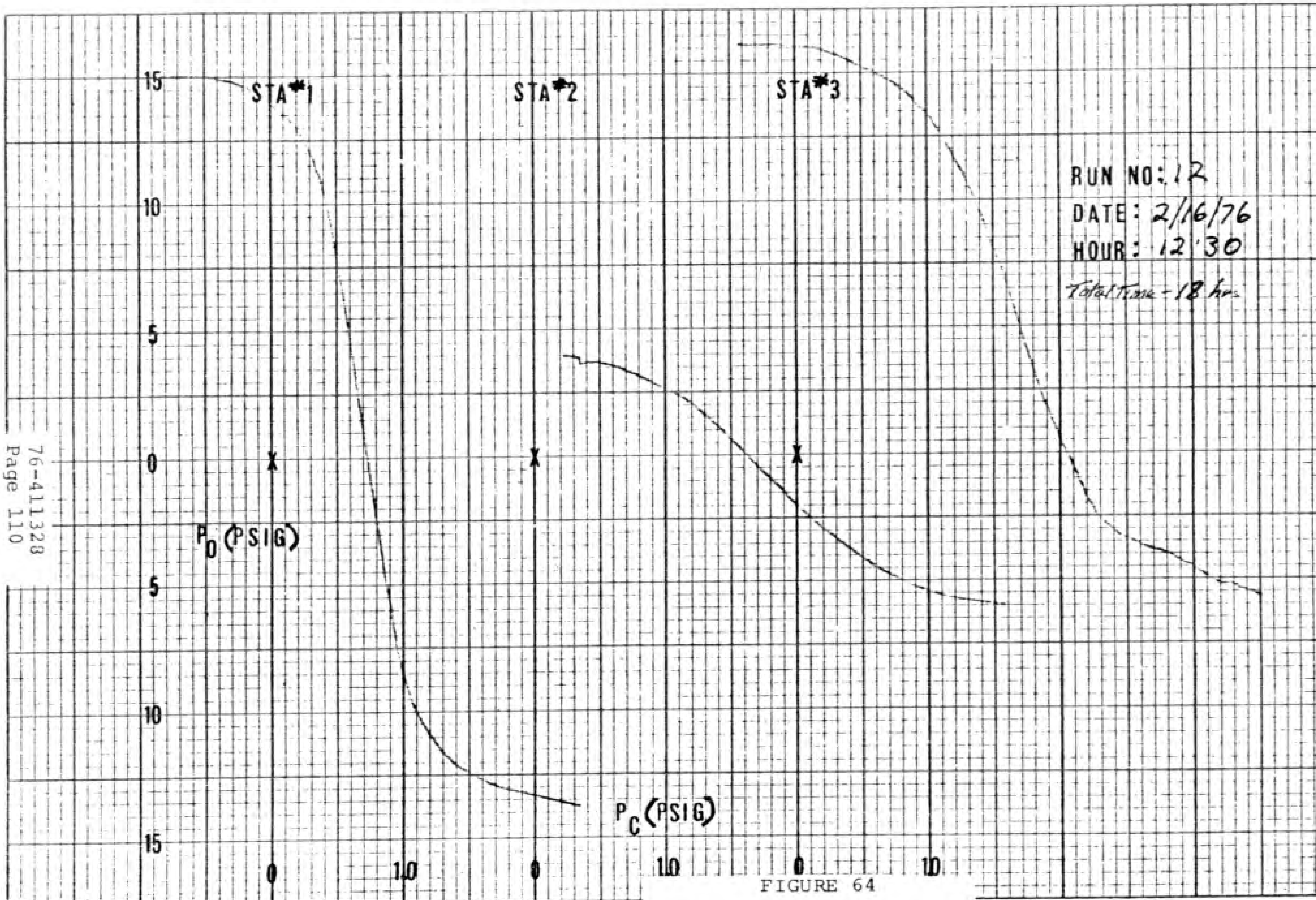


FIGURE 64

RECORDING 4 - END RUN 12

In the final teardown at the conclusion of Run 12, the inlet screen was found to be approximately 50 percent blocked, and the condition of the inlet filter is shown in the photograph of Figure 65. The supply passages showed some light dirt deposits on passage walls, but no blockage. The supply passages to the first and third stages showed slightly more dirt than the passage to the second stage. All transfers were clean except the supply transfer, shown in Figures 66 and 67, which had dirt deposits the entire length but not enough to impede flow. The amplifiers had about the same appearance as in the two previous teardown inspections. They are depicted in Figures 68 through 70. The photographs of Figures 71 through 76 present magnified views of first, second, and third-stage laminations for comparison of contaminant flow and wear patterns.

The disassembly inspection of Circuit 1 after 18 hours of accumulated time without removal during Run 12 revealed the overall circuit to be relatively clean, with no blockage in the stack. The Hydraulic Research filter was installed upstream in Station 1 and the condition of the filter element following the 18-hour test period is shown in Figure 77. Inspection disclosed only a very light deposit of dirt on the vent plates in the amplifier output ports of Circuit 1. To verify that this circuit and filter was subjected to the programmed quantity of contamination, the contaminants were extracted from the filter and compared to previous runs. The filter contained 0.0404 gram of dirt per pound of air (average) flowing through it, or 0.485 gram per hour, for Run 12.

The final teardown inspection of Circuit 3 following the 18-hour exposure to contaminated airflow showed that the inlet screen had very little blockage. The supply passages to the first and third stages contained light dirt deposits on the walls; but the supply passage to the second stage was approximately 30 percent blocked by the dirt buildup on the walls. That portion of the second-stage supply passage which extends beyond the second-stage amplifier supply port was filled with dirt up to the entry into the amplifier. All transfer passages contained a significant amount of dirt to the extent that some were partially blocked. Partial blockage was also evident in the needle valve ports. In general, passages with higher airflow velocities were cleaner, as expected, than those with lower velocities. An obvious eroding of splitters and sharp cusps at the entry to receiver ports was visible in all stages.

FIGURE 65

AIRESEARCH 10-MICRON FILTER ELEMENT
CIRCUIT 2, RUN 12

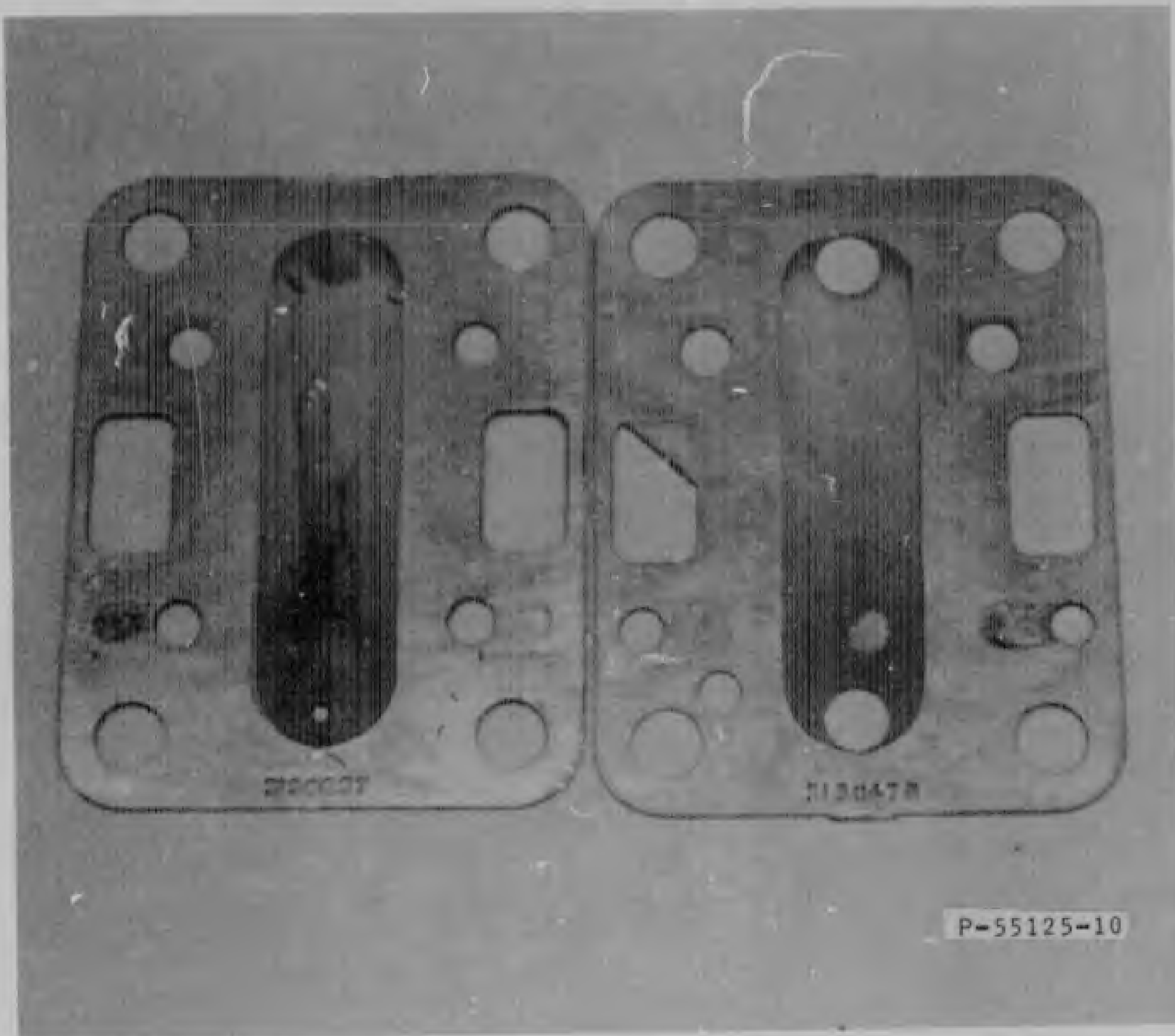


FIGURE 66

SUPPLY TRANSFER
CIRCUIT 2, RUN 12

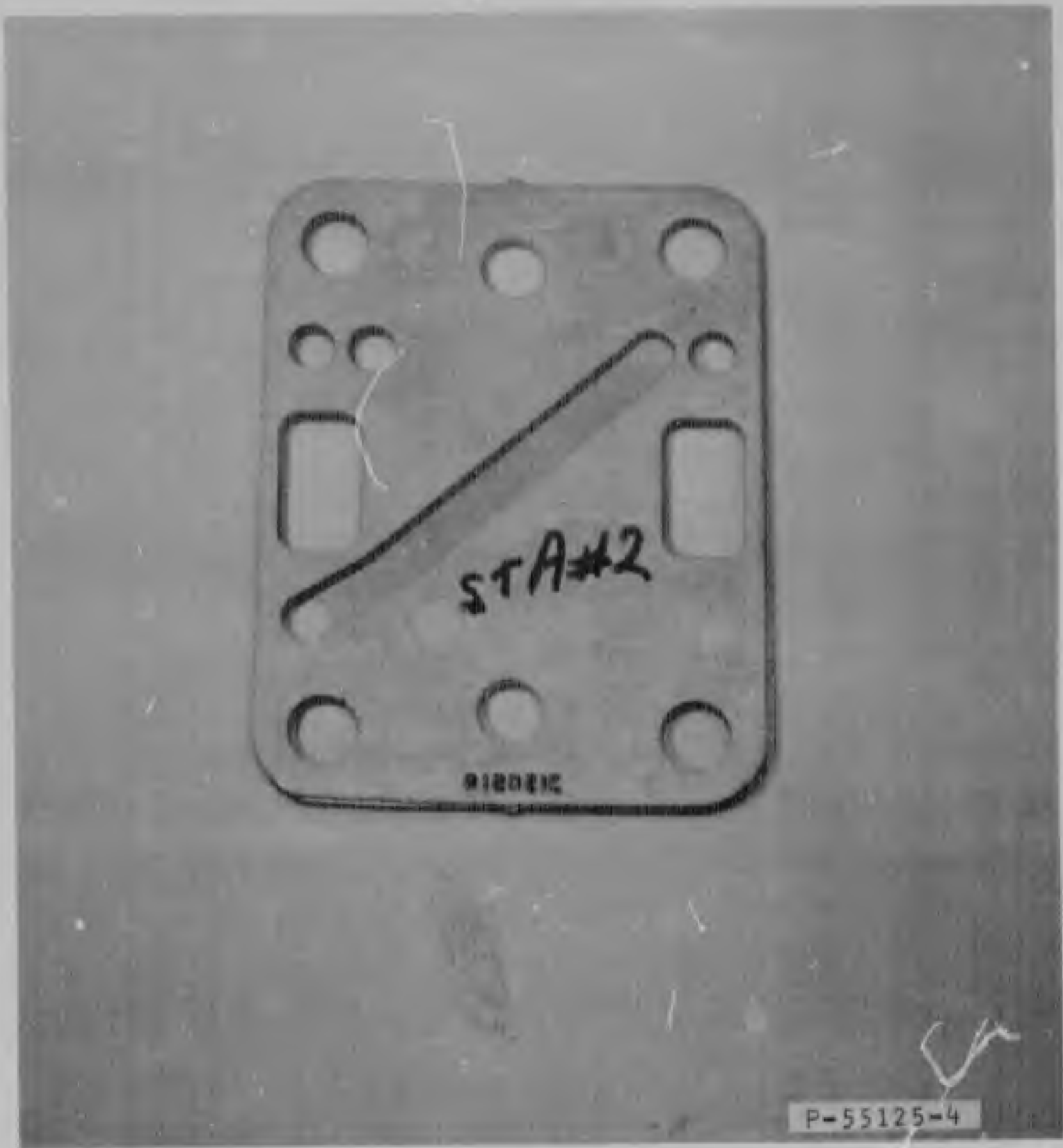


FIGURE 67

NULL ADJUST TRANSFER
CIRCUIT 2, RUN 12

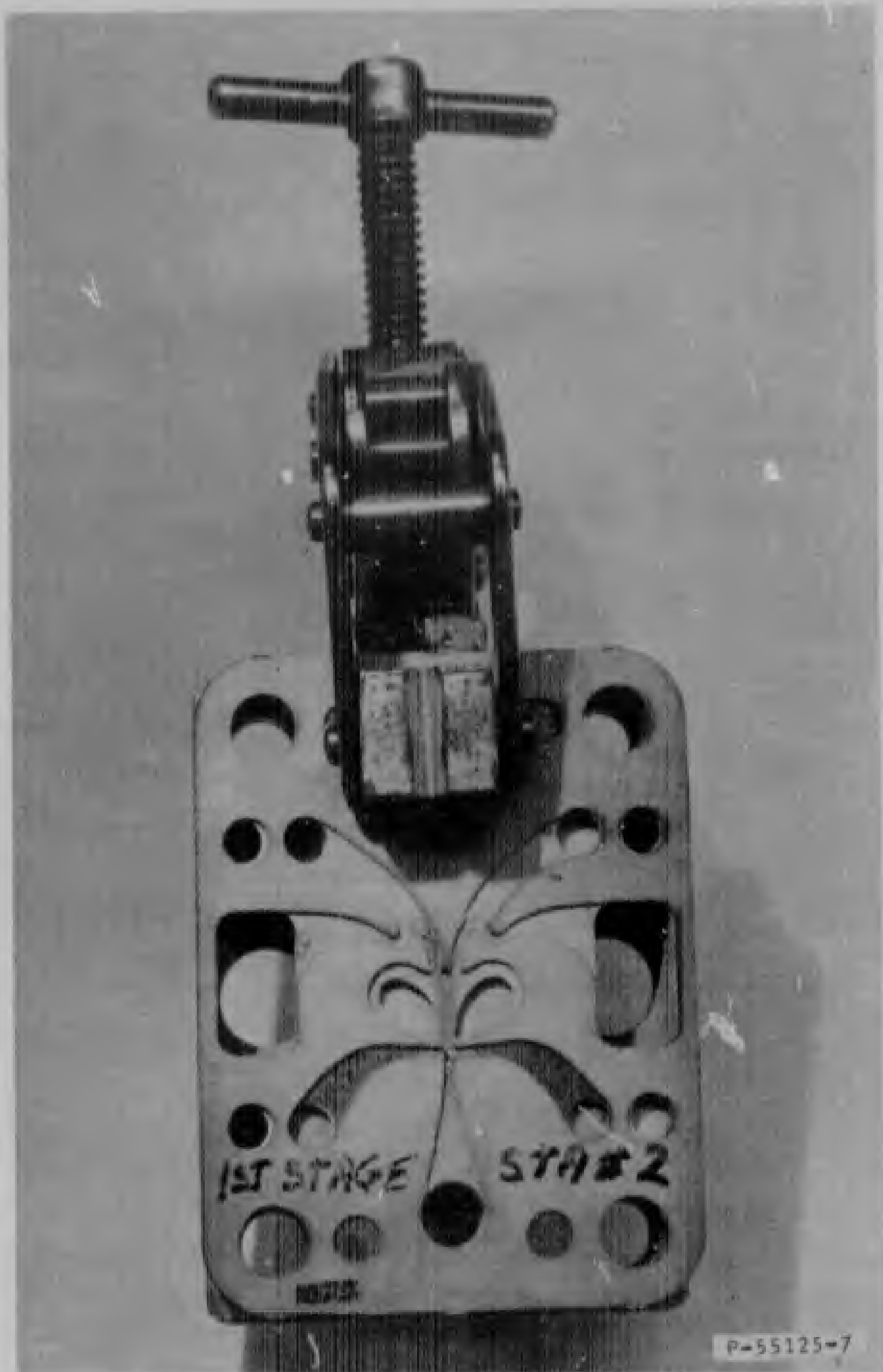


FIGURE 68

FIRST-STAGE AMPLIFIER
CIRCUIT 2, RUN 12

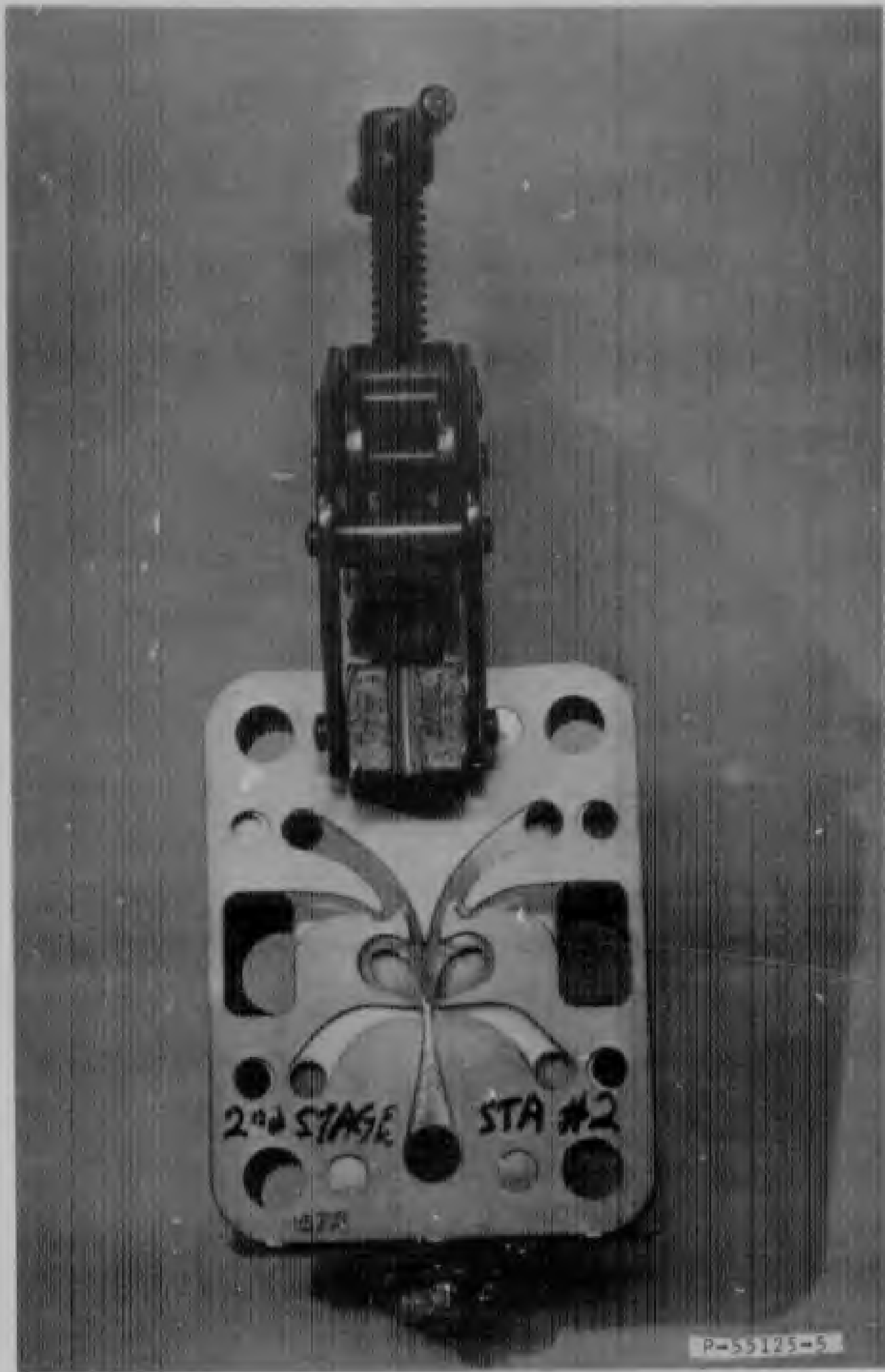


FIGURE 69

SECOND-STAGE AMPLIFIER
CIRCUIT 2, RUN 12

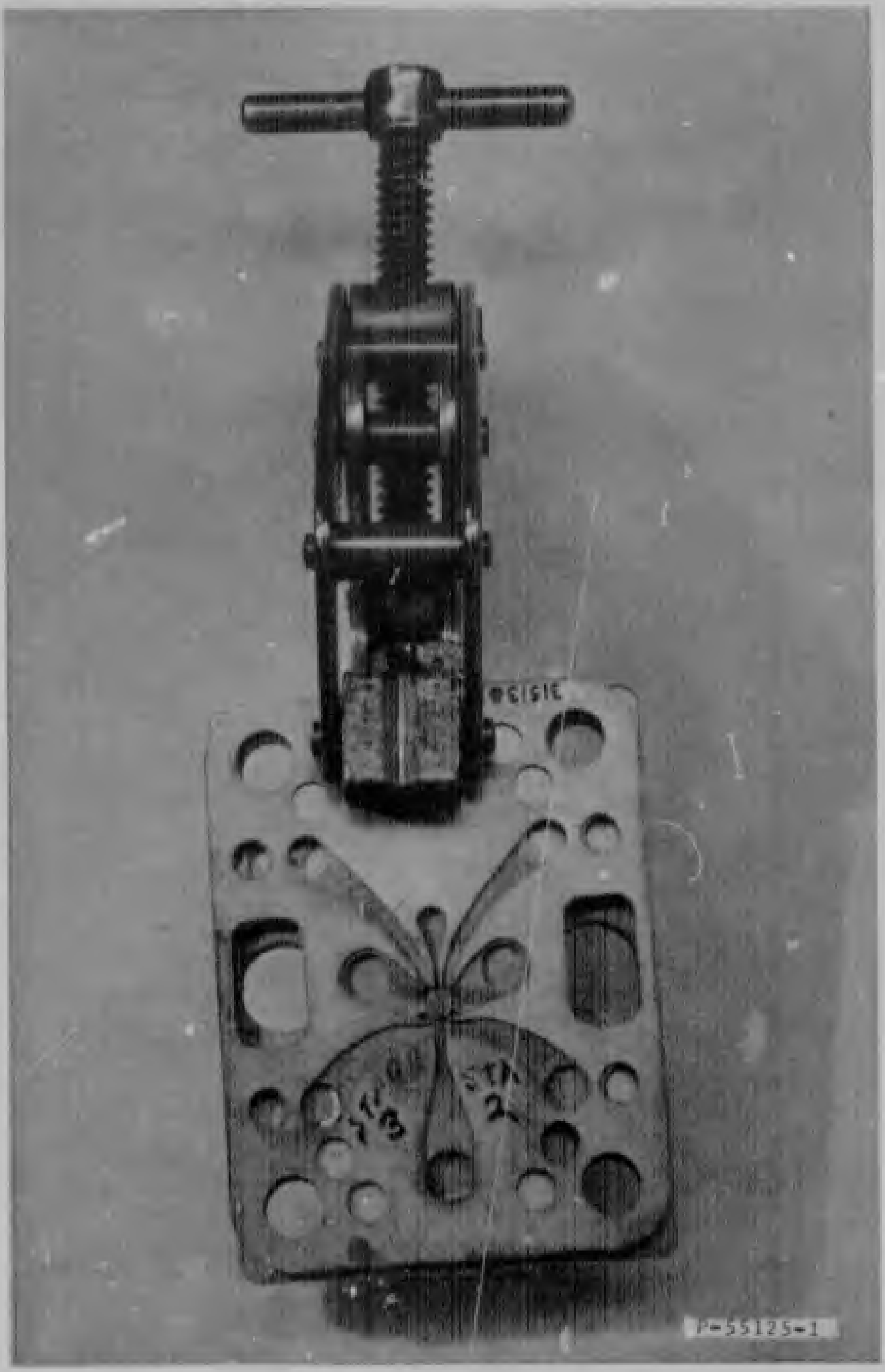


FIGURE 70

THIRD-STAGE AMPLIFIER
CIRCUIT 2, RUN 12

FIGURE 71

FIRST-STAGE VENT LAMINATION
CIRCUIT 2, RUN 12

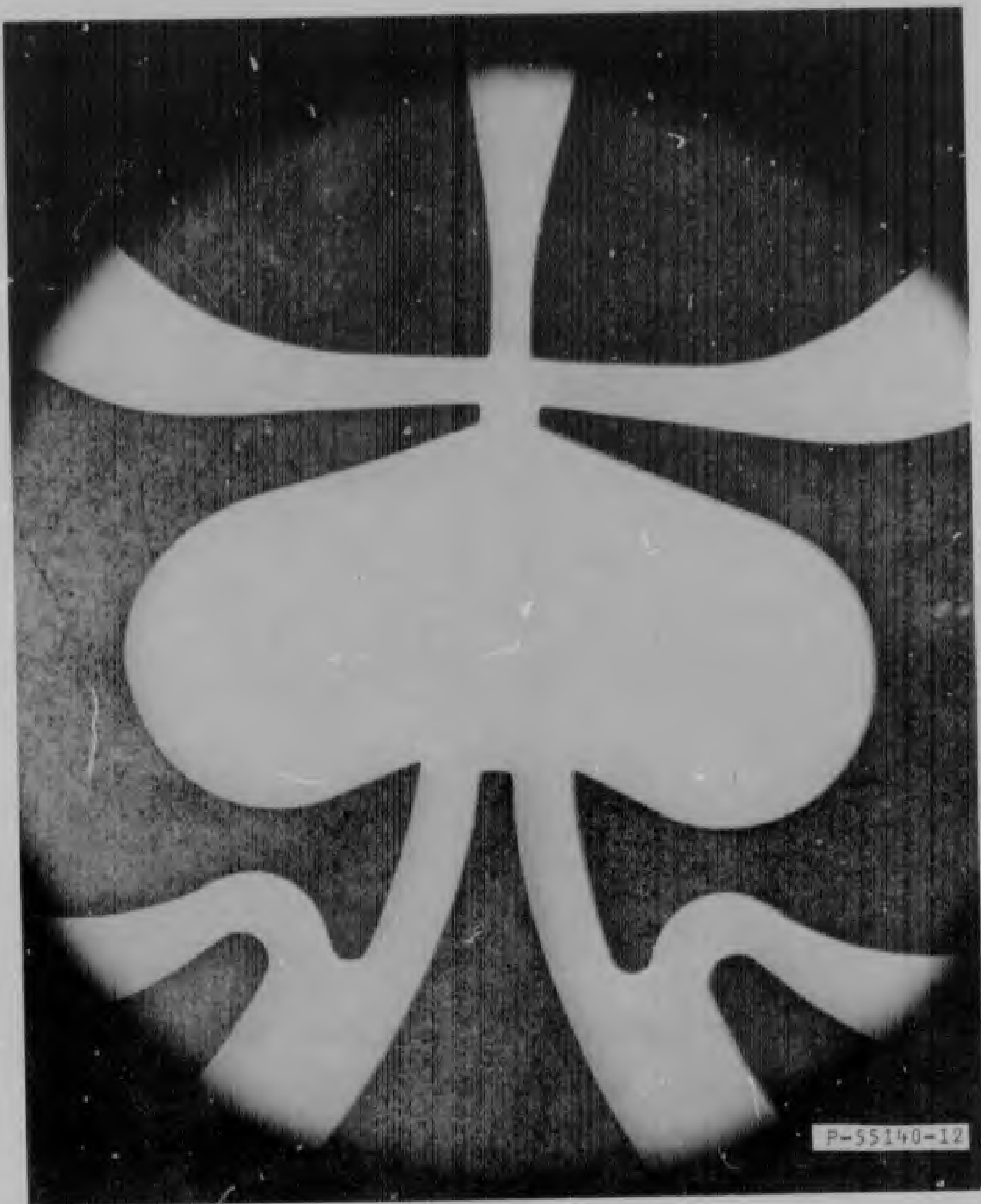


FIGURE 72

FIRST-STAGE AMPLIFIER LAMINATION
CIRCUIT 2, RUN 12

FIGURE 73

SECOND-STAGE VENT LAMINATION
CIRCUIT 2, RUN 12

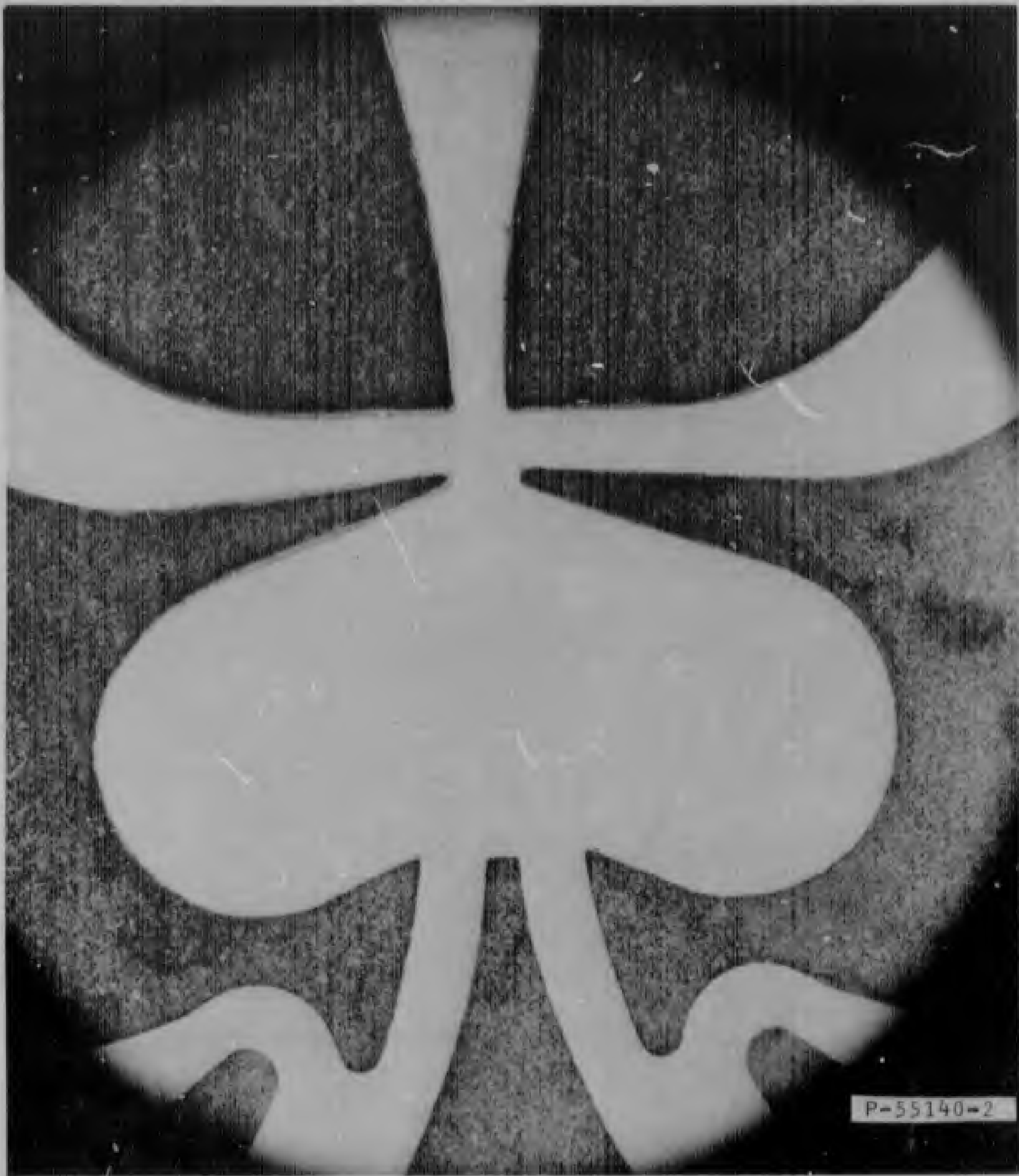


FIGURE 74

SECOND-STAGE AMPLIFIER LAMINATION
CIRCUIT 2, RUN 12

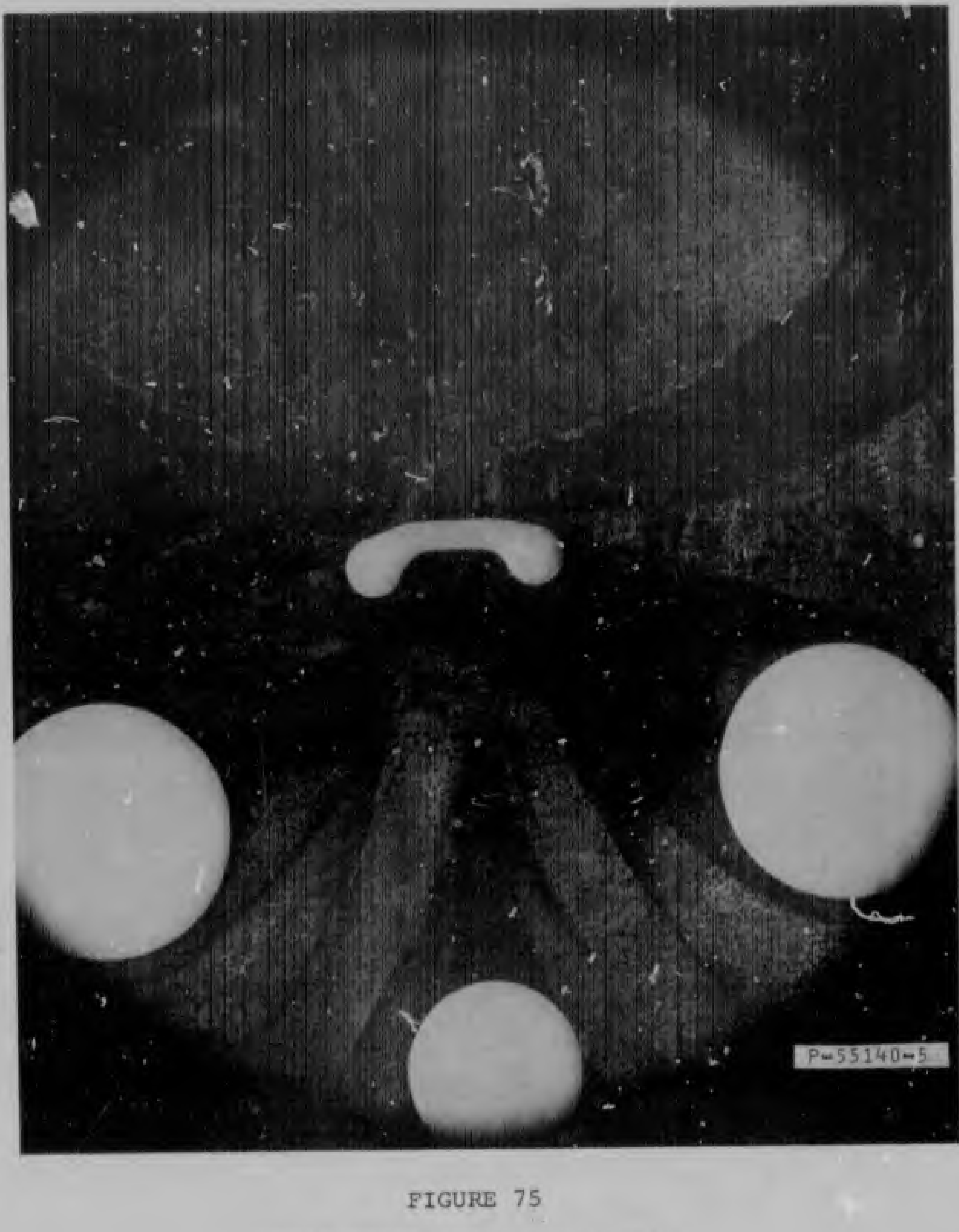


FIGURE 75

THIRD-STAGE VENT LAMINATION
CIRCUIT 2, RUN 12

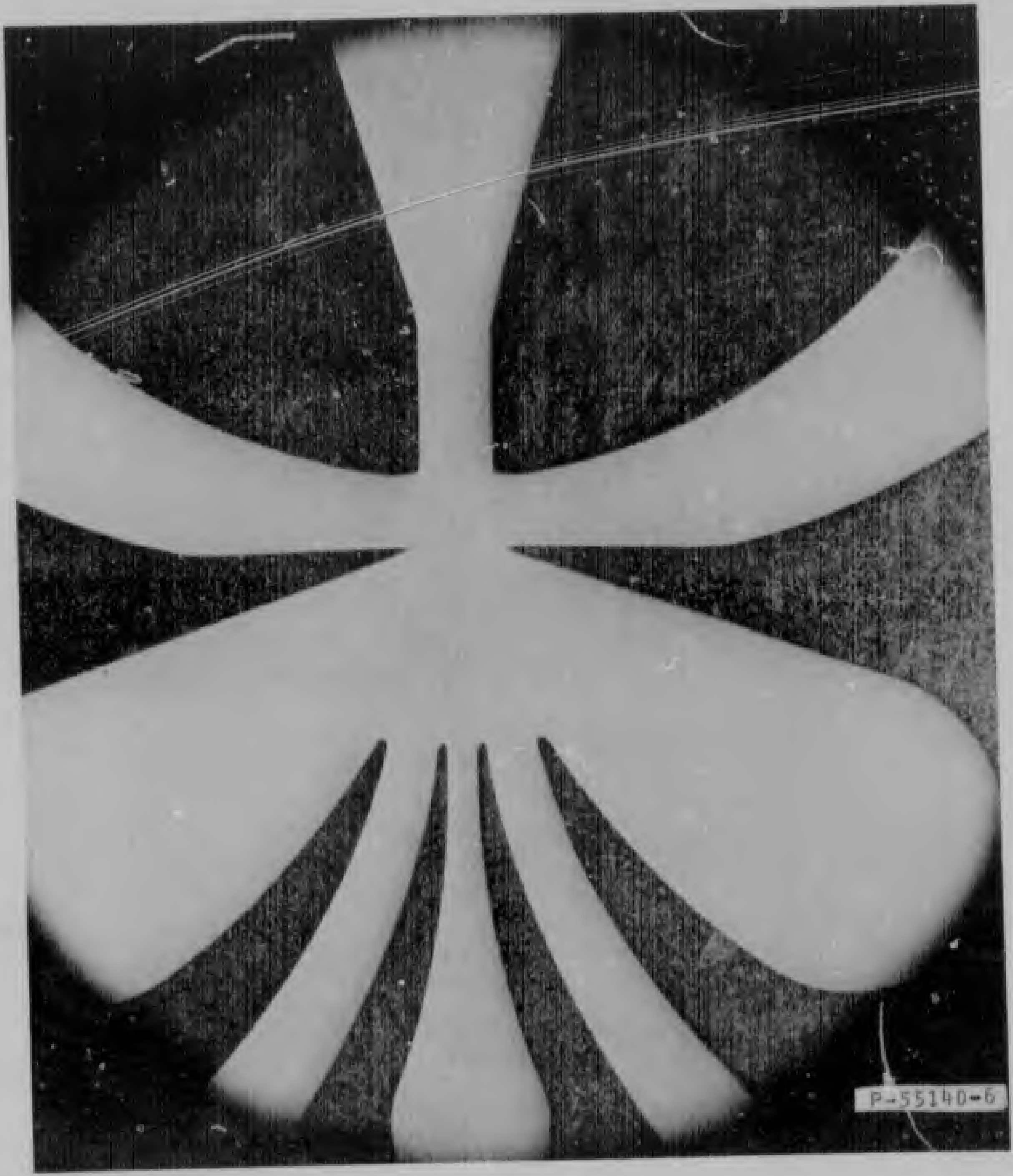


FIGURE 76

THIRD-STAGE AMPLIFIER LAMINATION
CIRCUIT 2, RUN 12

FIGURE 77

HYDRAULIC RESEARCH FILTER ELEMENT
CIRCUIT 1, RUN 12

The AiResearch 74μ filter element tested at Station 3 is depicted in the post-test photograph of Figure 78. The supply transfers for Circuit 3 are shown in Figure 79 and the null adjust transfer in Figure 80. The first, second, and third-stage amplifiers are pictured in Figures 81 through 83. The enlarged photographs of the vent and amplifier laminations for the three stages, Figures 84 through 89, clearly reveal the erosion of the splitters and sharp cusps. The vent plates from Circuit 3 were measured to determine the extent of erosion by the contaminated airflow. The maximum erosion was found at the entrance to the output port approximately 0.050 inch beyond the splitter cusp. The measured depth of erosion was as listed below.

