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MONOPROPELLANT EXHAUST CONTAMINATION INVESTIGATION

P.J.MARTINKOVIC

TECHNICAL REPORT AFRPL-TR-69-72

APRIL 1969

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AFRPL-TR-69-72

MONOPROPELLANT EXHAUST CONTAMINATION INVESTIGATION

P. J. Martinkovic

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FOREWORD

This report summarizes work performed during a USAF in-house program under Project 624AOODRV, during the period November 1967 through November 1968.

The program was conducted by the Liquid Rocket Division of the Air Force Rocket Propulsion Laboratory (AFRPL) at Test Stand 1-15, Space Chamber Number 4. Mr. Paul J. Martinkovic was the project engineer.

The author gratefully acknowledges the assistance of the following individuals and organizations in support of this program: Mr. R. Fern and Mr. K. Johnson of the Martin Marietta Corporation, Denver, Colorado, for providing and applying the Transtage thermal paint to AFRPL-furnished coupons and also conducting the pretest and posttest measurements of the test specimens; Mr. L. D. Massie of the Aero Propulsion Laboratory, Wright-Patterson AFB, Ohio, whose organization provided the solar cells and also conducted the pretest and posttest measurements of the cells; Mr. R. Winn of the Materials Laboratory, Wright-Patterson AFB, Ohio, whose organization conducted the pretest and posttest measurements of the optical coupons; Mr. R. L. Kline and Mr. V. DeMattia of Hamilton Standard, a division of United Aircraft Corporation, Windsor Locks, Connecticut, who provided the plume source engine as well as engine operational data.

This report has been reviewed and approved.

E. E. STEIN
Chief, Propulsion Subsystems Branch
Liquid Rocket Division
Air Force Rocket Propulsion Laboratory

ABSTRACT

This report presents the results of the Monopropellant Attitude-Control Rocket (ACR) Exhaust Contamination Investigation. The purpose of this effort was to determine ACR engine plume effects on vehicle space-borne equipment, i. e., thermal control paint, solar cells and optics. Plume impingement tests were conducted at an altitude of 400,000 feet using a 25-lb-thrust, monopropellant, attitude-control rocket engine. The propellant was hydrazine (N_2H_4) and the ignition source was Shell 405 catalyst. A series of 200 firings were conducted at each test position at an engine pulse width of 200 milliseconds. The analysis of the test data revealed that the monopropellant ACR exhaust plume had little or no effect on the operating characteristics of the space-borne equipment involved in the test program. Furthermore, the monopropellant exhaust plume is very clean from the contamination standpoint when compared to a bipropellant ACR plume using N_2O_4/A-50 and/or N_2O_4/MMH. This comparison is based on past bipropellant plume contamination test results.

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SECTION I

INTRODUCTION

The Space and Missile Systems Organization (SAMSO) requested the Air Force Rocket Propulsion Laboratory (AFRPL) to investigate two potential vehicle and propulsion integration problems associated with the operation of the attitude-control engines on the Transtage vehicle. These problems were Attitude-Control Rocket (ACR) exhaust contamination of (1) thermal control coating paint on the vehicle radiators and (2) on-board satellite equipment such as solar cells and optics.

Attitude-control rocket plume impingement on thermal paint can result in deposit of contaminants and/or mechanical effects similar to sandblasting which could severely degrade the ratio of solar absorptance and emittance of the thermal paint. This condition can cause thermal problems within a vehicle compartment housing temperature-sensitive components.

Plume impingement on solar cells can result in severe damage to the cells, i.e., sandblasting of the reflective coatings and/or melting of the solder connections due to high exhaust gas temperatures. Furthermore, the operational characteristics of the cell can be affected by exhaust contaminant buildup. These conditions can severely deteriorate the power output of the solar panels.

ACR exhaust contamination of optics used for various functions (i.e., telescopes, viewports, sensor windows and navigational equipment) can create major problems. These problems are image distortion and deterioration of optical transmittance.

SECTION II

OBJECTIVES

The objectives of this program were to determine the severity of ACR exhaust impingement effects on space-borne equipment. This was accomplished by (1) measuring any change in the initial ratio of absorptance and emittance of thermal control paint, (2) observing change in solar cell output and physical damage incurred, (3) observing image distortion and loss of transmittance through the optics as well as physical damage incurred, and (4) attempting to identify the exhaust plume contaminants.

SECTION III

APPROACH

The thermal control paint, solar cells and optics were subjected to ACR plume impingement under vacuum conditions. During tests, in situ measurements were taken at various intervals to analyze contamination trends for correlation with posttest measurements. The test coupons were maintained under vacuum conditions during the entire test phase, and upon completion of each test phase, the test specimens were removed from the altitude chamber under a gaseous nitrogen atmosphere and placed into their respective shipping containers. The test specimens were maintained in this inert environment to minimize atmospheric contamination during shipment to the various laboratories for posttest measurements.

SECTION IV

TEST FACILITY AND TEST SYSTEM

1. ALTITUDE CHAMBER

The test facility used for these tests was Space Chamber No. 4, located in Test Area 1-15. The altitude chamber (reference Figures 1, 2, and 3) is 8 feet in diameter and 13 feet in length and incorporated a 5- by 5-foot cryogenic (LN_2) panel which served a twofold purpose: (1) cryopumping to obtain the high start altitude and (2) the entrapment of exhaust particles to minimize recirculation of the exhaust particles during an ACR firing. The pumping system consisted of two 300-cfm mechanical pumps, a Roots blower rated at 615 cfm and two 10-inch diffusion pumps, each rated at a pumping capacity of 4200 liters per second. The pumping system incorporated three isolation valves to isolate the altitude chamber from the pumping system. Such isolation (1) maintained a vacuum in the altitude chamber during the evening hours and weekends without the pumping system on the line to prevent atmospheric contamination of the test specimens during extended test periods and (2) prevented ingestion of large quantities of propellants by the pumping system in the event of a major failure of the rocket engine and/or the ACR subsystem during tests. The test start altitude and altitude degradation following each rocket engine firing was measured by the use of a Pirani and ion vacuum gage and recorded on a Leeds and Northrup Type "G" Recorder.

2. PLUME SOURCE ACR ENGINE

The attitude-control rocket engine used for the contamination tests was a Hamilton Standard monoporpellant rocket engine, reference Figure 4. The ACR engine technical data are as follows:

Thrust	25 lb
Propellant	98% Hydrazine, 2% Water
Catalyst (two-stage)	Shell 405
Weight	2.70 lbs
Inlet Pressure	295 psia