Stage	Erosion Depth inch
1	0.0002
2	0.001
3	<0.0001

4.5.3.2 Test Run 13 - For this test, the Hydraulic Research filter was installed at Station 2 with the cyclone separator as a prefilter, and the Fluid Conditioning Products filter assembly was set up in Station 1 as shown in Figure 90. The first hourly recording of Run 13 is presented in Figure 91, at which time condensation was noted in the output tubes of both circuits. After a five-hour period with the noted condensation, the system was dried with high temperature, dry, clean air and then the circuits were removed from the setup, disassembled, inspected, cleaned, and again installed in the test system. The recording of Figure 92 shows the performance of the two circuits during the drying period prior to removal. The disassembly inspection of Circuit 1 revealed a slight buildup of dirt on the inlet screen, minor dirt deposits around the inlet side of the orifice, and slight deposits on the vent plates of the first-stage amplifier in the interaction vent region, on the second-stage amplifier in the output leg vent region, and at the third-stage passive inlet port. The supply transfer appeared clean. During the teardown of Circuit 2, fibrous material was found on the screen at the active inlet port, and slight, dark brown deposits were apparent in the interaction regions of all amplifier stages. No significant buildup of dirt was found in either circuit. The fibrous material was presumed to be particles of insulation which were inadvertently introduced during setup installation.

FIGURE 78

AIRESEARCH 74-MICRON FILTER ELEMENT
CIRCUIT 3, RUN 12

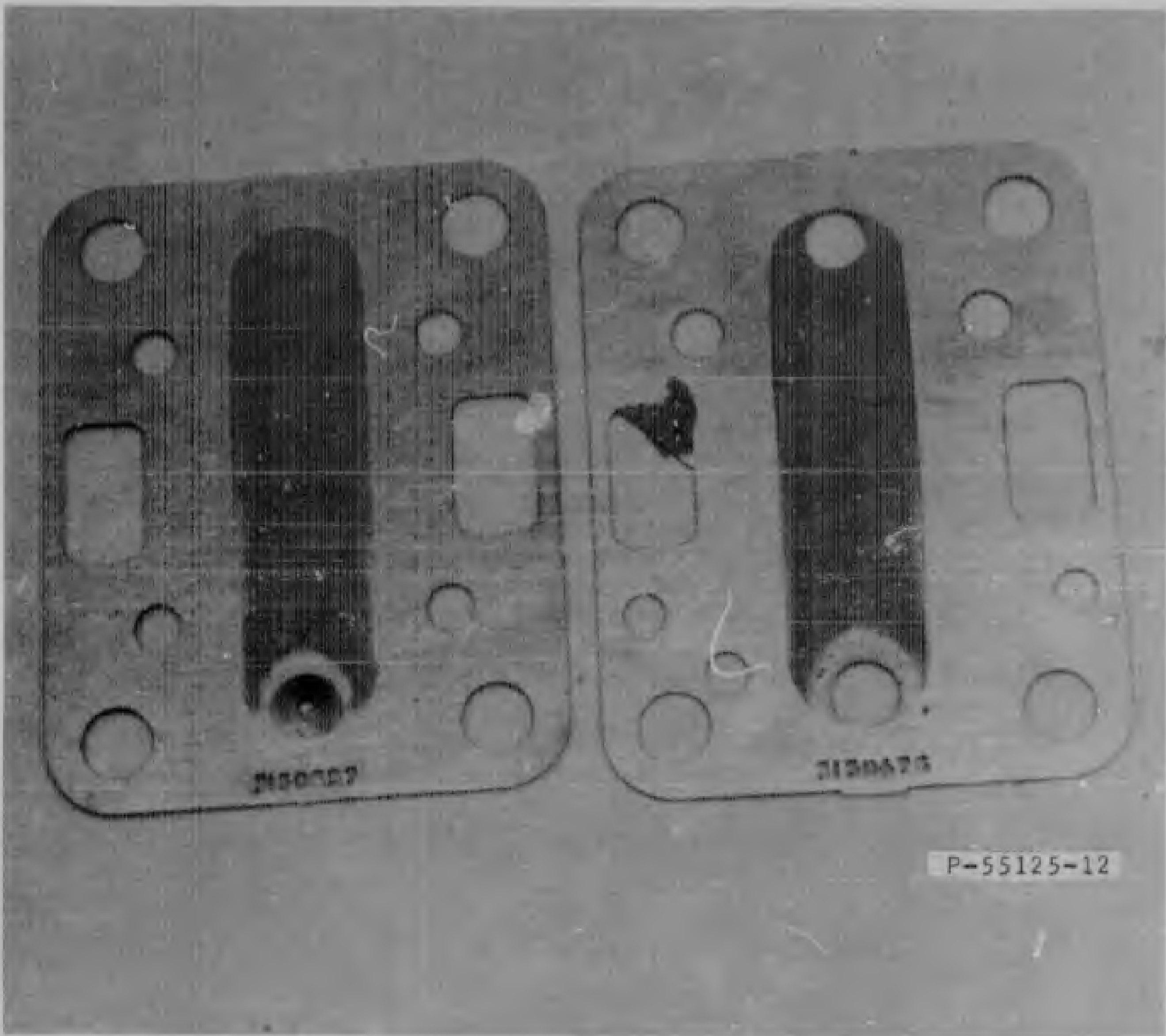


FIGURE 79

SUPPLY TRANSFERS
CIRCUIT 3, RUN 12

FIGURE 80

NULL ADJUST TRANSFER
CIRCUIT 3, RUN 12

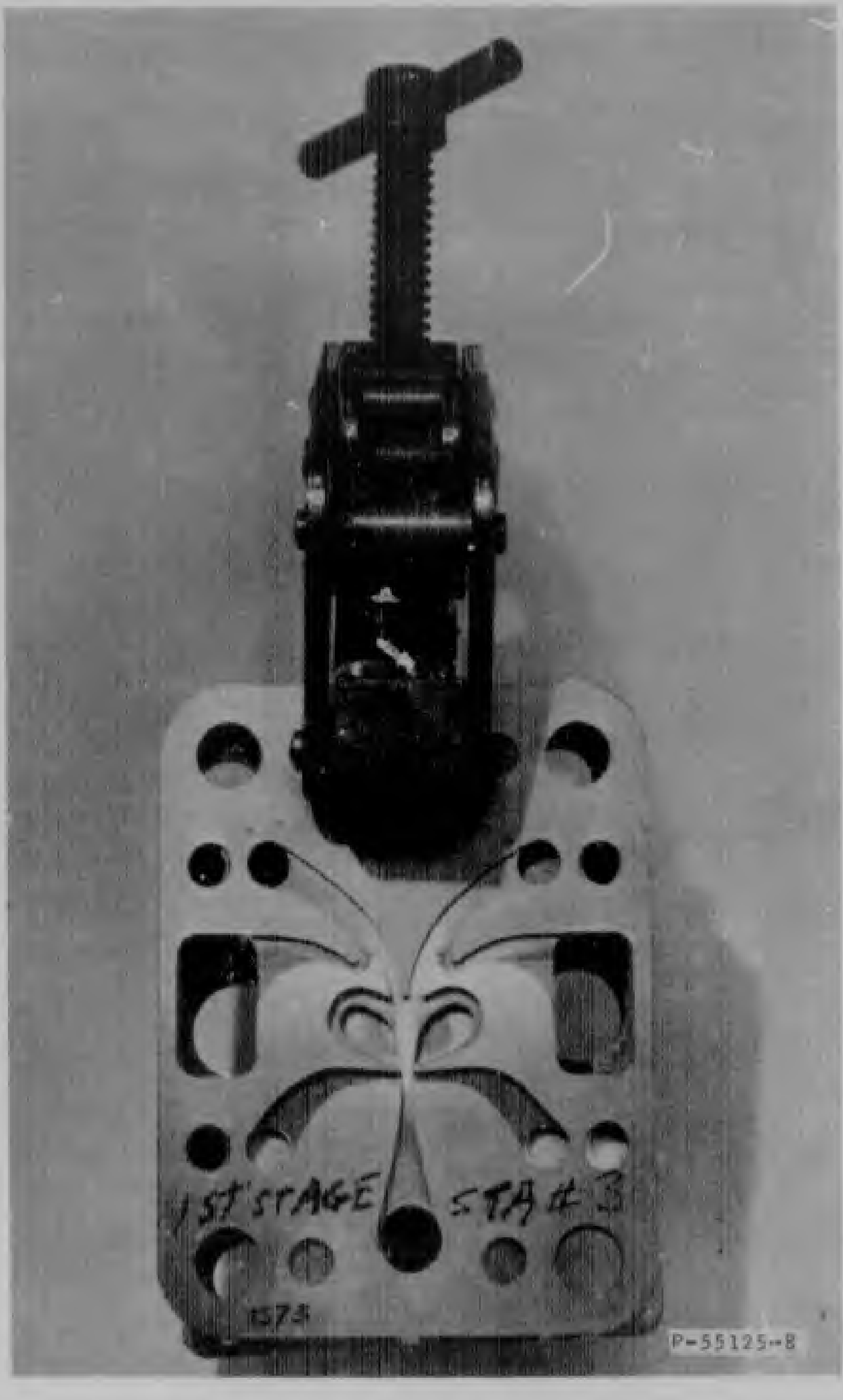


FIGURE 81

FIRST-STAGE AMPLIFIER
CIRCUIT 3, RUN 12

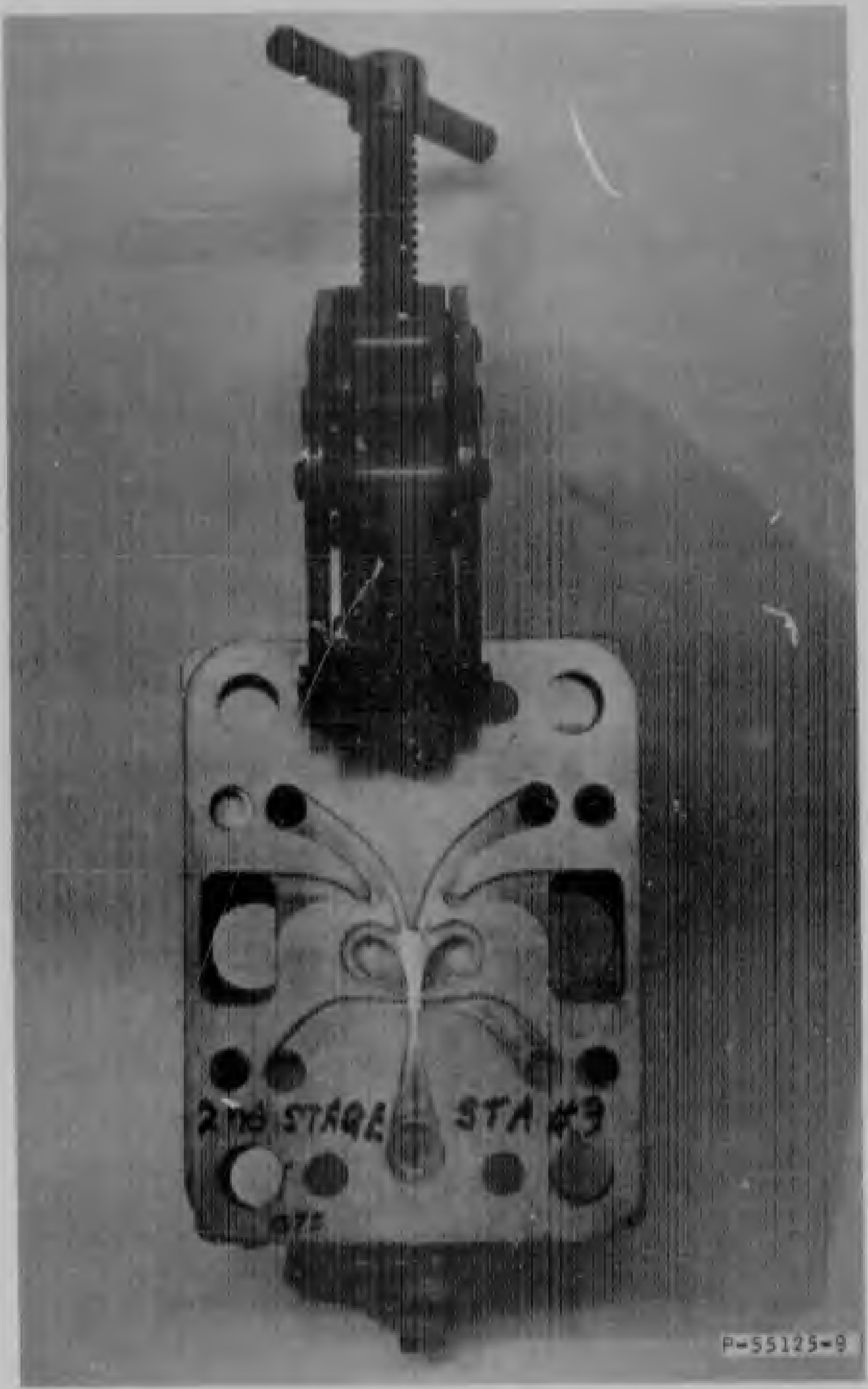


FIGURE 82

SECOND-STAGE AMPLIFIER
CIRCUIT 3, RUN 12

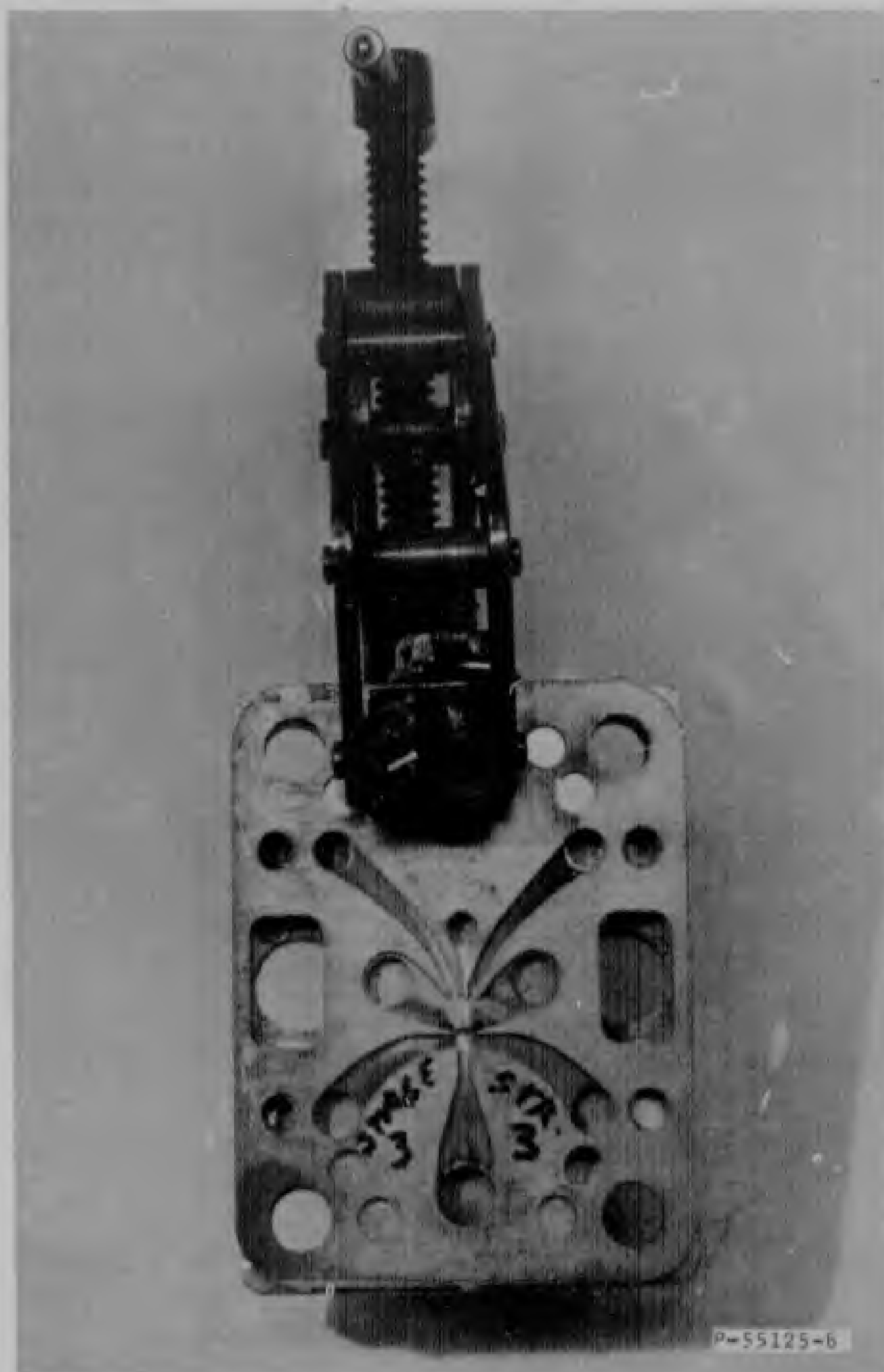


FIGURE 83

THIRD-STAGE AMPLIFIER
CIRCUIT 3, RUN 12

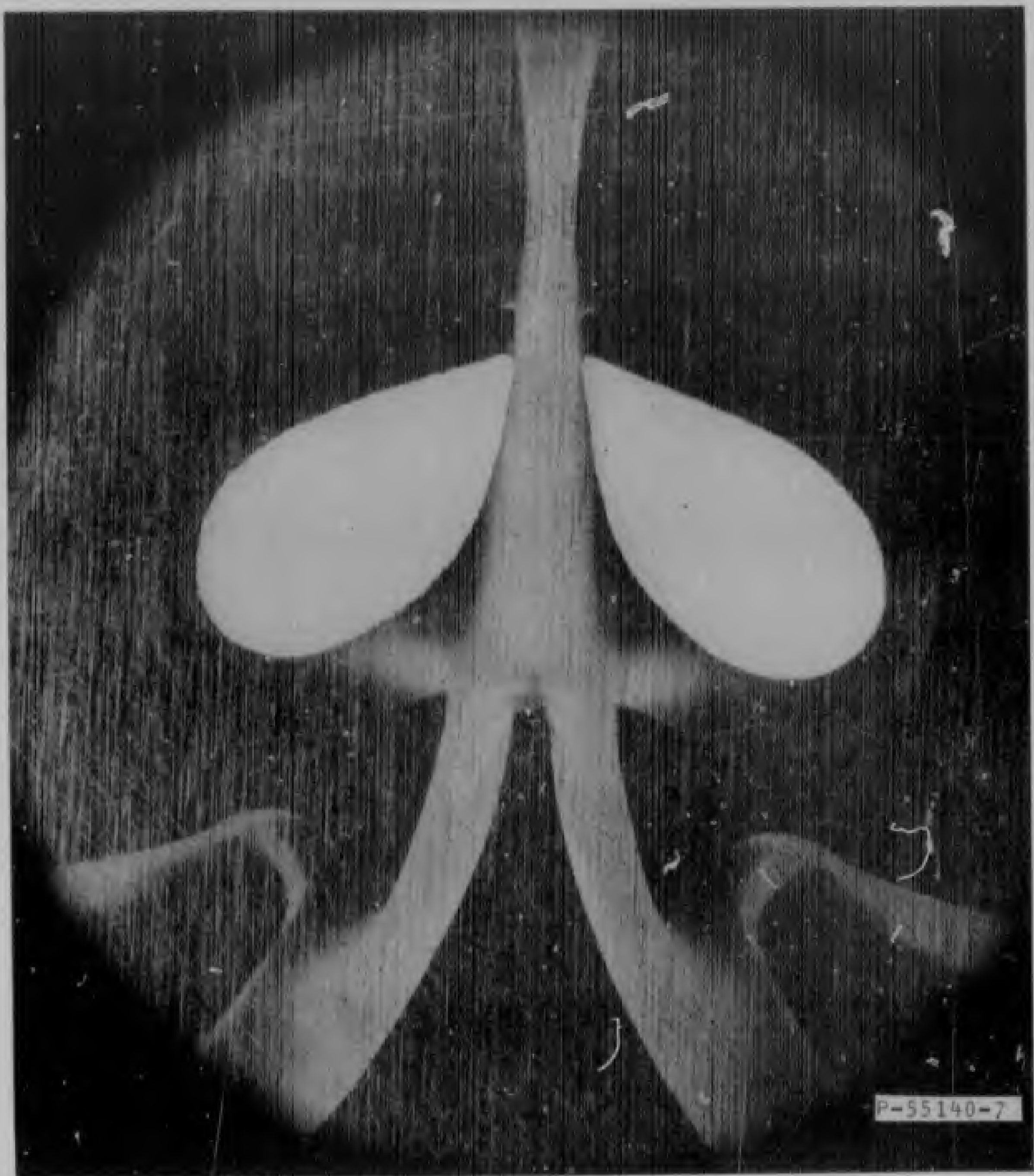


FIGURE 84

FIRST-STAGE VENT LAMINATION
CIRCUIT 3, RUN 12

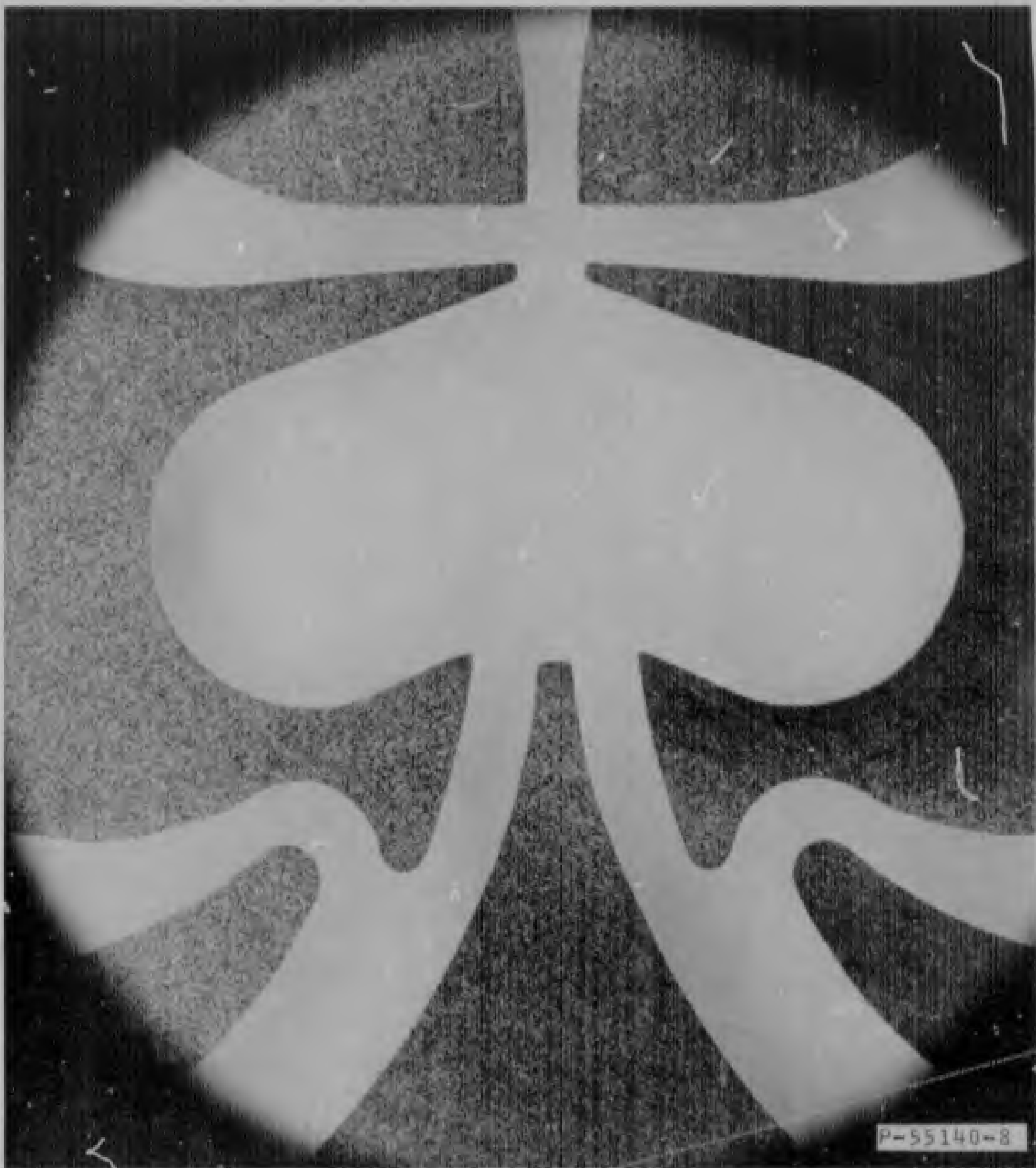


FIGURE 85

FIRST-STAGE AMPLIFIER LAMAINATION
CIRCUIT 3, RUN 12

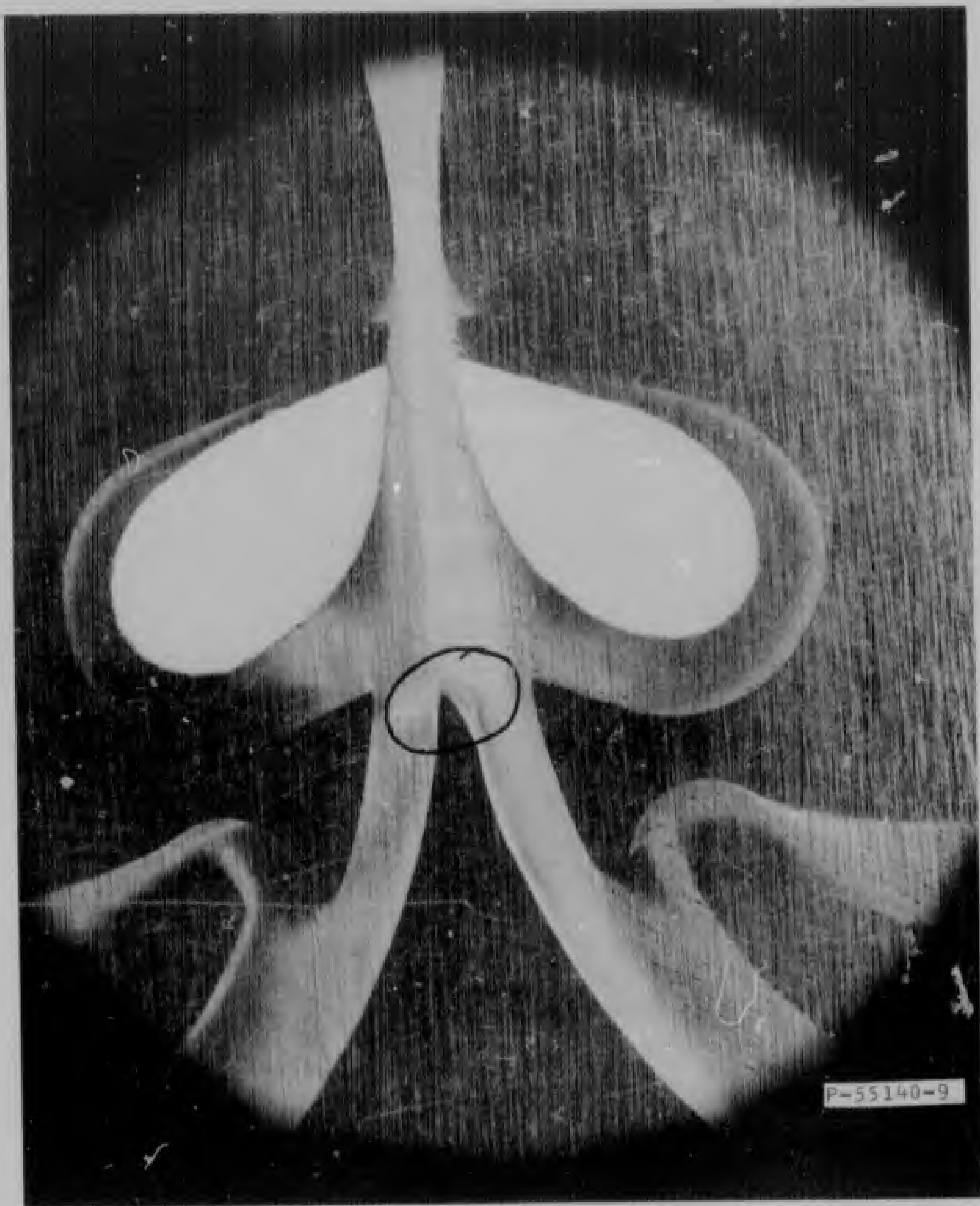


FIGURE 86

SECOND-STAGE VENT LAMINATION
CIRCUIT 3, RUN 12

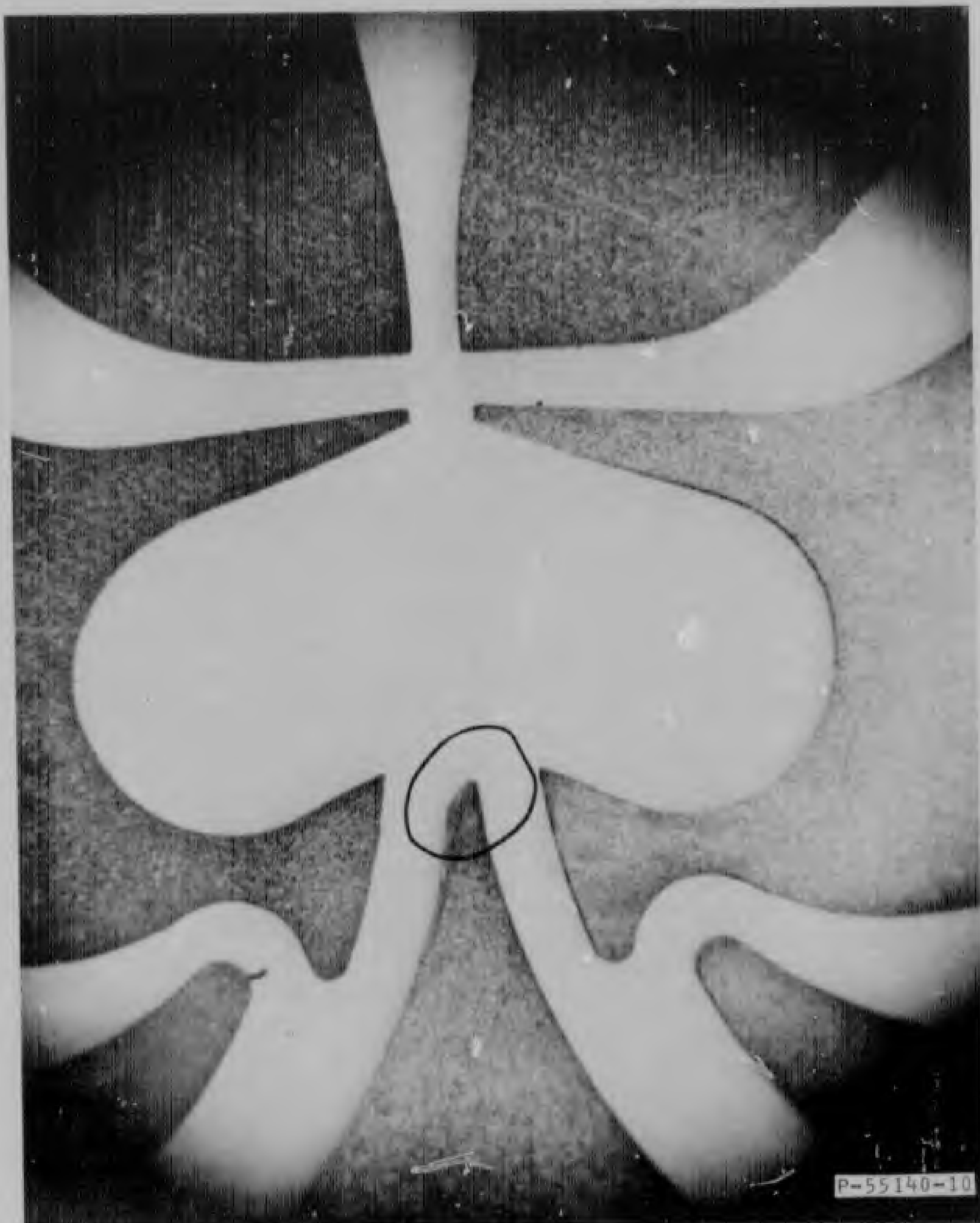


FIGURE 87

SECOND-STAGE AMPLIFIER LAMINATION
CIRCUIT 3, RUN 12

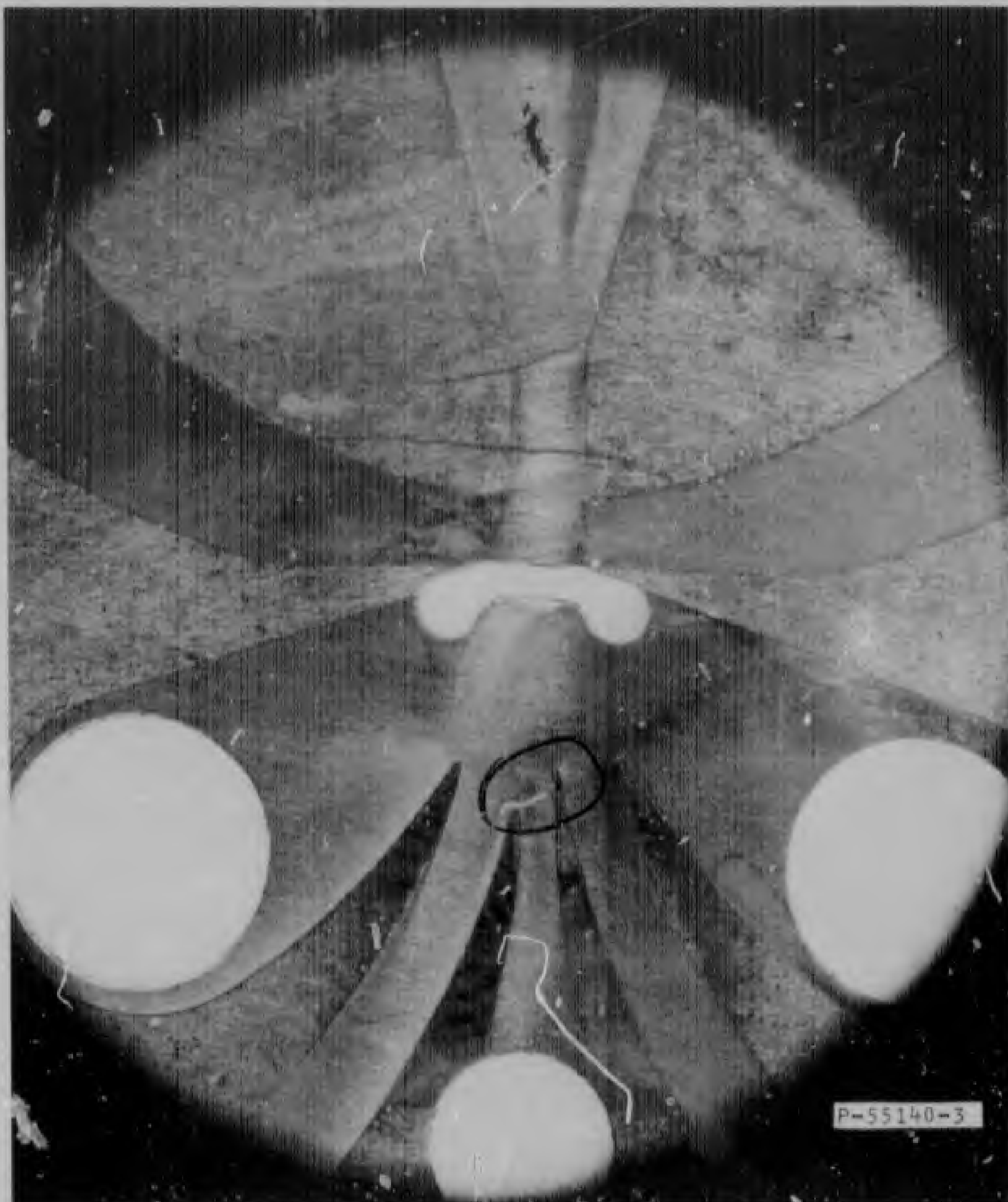


FIGURE 88

THIRD-STAGE VENT LAMINATION
CIRCUIT 3, RUN 12

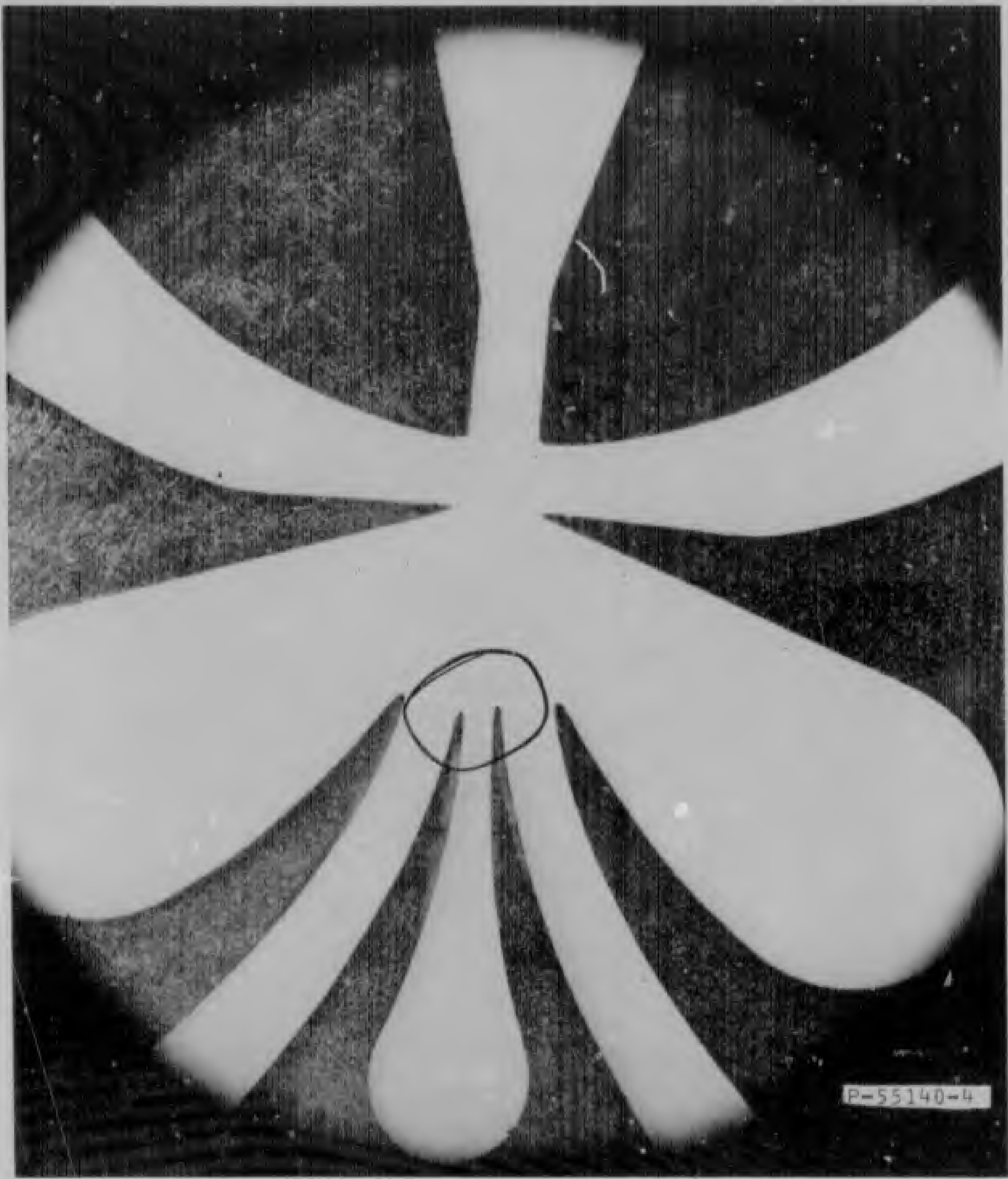


FIGURE 89

THIRD-STAGE AMPLIFIER LAMINATION
CIRCUIT 3, RUN 12

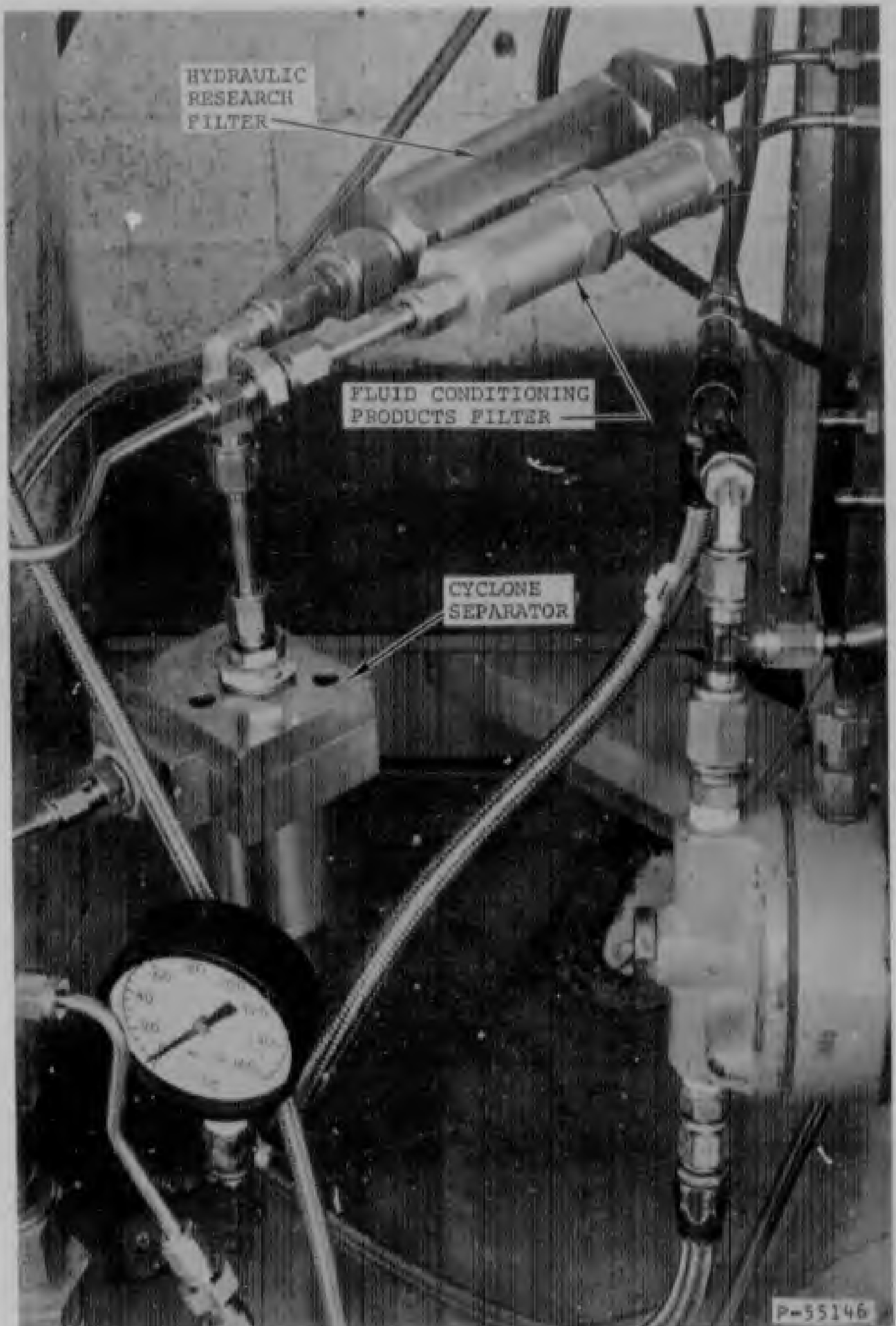


FIGURE 90

FILTER TEST SETUP
RUN 13

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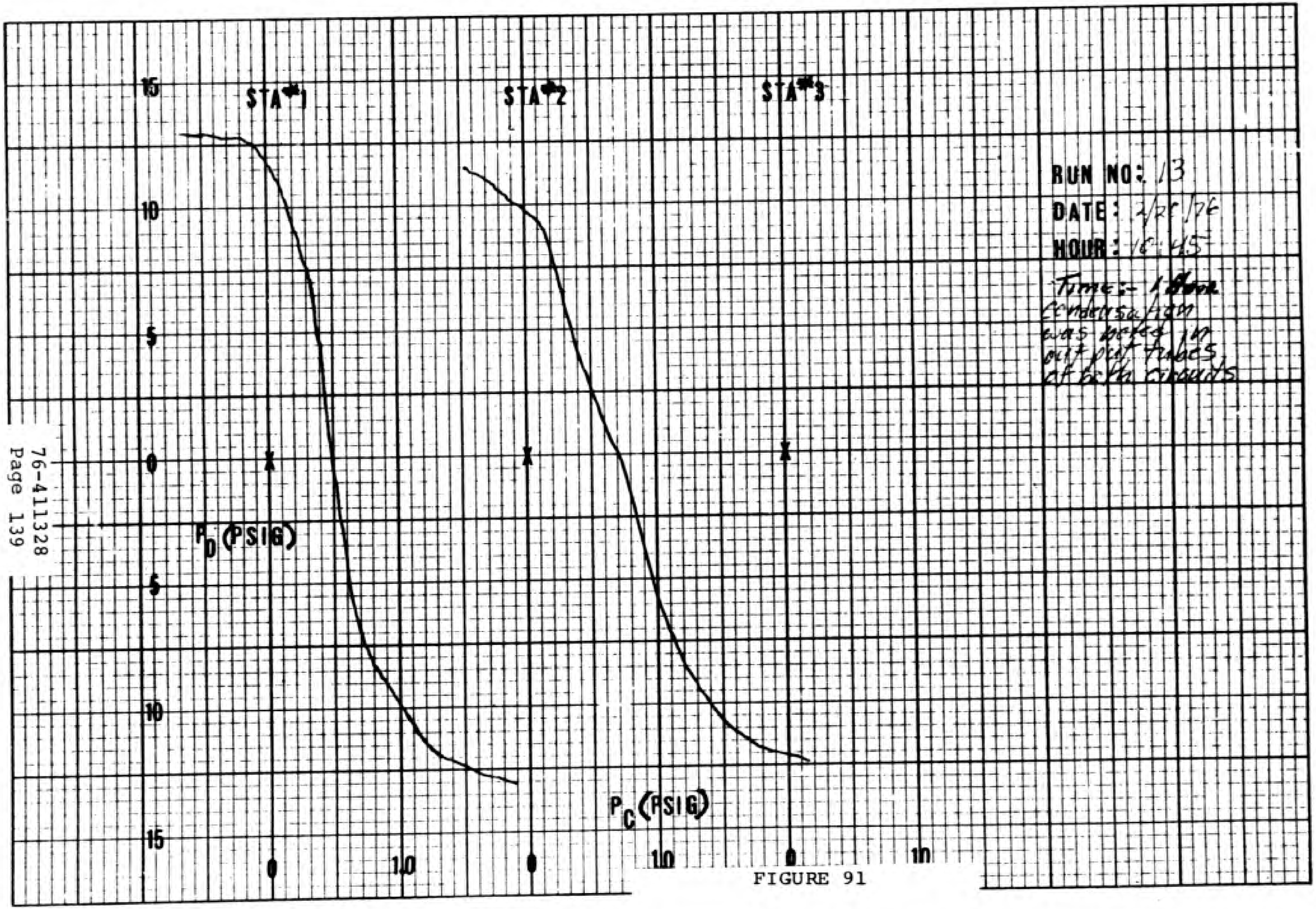

FIGURE 91

RECORDING 5 - START RUN 13

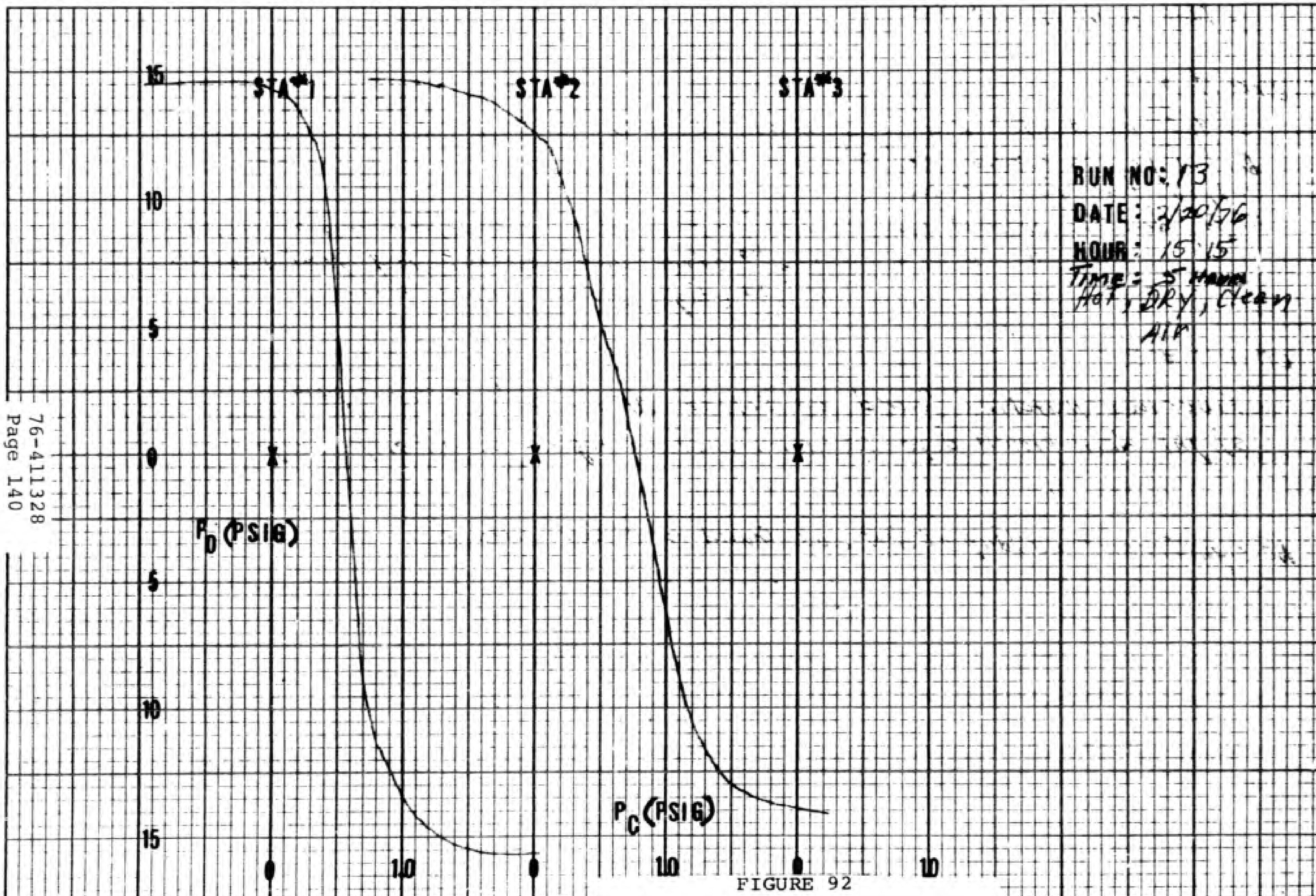

FIGURE 92

RECORDING 6 - FIVE HOURS RUN 13

Testing was then resumed with programmed contaminant injection until approximately 45 hours of testing had been completed. At this point, an error occurred in adjustment of the contaminant oil flow and, as a result, the circuits received the equivalent of 24 hours of oil contamination in about seven hours. The recording of circuit performance in Figure 93 was made at the end of 47 hours, and Figure 94 records the failure of Circuit 1 after 49 hours of testing. Both the circuit and filter assembly were removed from Station 1 of the test setup for subsequent examination for cause of failure and testing was continued. The circuit of Station 2 was still performing well despite the extra oil, although there was a slight degradation of performance. Circuit 2 was allowed to continue the test to accumulate an additional 15 hours of run time, during which there was no significant change. Run 13 was terminated after 64 hours, with performance as shown on Figure 95, and the circuit and filter were removed for inspection.

The Fluid Conditioning Products filter elements from Station 1 are shown in Figure 96 as they appeared after 47 hours of contaminated airflow. The disassembly inspection of Circuit 1 revealed a heavy buildup of dark brown deposits in the supply port in the test block and that the hole was approximately 30 percent blocked. The screen in the supply port also contained thick deposits as depicted in Figure 97. All amplifiers and transfer passages contained significant dark brown deposits, apparently an oil and dirt combination, and the supply port for the second-stage was filled with light brown dirt in the no-flow region. Figure 98 depicts the contamination on the downstream side of the orifice lamination and Figures 99, 100, and 101 show the three amplifier stages of Circuit 1. The difference in the color of deposits suggests that during the period of Run 13 when the bulk of the dirt was deposited, as in the second stage supply port, the ratio of oil to dirt was small as compared to the time when the dark deposits formed in the amplifiers. From these observations and the time factor, it was concluded that the excess oil was the primary cause of the failure of Circuit 1.

In this regard, it is noted that, although the excess oil injection during the test was an error, the possibility exists that such a condition could occur during the service life of a filter system due to the failure of a compressor section oil seal, thus permitting gross quantities of oil to be taken into the compressor bleed air port.

Run #13

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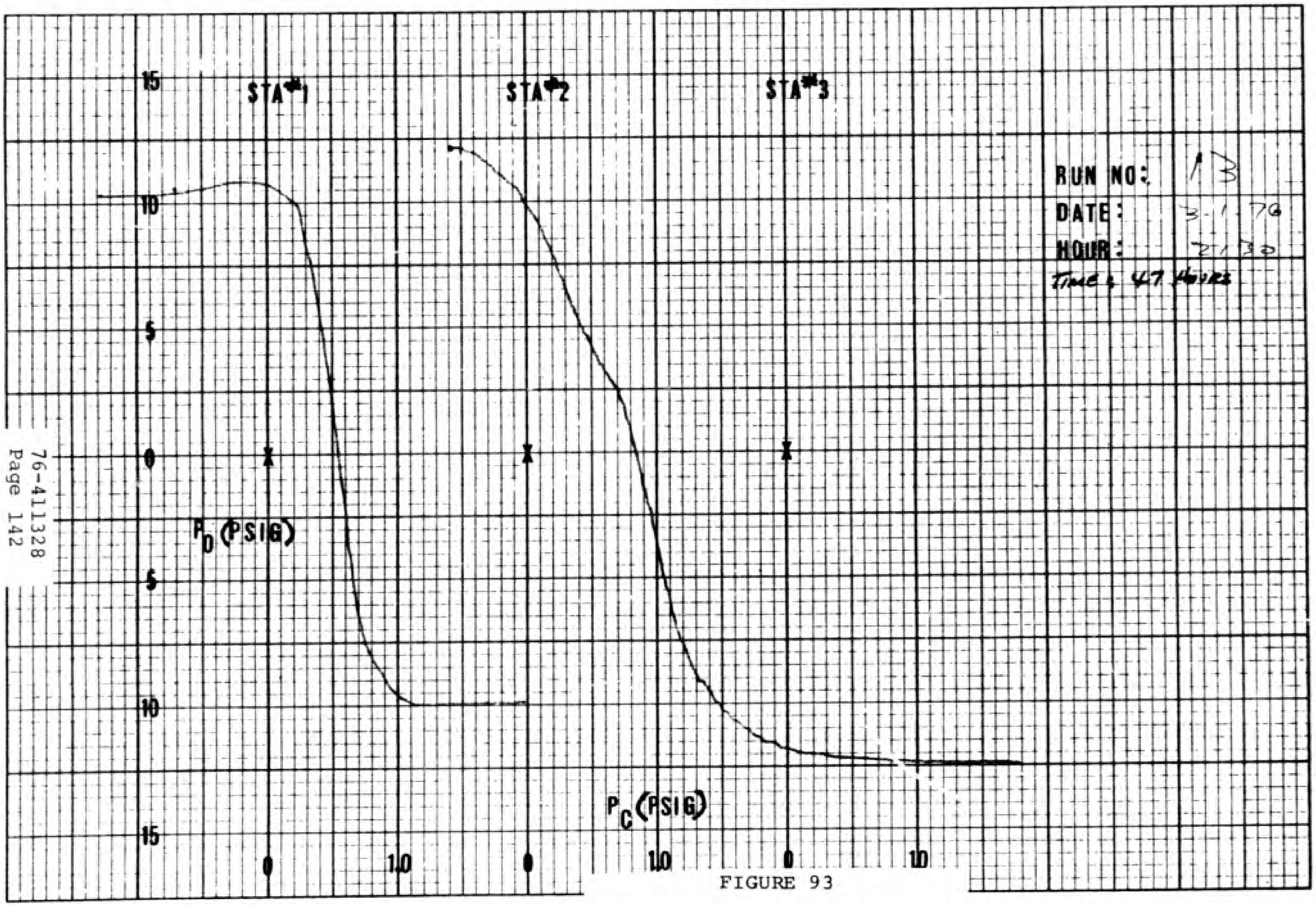

FIGURE 93

RECORDING 7 - 47 HOURS RUN 13

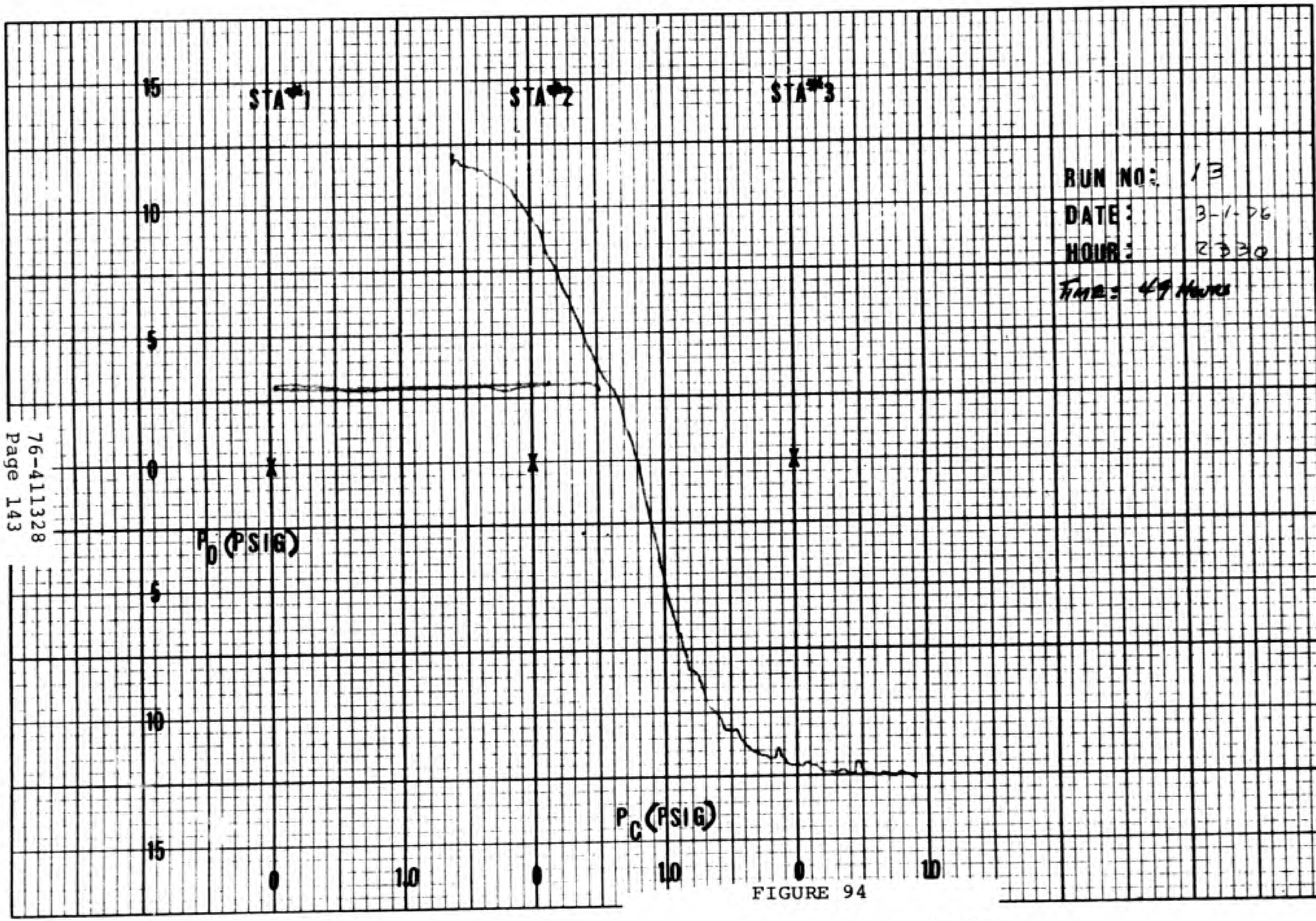

FIGURE 94

RECORDING 8 - 49 HOURS RUN 13

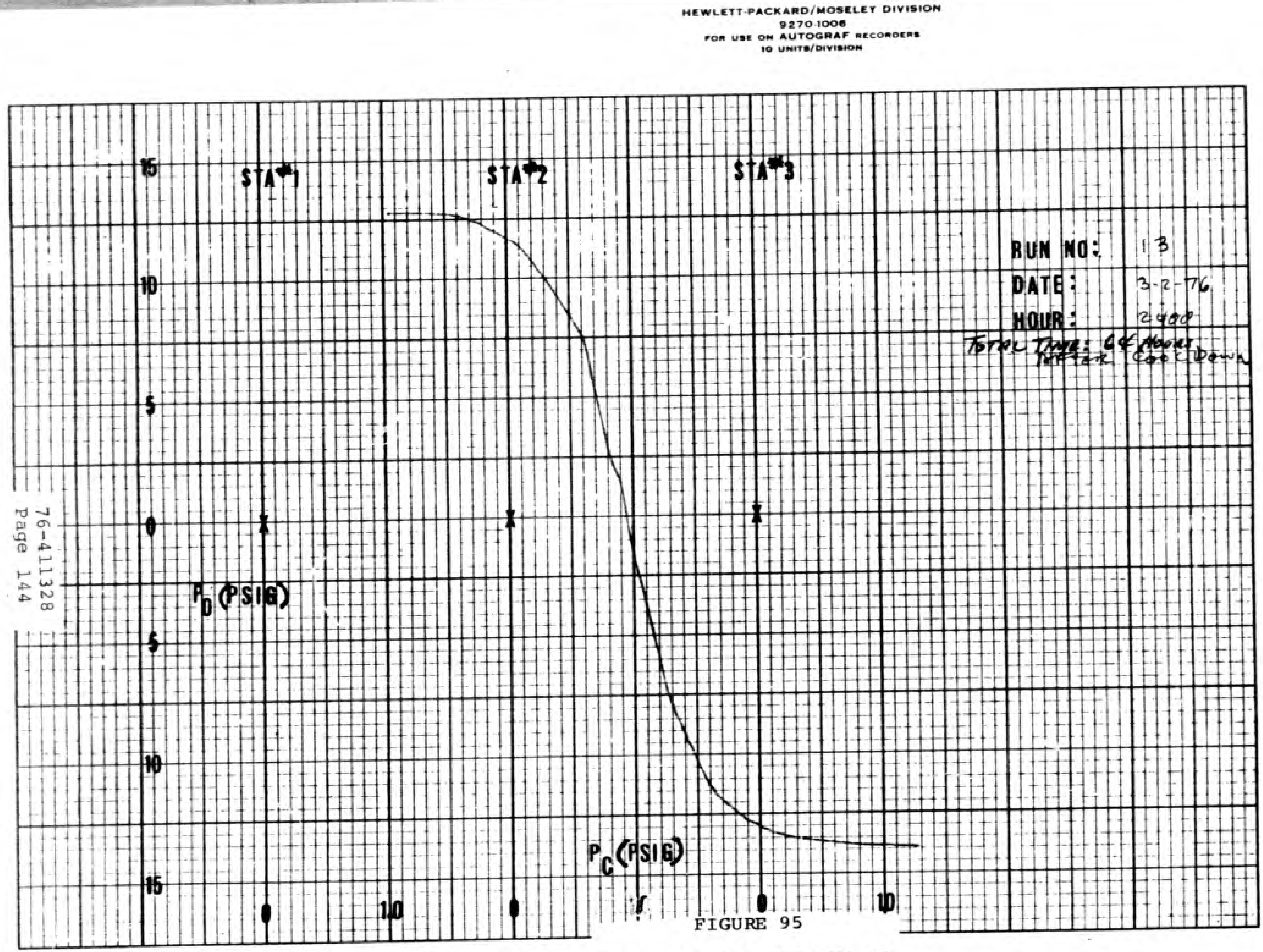

FIGURE 95

RECORDING 9 - END RUN 13

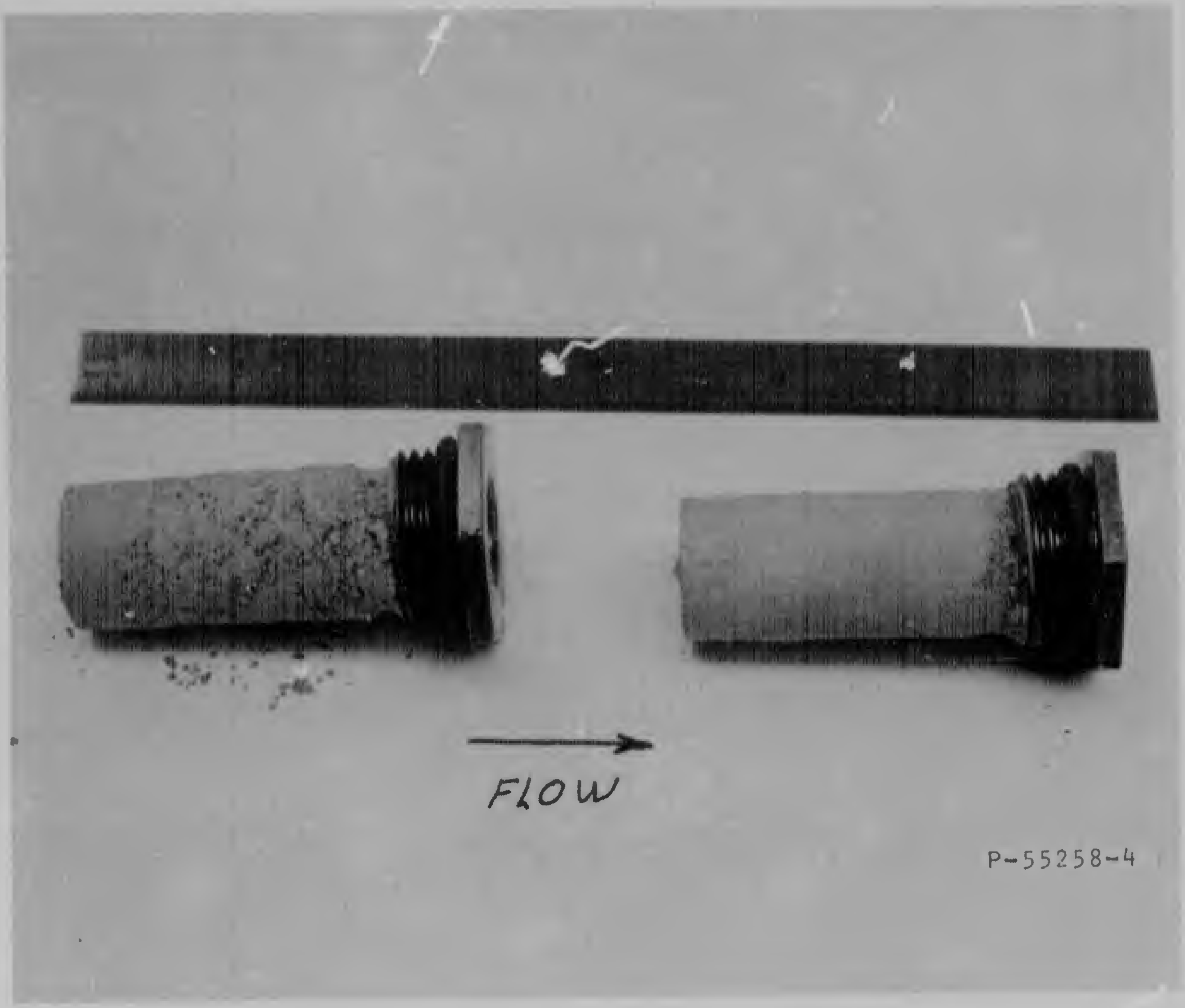

FIGURE 96

FLUID CONDITIONING PRODUCTS
FILTER ELEMENTS AFTER 47 HOURS
STATION 1, RUN 13

FIGURE 97

CONTAMINANT CLOGGED
SUPPLY PORT INLET SCREEN
CIRCUIT 1, RUN 13

FIGURE 98

ORIFICE LAMINATION
CIRCUIT 1, RUN 13

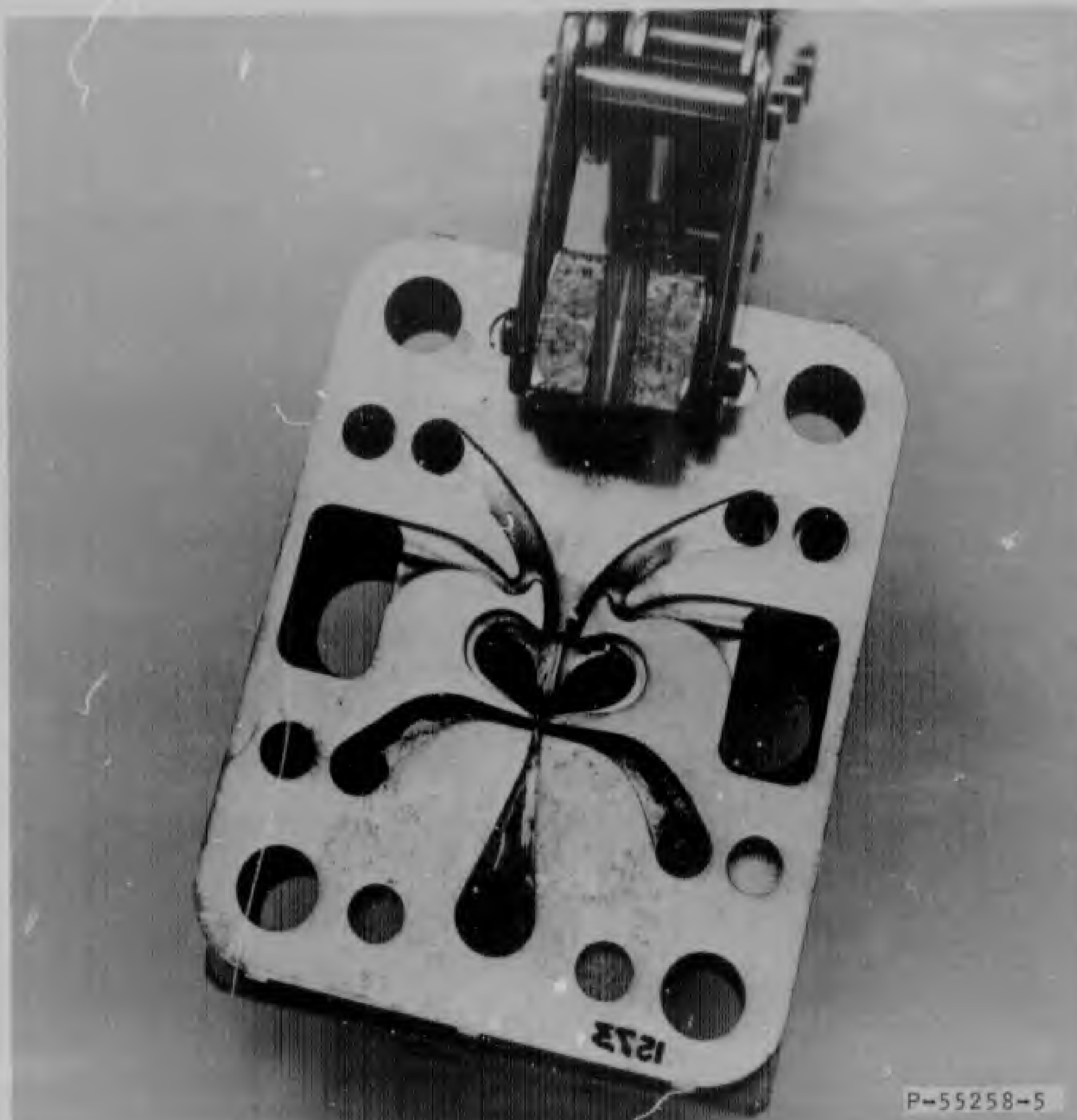

FIGURE 99

FIRST-STAGE AMPLIFIER
CIRCUIT 1, RUN 13

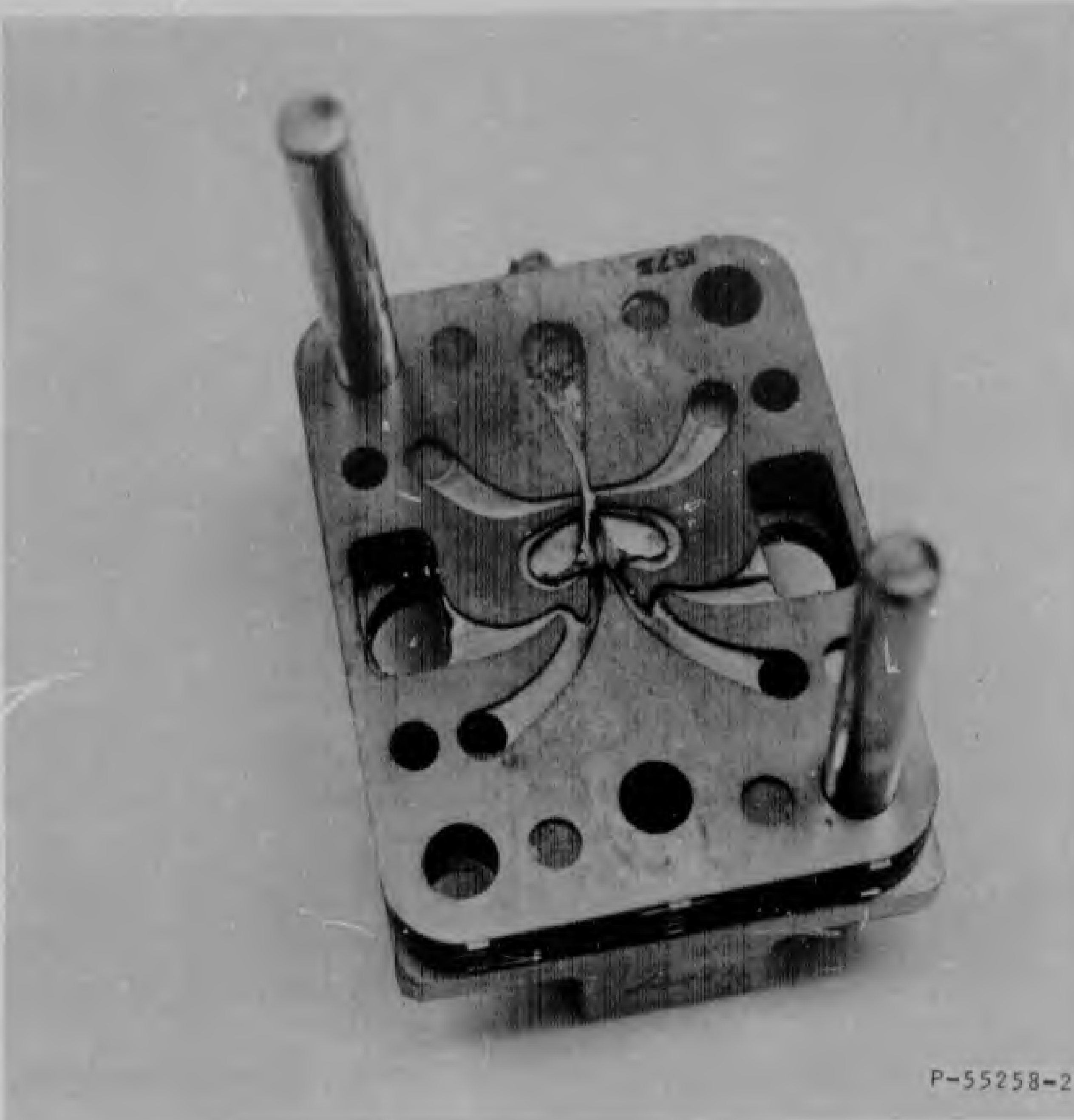

FIGURE 100

SECOND-STAGE AMPLIFIER
CIRCUIT 1, RUN 13

FIGURE 101

THIRD-STAGE AMPLIFIER
CIRCUIT 1, RUN 13

The teardown inspection of Circuit 2, following the 64 hours of contamination during Run 13, revealed no significant dirt deposits anywhere in the circuit, although all amplifiers and transfer passages contained an oil film with very light deposits of dirt. For purposes of comparison, photographs of the inlet screen, orifice lamination, and amplifiers from each stage of Circuit 2 are presented in Figures 102 through 106 which show the relatively minor contamination despite the oil injection error. The dirt collected by the Hydraulic Research filter element in Station 2 was extracted and weighed. The filter contained 0.97 gram of dirt, which corresponds to 0.015 gram per hour. From observations of the passages inside the circuit, this amount was virtually all that was passed by the cyclone separator.