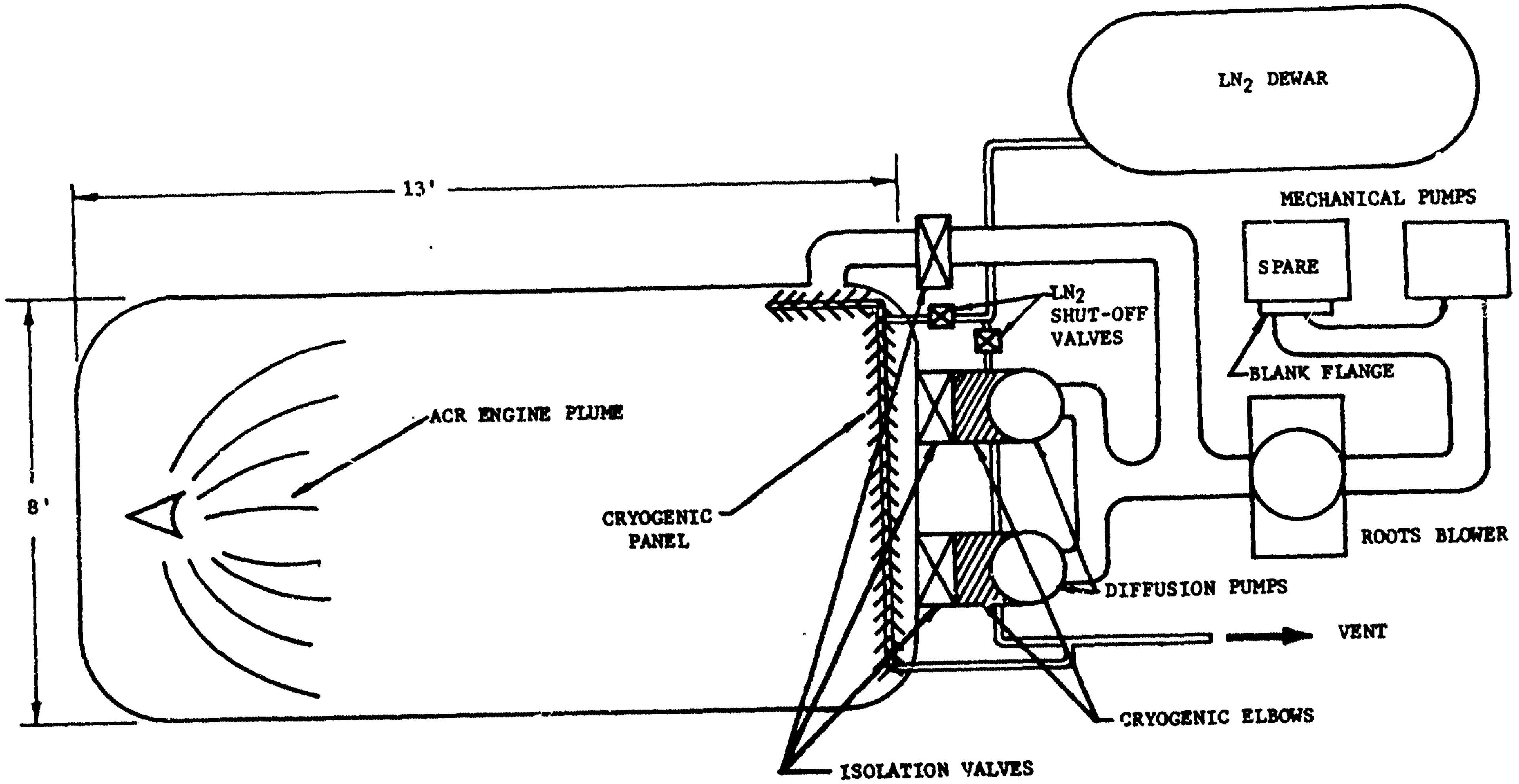

Figure 1. Schematic of Space Chamber No. 4, Test Area 1-15

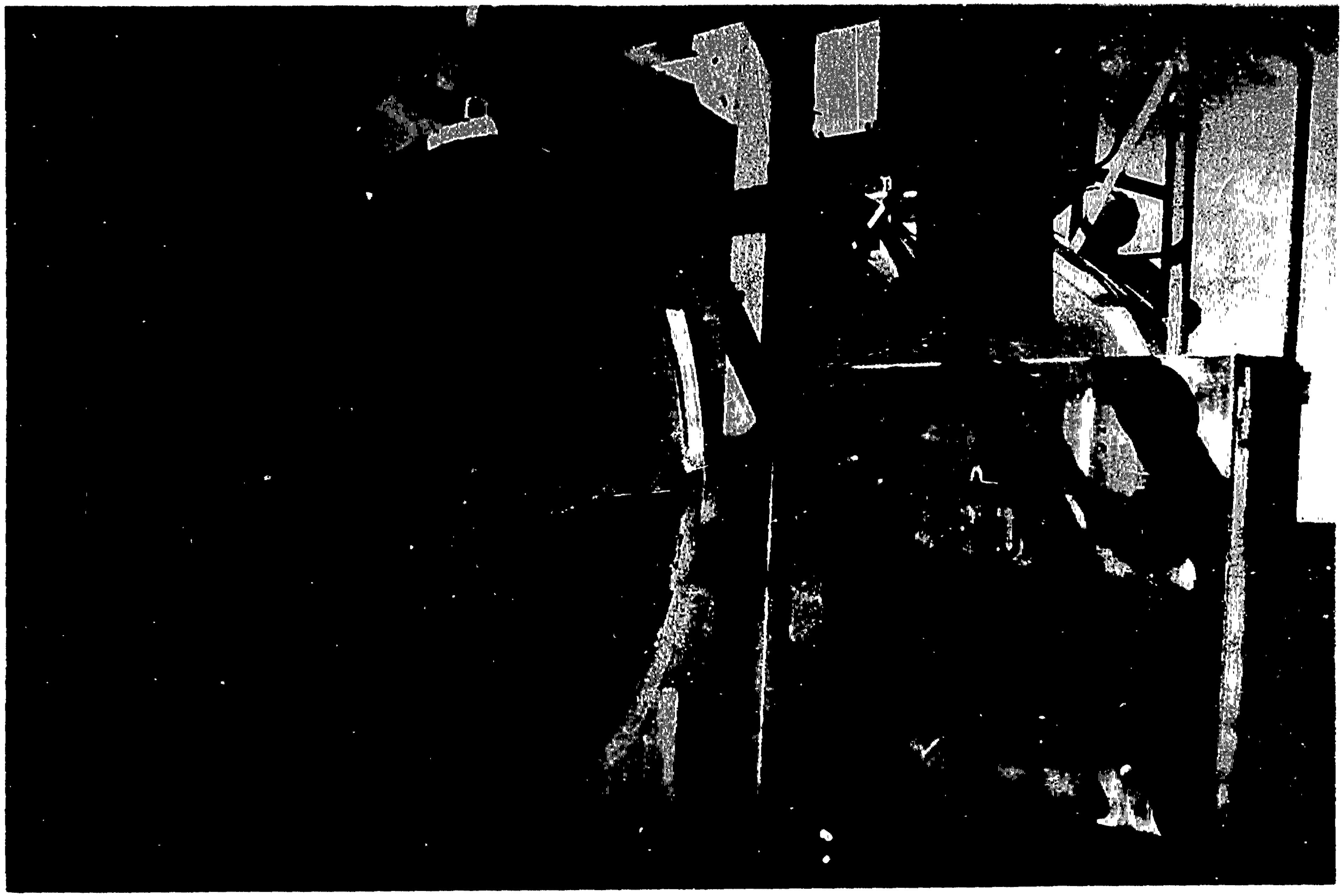

Figure 2. Space Chamber No. 4

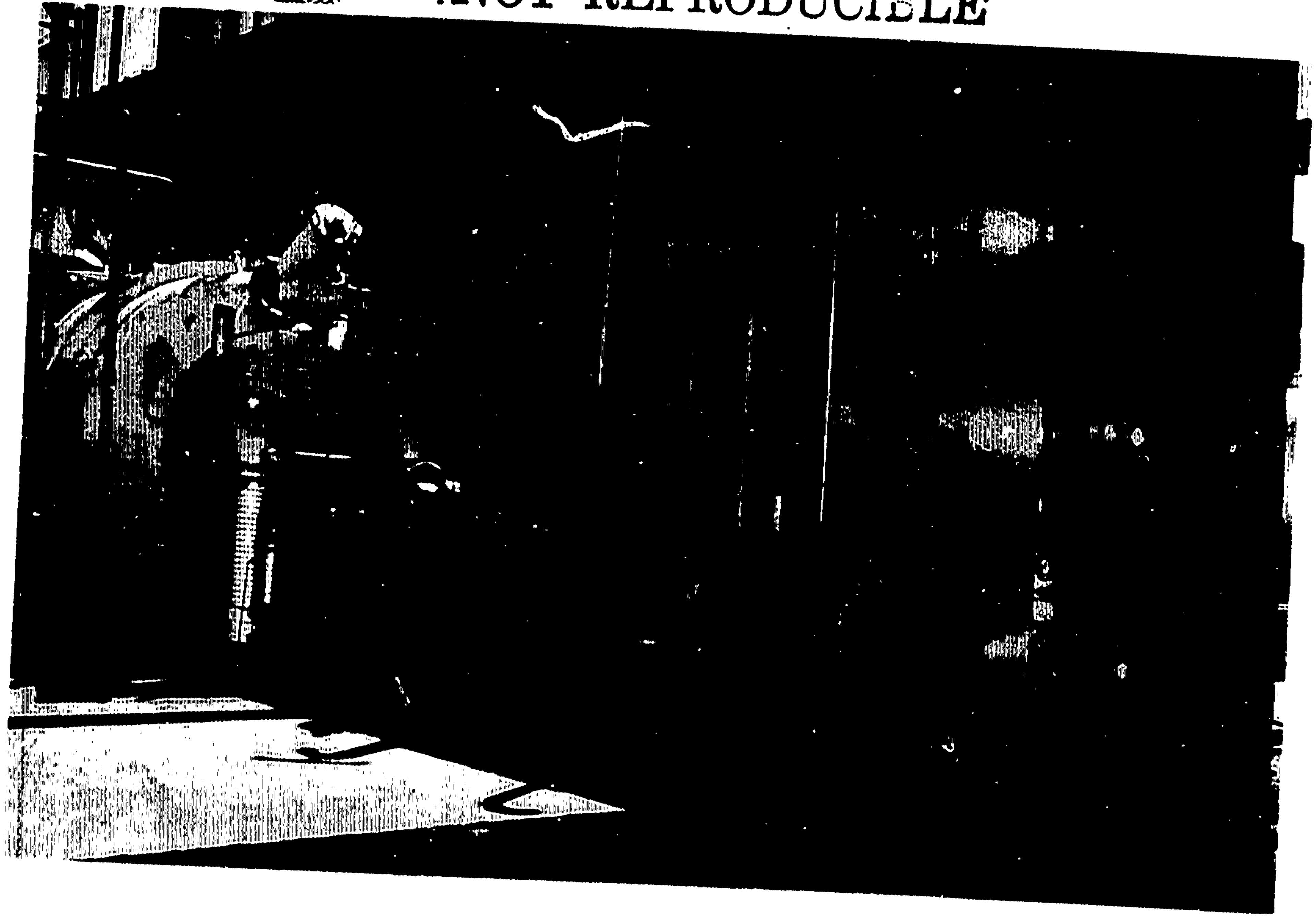

Figure 3. Vacuum Pumping System

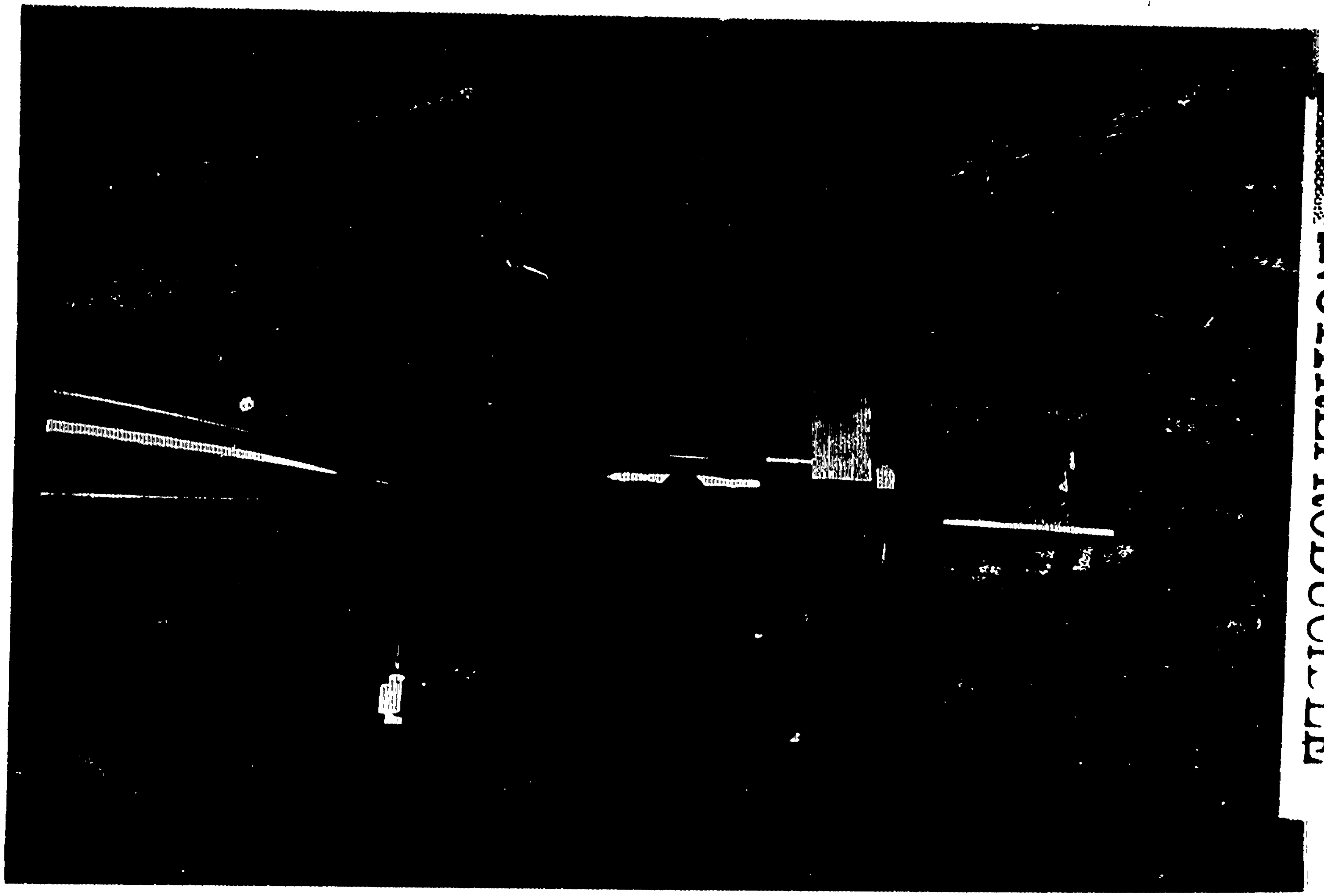

Figure 4. Monopropellant Attitude-Control Rocket Engine, 25-lb Thrust

Chamber Pressure	150 psia
Nozzle Area Ratio	50/1
Flow Rate	.111 lb/sec

3. ACR ENGINE SUBSYSTEM

The ACR fluid system (reference Figure 5) consisted of two 3-liter run tanks, associated valving and a GN_2 pressurization system. The propulsion subsystem incorporated a fuel dumping feature in order to remove the hydrazine from the system in minimum time in the event of an emergency. The H_2O scrubber system was designed to dilute the hydrazine to a safe level of 60% water and 40% hydrazine. A 10-micron filter was installed upstream of the rocket engine to prevent foreign material, if any, from entering the redundant-series rocket engine propellant valves.

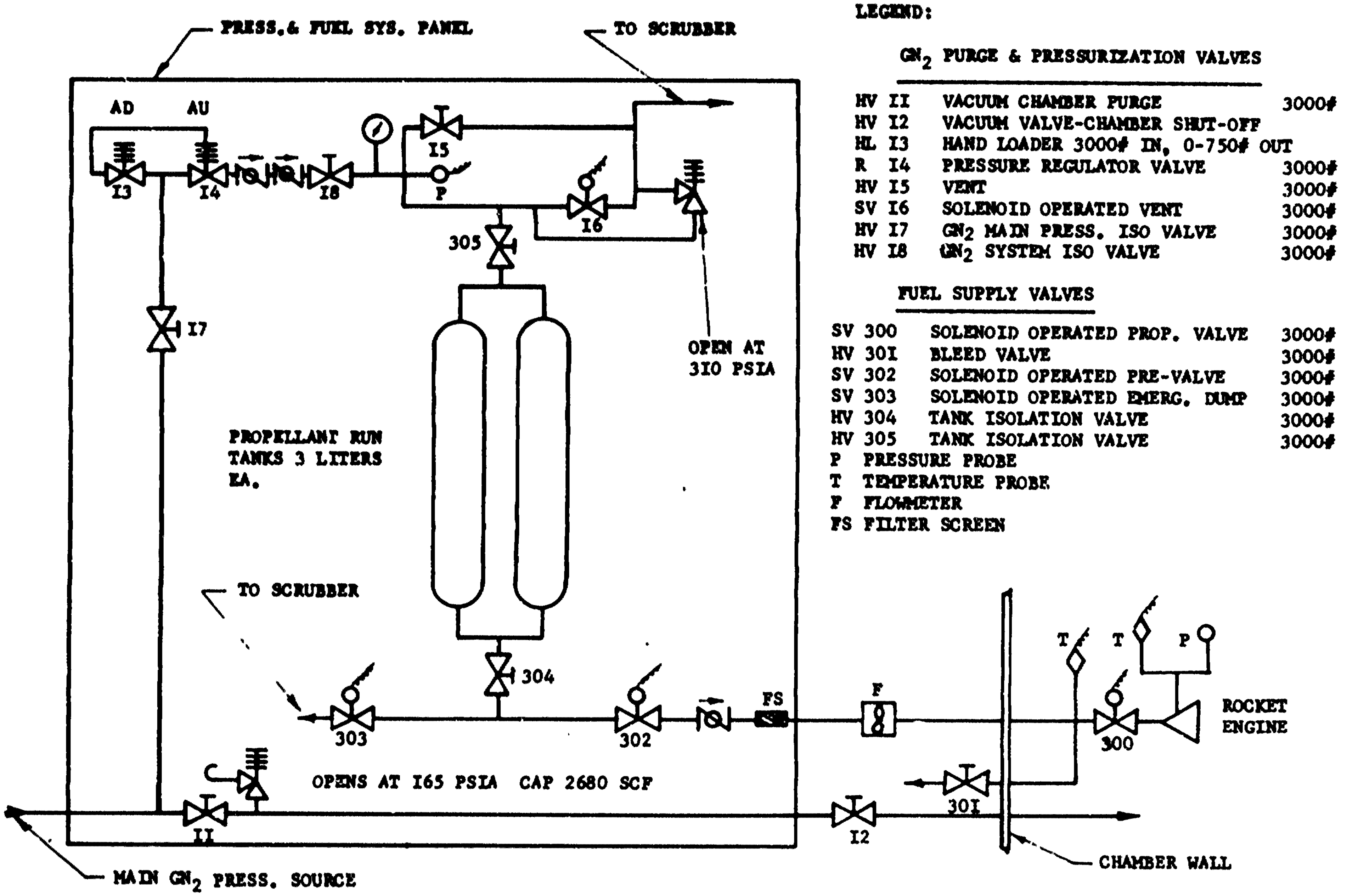

Figure 5. Monopropellant Rocket Engine System

SECTION V

PHASE I TESTS - THERMAL CONTROL COATINGS

1. TEST CONFIGURATION

The Phase I test hardware (reference Figure 6) consisted of a flat surface panel, 36 by 44 inches, which incorporated seven flush-mounted thermal-control coated coupons. The coupons were positioned downstream of the rocket nozzle exit within the plume envelope of an ACR firing at 400,000 feet as predicted by the Martin Marietta Company. Coupons 7 and 8 represented the lower area of the Transtage thermal radiator which is 10.5 inches from the centerline of the ACR roll engines. Coupons 2 through 6 were positioned closer to the ACR engine nozzle exit to obtain additional information for possible future reference. Coupons 1, 9 and 10 (which are covered in detail in Paragraph 4, Test Results) were also involved in this effort for control purposes.

The thermal-control coating was applied to a 3-inch-diameter aluminum disk which was epoxy-resin-bonded to a teflon flange (reference Figure 7). The purpose of the teflon flange was to minimize heat transfer between the coupon and the spacecraft panel during taking of in situ measurements with the xenon sun lamp. The test coupons were attached to the spacecraft panel by the use of several wing nuts to facilitate removal of same under a gaseous nitrogen atmosphere, upon completion of tests, by a test crew member wearing a Scott Air Pack breathing apparatus.

The instrumentation consisted of iron constantan (IC) thermocouples attached to the underside of the coupons, and the test data were recorded on a Leeds Northrup Type "G" recorder. Prior to the Phase I tests, baseline measurements were taken of the coupons which consisted of measuring temperature rise and temperature at equilibrium over a 75-minute period using the xenon lamp. Recordings were taken every 5 minutes during this time period. During tests, temperature measurements were taken following 31,

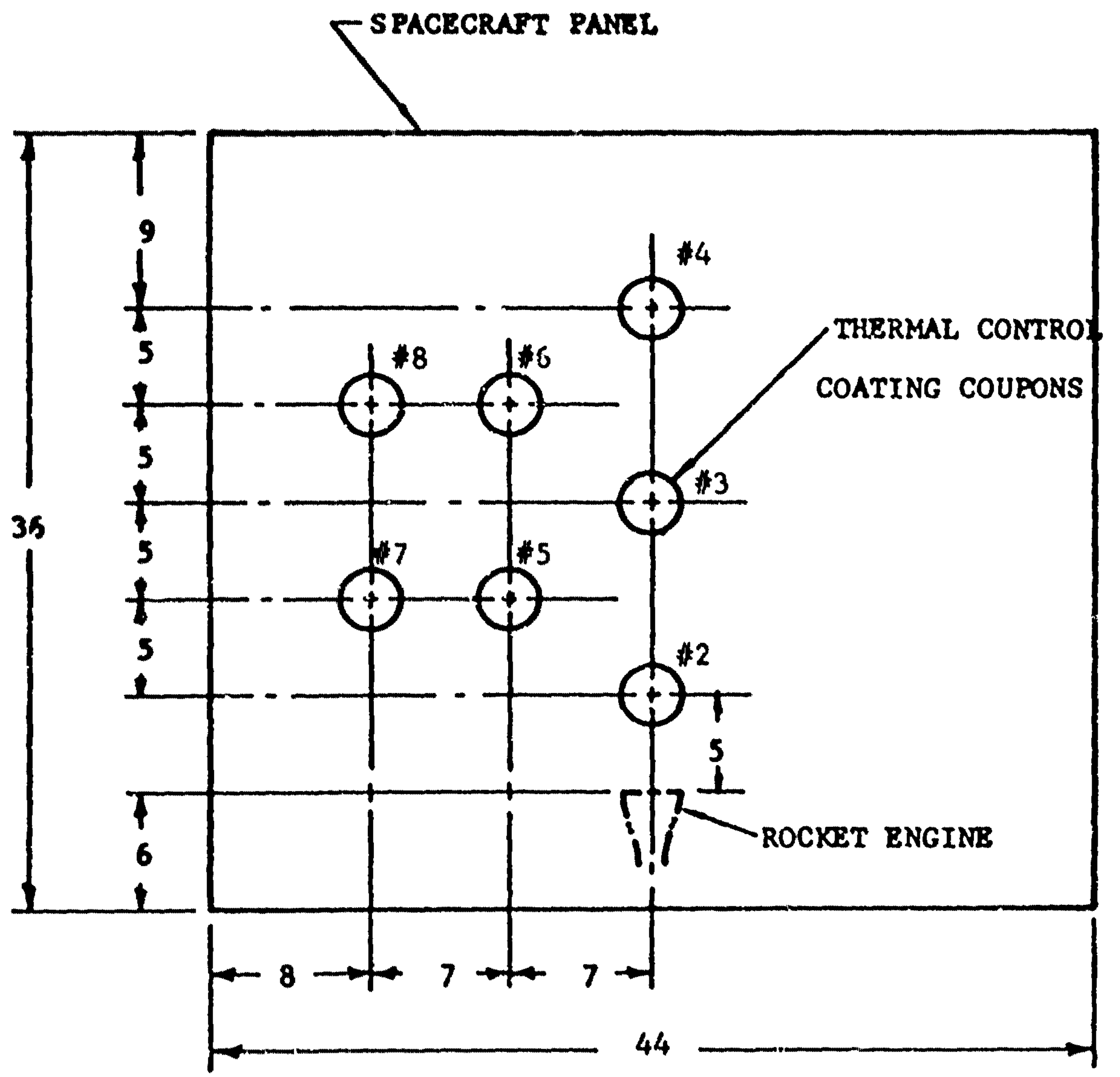

Figure 6. Phase I - Test Configuration

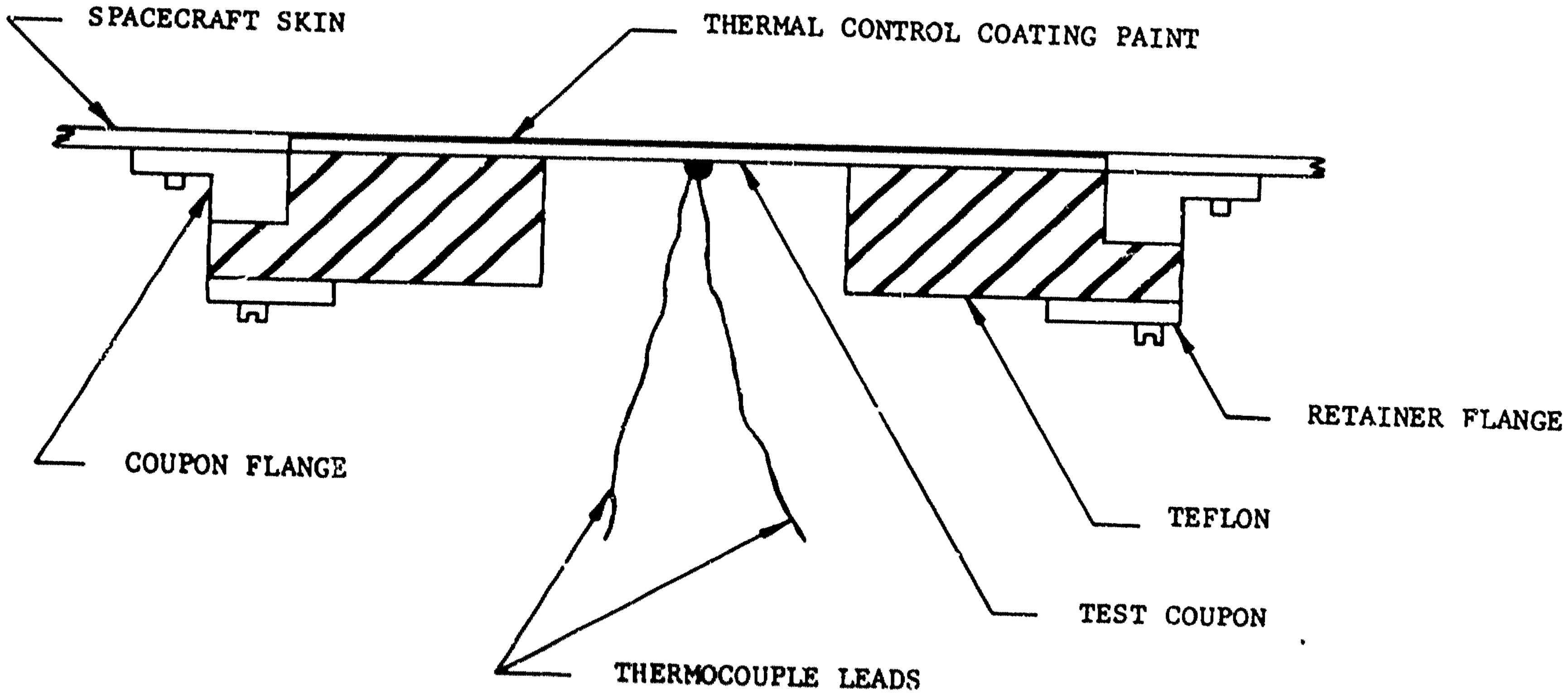

Figure 7. Thermal-Control Coating Coupon

116 and 211 ACR firings at an engine pulse width of 200 milliseconds per firing. The type of laboratory equipment used to obtain the pretest and posttest measurements by the Martin Marietta Company were a Lion Research Corporation emissometer Model 25B, and the R25C reflectometer. The emissometer measures α s/ϵ, the ratio of the solar absorptance to the emittance in the 7 to 25 μ range. Solar absorptance, α s, was measured in the 0.25 to 2.4 μ range using the R25C reflectometer.