4.5.3.3 Test Run 14 - This final test run was made with the test setup identical to that for Run 13, with the Fluid Conditioning Products filter installed in Station 1 and the cyclone separator in series with the Hydraulic Research filter in Station 2. The initial calibration curves of fluidic circuit performance are recorded on Figure 107. The test was conducted utilizing the programmed contamination introduced in the airflow to the test section of the CBAS, and continued without incident for 54 hours at which time a degradation in performance at Station 1 was apparent as seen on the recording of Figure 108. By the end of 56 hours of contaminated airflow, total failure of Station 1 had occurred as shown by Figure 109. Since this occurred on a Friday afternoon, the test stand was shut down for the weekend after 57 hours. On Monday morning, without having done anything to the stand or test units, the CBAS testing was renewed and Station 1 was found to be operative again as shown in Figure 110. Startup presumably dislodged the contamination.

Following 75 hours of Run 14, Station 2 performance was normal and Station 1 was still operative, although the performance curve indicated a slow degradation as seen in Figure 111. The degradation in performance at Station 1 became more pronounced after 81 hours, with failure evident after 83 hours, as depicted in Figures 112 and 113. The test filter and circuit were then removed from Station 1 of the CBAS for examination, and testing at Station 2 continued.

The totally clogged condition of the Fluid Conditioning Products filter elements following removal from Station 1 is evident in the photograph of Figure 114. These elements retained 5.95 grams of contaminant during the 83-hour run in Station 1, which is equivalent to 0.072 gram per hour.

FIGURE 102

INLET SCREEN
CIRCUIT 2, RUN 13

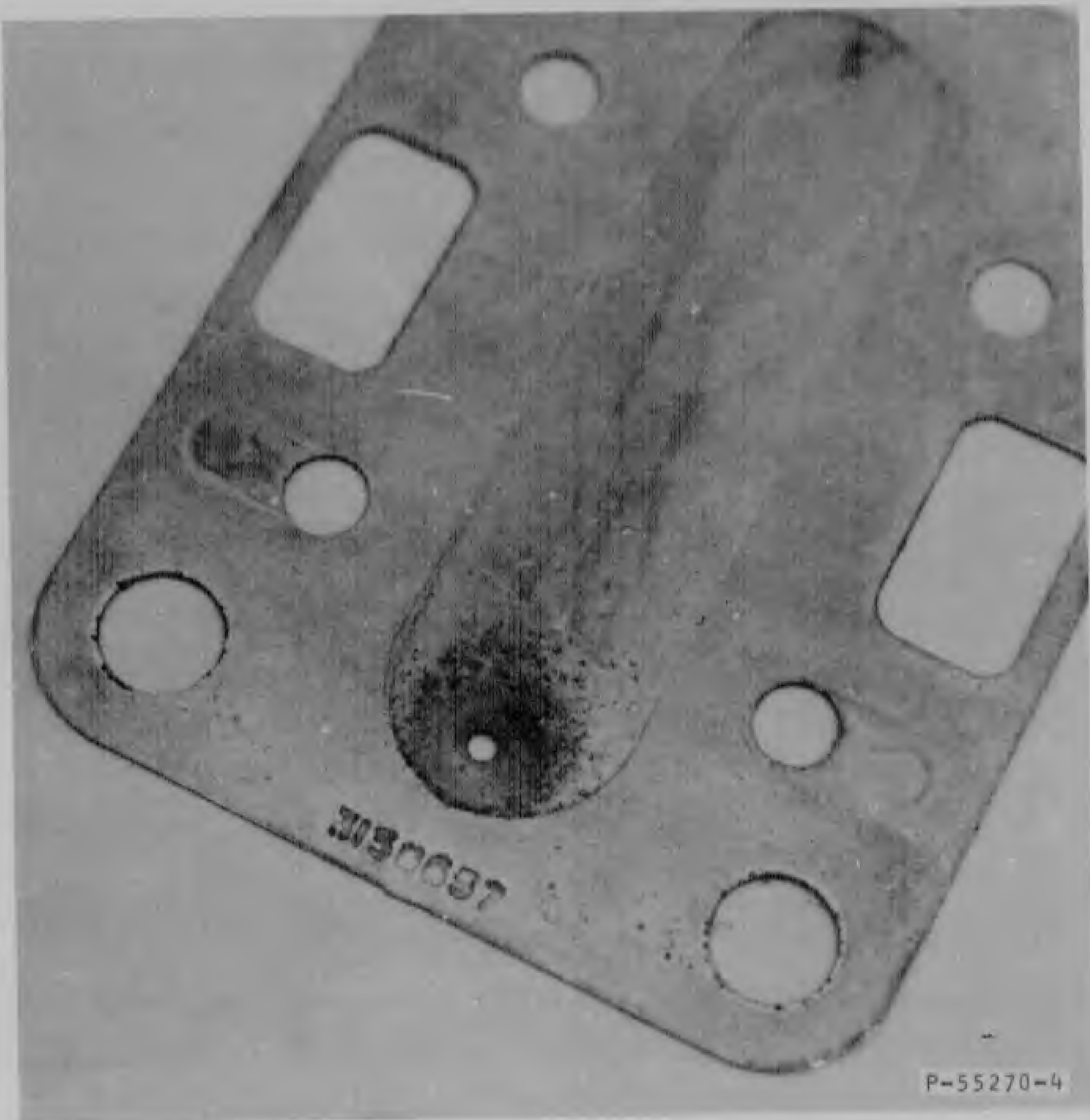

FIGURE 103

ORIFICE LAMINATION
CIRCUIT 2, RUN 13

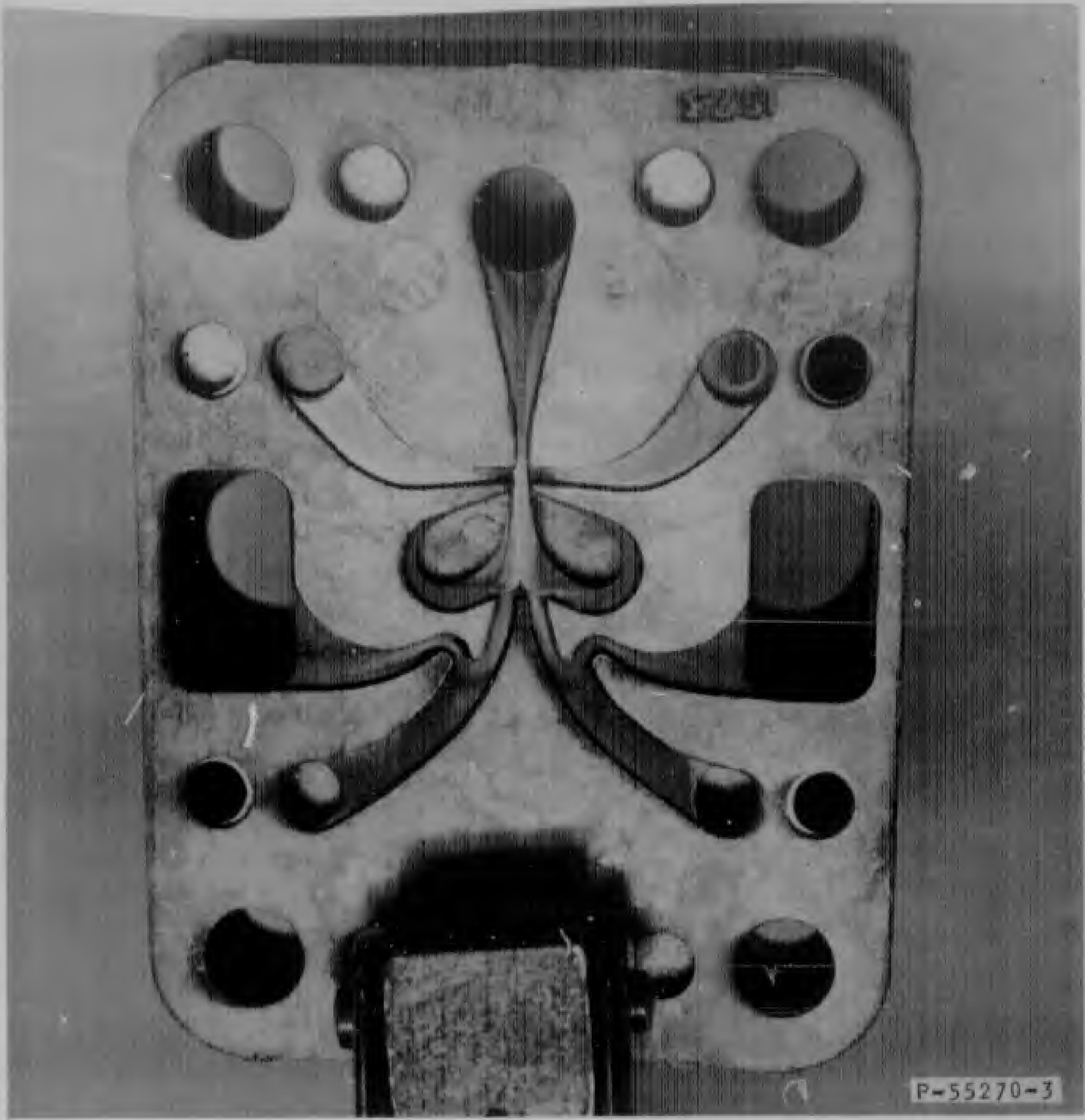

FIGURE 104

FIRST-STAGE AMPLIFIER
CIRCUIT 2, RUN 13

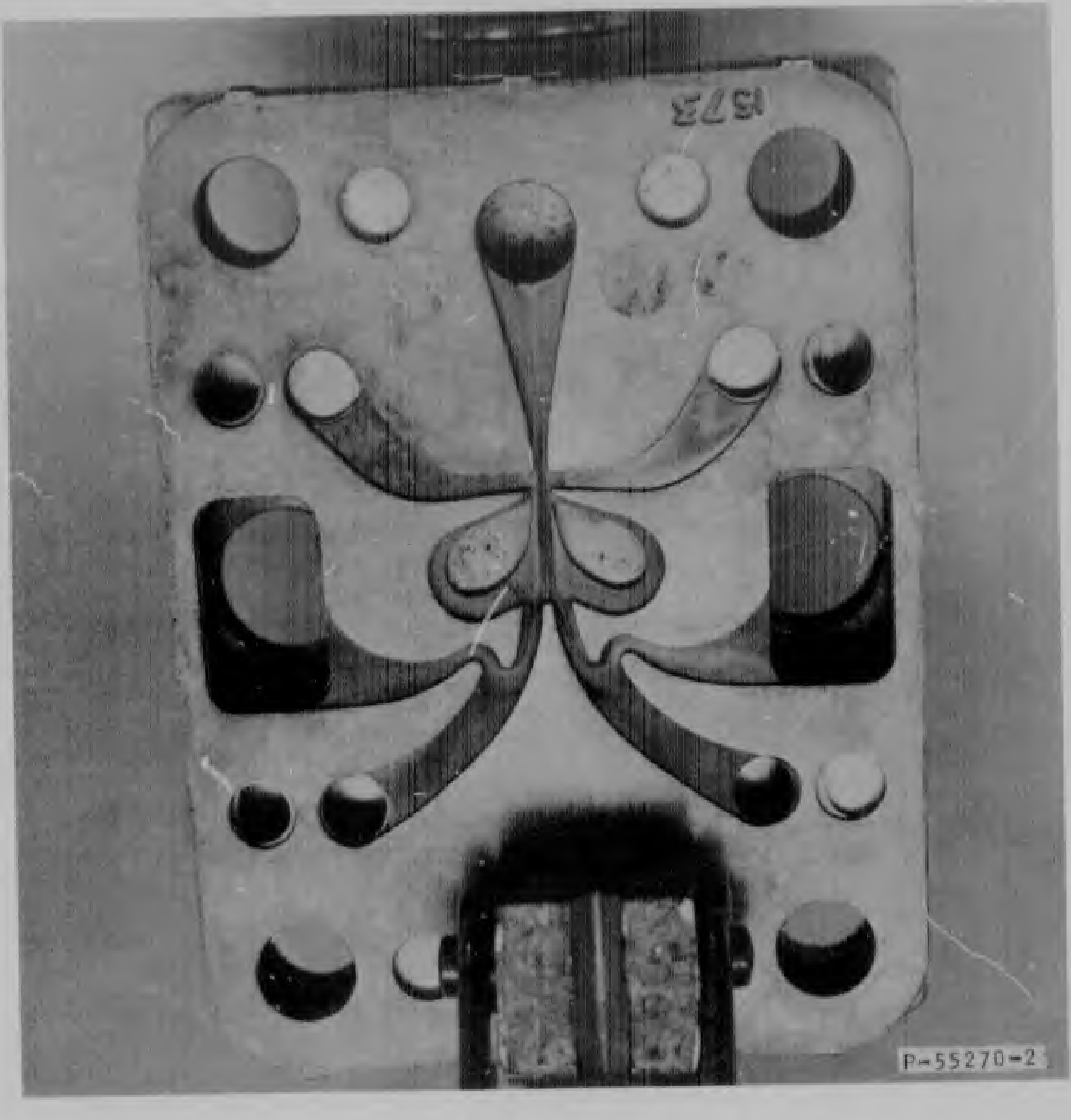

FIGURE 105

SECOND-STAGE AMPLIFIER
CIRCUIT 2, RUN 13

FIGURE 106

THIRD-STAGE AMPLIFIER
CIRCUIT 2, RUN 13

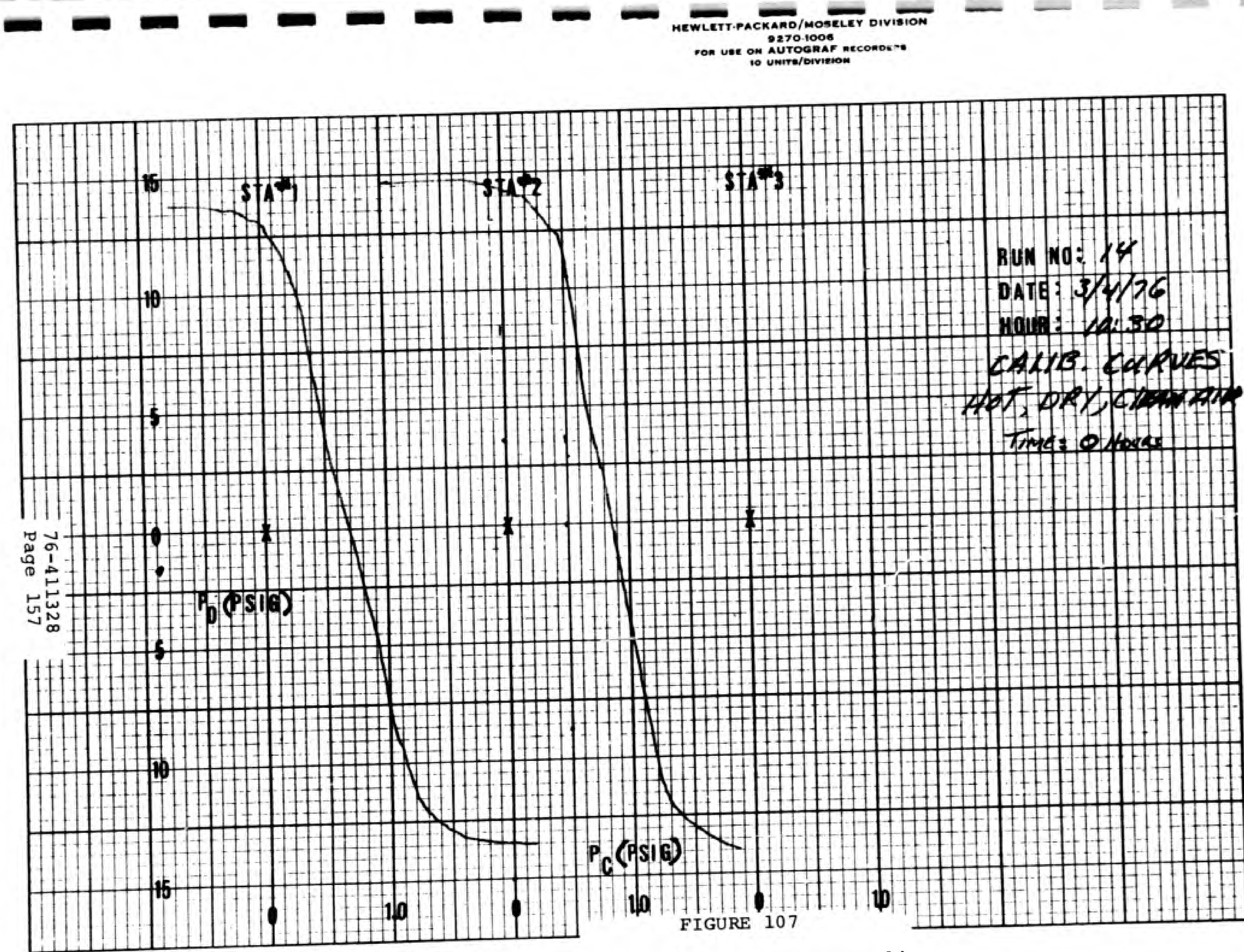

FIGURE 107

RECORDING 10 - START RUN 14

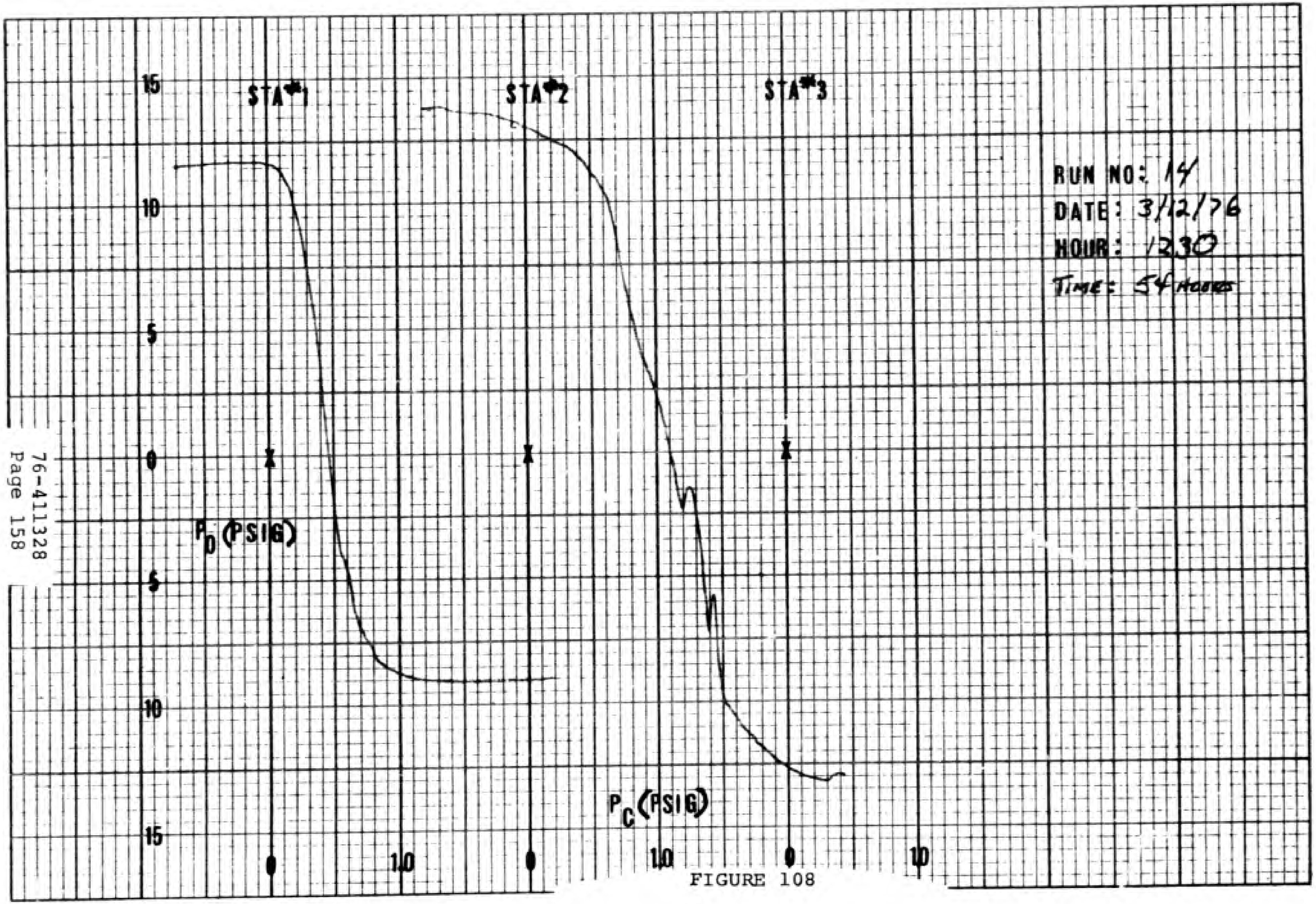

FIGURE 108

RECORDING 11 - 54 HOURS RUN 14

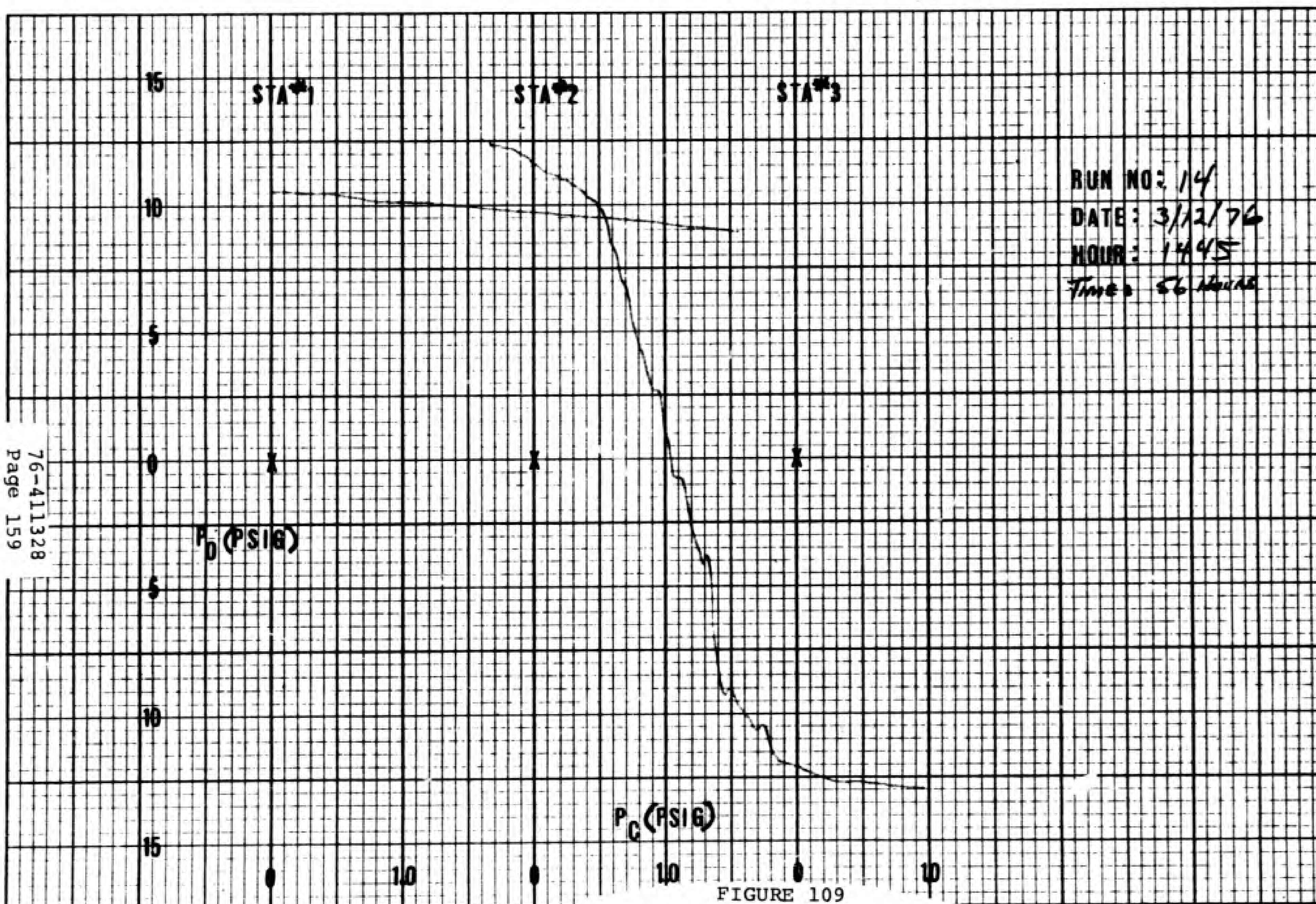

FIGURE 109

RECORDING 12 - 56 HOURS RUN 14

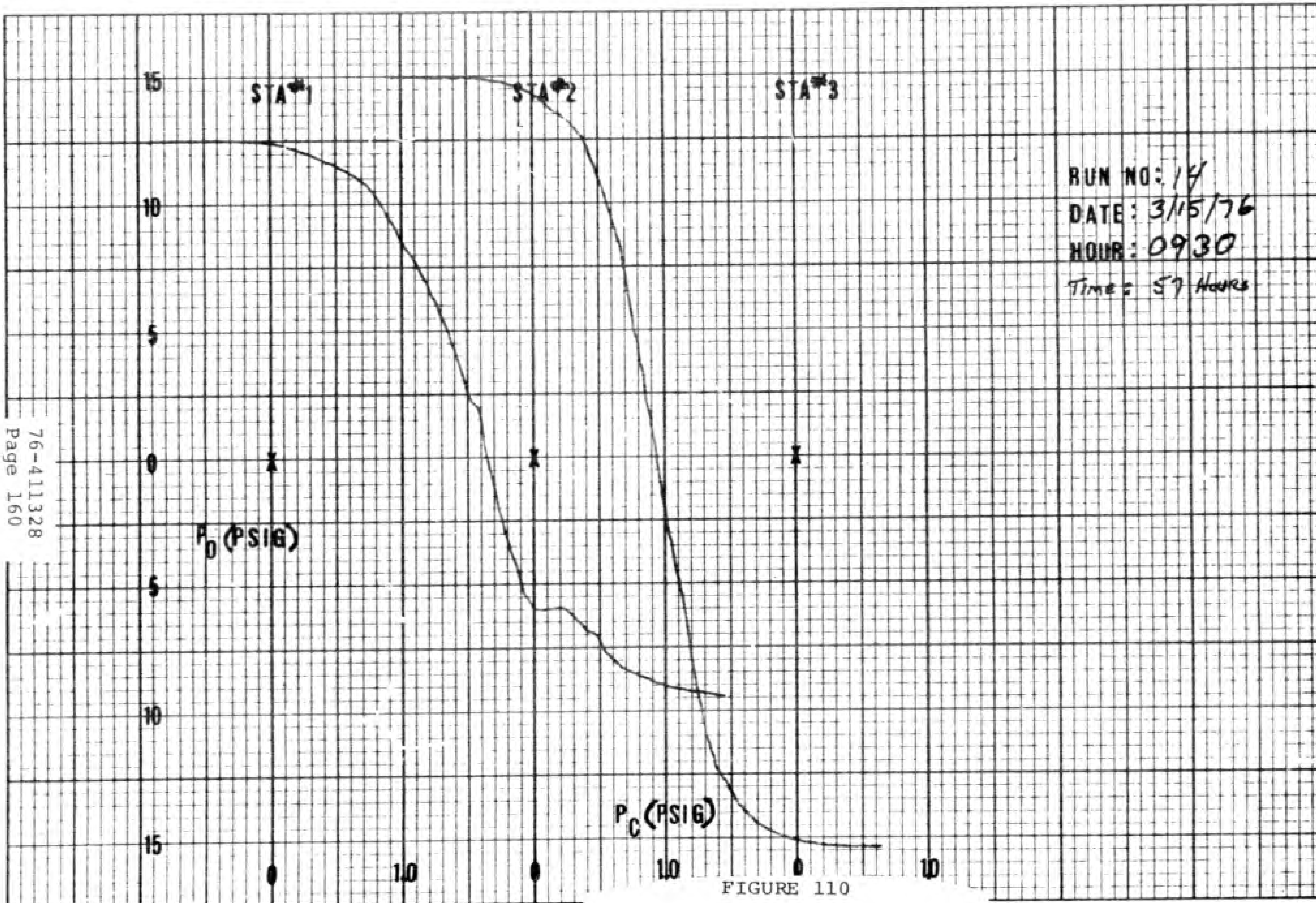

FIGURE 110

RECORDING 13 - 57 HOURS RUN 14

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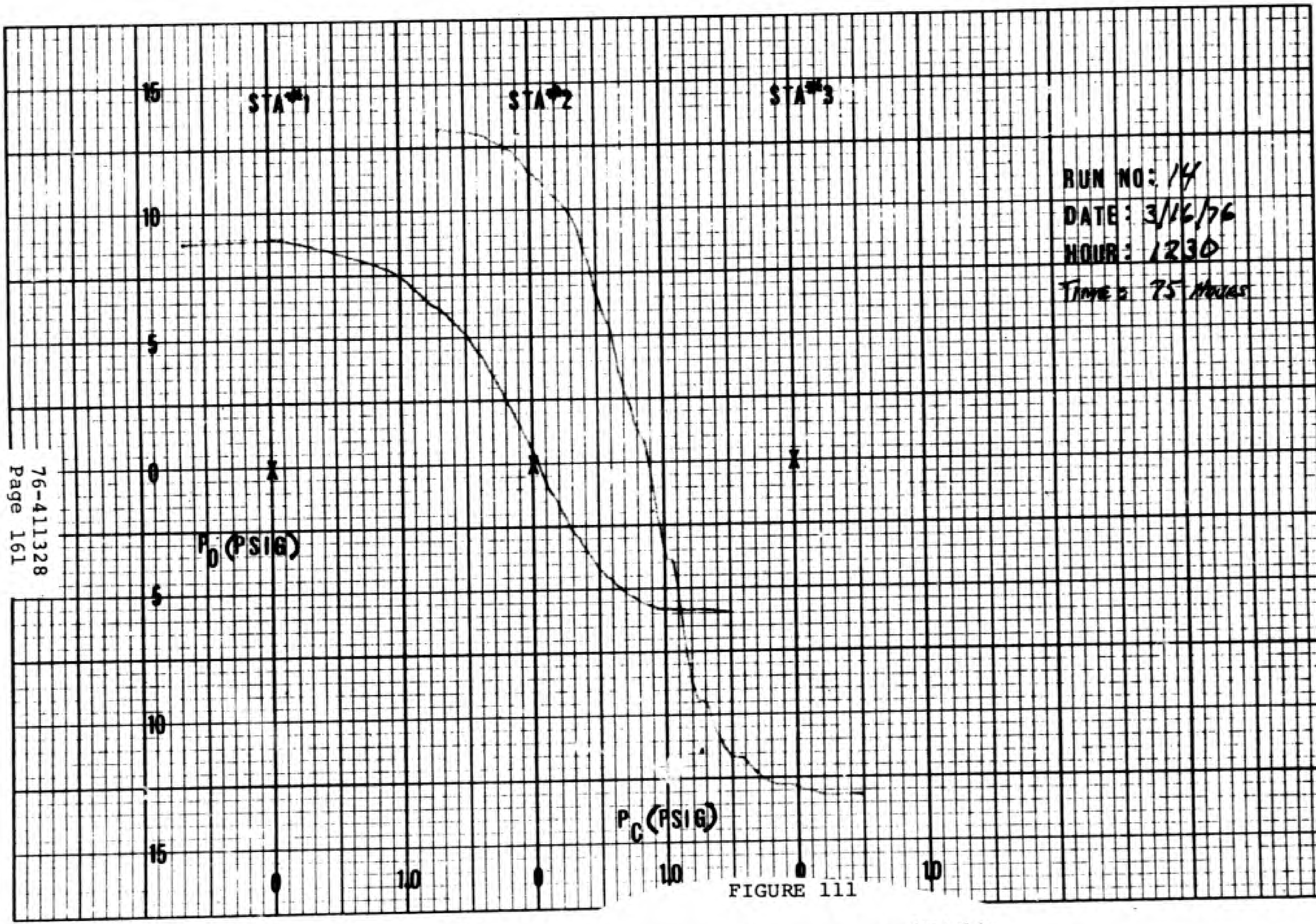