2. TEST POSITION

The Phase I test hardware (reference Figure 8) was positioned paralled to the ACR plume and the distance from the centerline of the rocket engine to the surface of the panel was 3.5 inches. The xenon lamp and reflector were positioned directly above the test coupons. The reflector of the lamp was protected from exhaust particles during an ACR firing by the use of a solenoid-actuated protective shield.

3. TEST CONDITIONS

During the Phase I tests, the thermal-control coated coupons were maintained under a continuous vacuum condition for a period of 432 hours and were subjected to 211 ACR firings at an engine pulse width of 200 milliseconds. Start altitude for the ACR firing was 400,000 feet and upon completion of a firing, the altitude decreased to 180,000 feet. The altitude recovery time between ACR firings was approximately 15 minutes.

4. TEST RESULTS

The comparison of the pretest and posttest measurements (reference Table I) reveals that the coupons 2 through 8 subjected to the plume experienced a change in absorptance but no change in emittance. The change in absorptance value varied from .03 to 18.5%. Visual observation of the coupons upon completion of the tests revealed no physical damage such as a sandblasting or pitting effect. Coupon 1, which was left in the shipping container, showed no change in absorptance or emissivity value indicating that storage conditions had no effect on the thermal paint. Coupons 9 and

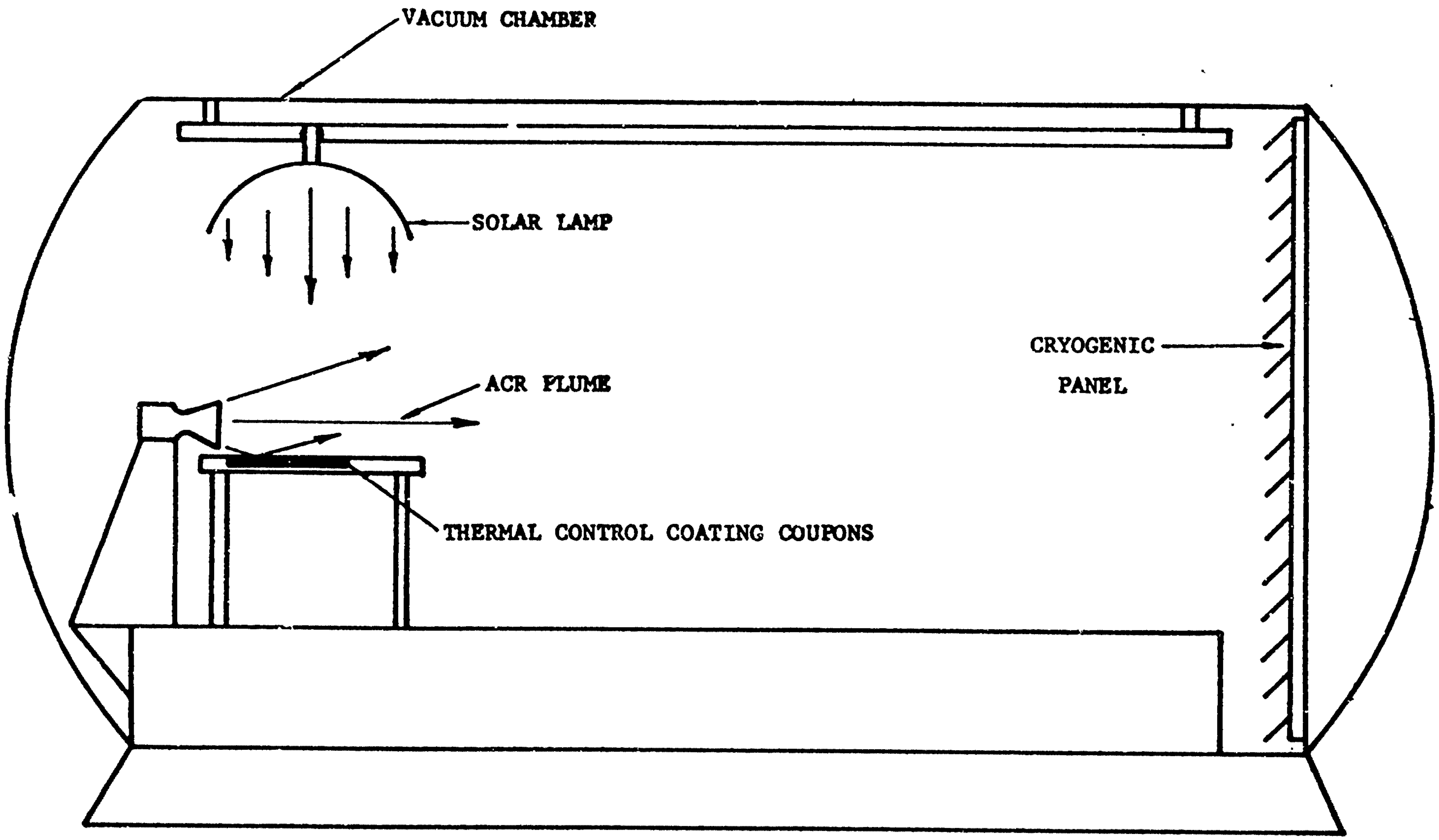

Figure 8. Phase I - [illegible] Article Position

10, which were positioned in the altitude chamber but outside of the plume boundary, showed no change in either absorptance or emittance value, which indicated that ACR exhaust particle recirculation during an ACR firing was not a problem when using a cryogenic panel downstream of the rocket engine nozzle exit. Coupons 7 and 8, which represented the location of the Transtage thermal-paint area with relation to the ACR roll engine centerline, showed an insignificant increase in absorptance value which varied from .03% to .04%. Coupons 2 through 6 showed an increase in absorptance value from .04% to 18.5%. The coupons showing the largest increase in absorptance value were 2 and 3, which were 17% and 18.5% respectively. These test specimens were located fairly close to the rocket engine nozzle exit.

TABLE I. PRETEST AND POSTTEST MEASUREMENTS OF THERMAL-CONTROL COATING COUPONS, MARTIN/DENVER

	PRETEST MEASUREMENTS			POSTTEST MEASUREMENTS		
COUPON NO.	ABSORPTION	EMITTANCE	α/ϵ	ABSORPTION	EMITTANCE	α/ϵ
1*	.185	.87	.212	.185	.87	.212
2	.185	.87	.212	.217	.87	.250
3	.187	.86	.218	.222	.86	.274
4	.185	.85	.218	.205	.85	.237
5	.187	.86	.218	.198	.86	.230
6	.185	.86	.215	.193	.86	.224
7	.185	.85	.218	.193	.85	.227
8	.185	.86	.215	.191	.86	.222
9**	.185	.85	.218	.185	.85	.218
10**	.185	.85	.218	.186	.85	.219

NOTE: * COUPON REMAINED IN SHIPPING CONTAINER

** COUPONS WERE PLACED OUTSIDE THE PLUME

SECTION VI

PHASE II TESTS - OPTICS AND SOLAR CELLS

1. TEST CONFIGURATION

The Phase II test hardware (reference Figure 9) consisted of two major components: (1) a reference test specimen module of two optical coupons and two solar cells, protected from the ACR exhaust particles by the use of a solenoid-actuated protective shield; and (2) the main test specimen module which incorporated six optical coupons, six solar cells and a contamination coupon. The main test specimen module was positioned perpendicular to the centerline of the ACR engine for the direct plume impingement tests. For the in situ measurements, the module was rotated to the horizontal position. Rotation of the main test specimen module was accomplished by the use of an AC motor in combination with mechanical linkage.

The solar cells were bonded to a teflon disk (reference Figure 10) 1.5 inches in diameter and .250 inch thick. The cell coupons (reference Figure 11) were secured to the specimen module by the use of a retainer ring.

The optical coupons (reference Figure 12) were 1.5 inches in diameter and .250 inch thick. These coupons were secured to the specimen module by the use of a cross-slit collimator as shown in Figure 13. The light collimator was used to narrow down the acceptance angle of the photocell which is normally rated at 5%, but which can, based on past experiences, in some cases be as much at 15%. The inner dimensions of the cross-slit collimator were 1.75 inches in length and 1.00 inch in diameter. The slot widths were .070 inch, and the interior of the unit was painted flat black to minimize reflection.

A photocell was used to measure transmittance through the optics. These data were recorded on a Leeds and Northrup Type "G" recorder.

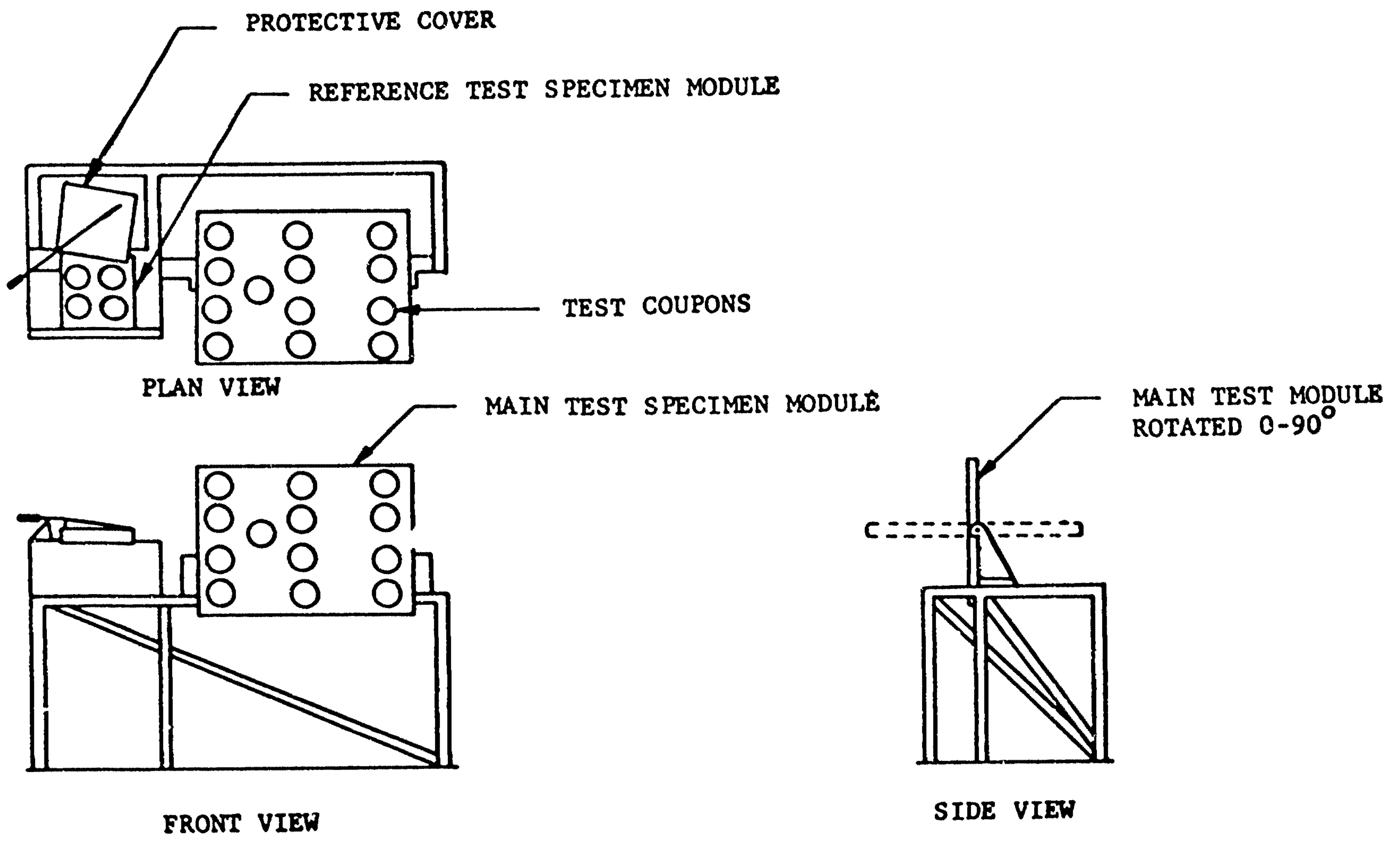

Figure 9. Phase II - Test Configuration

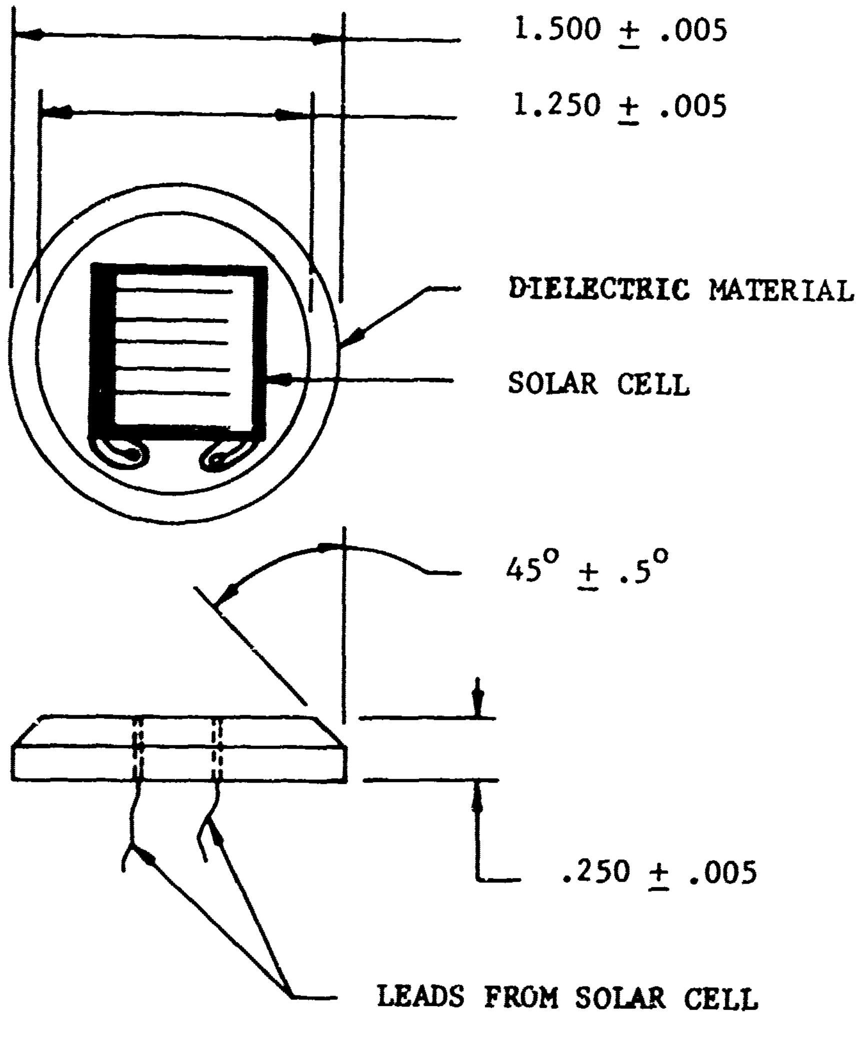

Figure 10. Solar Cell Coupon

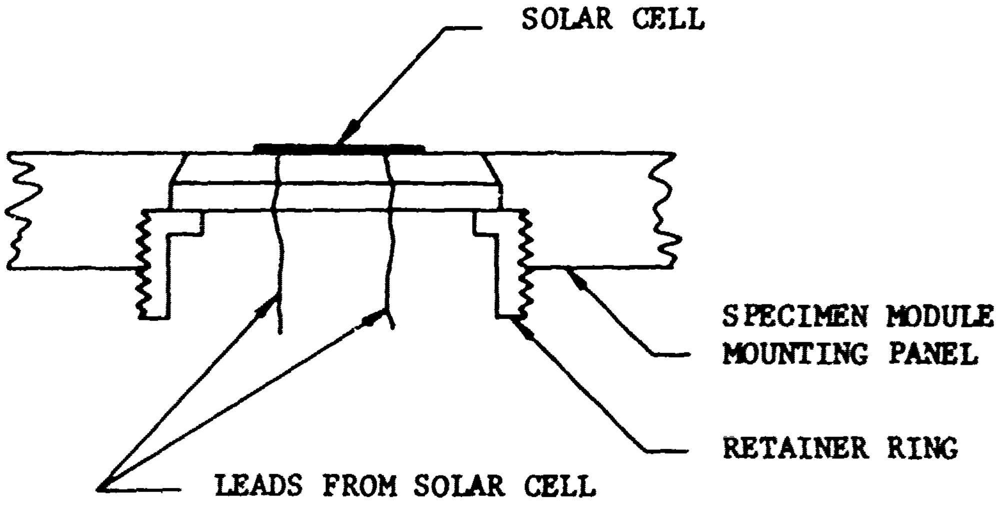

Figure 11. Solar Cell Installation

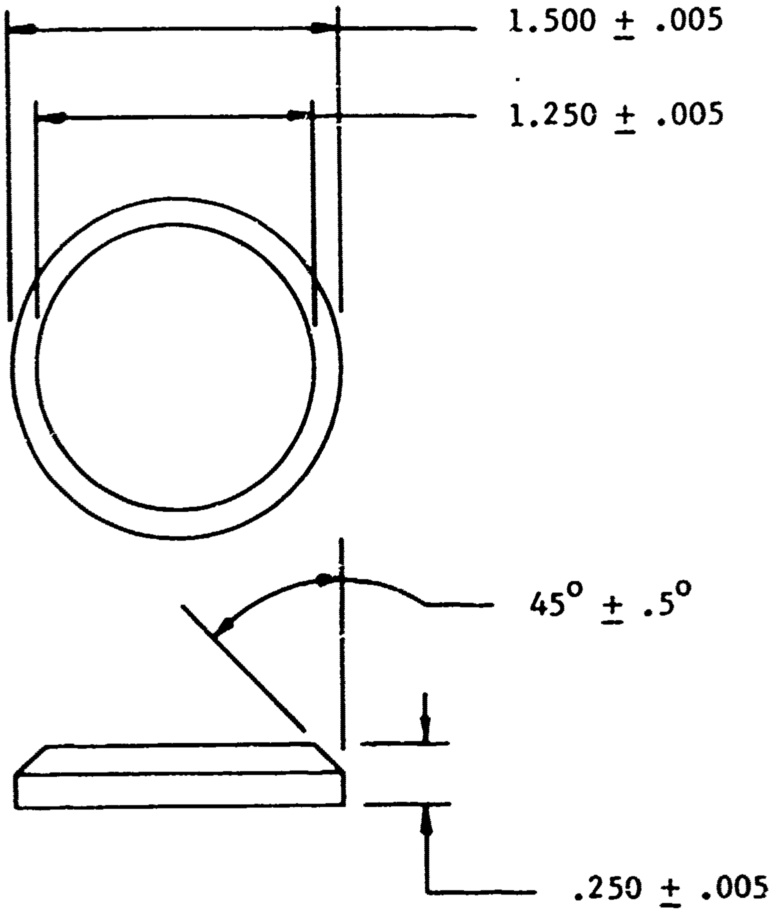

Figure 12. Optical Coupon

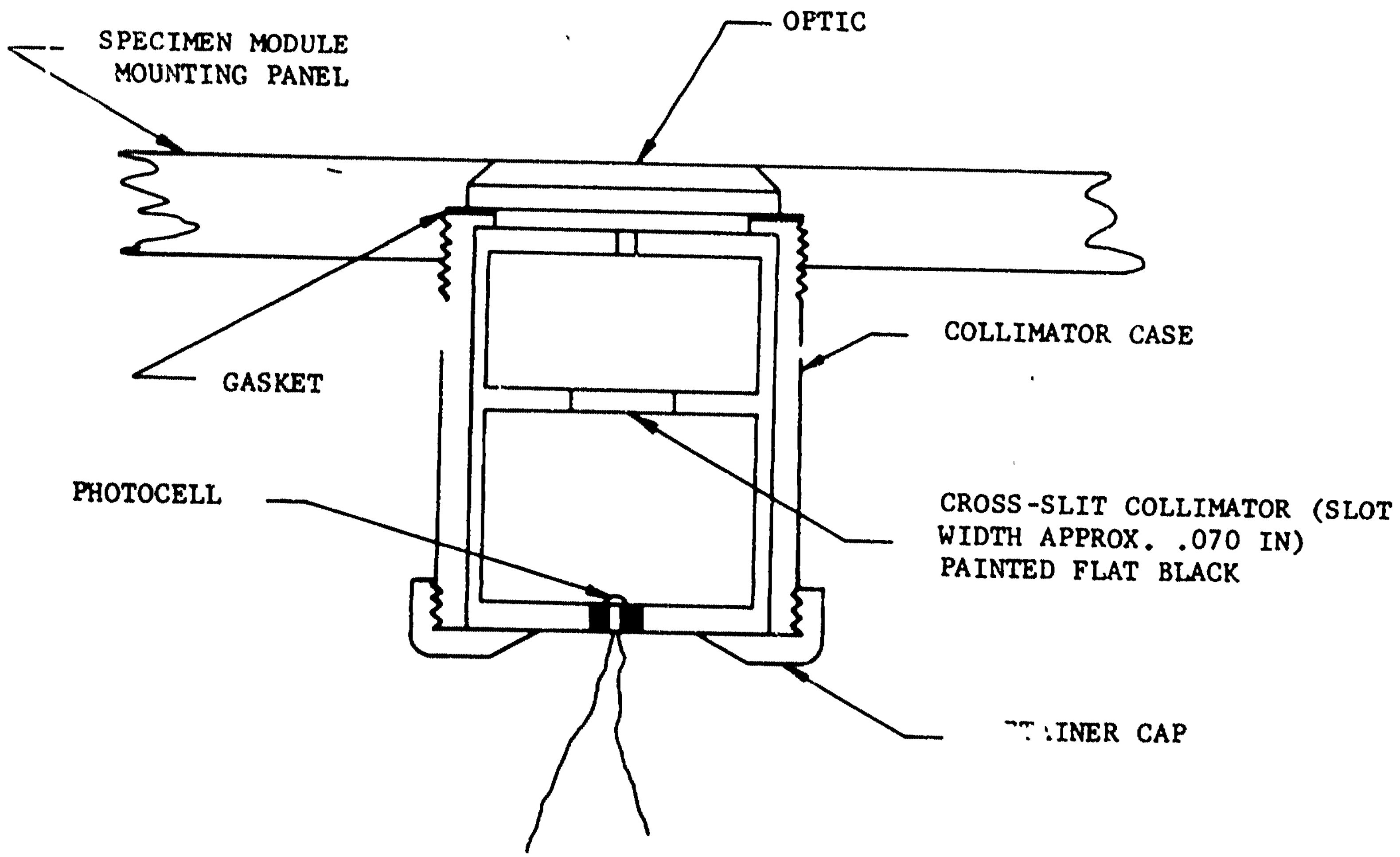

Figure 13. Optical Coupon Installation

This same type of equipment was used to record the power output of the solar cell coupons. Standard illumination was used to obtain baseline measurement of each test specimen, as well as test measurements following 50, 100, 150 and 200 ACR firings at a pulse width of 200 milliseconds. The types of laboratory equipment used for the pretest and posttest measurements of the optical coupons were a General Electric recording spectrophotometer which covered the 0. 38 to 0. 7-micron range and the Beckman DK-2 ratio-recording spectrophotometer, in combination with a hydrogen lamp and photomultiplier tube detector and a tungsten lamp and thermocouple detector. The hydrogen lamp photomultiplier tube detector covered the 0. 25 to 0. 35-micron and the 0. 3 to 0. 7-micron range where the tungsten lamp and thermocouple detector covered the 0. 5 to 2. 5-micron range. The laboratory equipment used for the pretest and posttest measurements of the solar cells was an X-25-96-13-L solar simulator.