FIGURE 111

RECORDING 14 - 75 HOURS RUN 14

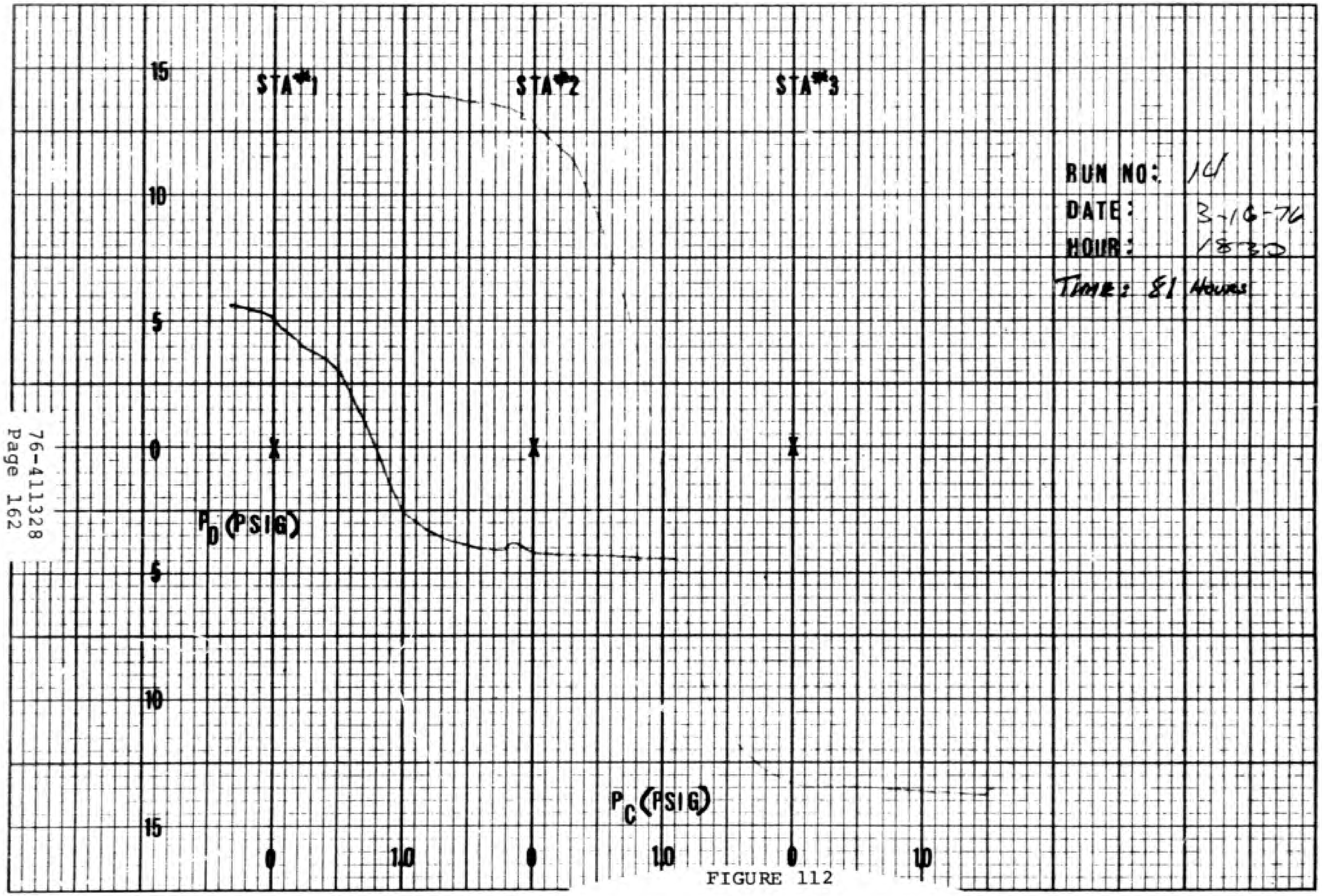

FIGURE 112

RECORDING 15 - 81 HOURS RUN 14

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10 UNITS/DIVISION

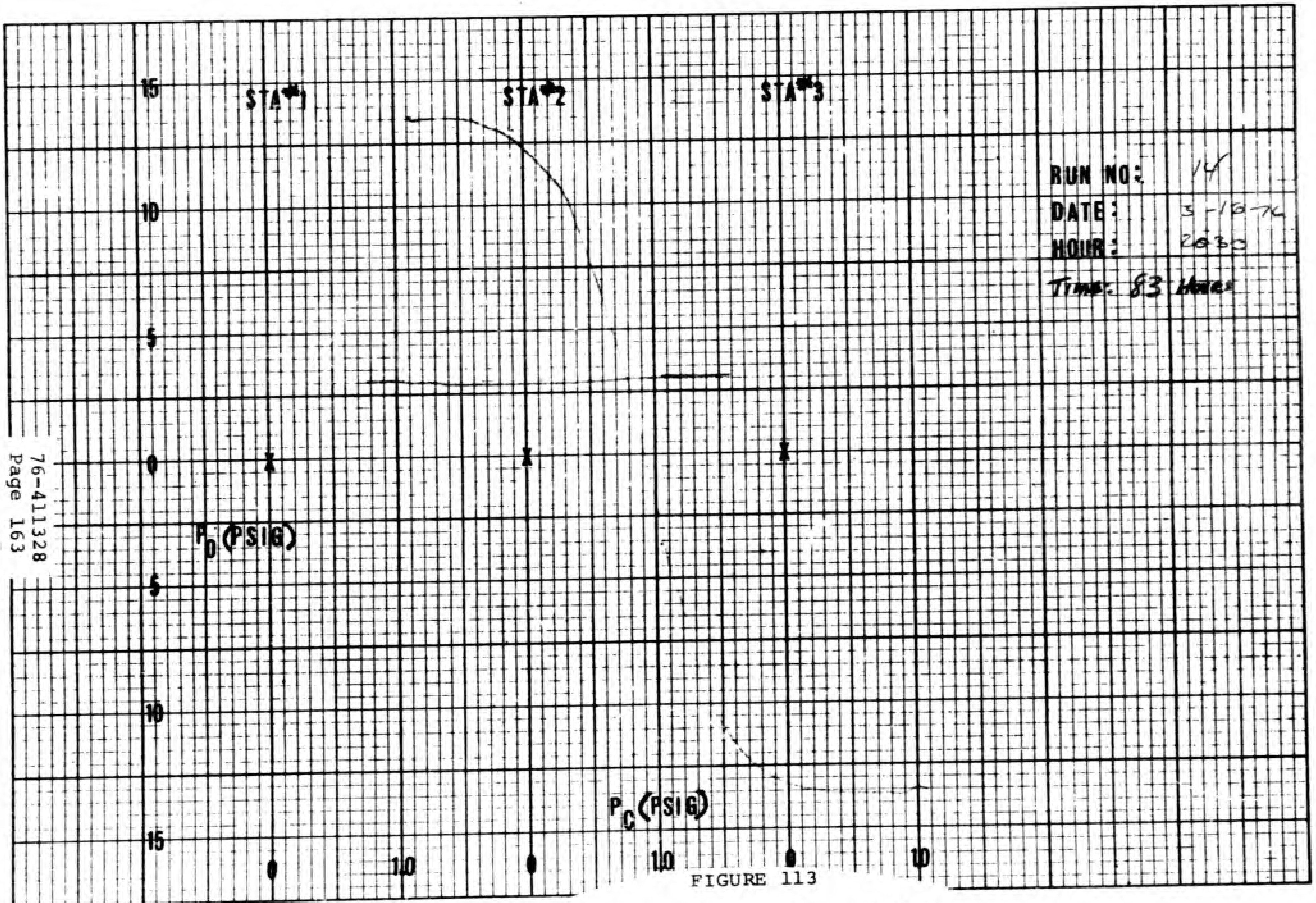


FIGURE 113

RECORDING 16 - 83 HOURS RUN 14

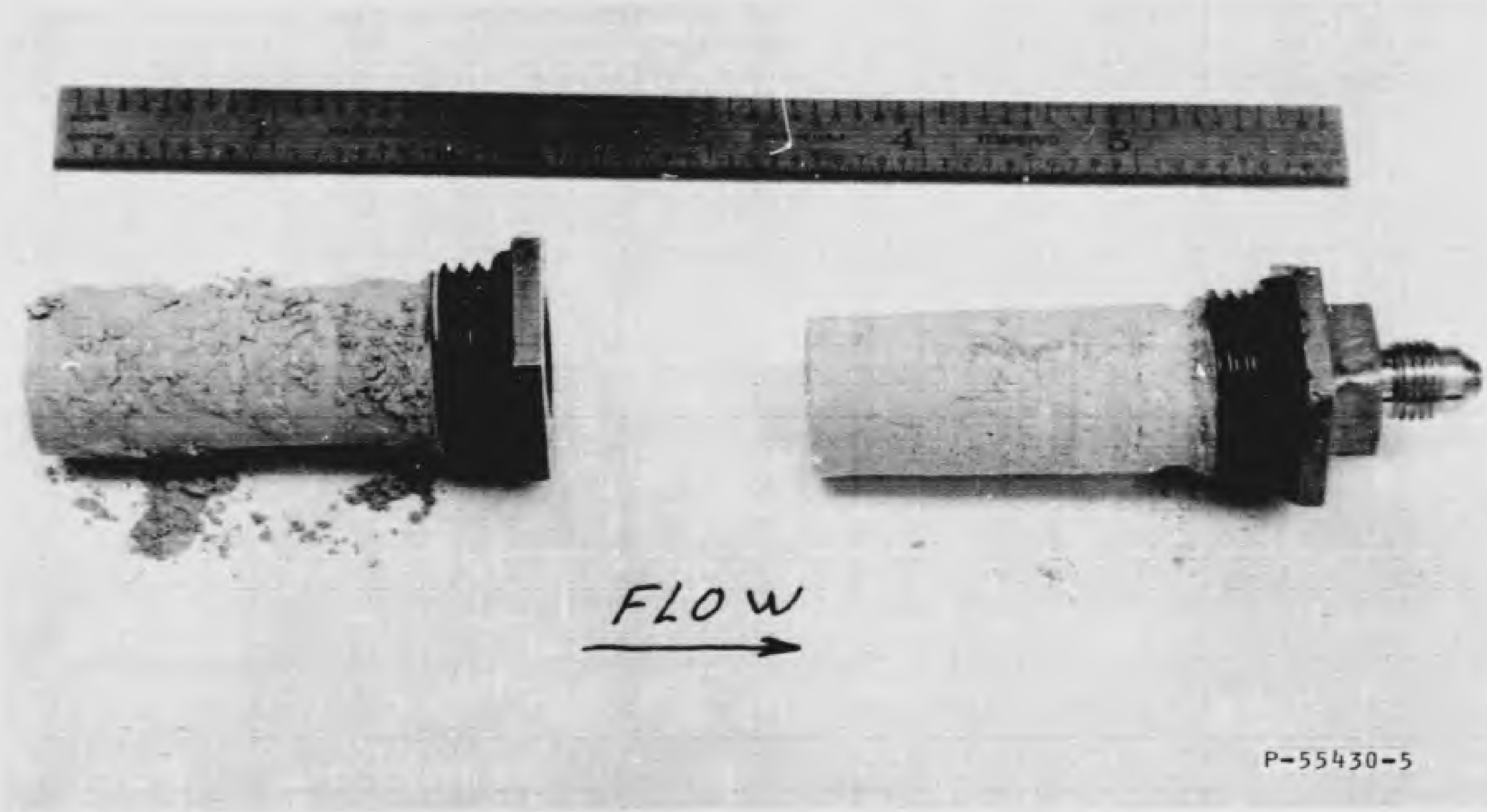


FIGURE 114

FLUID CONDITIONING PRODUCTS
FILTER ELEMENTS AFTER 83 HOURS
STATION 1, RUN 14

A critical examination of Circuit 1 during disassembly found the supply passage in the test block was approximately 95 percent blocked and the first-stage filter area was essentially 50 percent filled, with dirt packed solid between filter and housing. The supply inlet screen was essentially 50 percent blocked as shown in Figure 115. A significant buildup of contaminants was noted around the supply orifice on both the inlet and exit sides as may be seen in Figure 116. The deposits were quite hard and appeared to be dirt particles bonded together with crystallized salt deposits. Some dark areas indicated the presence of oil in these orifice deposits also.

The supply passage that powers the first and third stages was found to be relatively clear downstream of the orifice except for an obvious buildup on the wall. The supply passage powering the second stage was relatively clear to the amplifier; but, beyond that point, it was virtually filled with dirt due to no flow in that area of the passage. The condition of supply transfer, Lamination 5, is shown in Figure 117. The control pressure cross-over passage, Lamination 7, was totally blocked on the side that is vented to ambient. The blockage occurred in the control port of the first-stage amplifier and extended back for approximately one-third the length of the transfer passage, as is clearly evident in Figure 118. The first-stage amplifier contained significant deposits of particulate matter in the entire interaction region, with the greater buildup in the lower velocity regions as expected. The second-stage amplifier appeared to have no significant buildup of contaminants in any of the main flow areas but did contain small deposits in the low flow areas. The photographs of Figures 119, 120, and 121 reveal the extent of the contamination of the first, second, and third-stage amplifiers, respectively, of Fluidic Circuit 1 from 83 hours of Run 14. Detailed examination of the circuit after cleaning revealed only minor indications of erosion.

Meanwhile, testing on Station 2 of the CBAS was still in progress. As of March 26, the system had completed 166 hours of operation with contaminated airflow, and performance was normal as shown by the recording trace of Figure 122. Run 14 was arbitrarily terminated after 266 hours of contaminated airflow. Although circuit performance was still acceptable, a slight degradation was apparent. This test duration was far in excess of the 50-hour contaminated air test requirement of MIL-P-8686.

Table V presents a summary of the test results of the filter configurations subjected to the contamination tests described herein.

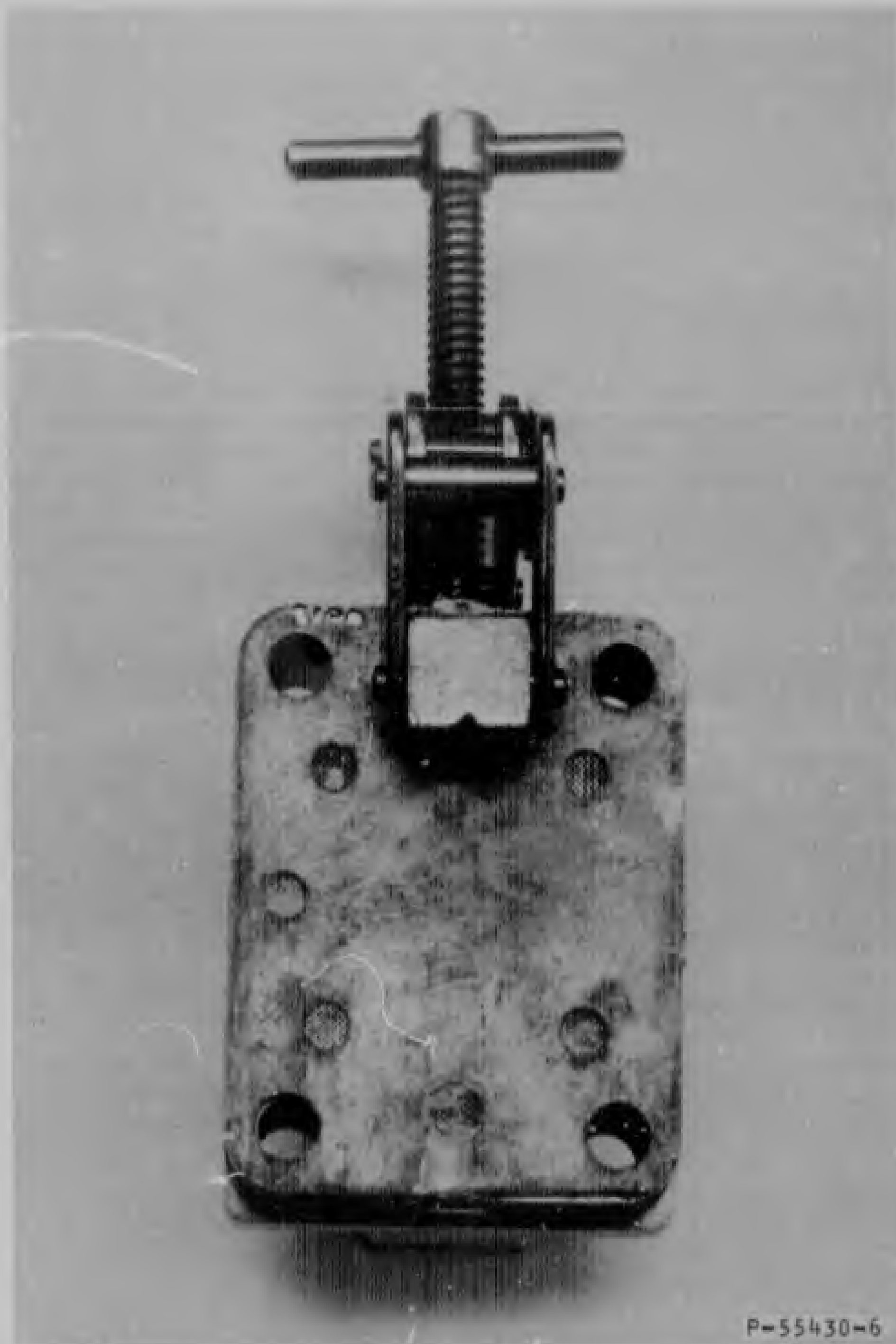


FIGURE 115

INLET SCREEN
CIRCUIT 1, RUN 14

MP-54087

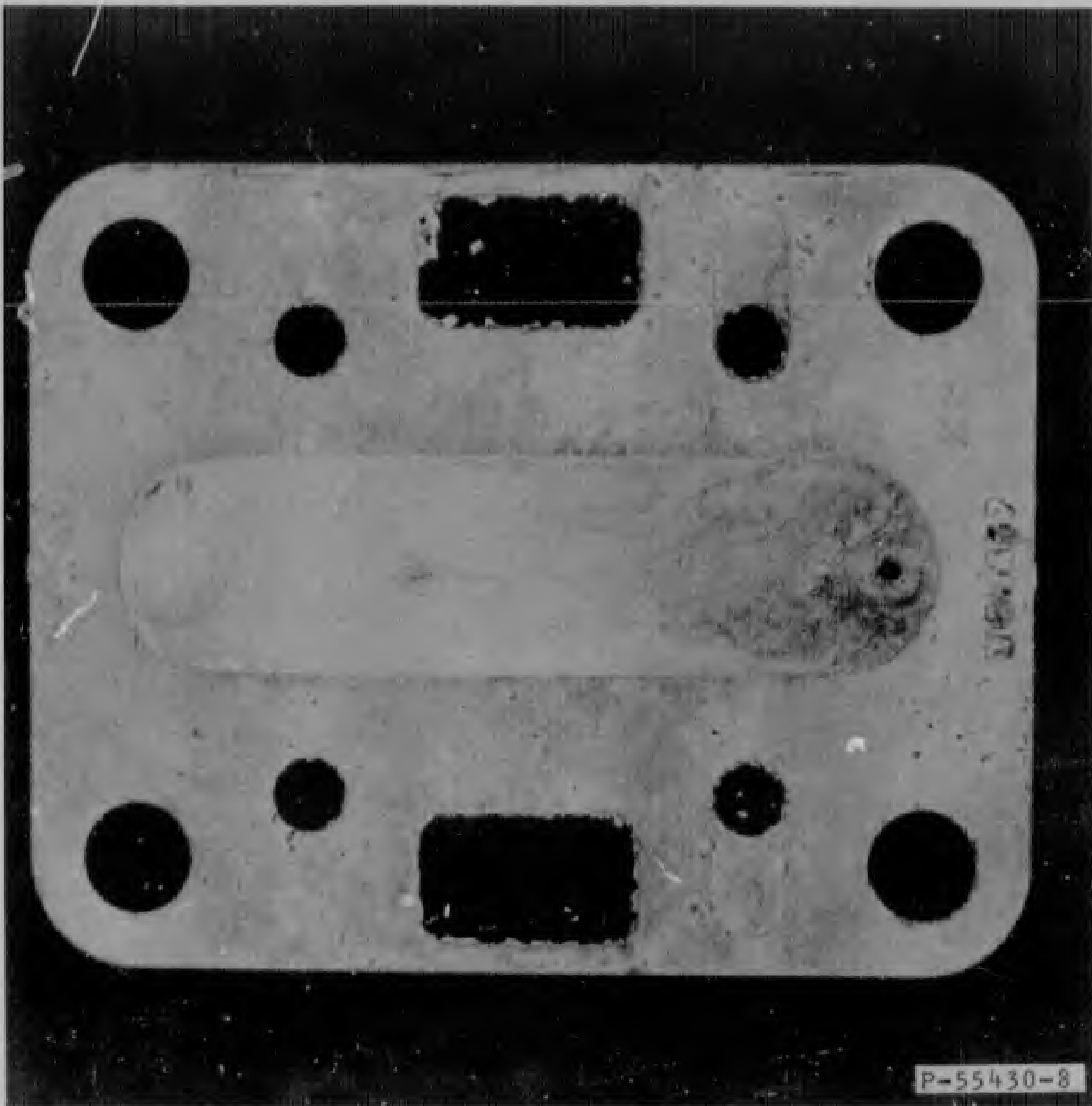
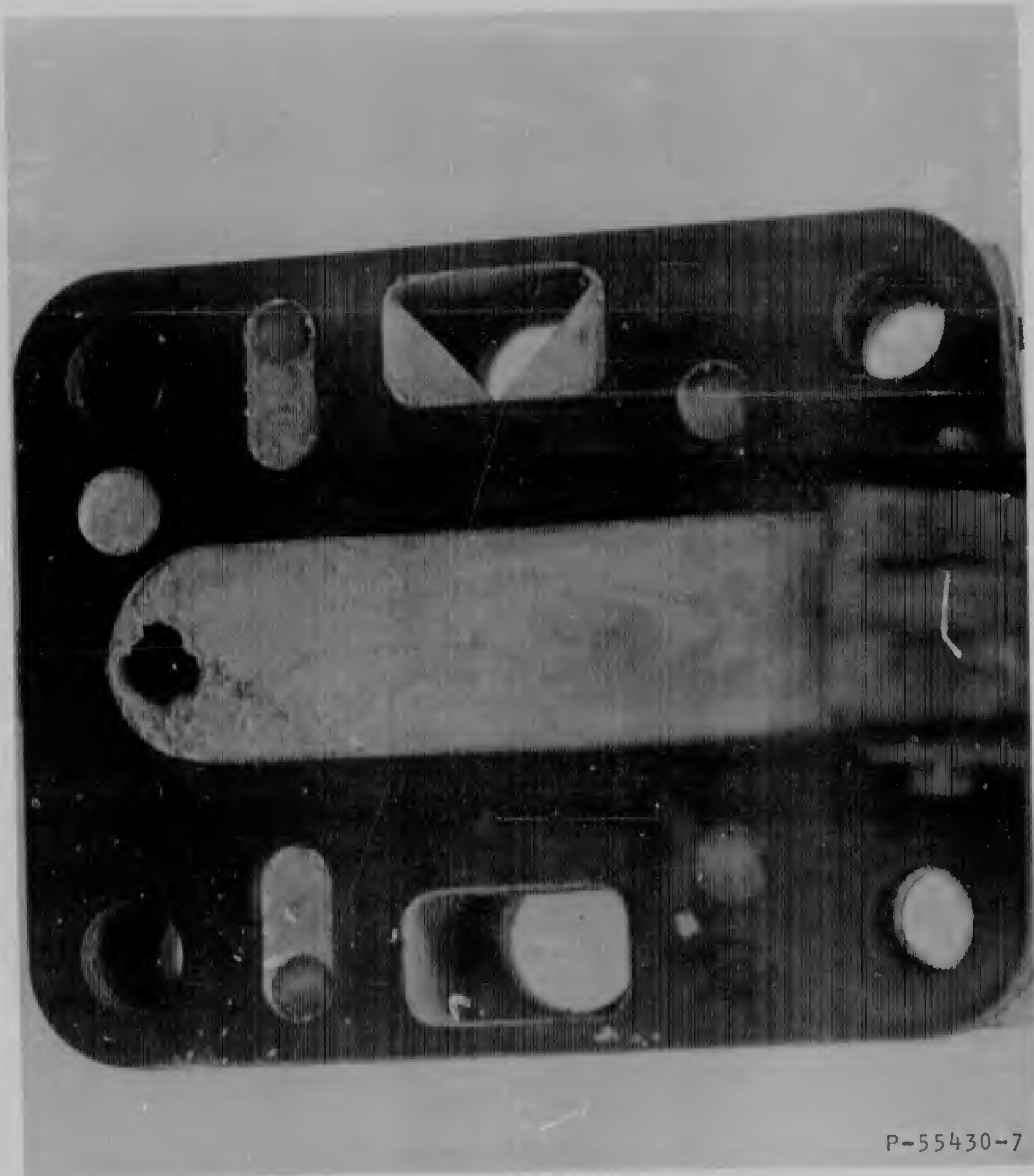


FIGURE 116

SUPPLY ORIFICE
LAMINATION 4
CIRCUIT 1, RUN 14



P-55430-7

FIGURE 117

SUPPLY TRANSFER
LAMINATION 5
CIRCUIT 1, RUN 14

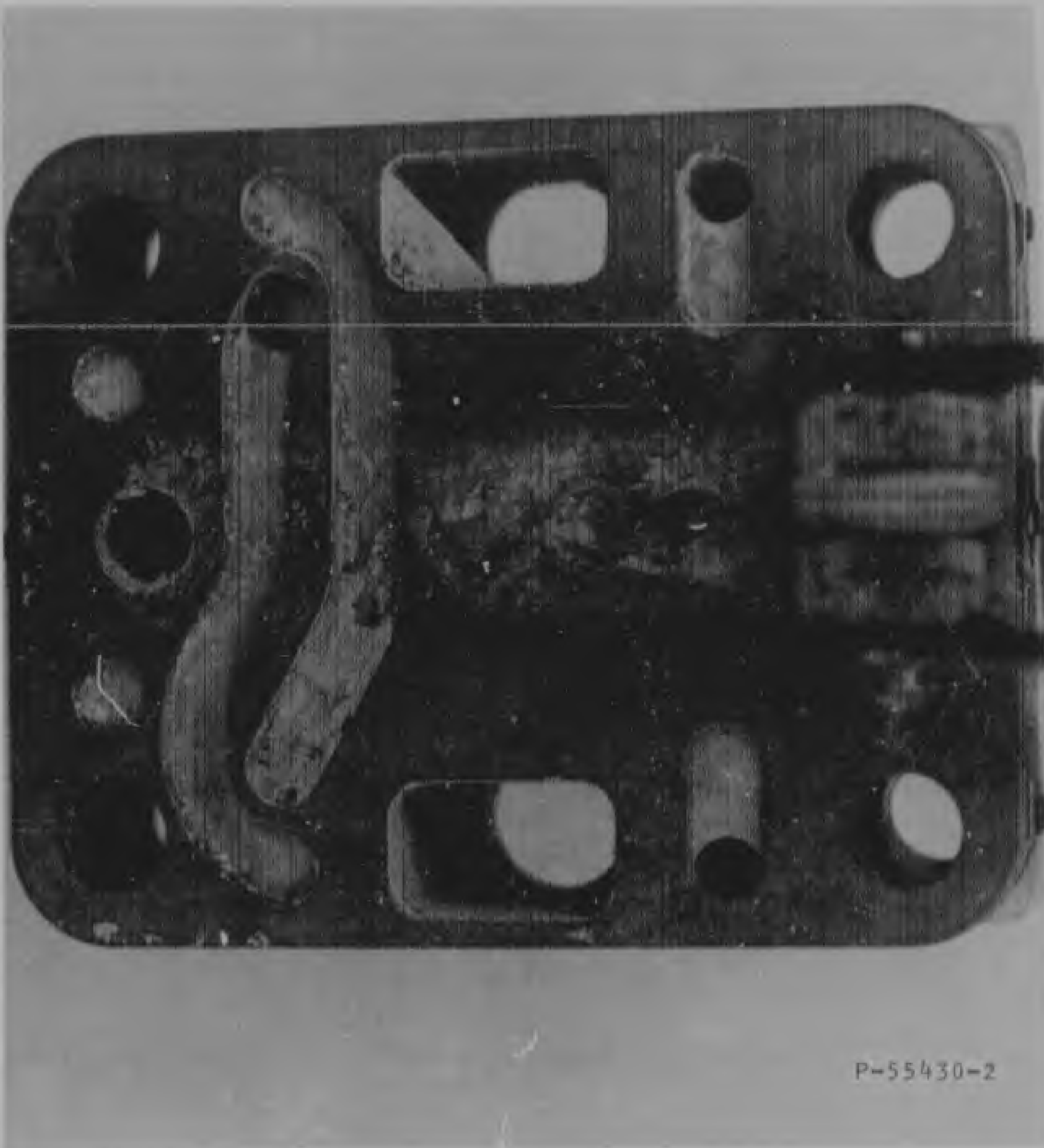


FIGURE 118

CONTROL TRANSFER
LAMINATION 7
CIRCUIT 1, RUN 14

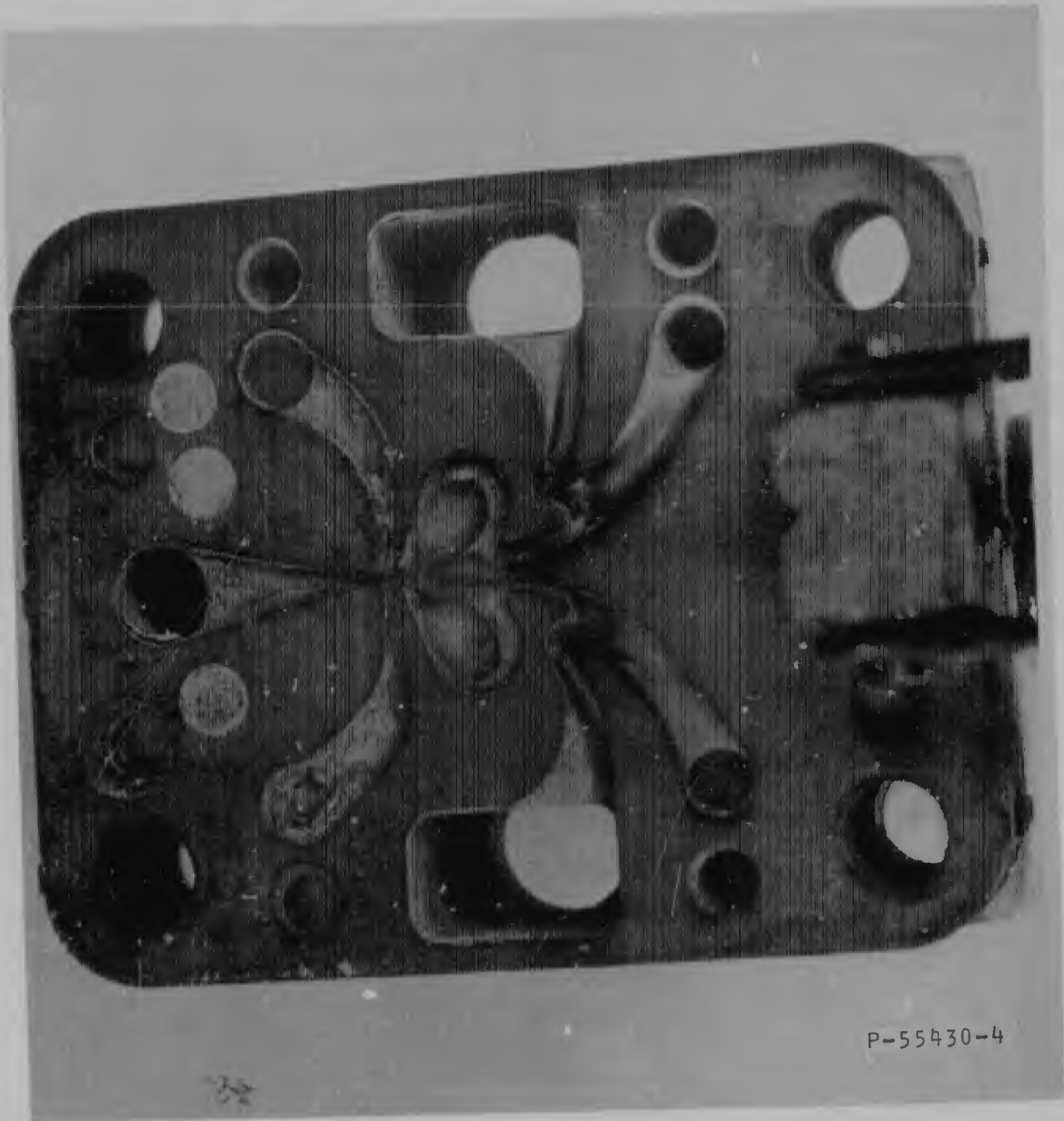


FIGURE 119

FIRST-STAGE AMPLIFIER
CIRCUIT 1, RUN 14

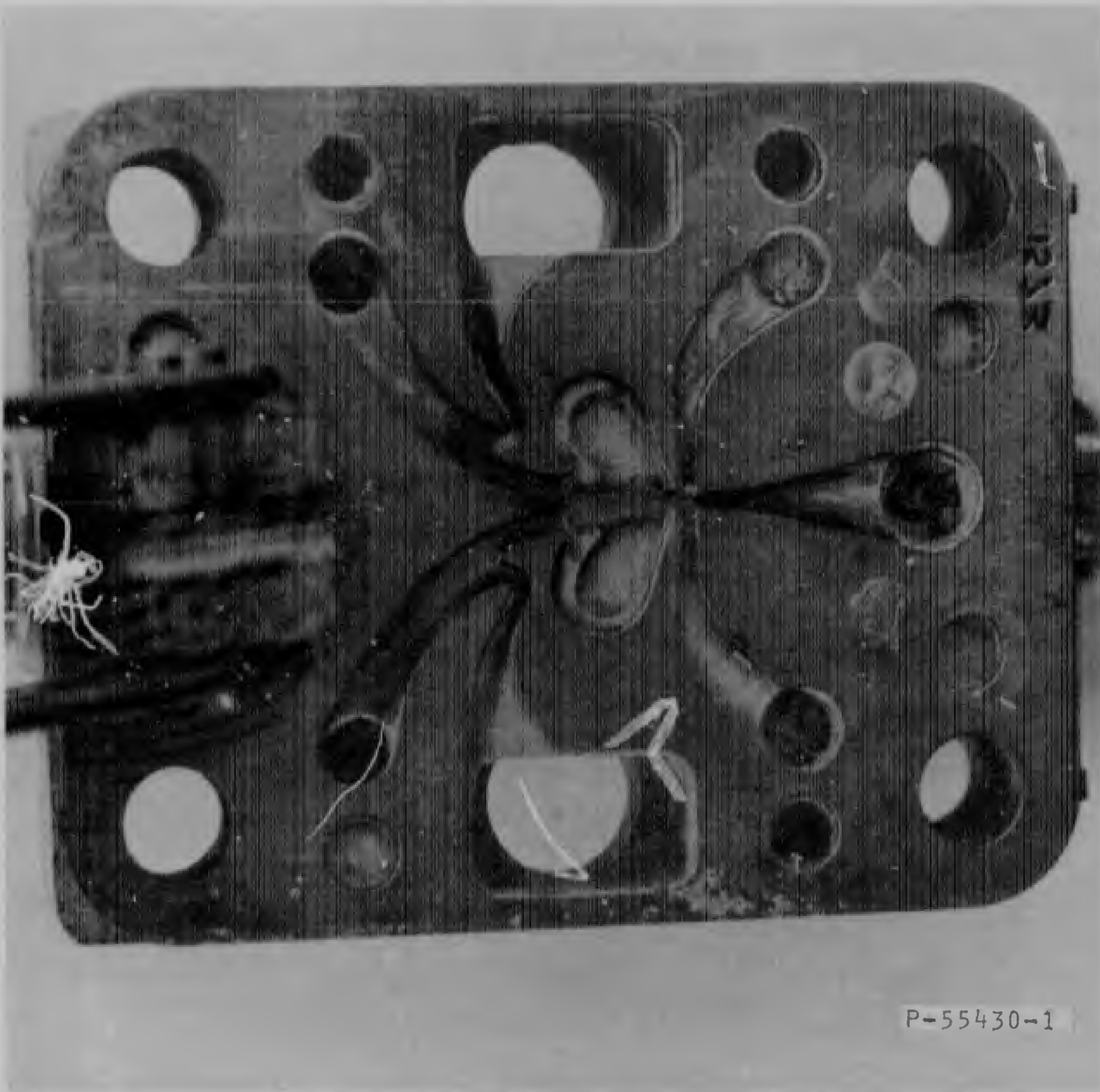


FIGURE 120

SECOND-STAGE AMPLIFIER
CIRCUIT 1, RUN 14

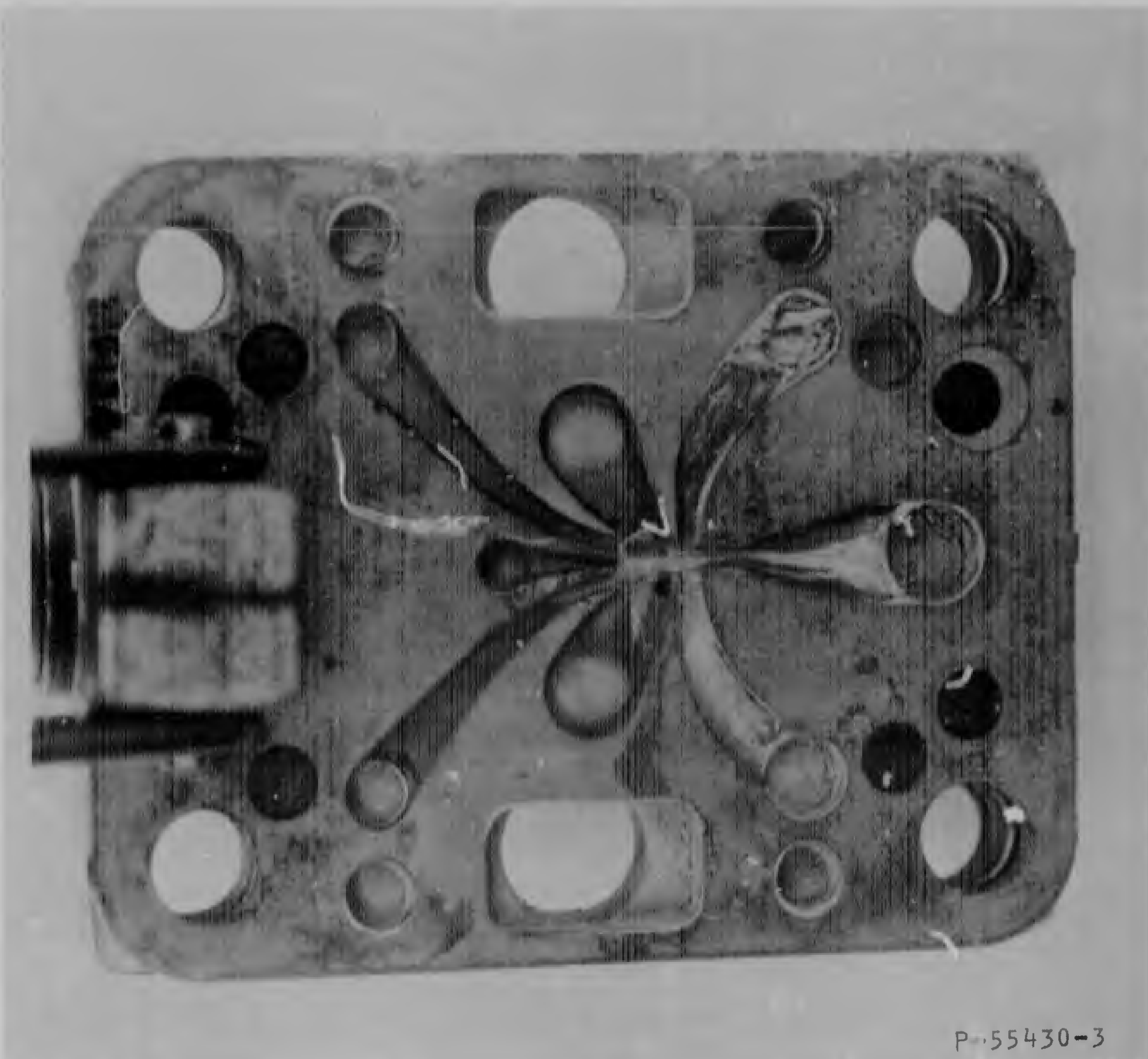


FIGURE 121

THIRD-STAGE AMPLIFIER
CIRCUIT 1, RUN 14

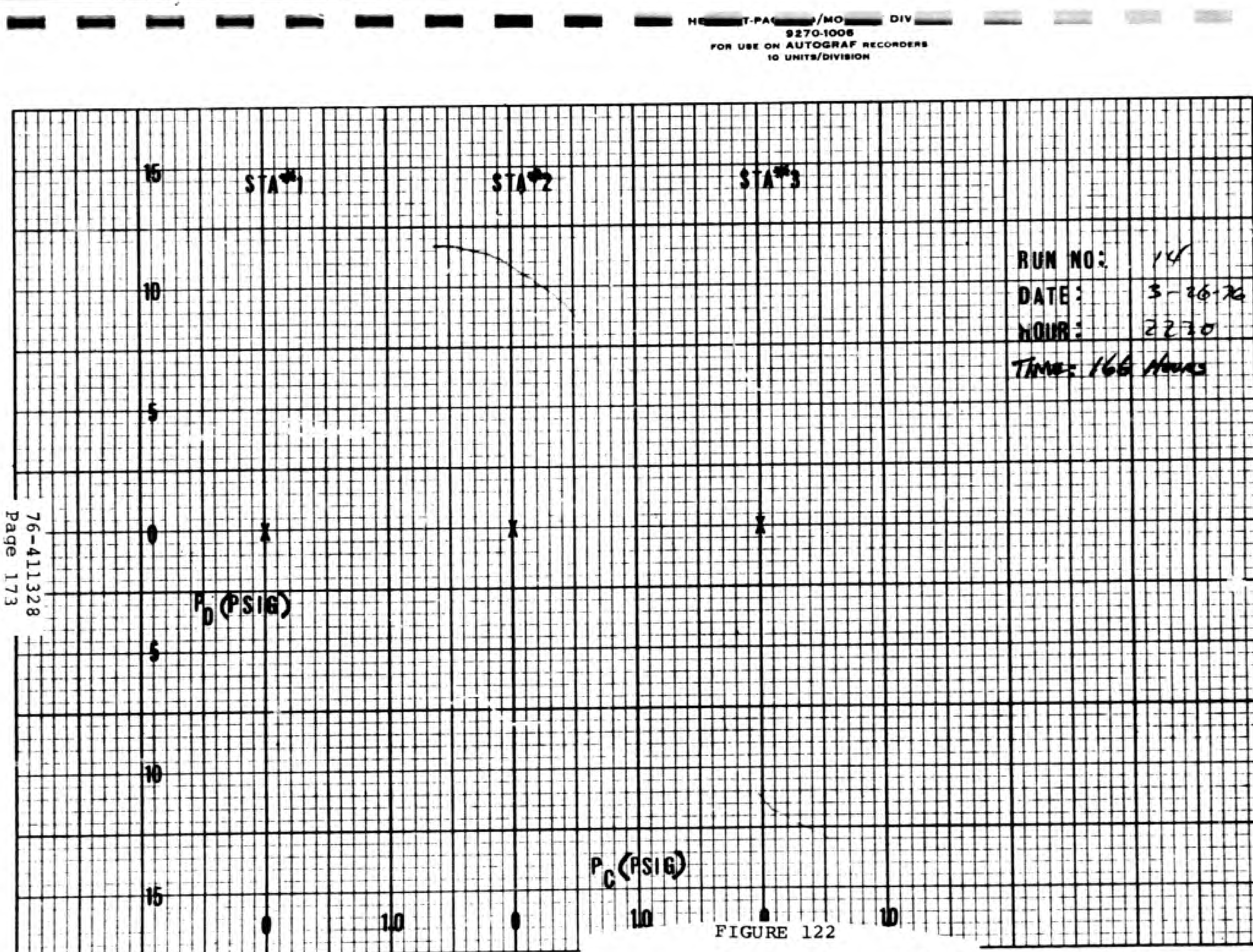


FIGURE 122

RECORDING 17 - 166 HOURS RUN 14

TABLE V

FILTER TEST RESULTS

Test Filter	Filter Type	Filter Area sq in.	Efficiency percent	Hydrocarbons Parts per Million	Remarks
1. AiResearch Part 111790	CRES Mesh				
-1 5 microns	Depth	3	96		Surface area too small, particularly 5 to 10 microns. 5μ filter life less than two hours with cyclone separator prefilter. Very sensitive to liquid contamination. Use of 74μ filter produced fluidic element erosion.
-2 10 microns	Depth	3	80		
-3 20 microns	Depth	3	80	No Data	
-4 40 microns	Depth	3	85		
-7 74 microns	Depth	3	73		
2. Hydraulic Research Part 11-11852	CRES Mesh				
15 micron	Depth	30	99.84	No Data	Circuit passed 266 hours. Condition of circuit is excellent.
3. Fluid Conditioning Product Part 9377-4052	Surface Sintered Bead, Two Stages				
10 micron		2.6	99	No Data	Circuit tested with this filter showed heavy oil deposits with dirt. Circuit life 83 hours.
4. Balston Part 95A	Coalescer Microfiber Depth				
0.1 micron		5	99	2.5	Filter loaded 9.5 hours. High hydrocarbon readings.
5. Koby Filter Model Senior	Cellulose Pad and Activated Charcoal				
0.5 micron		7	99.7	1.2	Filter loaded up in 9.5 hours.
6. Cyclone Separator	Inertia	-	91	1.8	Excellent candidate as prefilter.
100 percent at 5 micron					
50 percent at 1 micron					

5. CONCLUSIONS AND RECOMMENDATIONS

This program has made several significant contributions to the study of fluidic filtration systems where contaminated (engine) bleed air is the source of power. First, it demonstrated the feasibility of building a mobile test stand capable of simulating contaminated engine bleed air conditions in accordance with MIL-E-5007. Secondly, during the course of this program, several bleed air extraction techniques and many filtration devices were performance tested. Finally, several of the more promising filtration concepts were each performance tested with a three-stage amplifier cascade to establish service life capability.

At the present time, the most optimum filtration system evaluated is as follows: First, an ID bleed extraction port is preferable to OD bleed extraction. As previously mentioned, this position was developed from DC-10 development experience. Use of a trailing hooded probe is recommended to minimize entrainment of particles. Second, a two-stage filtration system is advised. The first stage should be a cyclone separator with overboard scavenge. The second stage should utilize a depth media filter similar to the multiple-stage Hydraulic Research element. This recommendation is based on the efficiency, not the capacity, of the 30-square-inch element. Further development should be conducted to reduce the surface area of the Hydraulic Research element and determine correlation between surface area and operating life. This filtration system completed 266 hours of testing, when initial indications of performance degradation were noted.

Further studies utilizing the CBAS are recommended in order to optimize the two-stage filtration system. Analytical and development investigation of the cyclone separator should be conducted to reduce physical size and yet retain acceptable performance. Low cost fabrication techniques (i.e., bonded laminations, etc.) should be evaluated. In conjunction with the first-stage filter optimization program, a development study should be conducted to optimize second-stage filter micron size and minimize surface area consistent with service life. Finally, after optimization of both stages, a service life program utilizing a sophisticated fluidic control (i.e., approach power compensator or AiResearch fluidic fuel and bleed control for the GTCP85-180 gas turbine engine) should be performed to demonstrate service life capability.

APPENDIX 1

OPERATING PROCEDURES
FOR THE
COMPRESSOR BLEED AIR SIMULATOR (CBAS)
(AIRESEARCH SYSTEM 710403)

APPENDIX 1

OPERATING PROCEDURES FOR THE COMPRESSOR BLEED AIR SIMULATOR (CBAS) (AIRESEARCH SYSTEM 710403)

1. INTRODUCTION

This appendix presents the operating procedures for the CBAS which include an initial start-up safety check list, the operating sequence, establishing test conditions, system recharging, and system shutdown.

2. OPERATING PROCEDURE

2.1 Initial Start-Up Safety Check List

To assure safe operation of the CBAS, a safety check should be conducted to verify that all system controls are in an inactivated position. With reference to the photographs and Schematic Diagram P710403-1 at the back of this appendix, verify that each number-identified control is in the inactive position indicated below.

Control	Position
Electrical: 190, 41, 39, 205	Off
Connector for belt drive and vibrator:	Unplugged
Over Temp: 13	1400F
Temp: 27	Lowest setting
Regulators: R-1, R-2, R-3, R-4, R-9	ccw until free (no pressure)
Valves: V-1, V-4, V-2, V-8, V-9, V-10, V-19, V-20, V-13, V-14, V-11, V-12	Closed (full cw)
Valves: V-23, V-18	Open (full ccw)
Valve: V-16	Open (full cw)
Valves: V-6, V-5, V-7, V-15	Open slightly (1/4 turn)
Valves: V-21, V-22, V-25, V-28, V-3, V-29	Closed

2.2 Operational Sequence

2.2.1 To Initiate Operation of the CBAS

1. Move Master Switch 190 to ON position.
2. Flip Switch 40 to FLOW SECTION.
3. Slowly open Valve V-1 (while observing Gauge G-3 to see that ΔP does not exceed 100 in. H_2O).
4. Adjust Regulator R-3 to desired test section pressure.
5. Adjust Regulator R-9 to approximately 5 psi higher than test section pressure.
6. Adjust Regulator R-4 to desired airflow rate (approximately 64 in. H_2O ΔP indicated on G-3).

2.2.2 To Inject Oil or Salt Water

1. Slowly turn Valve V-16 full ccw to PRESSURIZE.
2. Slightly open (1/4 turn) Valves V-19 and V-20 to monitor injector ΔP.
3. Open toggle Valve V-28.
4. Turn Valve V-21 full ccw to OPEN (for oil).
5. Turn Valve V-22 full ccw to OPEN (for salt water).
6. Adjust Valves V-26 and V-27 to the desired flow rates (approximately 1.2 lb per min nominal).

   NOTE: Oil tube contains 1.0 cc/in.
   NaCl tube contains 2.22 cc/in.

2.2.3 To Injet Water

1. Verify that Valves V-3 and V-29 (on top of water tank) are CLOSED.
2. Turn Valve V-2 ccw to OPEN.
3. Adjust Regulator R-2 to regulate at 150 psig (indicated on G-7).

4. Turn Valve V-4 to OPEN.

5. Adjust R-2 to attain desired flow rate as indicated by Flowmeter 25.

2.2.4 To Inject Particulate

1. Slowly turn Valve V-23 full cw to PRESSURIZE.

2. Slowly turn Valve V-8 ccw to OPEN.

3. Slowly open Valve V-9 so that pressure slowly rises, as shown on Gauge G-8, to same level as test section pressure.

4. Slightly open Valves V-11 and V-12 (1/4 turn).

5. Open Valve V-25 fully.

6. Adjust Valve V-9 to indicate 8 in. H_2O on Gauge G-4.

7. Slightly open Valves V-13 and V-14 (1/4 turn).

8. Adjust Valve V-10 to indicate 10 in. H_2O on Gauge G-5.

9. Turn speed Control 41 to ON.

10. Adjust frequency to attain desired belt speed (60 Hz nominal).

11. Plug six-pin electrical connector into receptacle on clear plastic face of solid particle injector.

    NOTE: Belt travels approximately 1.56 inches per hour at 60 Hz.

2.2.5 To Establish Test Section Conditions

1. Adjust Regulator R-3 to attain desired pressure (indicated on Gauge G-2).

2. Adjust temperature Control 27 to desired temperature as indicated on digital temperature Indicator 8 with Switch 40 set to TEST SECTION and 480 vac switch ON (205).

3. Adjust temperature Control 39 to maintain line temperature (on Control 139 indicator) close to the heater discharge temperature shown on Control 27 indicator (do not exceed a setting of 4 on the secondary heater Control 39).

4. Set Switch 40 to FLOW SECTION to read the flow section temperature.

5. Read flow section pressure on Gauge G-1.

6. Calculate $\sigma\Delta P$, then ΔP for W (flow) desired.

7. Adjust Regulator R-4 to calculated ΔP as indicated on Gauge G-3 (approximately 65 in. H_2O).

2.2.6 <u>To Recharge System</u>

Each of the contaminant injection subsystems must be isolated from mainstream flow before recharging as described below.

2.2.6.1 <u>To Isolate and Recharge Water Injection System</u>

1. Turn Valve V-4 cw to CLOSED.

2. Turn Valve V-2 cw to CLOSED.

3. Slowly bleed off pressurized air by slowly opening Valve V-29.

4. Add distilled water through Valve V-3, as required.

2.2.6.1.1 <u>To Resume Water Injection</u>

1. Close Valves V-3 and V-29.

2. Open Valves V-2 and V-4.

3. Adjust Regulator R-2 to provide desired flow rate as indicated by Flowmeter 25.

2.2.6.2 <u>To Isolate Oil and Salt Water Injection Systems</u>

1. Turn Valves V-21 and V-22 cw to CLOSED, and close toggle Valve V-28.

2. Turn Valve V-16 cw to VENT.

3. Add oil and salt water solution, as required.

2.2.6.2.1 To Resume Oil and Salt Water Injection

1. Slowly turn Valve V-16 ccw to PRESSURIZE.
2. Open Valve V-28.
3. Turn Valves V-21 and V-22 ccw to OPEN.

   CAUTION: Be certain V-16 is turned to PRESSURIZE before opening V-21 and V-22.

2.2.6.3 To Isolate and Recharge the Solid Particle Injector

1. Unplug electrical connector for belt drive and vibrator from plastic face of particle injector.
2. Close Valve V-10 (fully cw).
3. Close Valves V-13 and V-14 (fully cw).
4. Close Valve V-25 (fully cw).
5. Close Valve V-9 (fully cw).
6. Close Valves V-11 and V-12 (fully cw).
7. Close Valve V-8 (fully cw).
8. Slowly open Valve V-23 until pressure on Gauge G-8 begins to drop, allow pressure to slowly drop to zero then fully open Valve V-23.
9. Add particulate, as required.

2.2.6.3.1 To Resume Particulate Injection

1. Close Valve V-23 by turning full cw.
2. Open Valve V-8 (ccw).
3. Pressurize the system by slowly turning Valve V-9 ccw to OPEN.
4. Open Valves V-11 and V-12.
5. Open Valve V-25 by turning full ccw.
6. Adjust Valve V-9 to provide 8 in. H_2O on Gauge G-4.

7. Open Valves V-13 and V-14.

8. Adjust Valve V-10 to provide 10 in. H_2O on Gauge G-5.

9. Replace electrical connector in receptacle on face of solid particle injector.

2.3 System Shutdown

1. Isolate all contaminant injection subsystems from the mainstream airflow as in the Recharging Process, paragraph 2.2.6.

2. Reduce temperature on controller (27) to lowest setting.

3. Turn off line heater (39).

4. Adjust Regulator R-3 to reduce system pressure to 30 psig or less.

5. Allow system to cool, as determined by readings on (27) and (13).

6. Reduce test section pressure to zero with R-3.

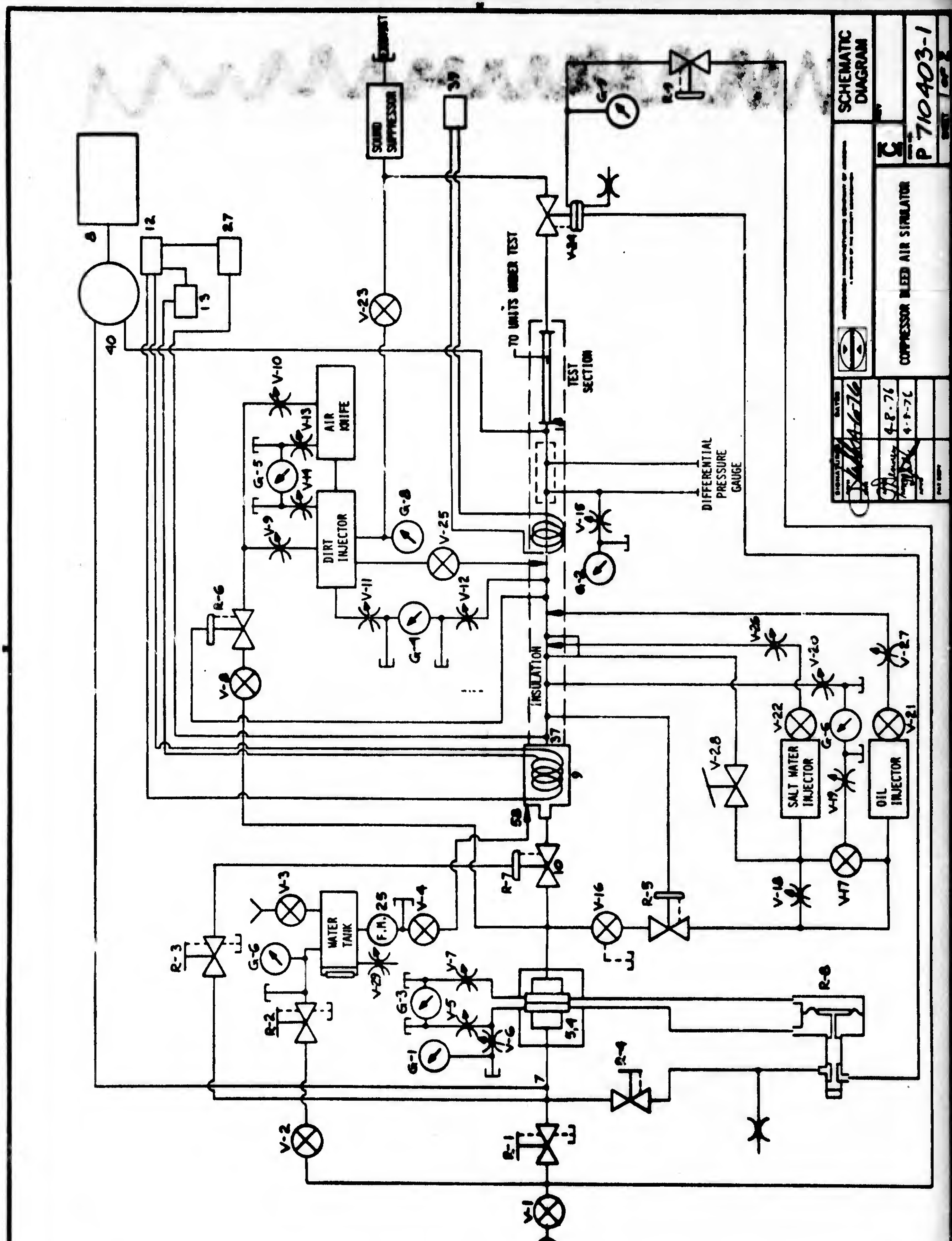
7. Back off Regulator R-4 until free (no pressure).

8. Close Valve V-1.

9. Turn electrical Switches 41 and 190 to OFF.

10. Turn master Switch 205 to OFF.

11. Verify that all controls are in the inactivated position as indicated in paragraph 2.1 herein.



SCHEMATIC DIAGRAM
COMPRESSOR BLEED AIR SIMULATOR
P 710403-1
SOUND SUPPRESSOR
TO UNITS UNDER TEST
TEST SECTION
AIR KNIFE
DIRT INJECTOR
DIFFERENTIAL PRESSURE GAUGE
INSULATION
SALT WATER INJECTOR
OIL INJECTOR
WATER TANK
F.M. 25
V-1
V-2
V-3
V-4
V-5
V-6
V-7
V-8
V-9
V-10
V-11
V-12
V-16
V-17
V-18
V-20
V-21
V-22
V-23
V-25
V-27
V-28
R-1
R-2
R-3
R-4
R-5
R-6
R-7
R-8
G-1
G-3
G-5
G-6
G-8

[redacted]

Item	Nomenclature
1	Quick Disconnect
V-1	Supply Valve
R-1	Flow Section Pressure Regulator
4.5	Flow Measurement Section and Orifice
G-1	Flow Section Pressure Gauge
G-3	Flow Section Differential Pressure Gauge
17	Flow Section Thermocouple
9	Primary Heater
R-7	Test Section Pressure Regulator
11	Secondary Heater
G-2	Test Section Pressure Gauge
18	Test Section Thermocouple
V-24	Test Section Flow Control Valve
R-4	Flow Rate Control Adjustment Pressure Regulator
R-8	Flow Control Valve Pressure Regulator
R-3	Flow Section Pressure Control Adjustment Pressure Regulator
V-2	Water Injector Pressurization Shutoff Valve
R-2	Water Injector Pressure Regulator
25	Flow Meter
58	Nozzle Assembly
V-3	Water Fill Valve
V-11	Gauge Isolation Valve
V-12	Gauge Isolation Valve
V-5	Gauge Isolation Valve
V-7	Gauge Isolation Valve
V-19	Gauge Isolation Valve
V-20	Gauge Isolation Valve
V-13	Gauge Isolation Valve
V-14	Gauge Isolation Valve
V-15	Gauge Isolation Valve
V-6	Gauge Isolation Valve
V-26	Salt Water Metering Valve
V-27	Oil Metering Valve

Item	Nomenclature
R-6	Solid Particle Injector Differential Pressure Regulator
V-9	Solid Particle Injector Cover Pressure Control Valve
V-10	Air Knife Pressure Control Valve
G-4	Solid Particle Injector Cover Differential Pressure Gauge
G-5	Air Knife Differential Pressure Gauge
V-25	Pinch Valve
V-23	Depressurizing Valve
R-5	Liquid Contaminant Injector Differential Pressure Regulator
V-18	Liquid Contaminant Injector Pressure Control Valve
V-17	Liquid Contaminant Injector Pressure Gauge Selector Valve
G-6	Differential Pressure Gauge
61	Dynamic Sampler
40	Thermocouple Selector Switch
8	Digital Temperature Indicator
13	Overheat Controller
27	Air Temperature Controller
12	Primary Heater Contactor
39	Secondary Heater Control
37	Air Temperature Thermocouple
V-21	Oil Injector Isolation Valve
V-22	Salt Water Injector Isolation Valve
V-16	Liquid Injector Depressurization Valve
V-14	Water Injector Isolation Valve
G-7	Water Injector Pressurization Gauge
V-8	Solid Particle Pressurization Shutoff Valve
V-28	Cooling Air Metering Valve
V-29	Water Tank Vent Valve

NOTE:

THIS ARTICLE IS FABRICATED, IDENTIFIED AND PROCURED AS PART NUMBER

SIGNATURES	DATES
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CHK	
APP	
APP [illegible]	4-6-76
APP	
PAT DEPT.	

SCHEMATIC DIAGRAM

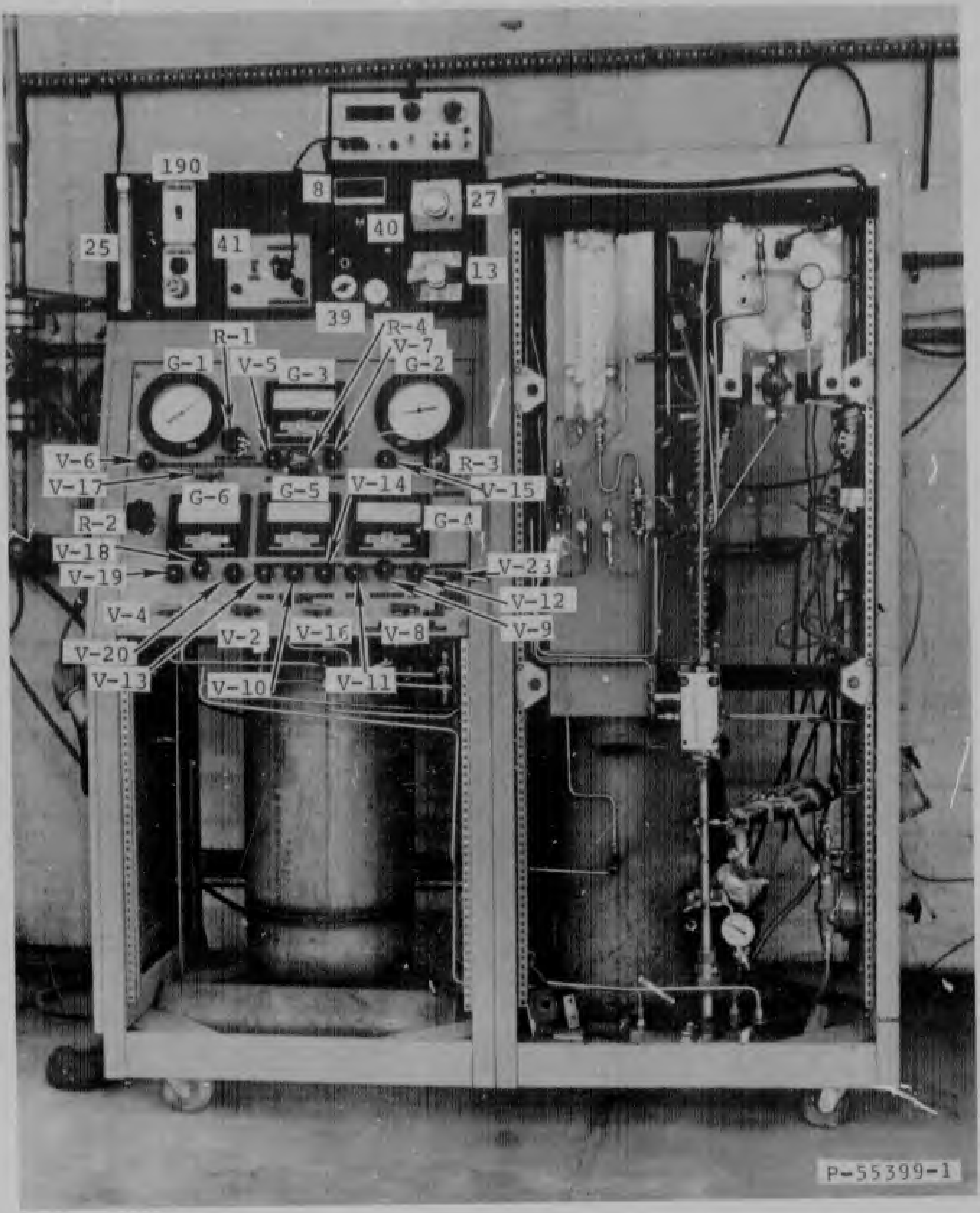
COMPRESSOR
BLEED AIR
SIMULATOR

AiResearch Manufacturing Company of Arizona
PHOENIX, ARIZONA
A division of THE GARRETT CORPORATION