2. TEST POSITION

The Phase II test hardware (reference Figure 14) was positioned 5 feet and 9 feet downstream of the rocket nozzle exit. The xenon lamp was positioned directly above the reference and main test specimen modules. The location of the test specimens on the specimen modules for the 5- and 9-foot test positions are shown in Figures 15 and 16, respectively.

3. TEST CONDITIONS

During the Phase II tests, the solar cells and optical coupons for each test position were maintained under a continuous vacuum condition for a period of 264 hours and during this period of time were subjected to 200 ACR firings at an engine pulse width of 200 milliseconds. The test conditions were the same for both the 5- and 9-foot test positions.

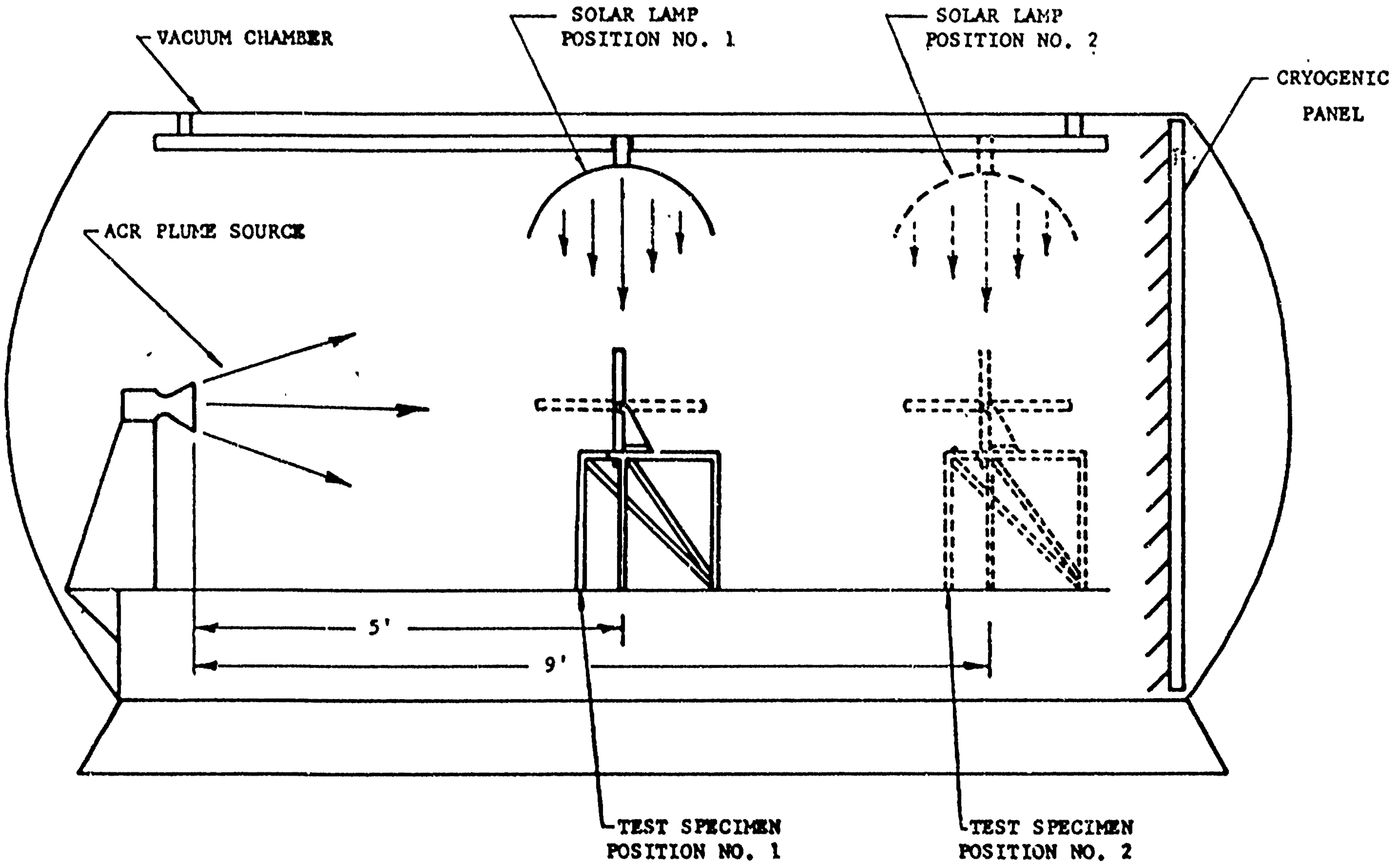

Figure 14. Phase II - Test Article Position

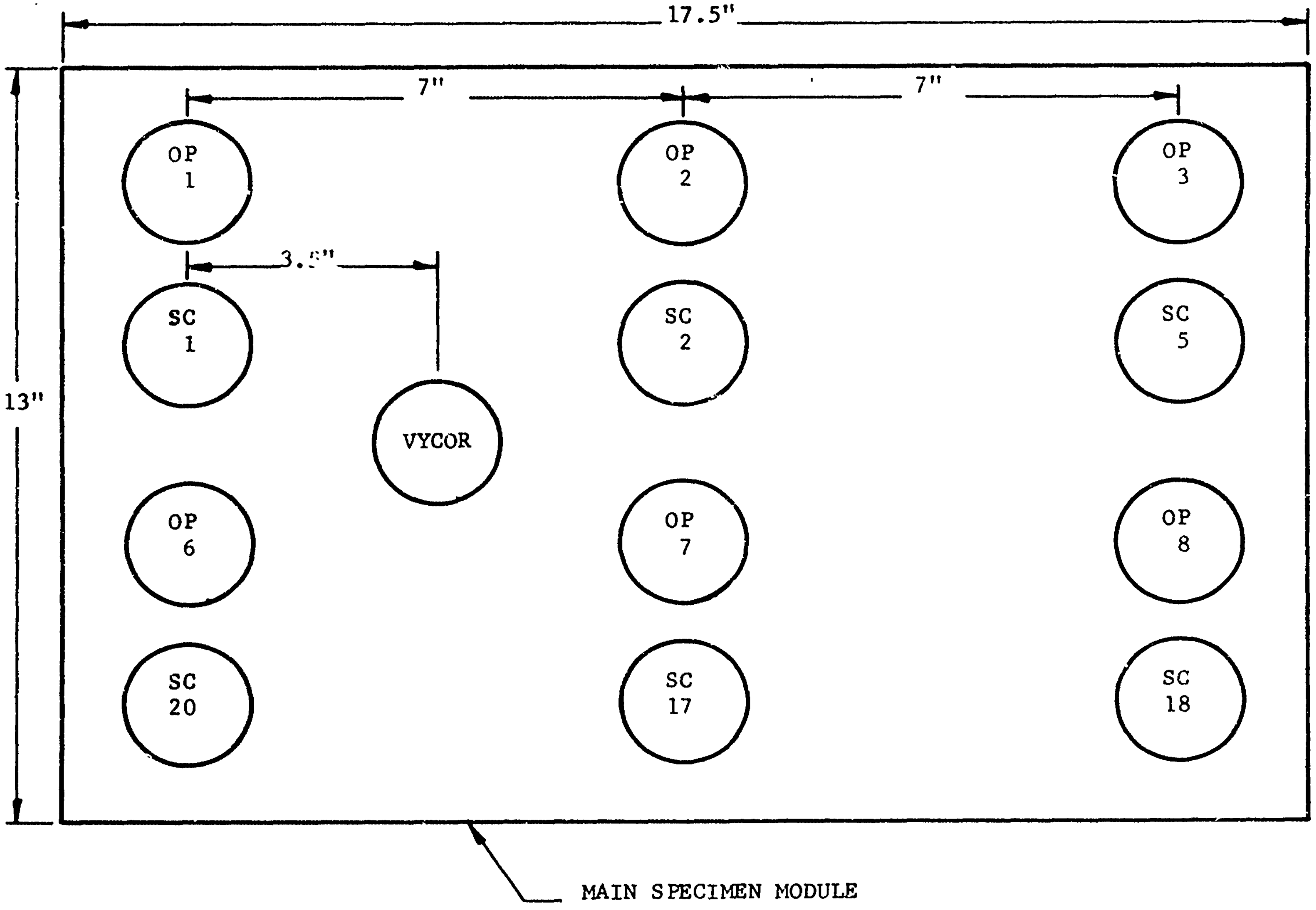

Figure 15. Test Locations of Optical and Solar Cell Coupons at the 5-ft Test Position

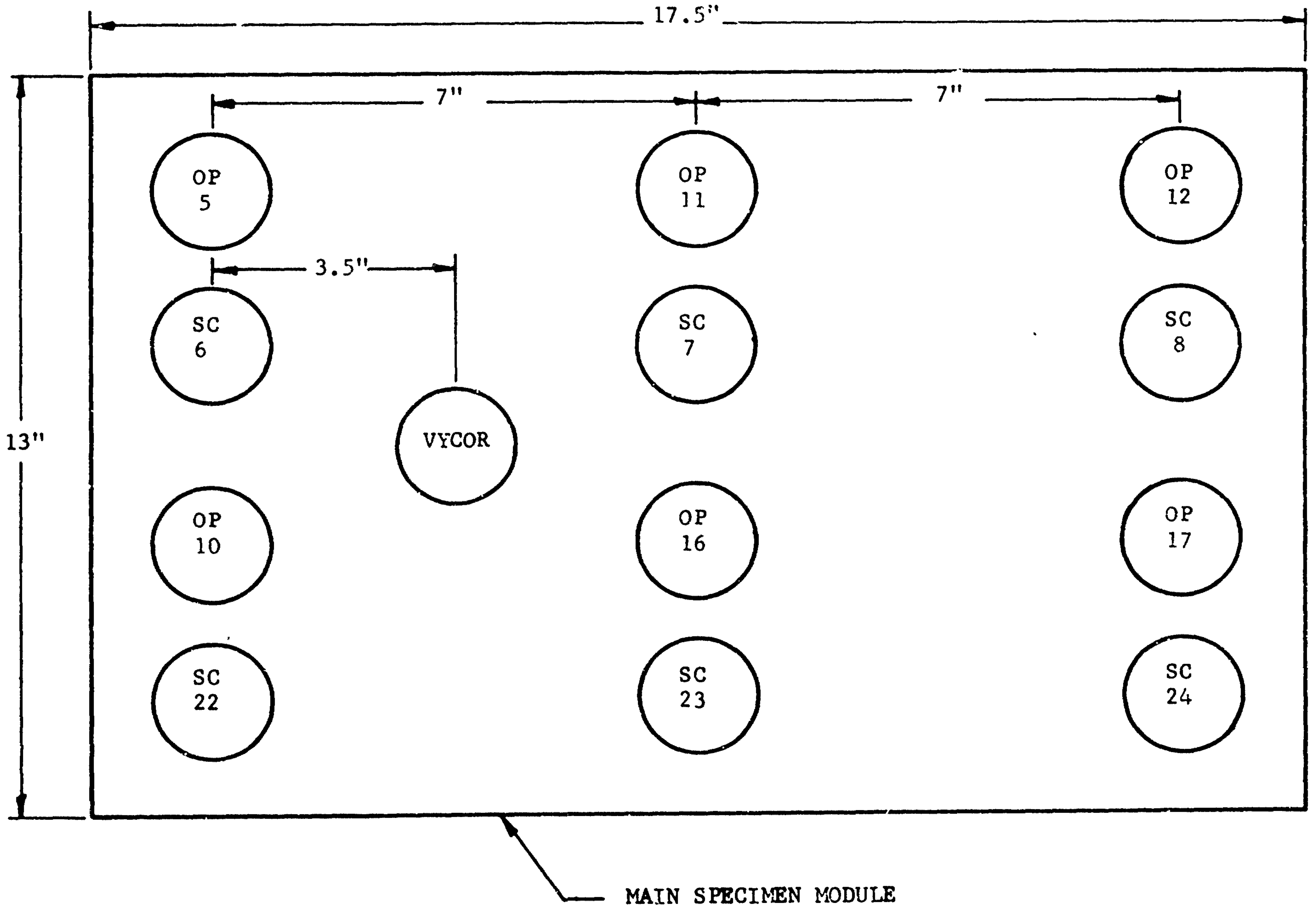

Figure 16. Test Locations of Optical and Solar Cell Coupons at the 9-ft. Test Position

4. TEST RESULTS

The comparison of the optical pretest and posttest measurements of the coupons located at the 5-foot test position (reference Figures 17 through 24) revealed a slight increase in optical transmittance. The percent of increase varied, dependent upon location of the test specimen with relation to the centerline of the ACR engine plume. For reference purposes, the centerline of the plume was directed at the contamination coupon for both the 5- and 9-foot test positions. Since bore sighting equipment was not available, a small tolerance could be expected since sighting was accomplished by visual means. Test coupons 1, 2, 6 and 7, which were located fairly close to the centerline of the ACR plume, showed an increase in transmittance from 3 to 7% at a wave length of 1.4 microns. Test coupons 3 and 8, located 10.5 inches off from the centerline of the ACR engine, showed an increase in transmittance from 1 to 2%. The protected specimens 4 and 9 showed no change in transmittance. . This increase in optical transmittance was noted when taking in situ measurements following 50 ACR firings. It was suspected that this condition was being caused by (1) photocell and recording equipment shift characteristics, (2) hydrazine contamination, or (3) ammonia contamination. It was determined to conduct laboratory tests to investigate this phenomenon.