DWG SIZE A — DWG NO. P 710403-1

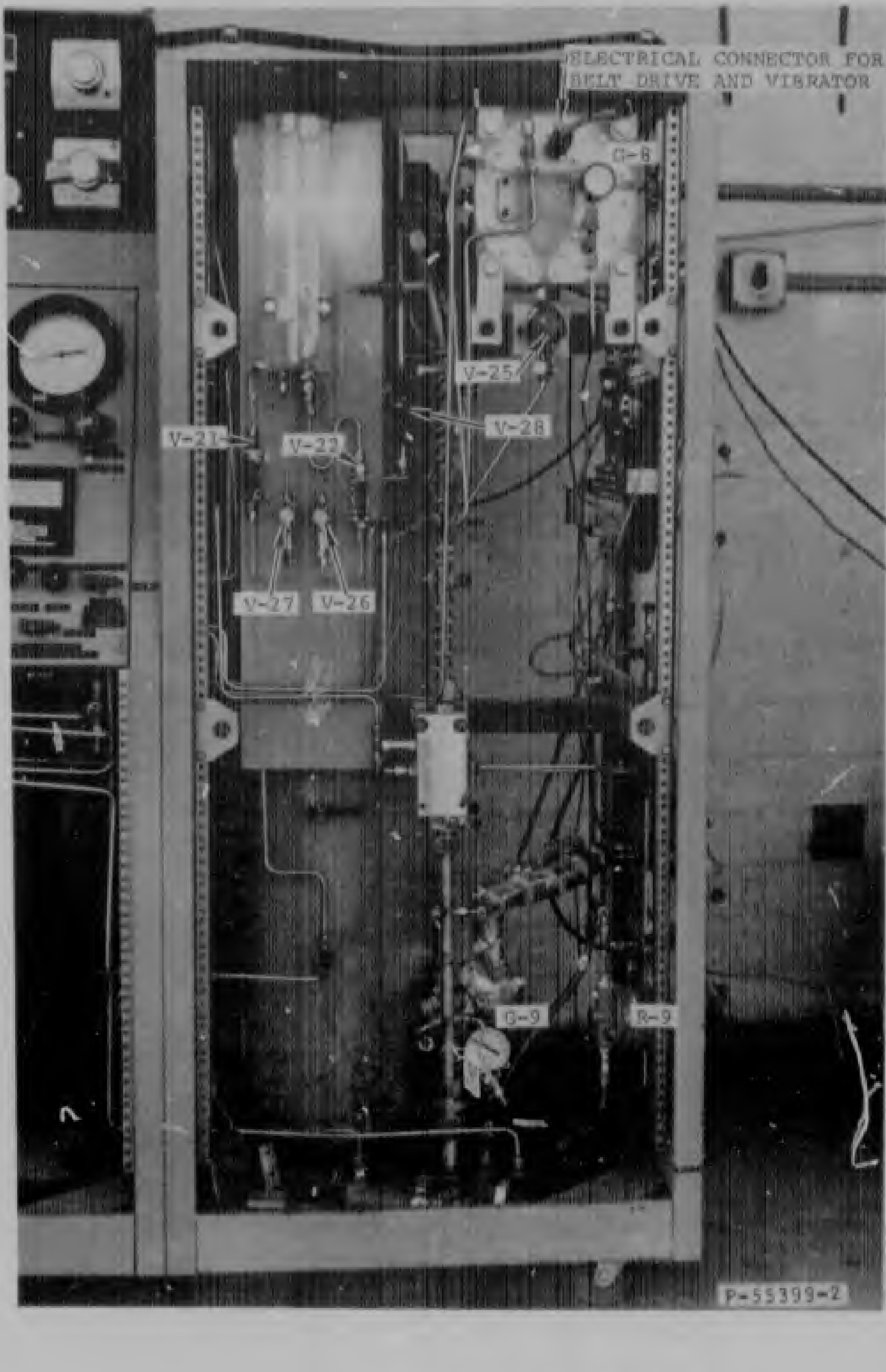
SHEET 2 of 2

GM P 3001-8

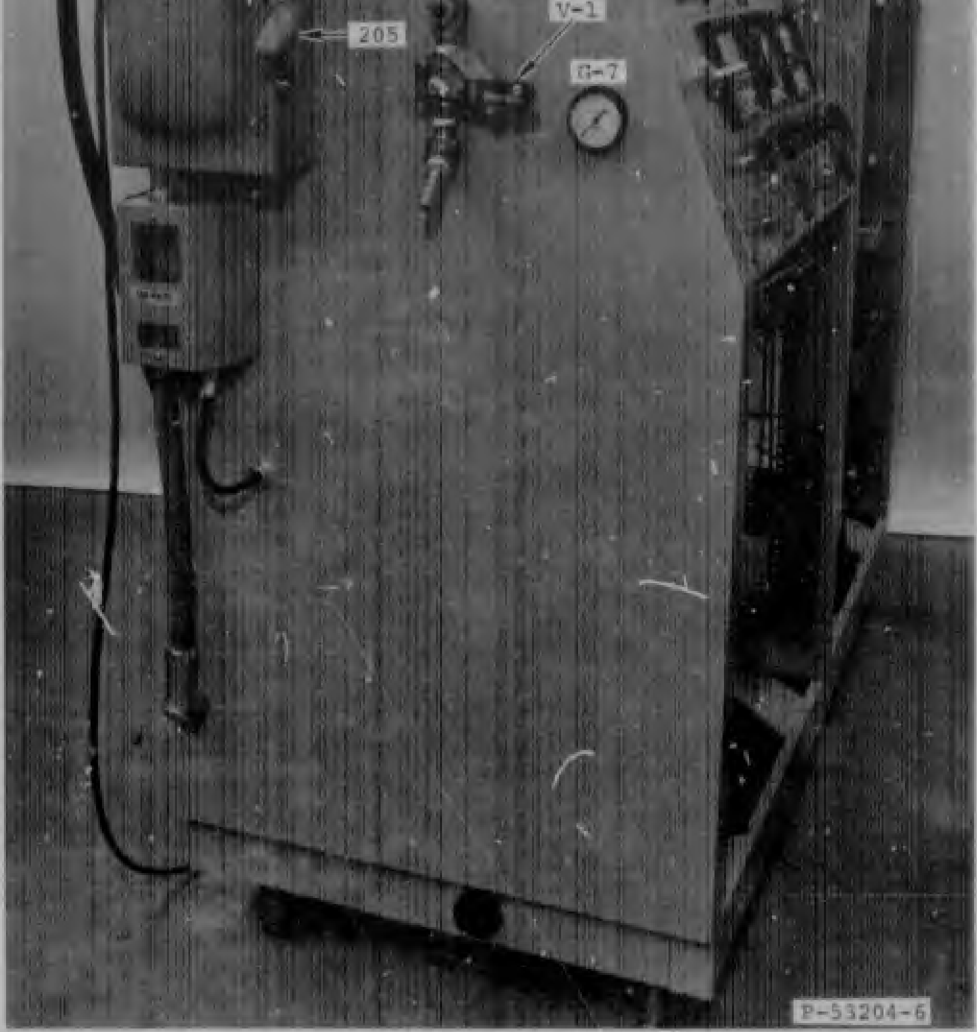


CONTROL PANEL
COMPRESSOR BLEED AIR SIMULATOR

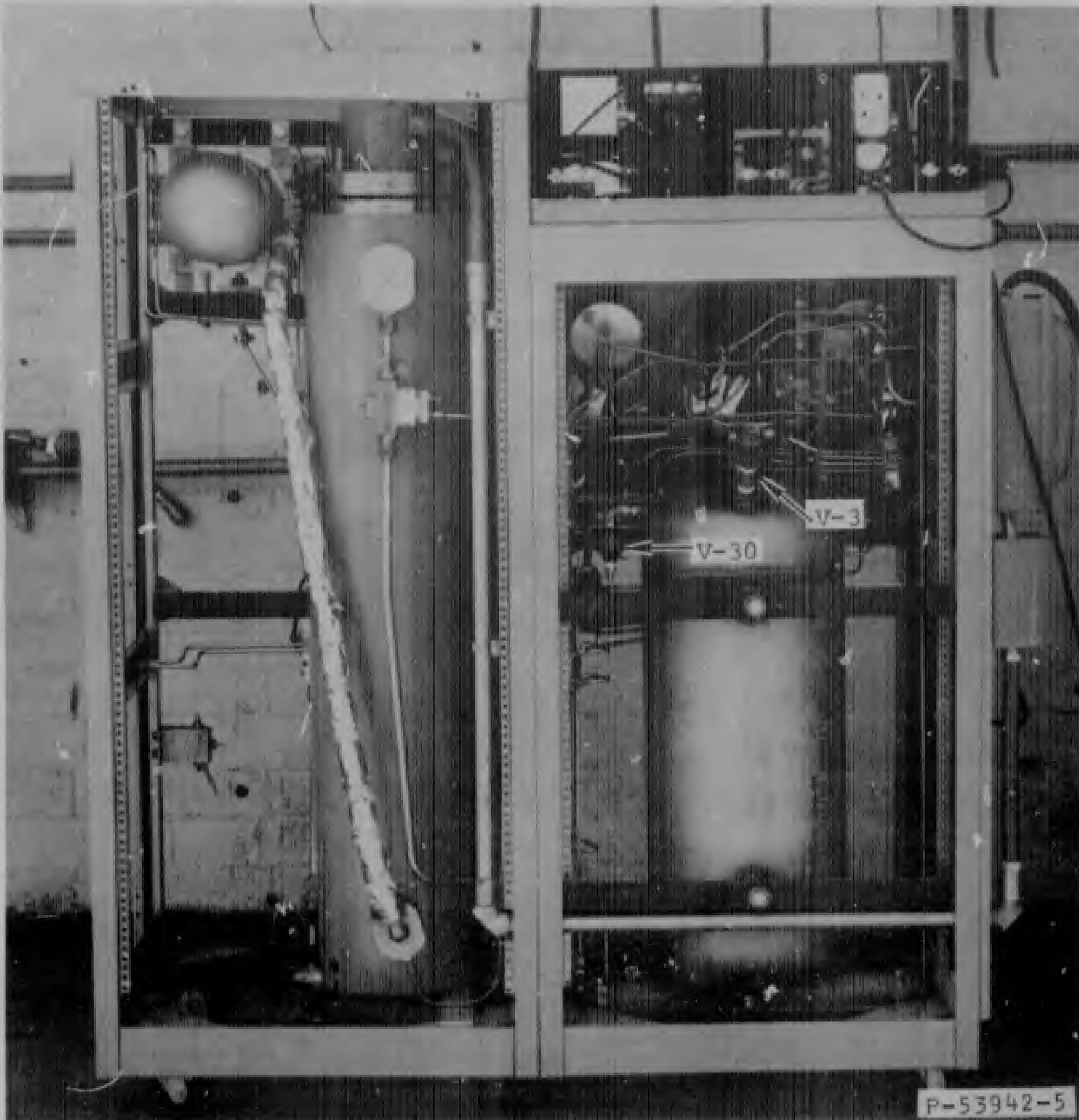
MP-54084



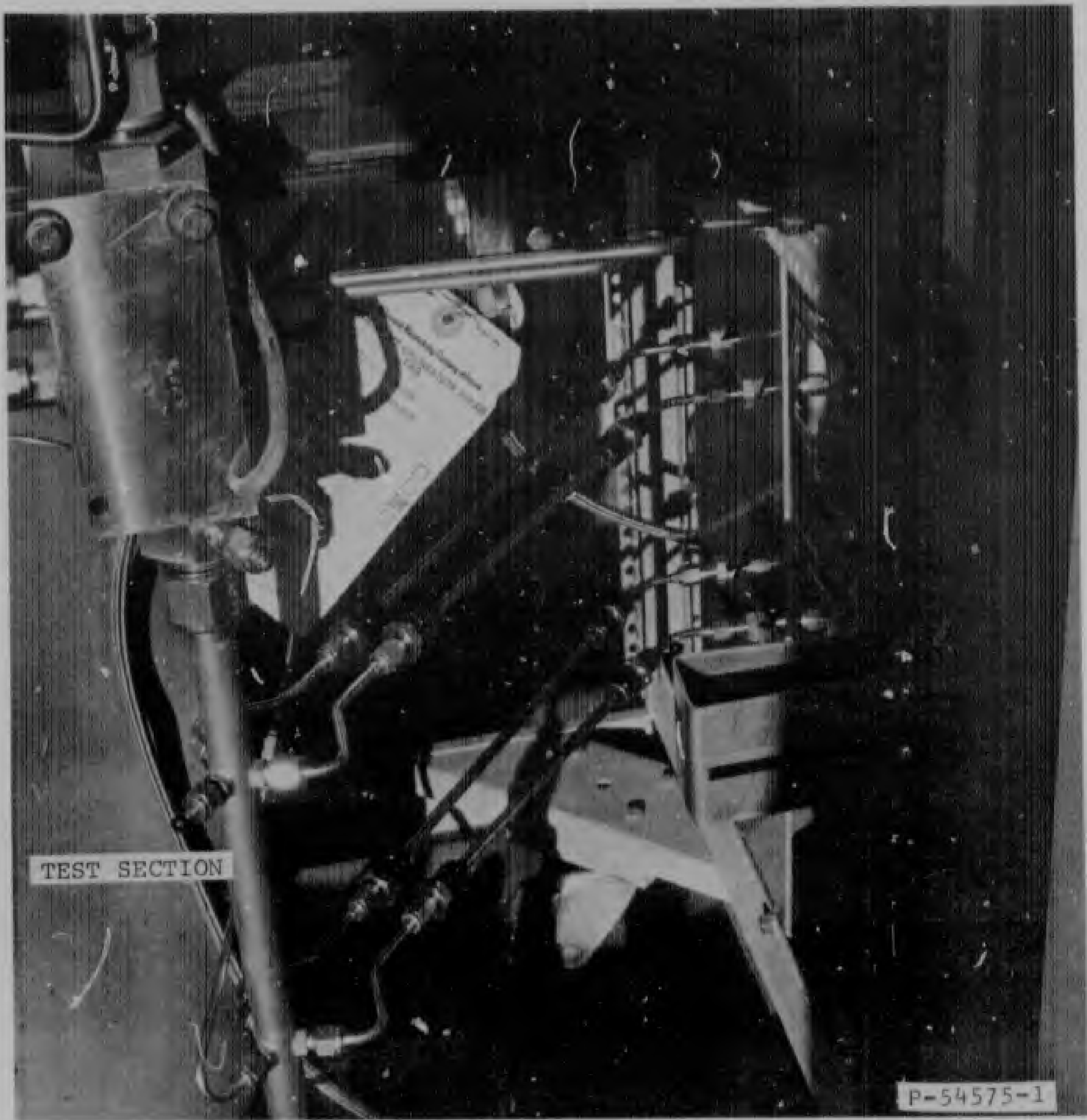
CONTAMINANT INJECTION SECTOR
COMPRESSOR BLEED AIR SIMULATOR



SIDE VIEW OF
COMPRESSOR BLEED AIR SIMULATOR

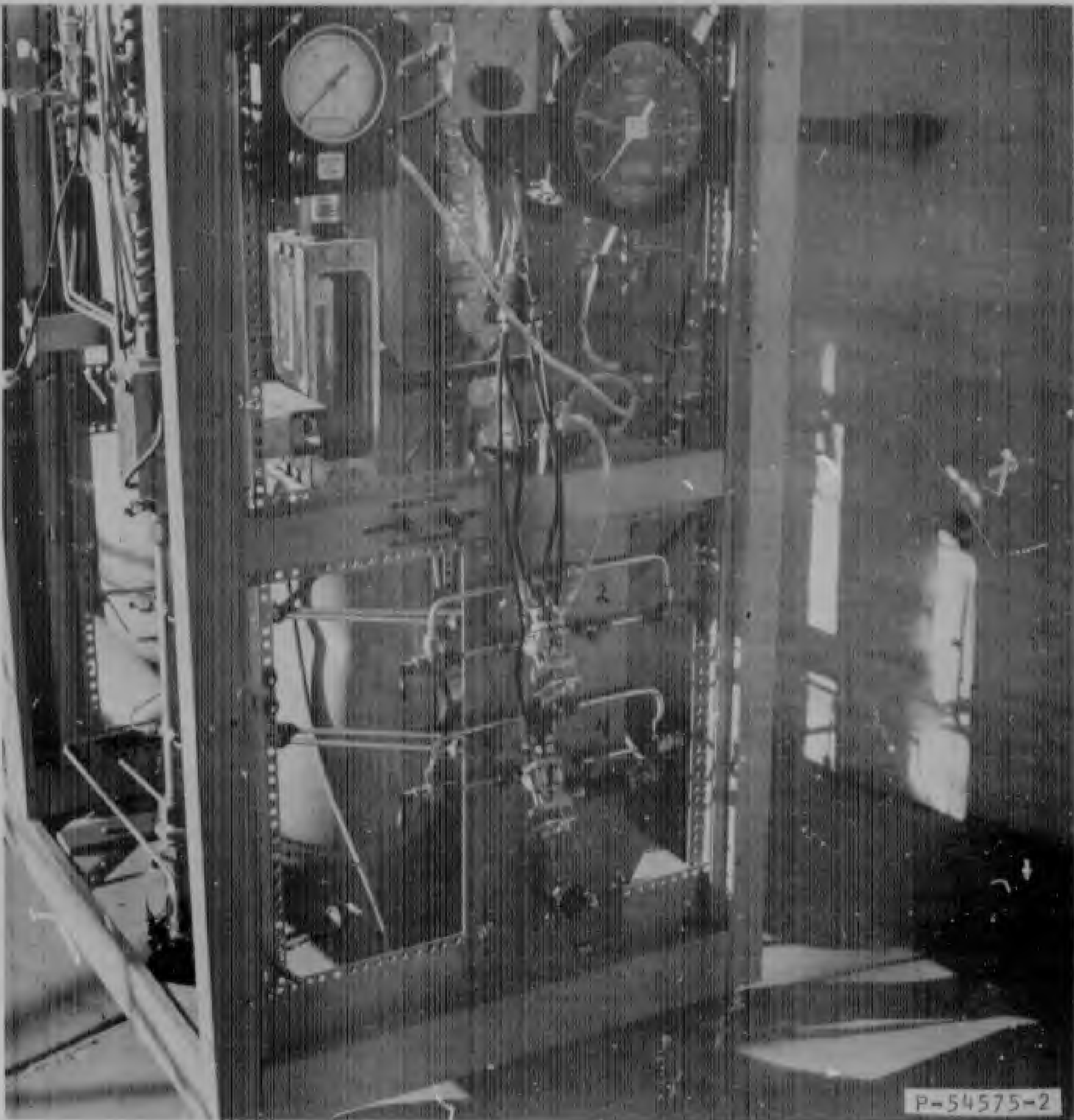


REAR VIEW OF
COMPRESSOR BLEED AIR SIMULATOR

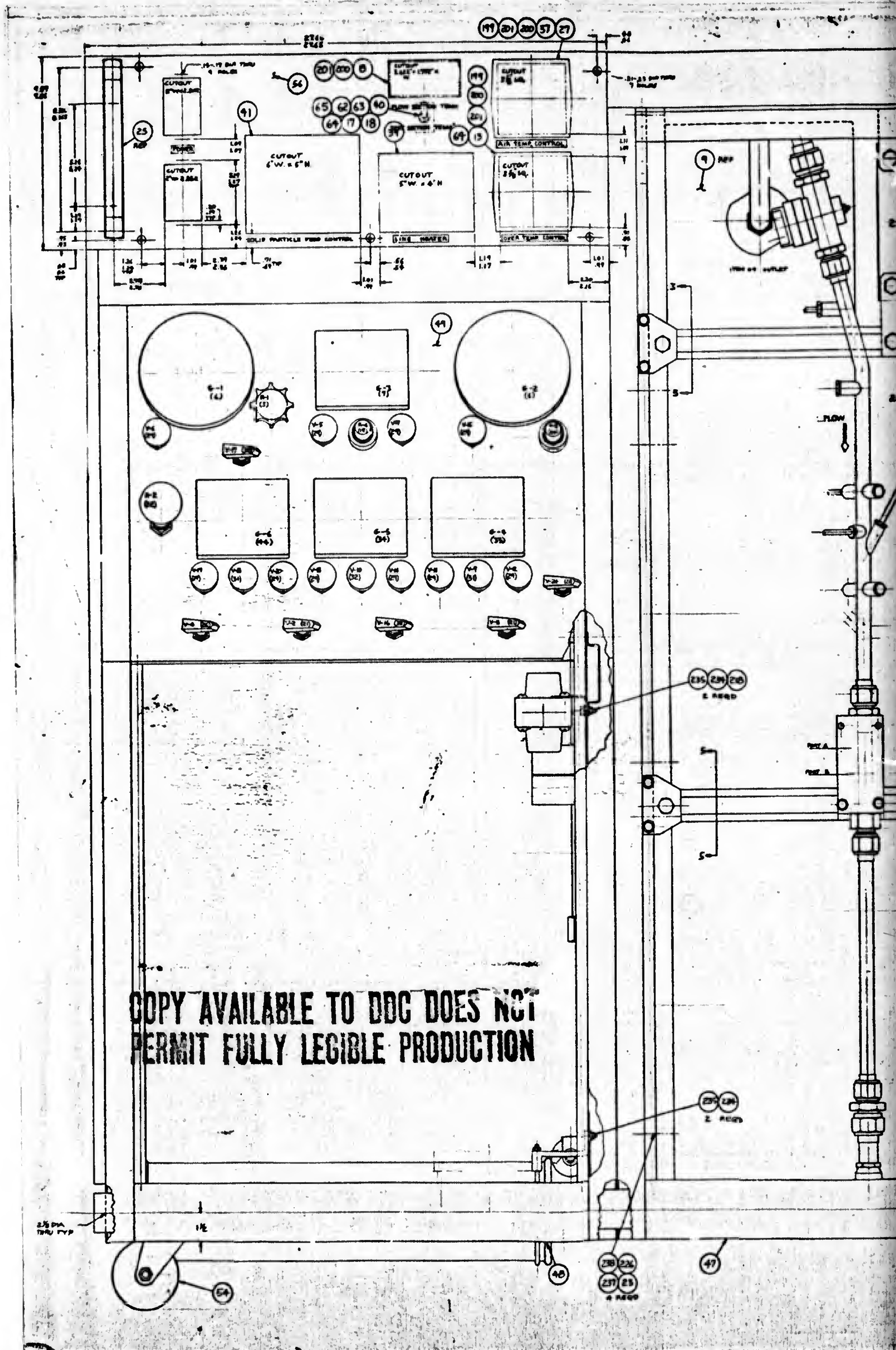


LINES CONNECTING CBAS
TEST SECTION TO TEST STATIONS

MP-54091



CBAS FLUIDIC CIRCUIT TEST STATIONS
(CIRCUITS MOUNTED AT STATIONS 1 AND 3)


CUTOUT
POWER
CUTOUT 5"W. x 5"H
CUTOUT 5"W. x 4"H
SOLID PARTICLE FEED CONTROL
LINE HEATER
AIR TEMP CONTROL
OVER TEMP CONTROL
FLOW
2 REQD
4 REQD
REF

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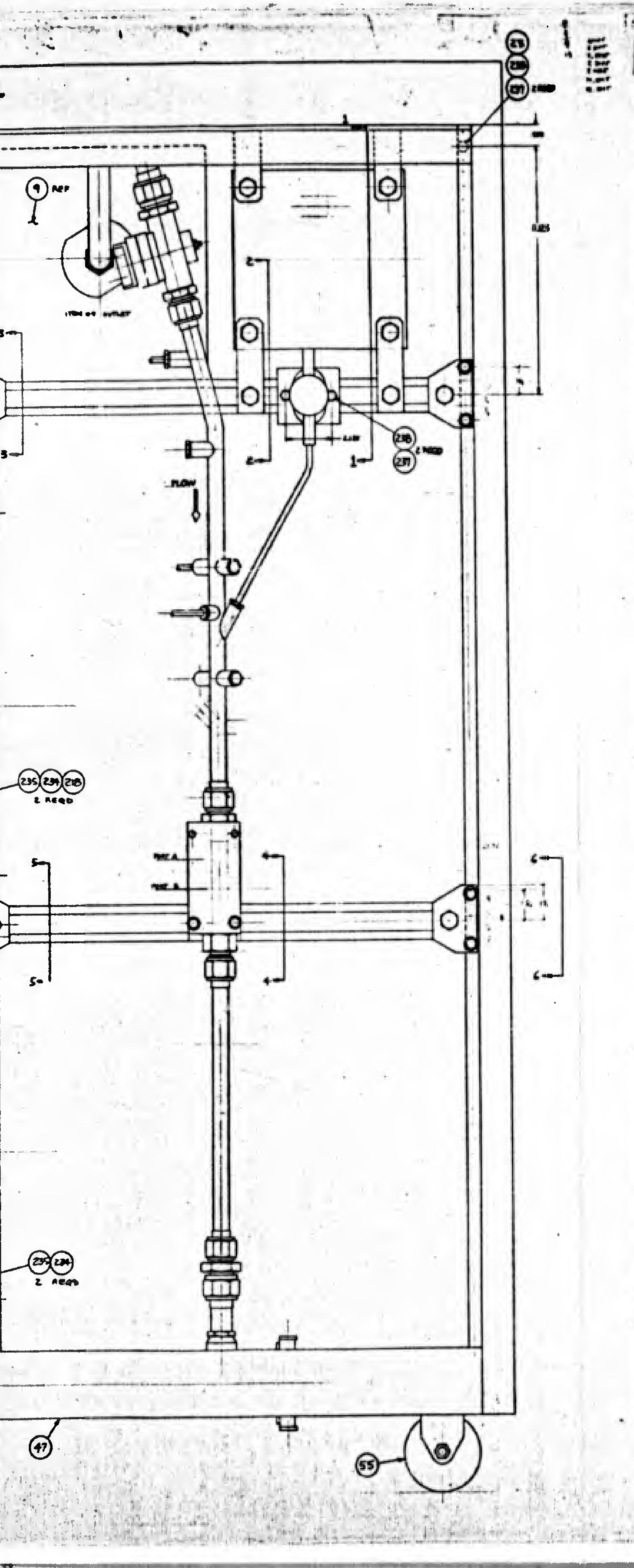

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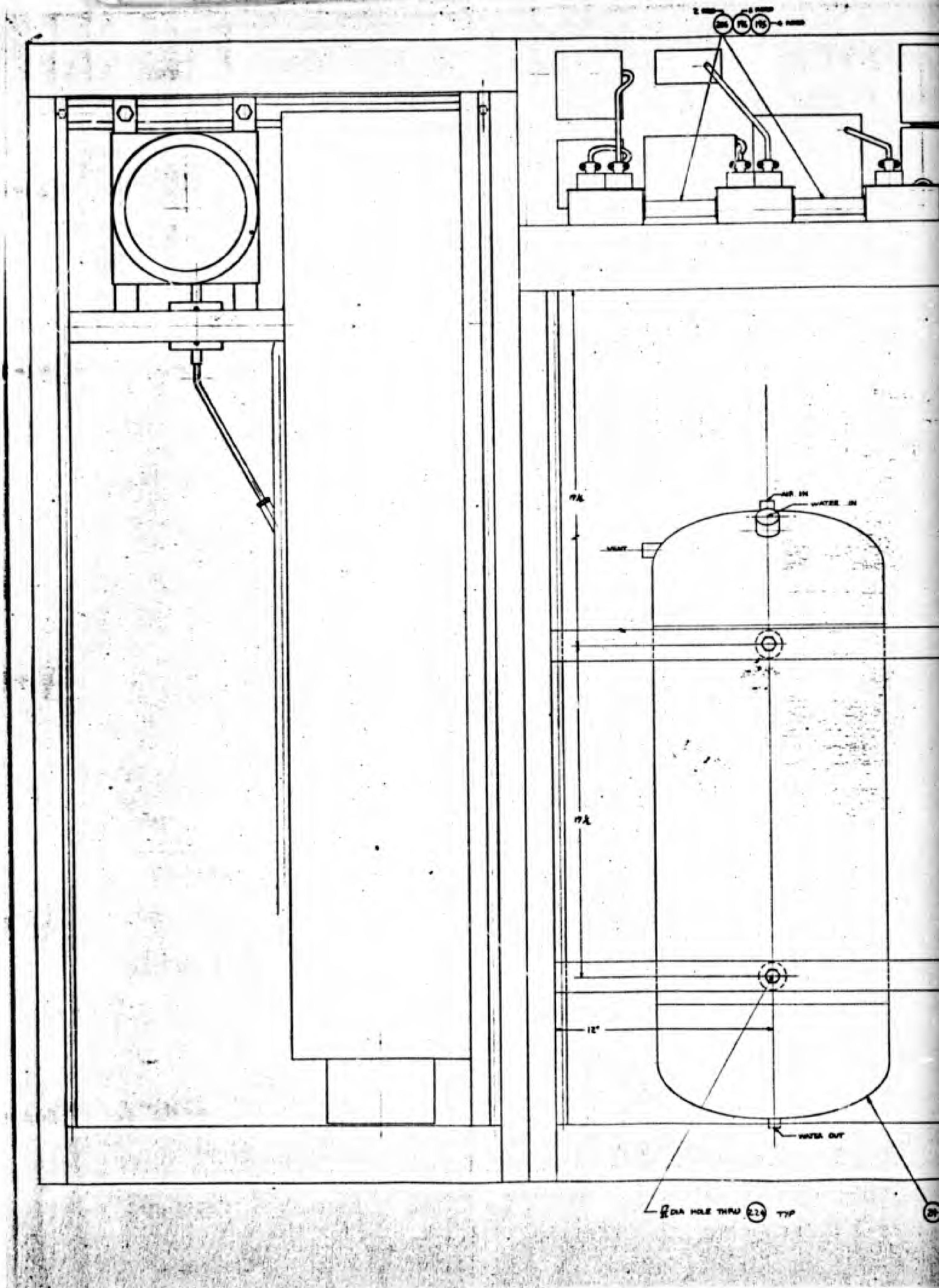
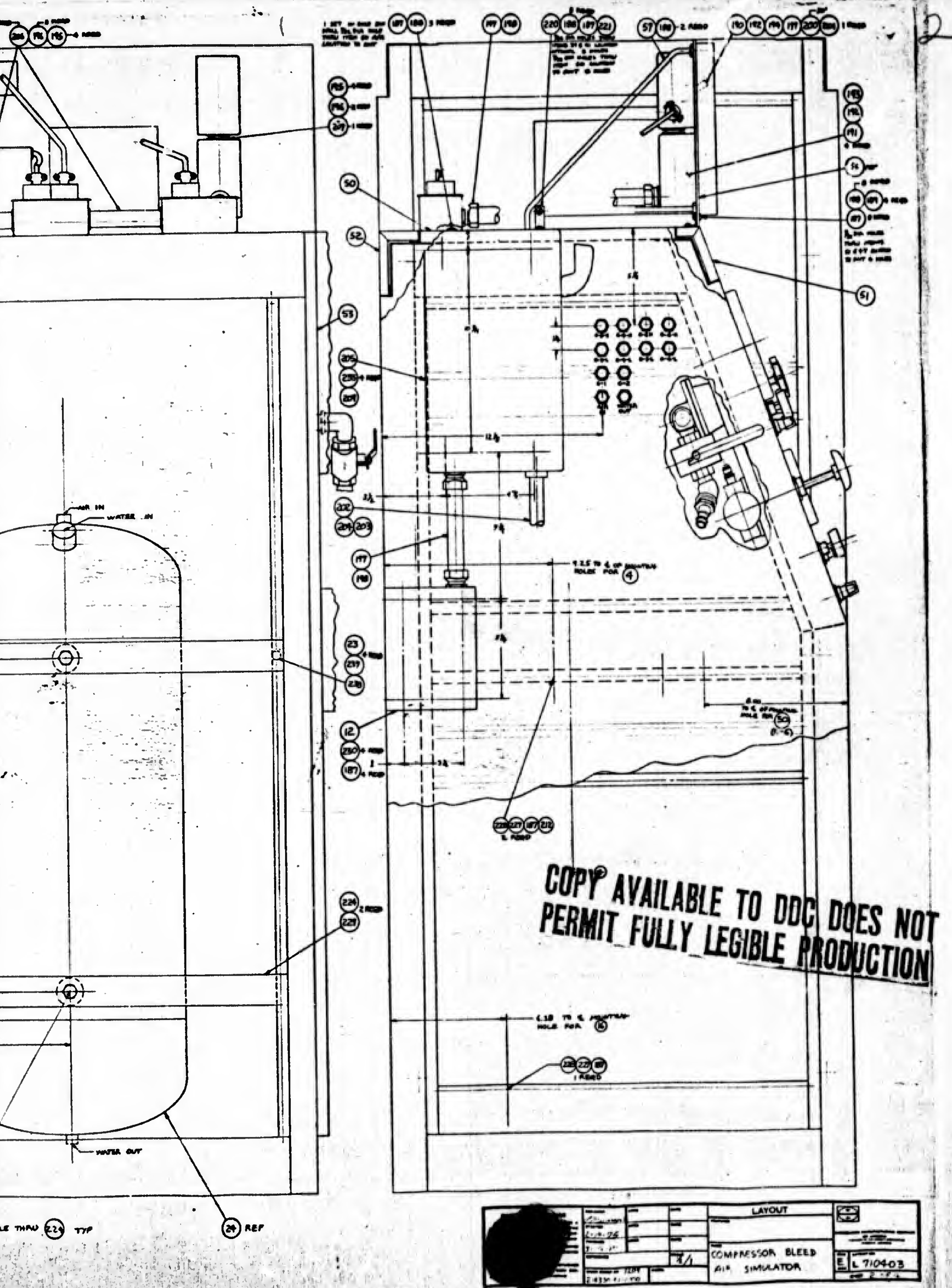
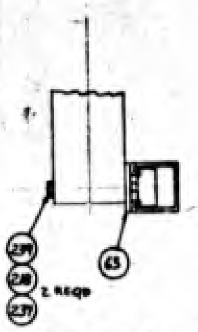
LAYOUT

COMPRESSOR BLEED AIR SIMULATOR

L710405


AIR IN
WATER IN
VENT
12"
WATER OUT
DIA HOLE THRU TYP


AIR IN
WATER IN
WATER OUT
24 REF
LAYOUT
[redacted]
COMPRESSOR BLEED
AIR SIMULATOR
L 710403



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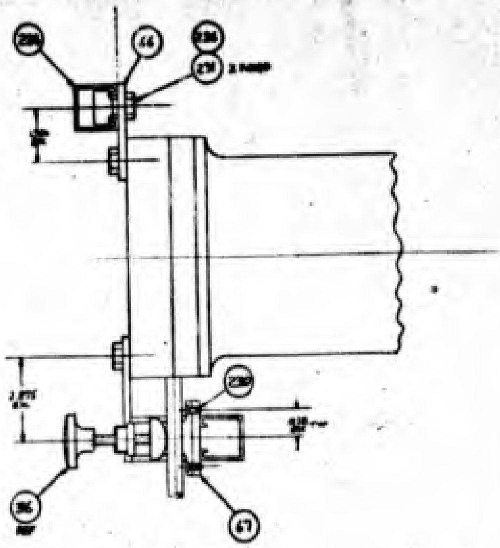

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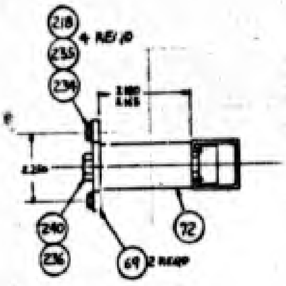

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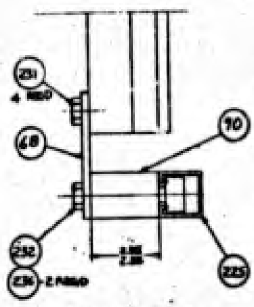

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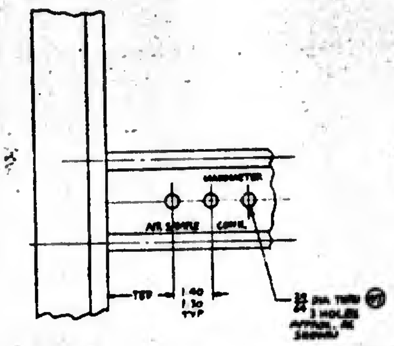

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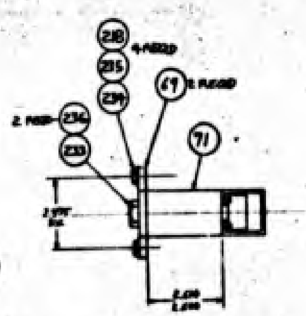

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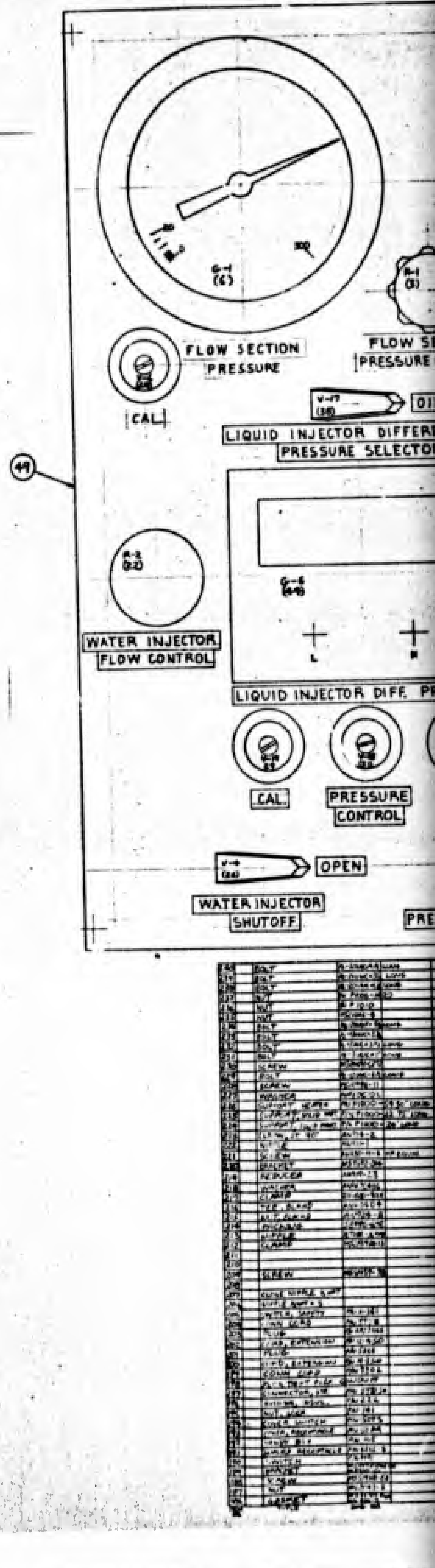

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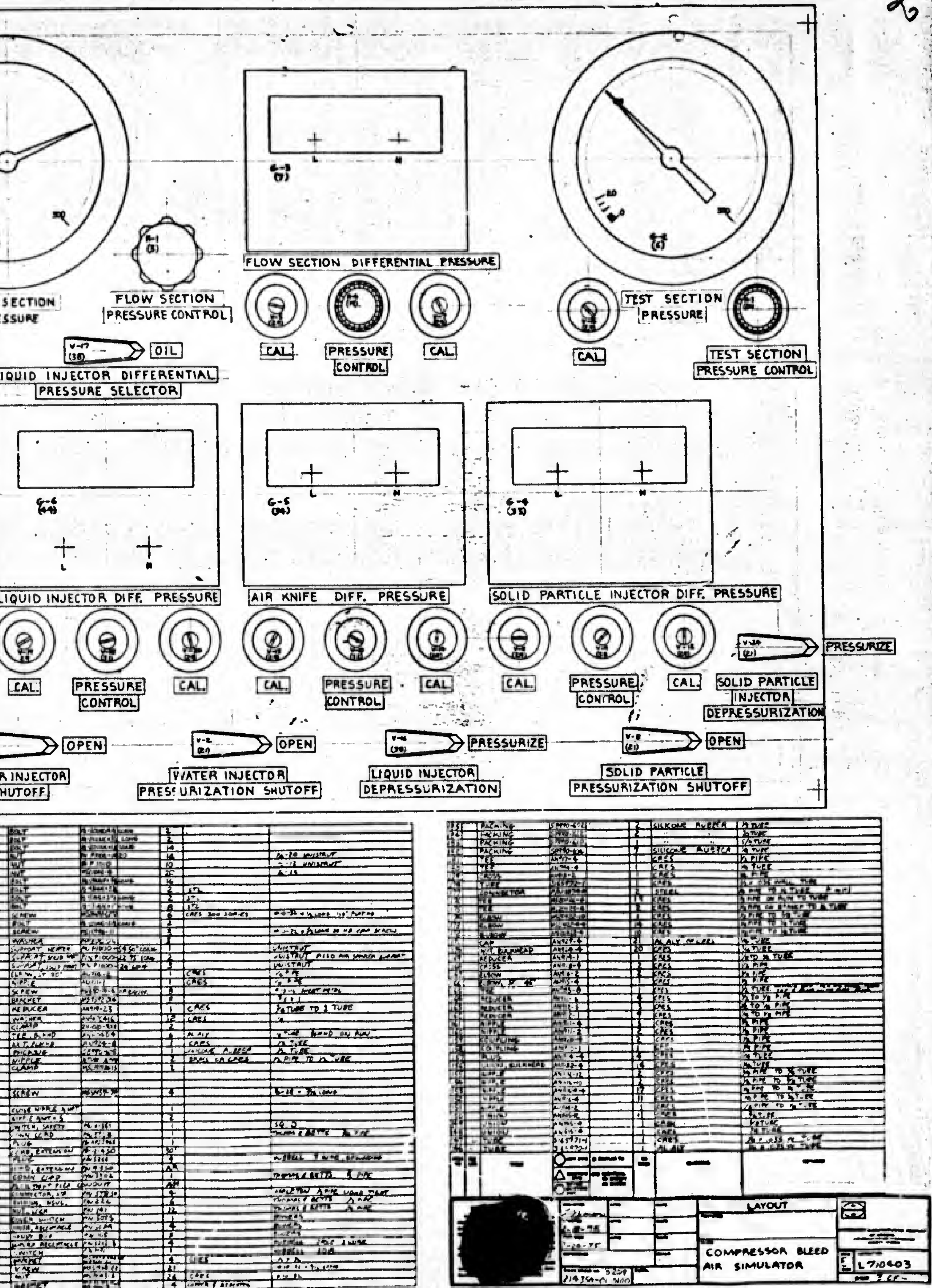
SECTION
SSURE
FLOW SECTION
PRESSURE CONTROL
FLOW SECTION DIFFERENTIAL PRESSURE
TEST SECTION
PRESSURE
TEST SECTION
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CAL
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OIL
IQUID INJECTOR DIFFERENTIAL
PRESSURE SELECTOR
LIQUID INJECTOR DIFF. PRESSURE
AIR KNIFE DIFF. PRESSURE
SOLID PARTICLE INJECTOR DIFF. PRESSURE
PRESSURIZE
SOLID PARTICLE
INJECTOR
DEPRESSURIZATION
OPEN
R INJECTOR
HUTOFF
WATER INJECTOR
PRESSURIZATION SHUTOFF
LIQUID INJECTOR
DEPRESSURIZATION
SOLID PARTICLE
PRESSURIZATION SHUTOFF
LAYOUT
COMPRESSOR BLEED
AIR SIMULATOR
L710403

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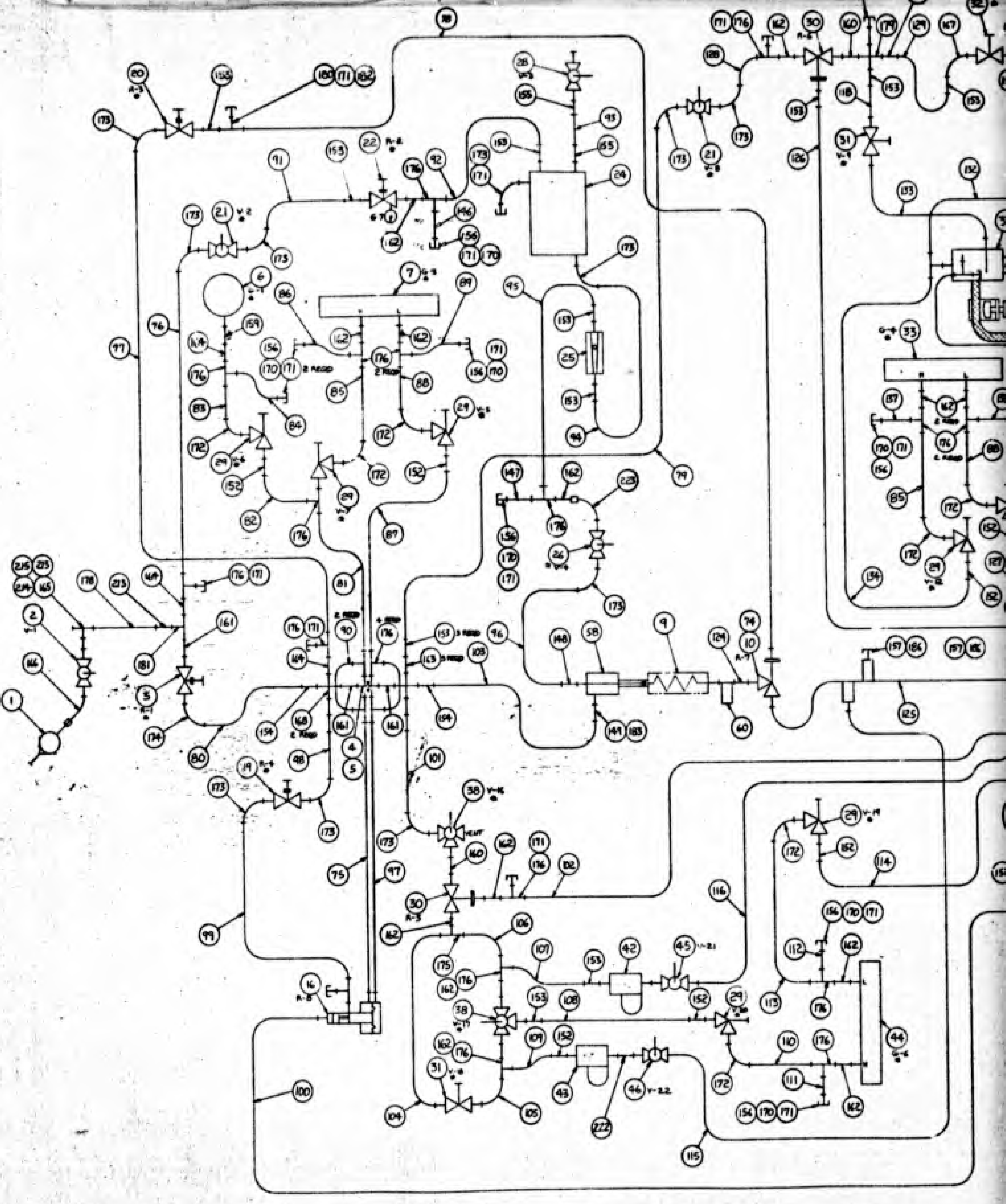

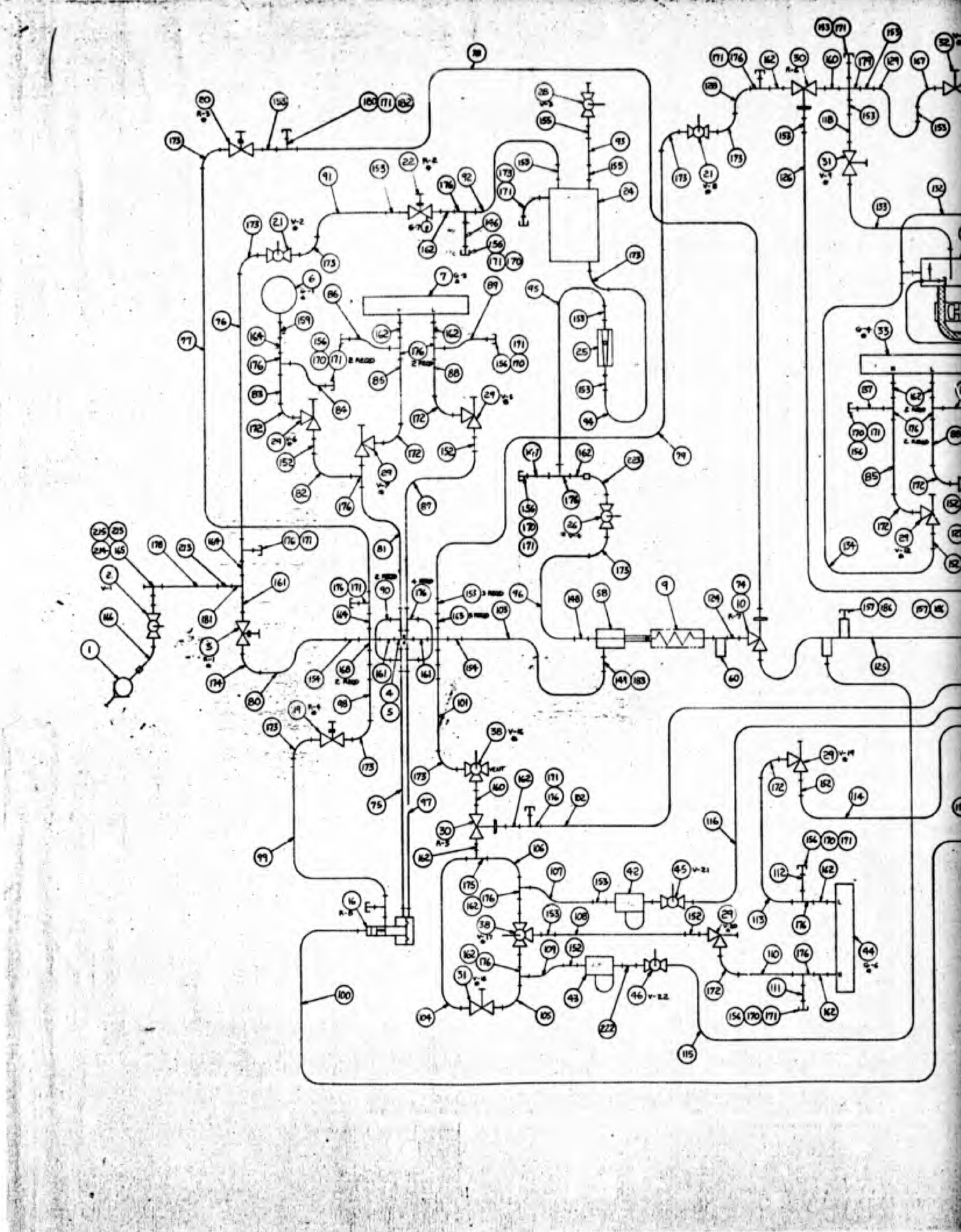

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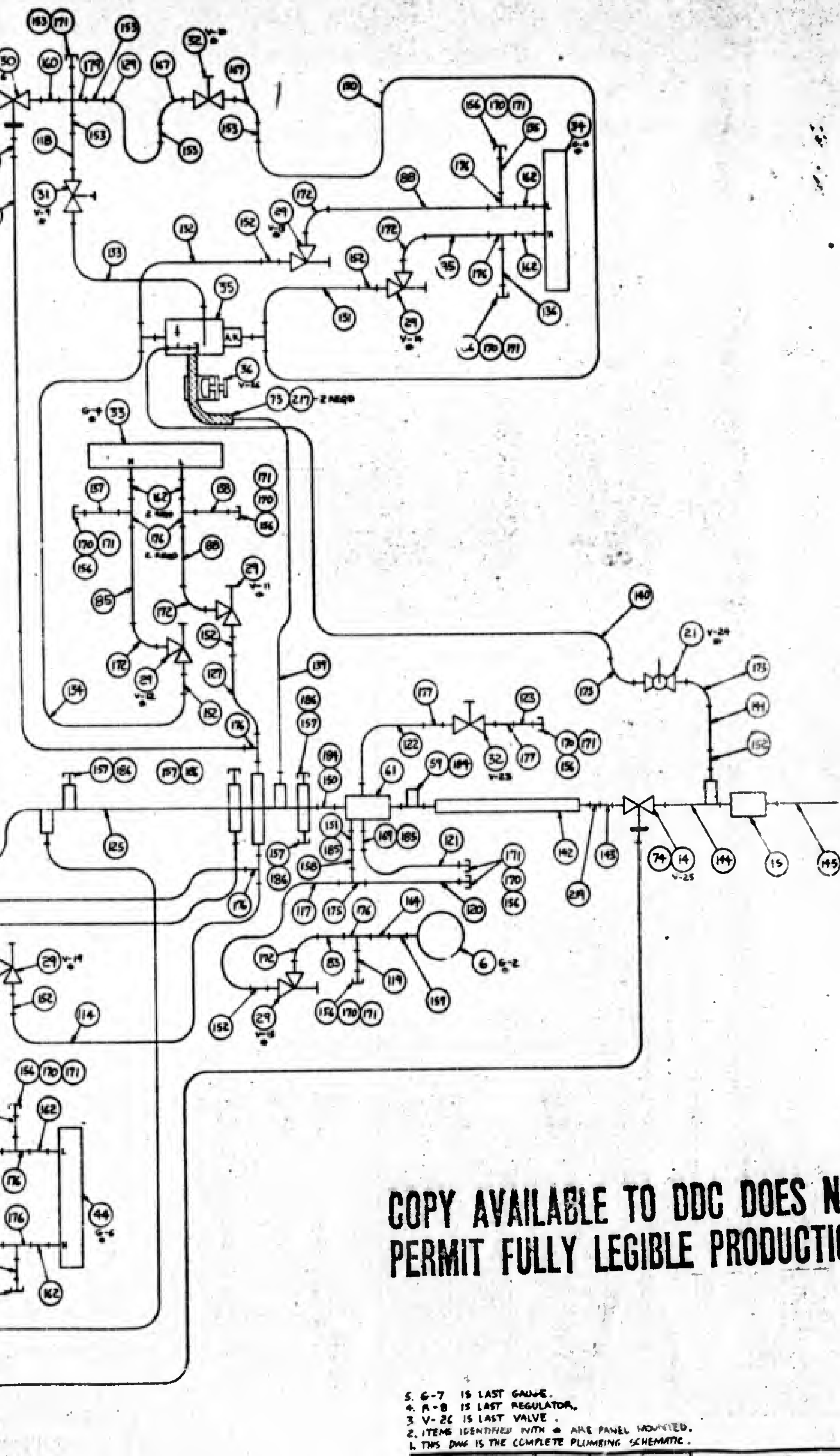

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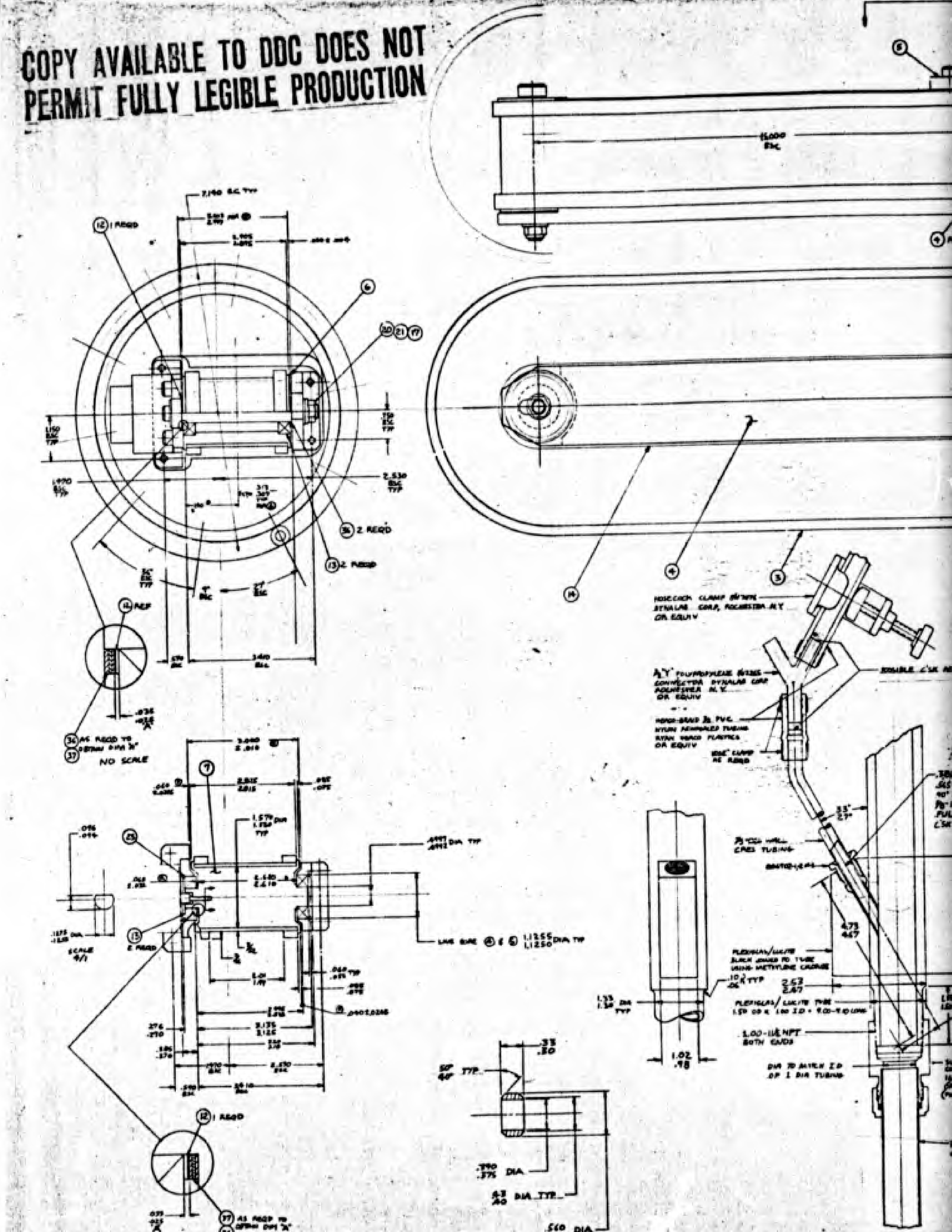
5. G-7 IS LAST GAUGE.
4. R-8 IS LAST REGULATOR.
3. V-26 IS LAST VALVE.
2. ITEMS IDENTIFIED WITH ● ARE PANEL MOUNTED.
1. THIS DWG IS THE COMPLETE PLUMBING SCHEMATIC.

[redacted]

LAYOUT

BLEED AIR SIMULATOR

E L 710403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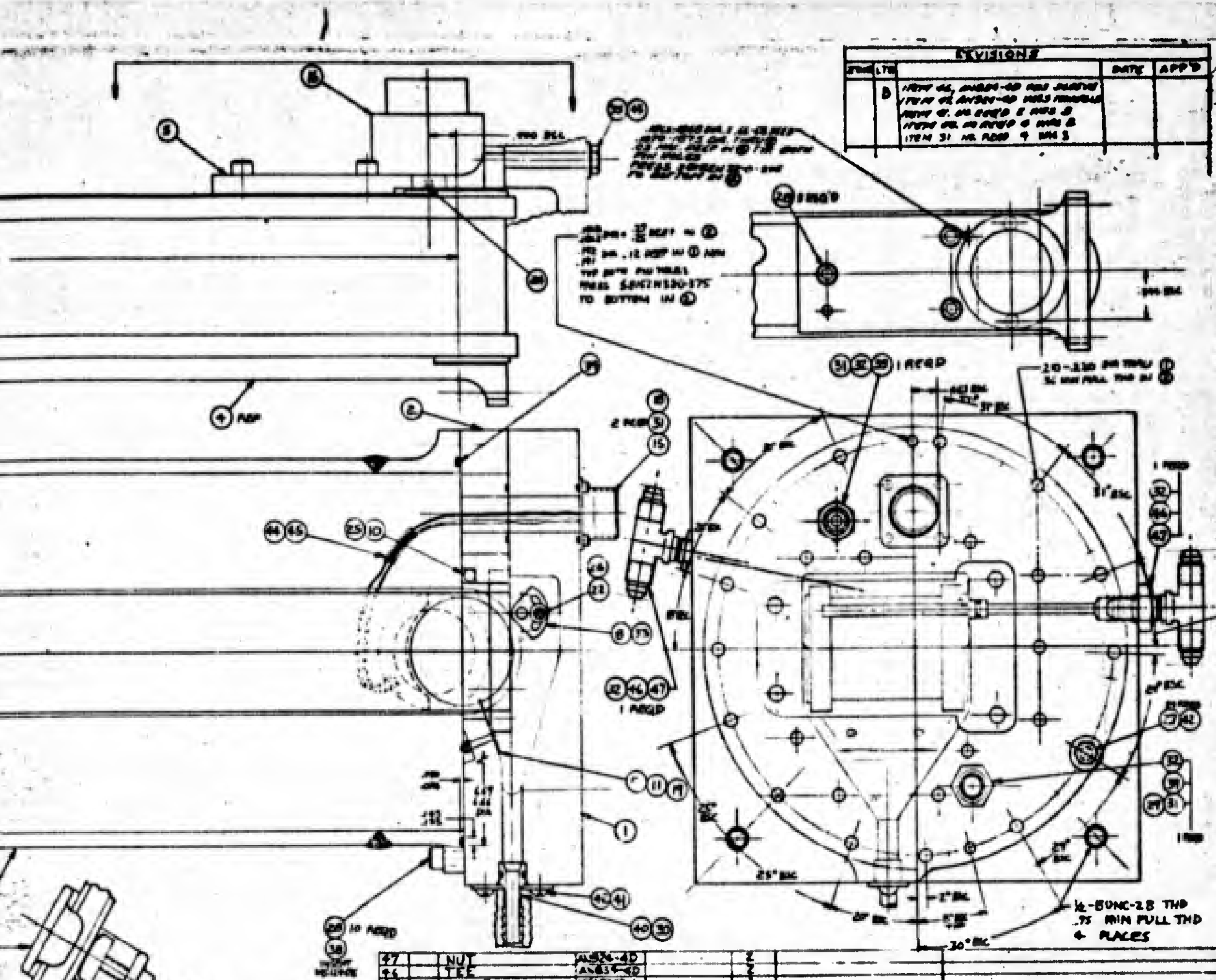
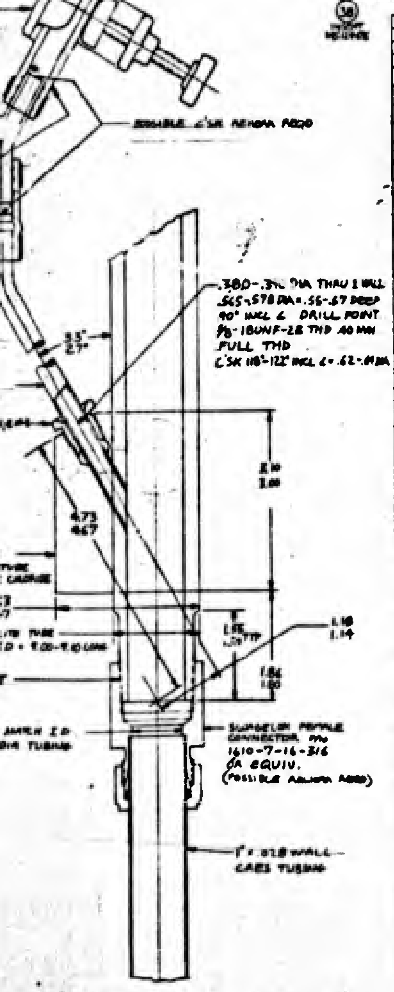
NO SCALE
NYLON SLEEVE
.560 DIA
.550
1.02
.98





47		NUT	AN924-4D	2		
46		TEE	AN834-4D	2		
45		SPLICE	[illegible]	2		
44		INSULATION	[illegible]	1		HEAT SHRINK
43		WASHER	[illegible]	4		.61-.63 OD .260-.265 ID
42		WASHER	[illegible]	26		.60-.62 OD [illegible]
41		SCREW		2		#10-24UNC-[illegible] LONG SLOTTED ROUND HEAD
40		FITTING	○	1	BRASS OR CRES	MAY BE MADE FROM A [illegible] FITTING
39		UNION	AN815-4D	2		
38		WASHER	[illegible]	10		
37		WASHER	[illegible]	A/R		
36		WASHER	[illegible]	A/R		
35		BOLT		4		¼-20UNC × 2.00 LONG HEX HEAD
34		PACKING	[illegible]-165	1		
33		PACKING	[illegible]-585	1		
32		PACKING	[illegible]-604	4		
31		PACKING	[illegible]-016	4		
30		PACKING	[illegible]-015	1		
29		FILTER		1		[illegible] AA-[illegible] P/N 20312-3
28		SCREW	MS[illegible]-23	15		¼ LONG #¼-20
27		BOLT	AN3-[illegible]	24		[illegible] LONG #10-32
26		SCREW	MS[illegible]-10	1		⅜ LONG #[illegible]
25		SCREW	MS[illegible]-11	2		[illegible] LONG #[illegible]
24		SCREW	MS[illegible]-[illegible]	2		[illegible] LONG [illegible]
23		RING, RETAINING	MS16625-[illegible]	2		[illegible]
22		WASHER	[illegible]	1		
21		WASHER	[illegible]	1		
20		NUT	[illegible]	1		
19		NUT	[illegible]-04	2		
18		SCREW	[illegible]-17	4		
17		BOLT, SHOULDER		1		[illegible]
16		MOTOR		1		[illegible] 115V 60 [illegible]
15		CONNECTOR	[illegible]-137-4	1		MATES WITH MS3106-14S-[illegible]
14		BELT	C	1	NEOPRENE	[illegible]
13		BEARING	[illegible]-1	4	SAE 52100 STEEL	SEALED BOTH SIDES
12		WASHER, [illegible]	[illegible]-20	2	CRES 17-7PH	
11		RETAINER, SCRAPER	○	1	300 SERIES CRES - [illegible]	BRAZE TOGETHER
10		RAKE, WIRE	○	1	[illegible] EPOXY FILLED	
9		SCRAPER	○	1	KAPTON	
8		KNIFE, AIR	○	1	CRES 300 SERIES	
7		ROLLER, DRIVE	○	1	ALUM ALY [illegible]	250/ OD OF ROLLER & SANDBLAST
6		ROLLER, IDLER	○	1	ALUM ALY 6061-T6	
5		SUPPORT, BEARING	○	1	ALUM ALY 6061-T6	
4		SUPPORT, BELT	○	1	ALUM ALY 6061-T6	
3		COVER	○	1	ALUM ALY 6061-T6	[illegible]
2		BODY, INTERMEDIATE	○	1	ALUM ALY 6061-T6 PLATE	
1		BODY, MOUNT	○	1	PLEXIGLAS / LUCITE	POLISH TO PERMIT VISUAL OBSERVATION
		TITLE	NEW DWG / EXISTING DWG / REVISE EXISTING DWG; SIMILAR TO / IDENTICAL TO EXCEPT AS SHOWN			

[redacted]

3-23-74

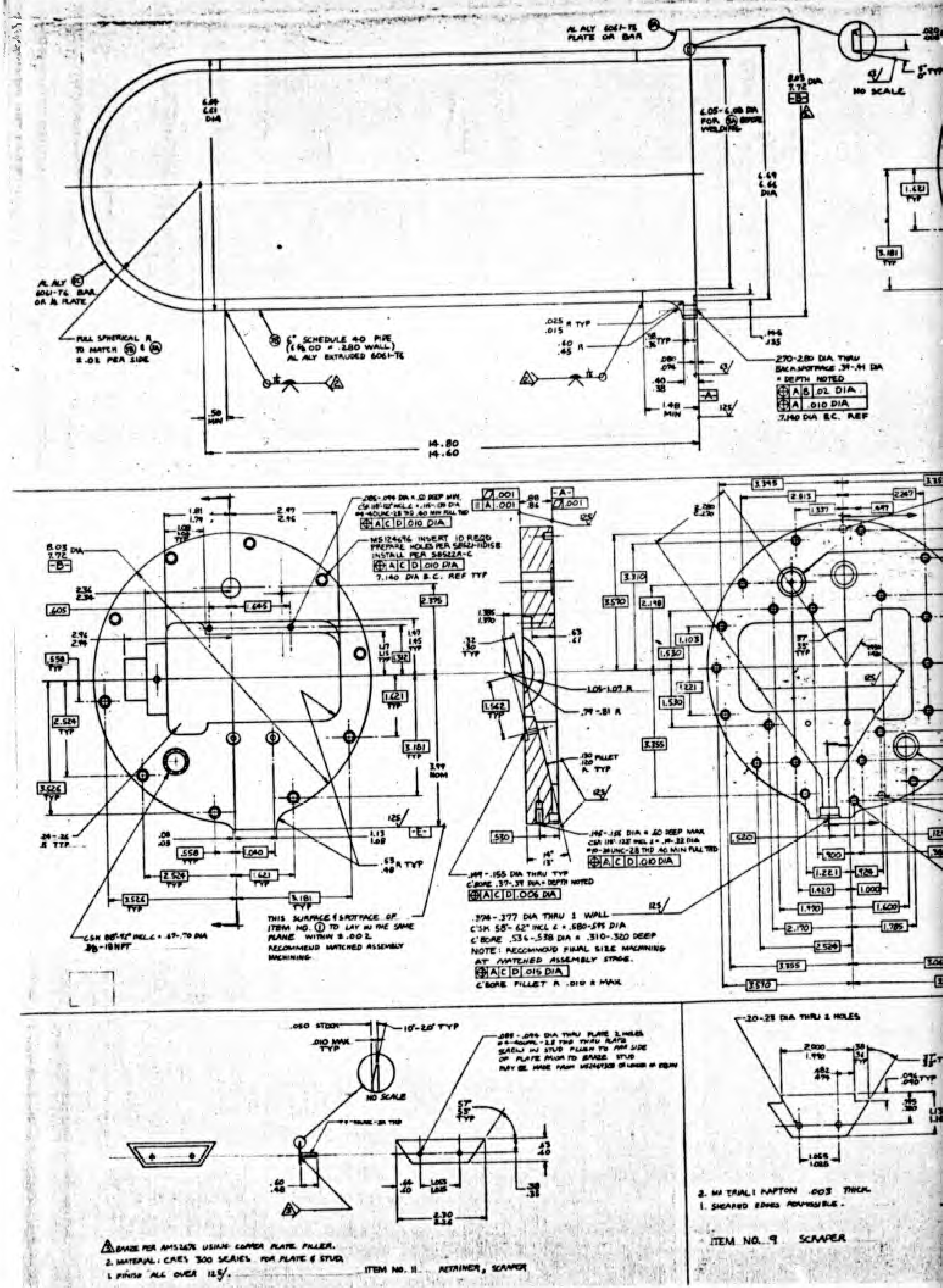
FULL

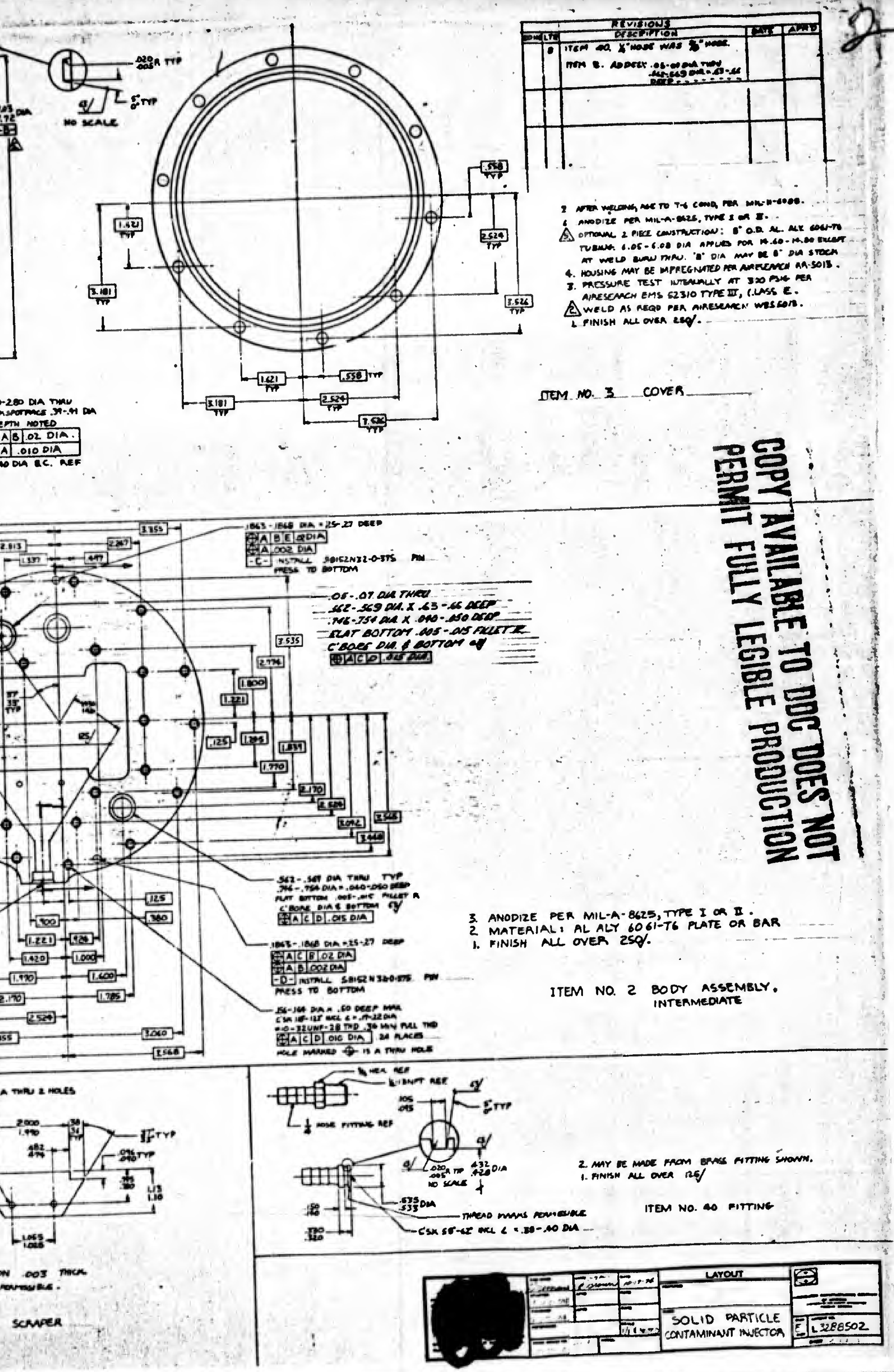
LAYOUT

PRESSURIZED DIRT CONTAMINATOR

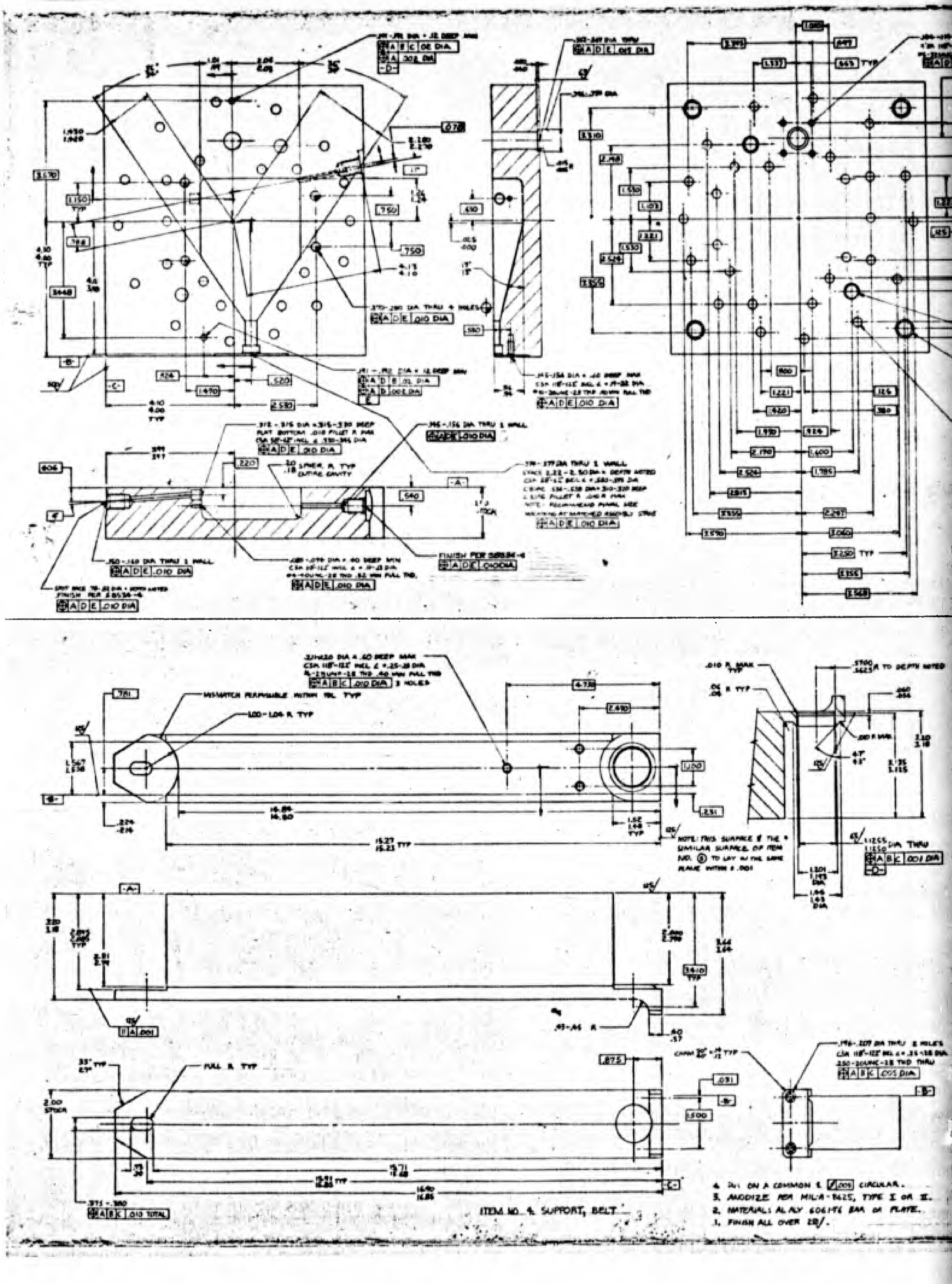
SOLID PARTICLE CONTAMINANT INJECTOR

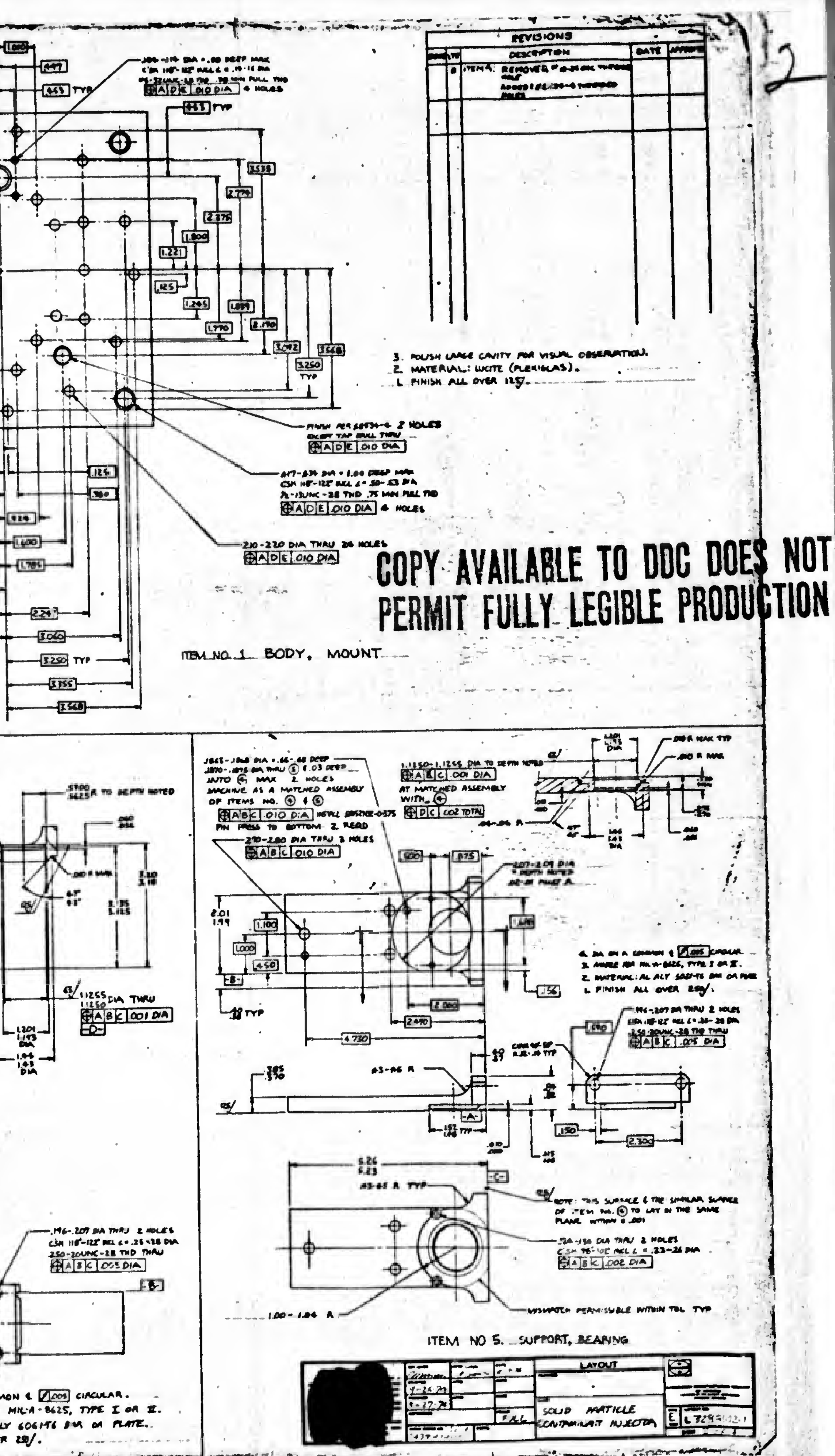
F L[illegible]502

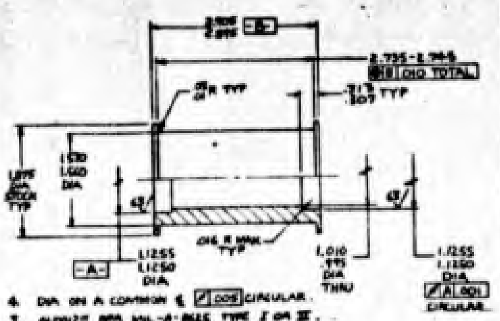

AL ALY 6061-T6 PLATE OR BAR
NO SCALE
AL ALY 6061-T6 BAR OR AL PLATE
FULL SPHERICAL R TO MATCH
6" SCHEDULE 40 PIPE (6⅝ OD × .280 WALL) AL ALY EXTRUDED 6061-T6
270-.280 DIA THRU
BACKSPOTFACE .39-.41 DIA
× DEPTH NOTED
7.140 DIA B.C. REF
14.80
14.60
MS124696 INSERT ID REQD
7.140 DIA B.C. REF TYP
NOTE: RECOMMEND FINAL SIZE MACHINING AT MATCHED ASSEMBLY STAGE.
C'BORE FILLET R .010 X MAX
THIS SURFACE & SPOTFACE OF ITEM NO. ① TO LAY IN THE SAME PLANE WITHIN ±.002. RECOMMEND MATCHED ASSEMBLY MACHINING.
.20-.23 DIA THRU 2 HOLES
NO SCALE
2. MATERIAL: KAPTON .003 THICK.
1. SHEARED EDGES PERMISSIBLE.
ITEM NO. 9 SCRAPER
BRAZE PER AMS2675 USING COPPER PLATE FILLER.
2. MATERIAL: CRES 300 SERIES FOR PLATE & STUD.
1. FINISH ALL OVER 125/.
ITEM NO. 11 RETAINER, SCRAPER


REVISIONS
DESCRIPTION
ITEM 40. ¼" HOSE WAS ⅜" HOSE.
ITEM 3. ADDED .05-.07 DIA THRU .562-.569 DIA x .63-.66 DEEP
NO SCALE
7. AFTER WELDING, AGE TO T-6 COND. PER MIL-H-6088.
6. ANODIZE PER MIL-A-8625, TYPE I OR II.
5. OPTIONAL 2 PIECE CONSTRUCTION: 8" O.D. AL. ALY 6061-T6 TUBING. 6.05-6.08 DIA APPLIES FOR 14.60-14.80 EXCEPT AT WELD BURN THRU. 'B' DIA MAY BE 8" DIA STOCK
4. HOUSING MAY BE IMPREGNATED PER AIRESEARCH RA-5013.
3. PRESSURE TEST INTERNALLY AT 320 PSIG PER AIRESEARCH EMS 52310 TYPE III, CLASS E.
2. WELD AS REQD PER AIRESEARCH WES 5013.
1. FINISH ALL OVER 250/.
ITEM NO. 3 COVER
COPY AVAILABLE TO DDC DOES NOT PERMIT FULLY LEGIBLE PRODUCTION
3. ANODIZE PER MIL-A-8625, TYPE I OR II.
2. MATERIAL: AL ALY 6061-T6 PLATE OR BAR
1. FINISH ALL OVER 250/.
ITEM NO. 2 BODY ASSEMBLY, INTERMEDIATE
2. MAY BE MADE FROM BRASS FITTING SHOWN.
1. FINISH ALL OVER 125/
ITEM NO. 40 FITTING
SCRAPER
LAYOUT
SOLID PARTICLE CONTAMINANT INJECTOR
E L3288502

PRECEDING PAGE BLANK NOT FILMED

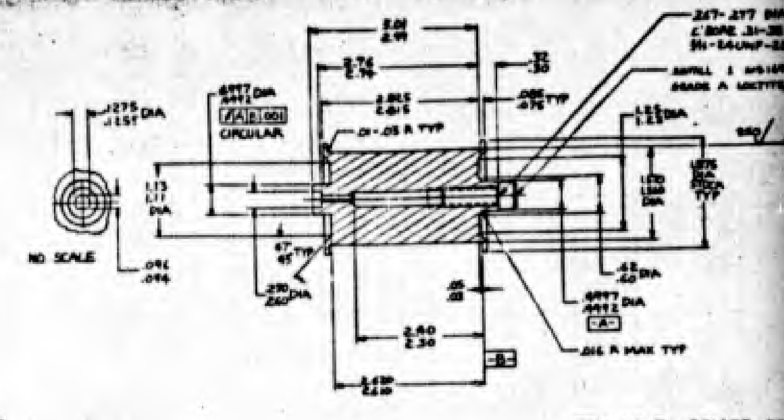



REVISIONS
DESCRIPTION
DATE
3. POLISH LARGE CAVITY FOR VISUAL OBSERVATION.
2. MATERIAL: LUCITE (PLEXIGLAS).
1. FINISH ALL OVER 125
.210-.220 DIA THRU 24 HOLES
ITEM NO 1 BODY, MOUNT
NOTE: THIS SURFACE & THE SIMILAR SURFACE OF ITEM NO. 6 TO LAY IN THE SAME PLANE WITHIN .001
MISMATCH PERMISSIBLE WITHIN TOL TYP
ITEM NO 5. SUPPORT, BEARING
[redacted]
LAYOUT
SOLID PARTICLE CONTAMINANT INJECTOR

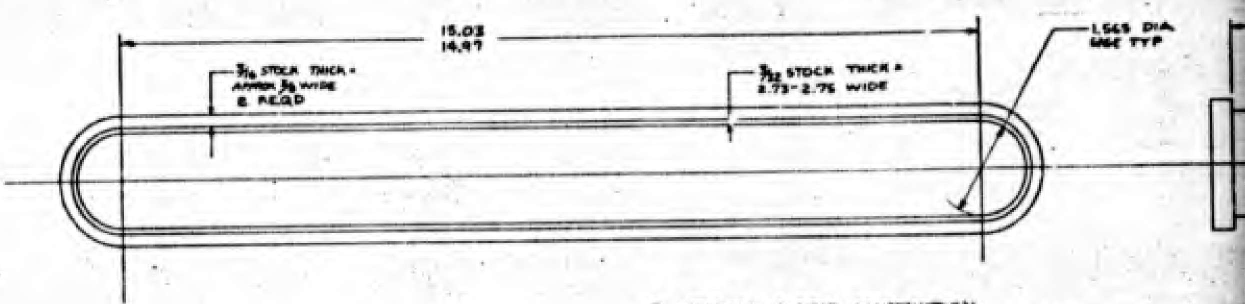


4. DIA ON A COMMON ℄ [↗ .005] CIRCULAR.
3. ANODIZE PER MIL-A-8625 TYPE I OR II.
2. MATERIAL: AL ALY 6061-T6 BAR OR PLATE.
1. FINISH ALL OVER 125/.

ITEM NO. 6 ROLLER, IDLER

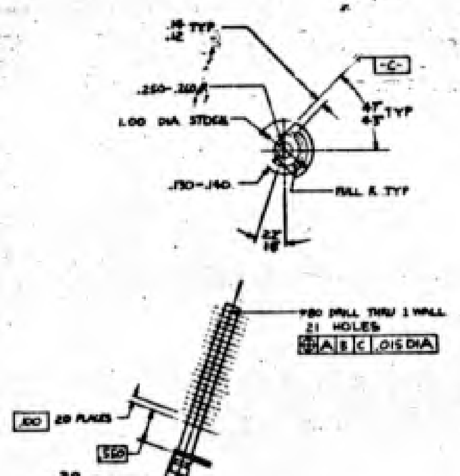


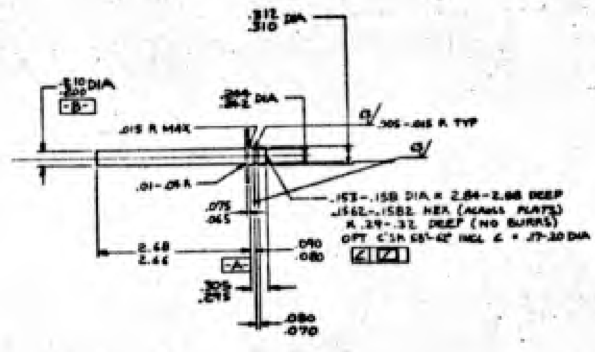
ITEM NO. 7 ROLLER, DR



3. OPTIONAL 1 PIECE CONSTRUCTION.
2. BOND TOGETHER PER AIRESEARCH PS-4 USING EC 976 (105-009-4001).
1. MATERIAL: NEOPRENE SHEET.

ITEM NO. 14 BELT



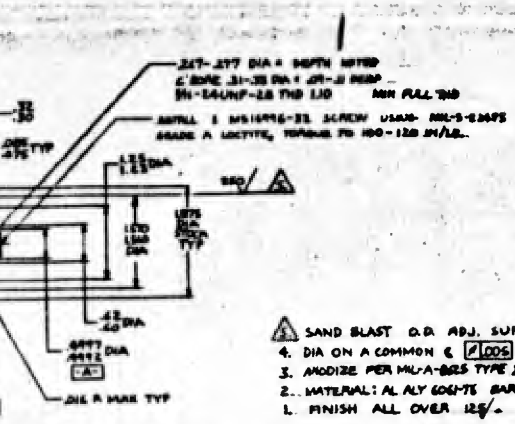


3. DIA ON A COMMON ℄ [↗ .005] CIRCULAR.
2. MATERIAL CRES 300 SERIES.
1. FINISH ALL OVER 125/.

ITEM NO. 8 KNIFE, AIR

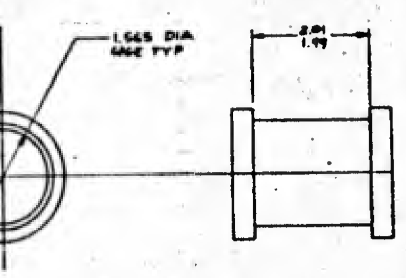
2

ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	[illegible]	[illegible]	[illegible]
	B	[illegible]		

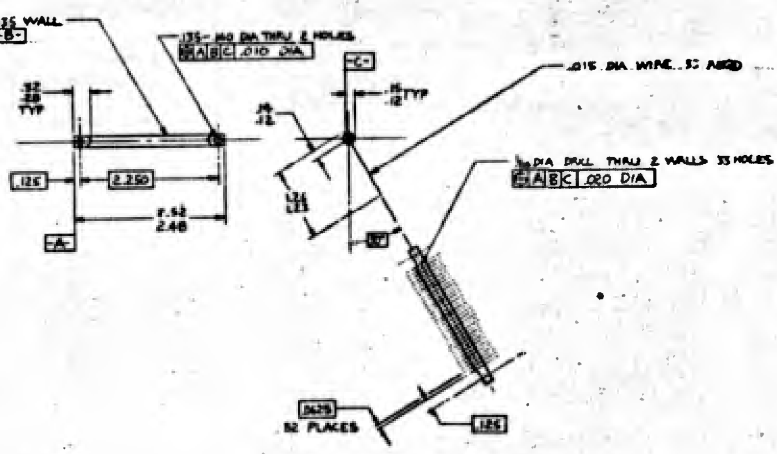


△ SAND BLAST O.D. ADJ. SURFACES OPT.
4. DIA ON A COMMON ℄ [◎ .005] CIRCULAR.
3. ANODIZE PER MIL-A-8625 TYPE I or II.
2. MATERIAL: AL ALY 6061-T6 BAR OR PLATE.
1. FINISH ALL OVER 125/.

ITEM NO 7. ROLLER, DRIVE



...5-4 USING EC 976 (105-009-4001).



ITEM NO. 10. RAKE, WIRE

2. POT WIRES IN TUBE BY COMPLETELY FILLING WITH EPOXYLITE 203.
1. MATERIAL: TUBE - AL ALY 6061-T4 OR T6
WIRE - CRES 300 SERIES OR CRS17-7PH SPRING WIRE COURSE, AMS5673

LAYOUT	
SOLID PARTICLE CONTAMINANT INJECTOR	E L 3288502