Following pretest measurements using a cross-slit collimator in combination with an incandescent light, one optical coupon was coated with N_2H_4 and another was coated with anhydrous ammonia and allowed to dry at room temperature. Upon completion of the drying operation, the optical coupons were visually inspected. The hydrazine-coated optic revealed a uniform coating of a very light white residue. The ammonia-coated optic revealed a residue coating which had a rainbow effect and was not uniform with regard to concentration of the various colors. The posttest measurements of the hydrazine-coated optics showed no change in transmittance value when compared with the pretest value. However, the ammonia-coated optical coupon revealed an increase in transmittance from 5% to 17%, the larger value experienced in areas where the rainbow effect was more pronounced.

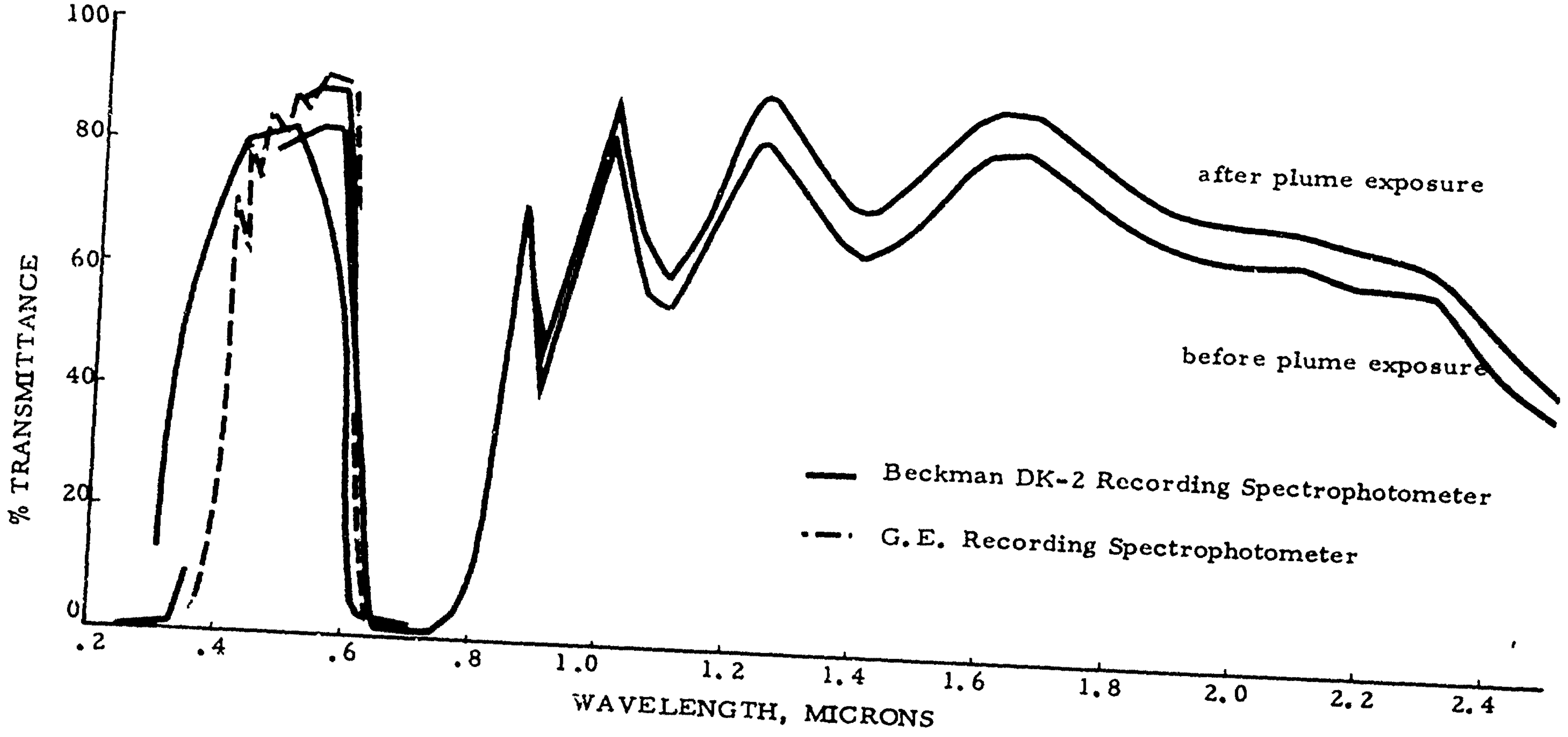

Figure 17. Spectral Transmittance of Optical Coupon No. 1

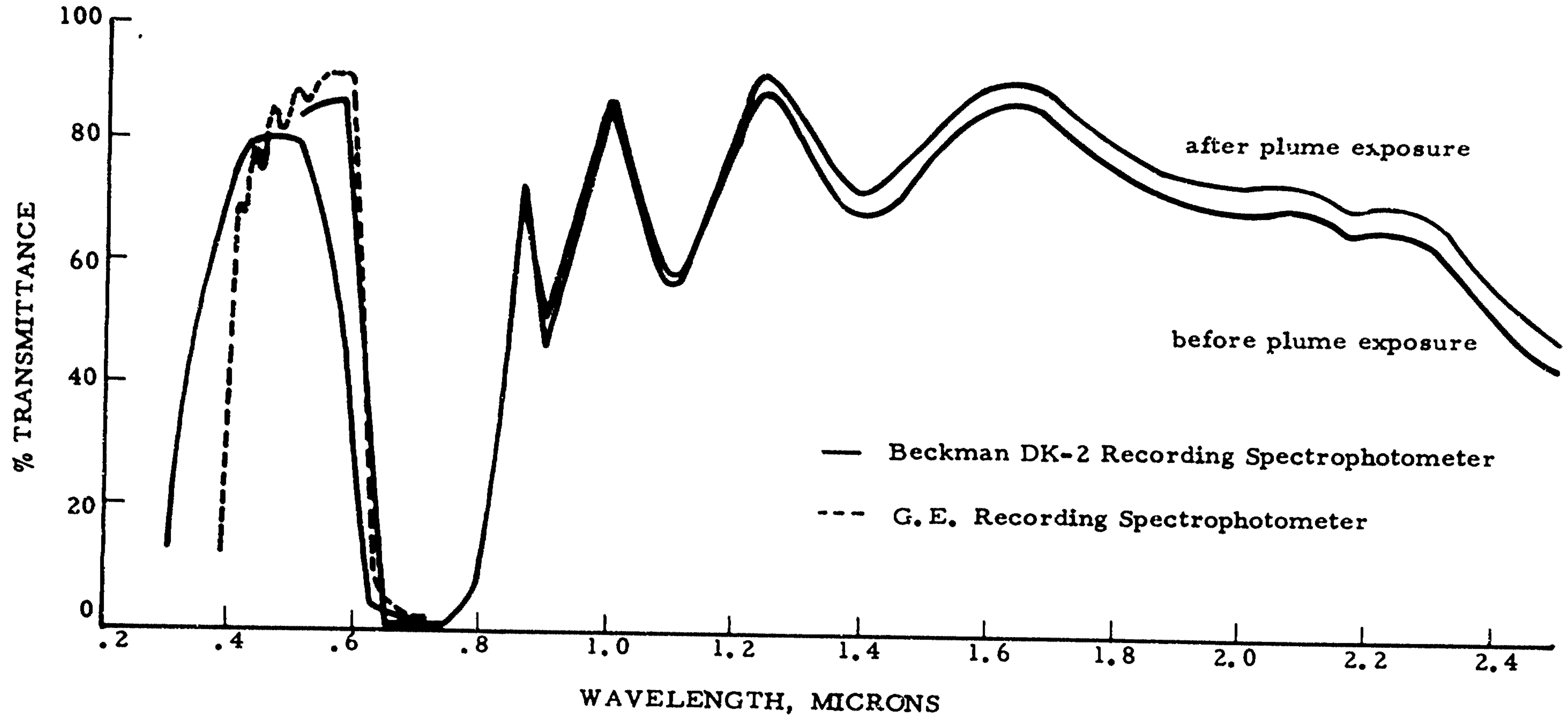

Figure 18. Spectral Transmittance of Optical Coupon No. 2

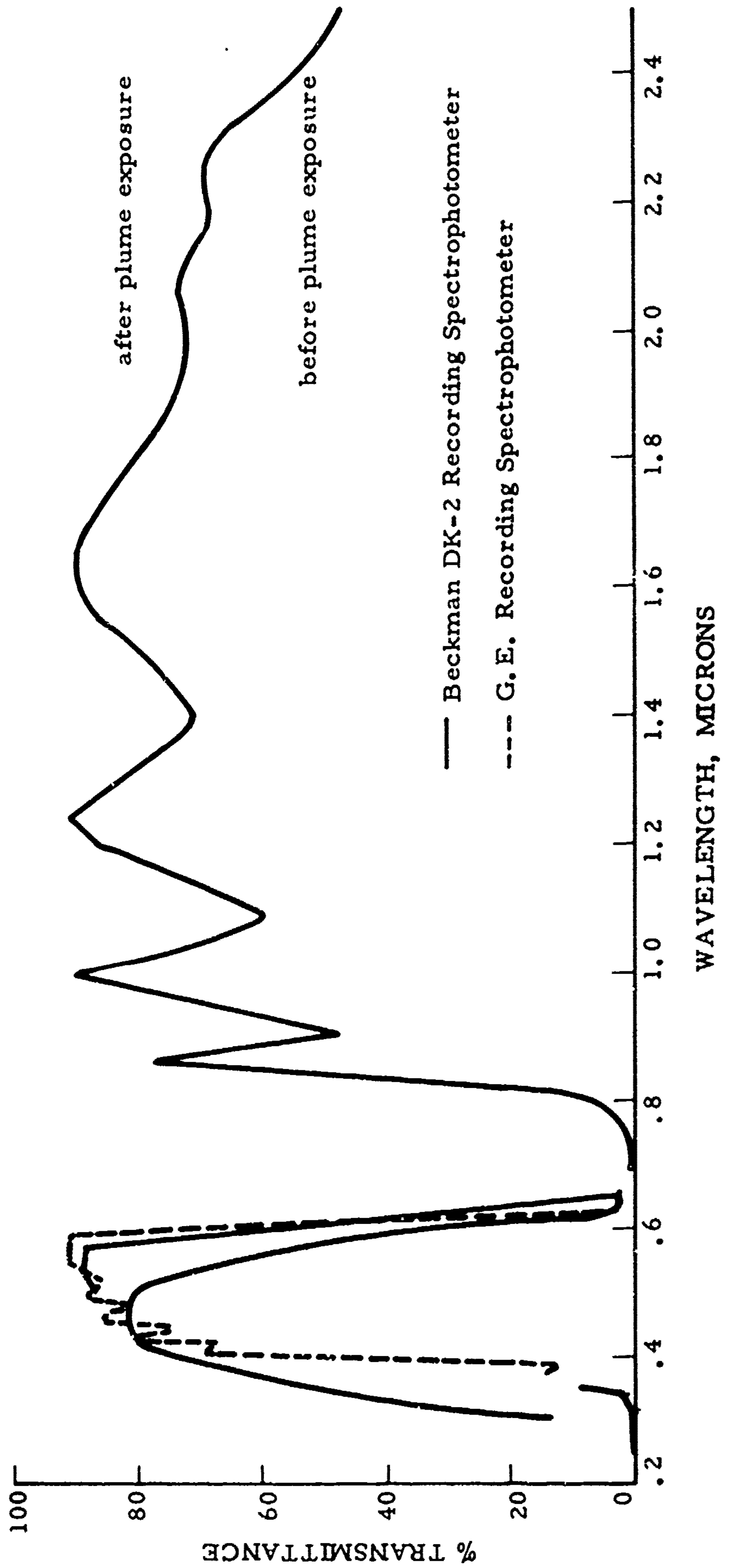

Figure 19. Spectral Transmittance of Optical Coupon No. 3

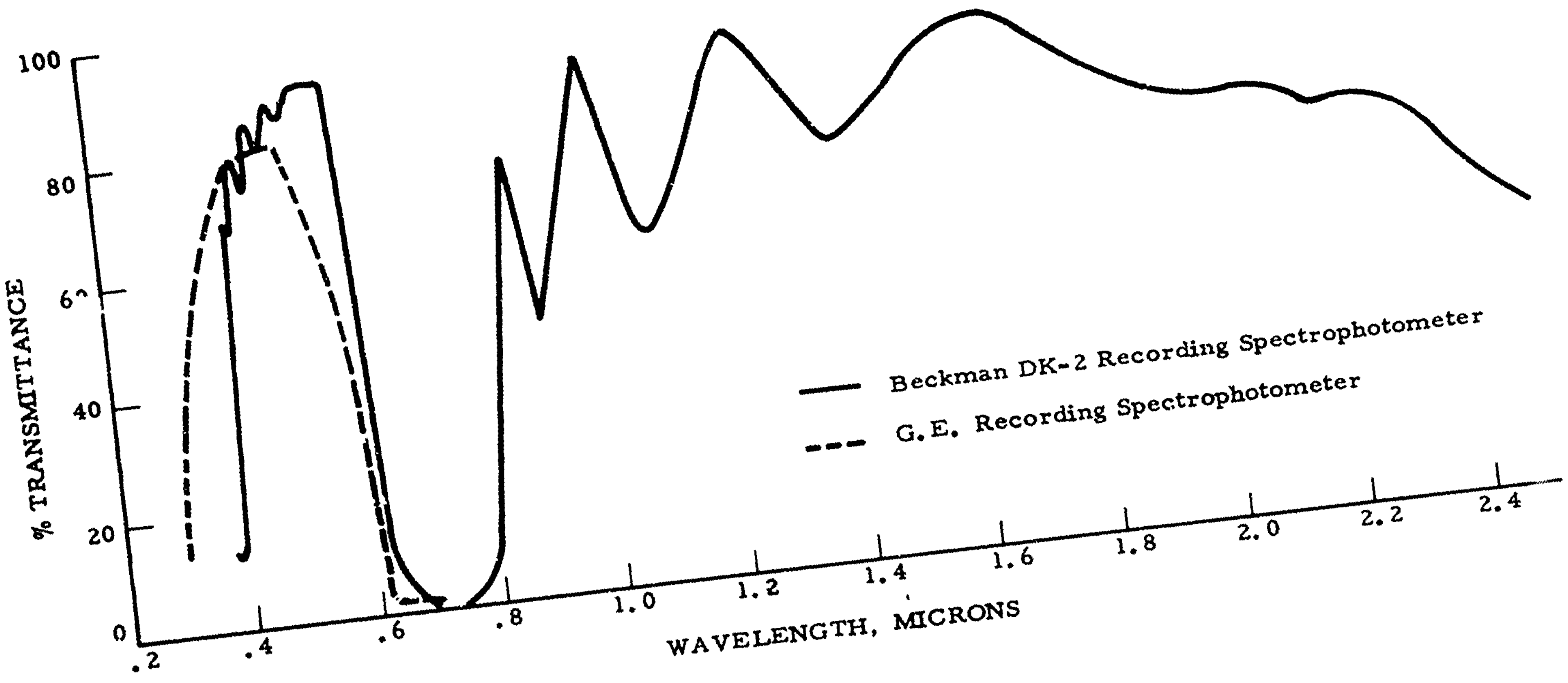

Figure 20. Spectral Transmittance of Optical Coupon No. 4

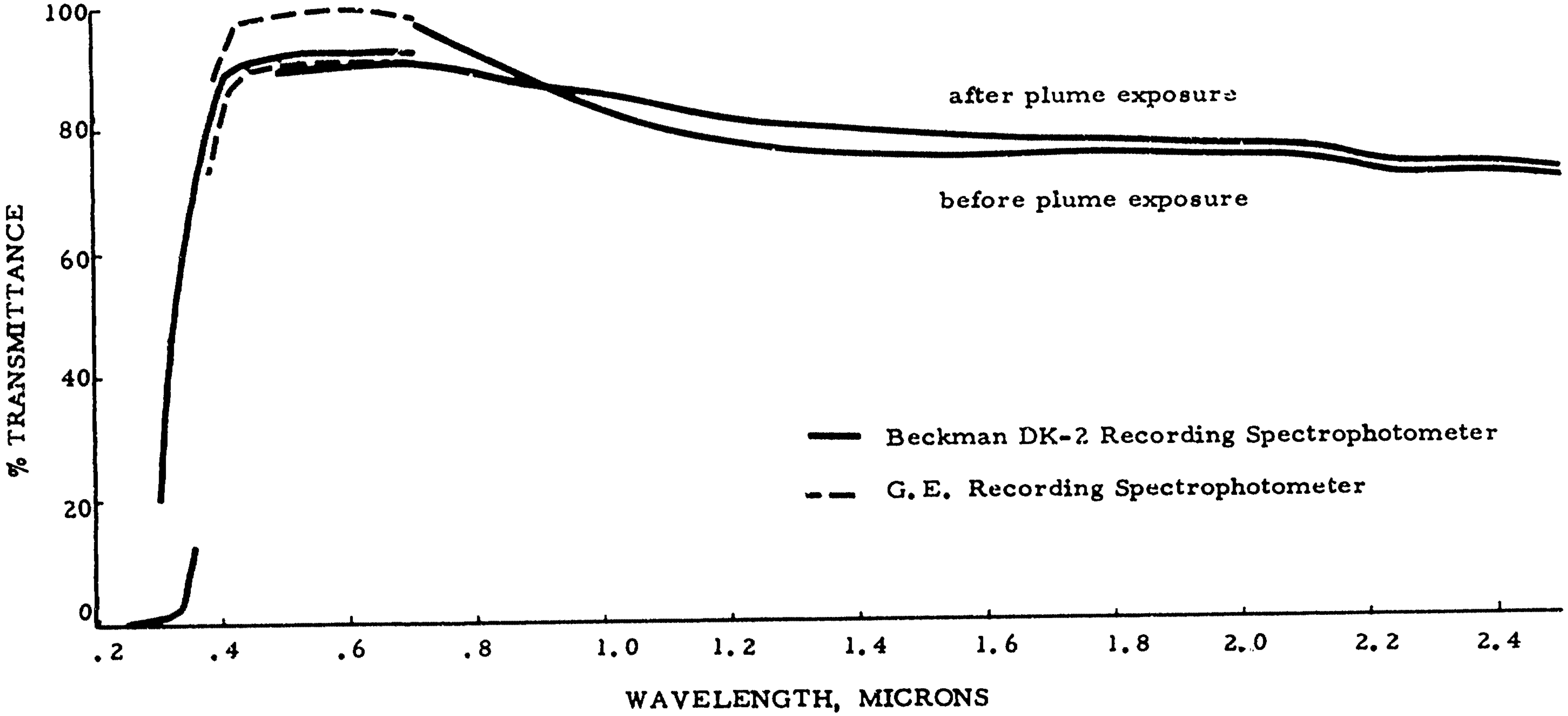

Figure 21. Spectral Transmittance of Optical Coupon No. 6

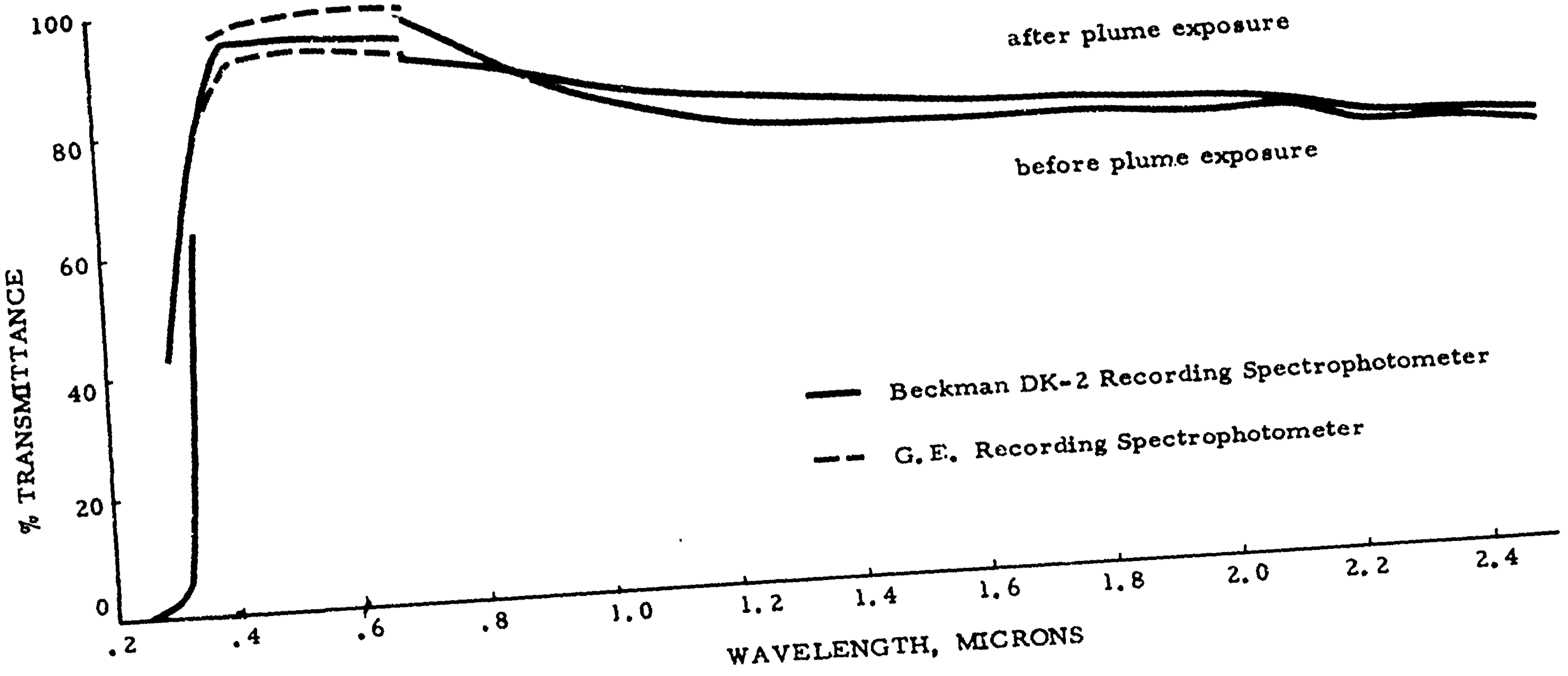

Figure 22. Spectral Transmittance of Optical Coupon No 7

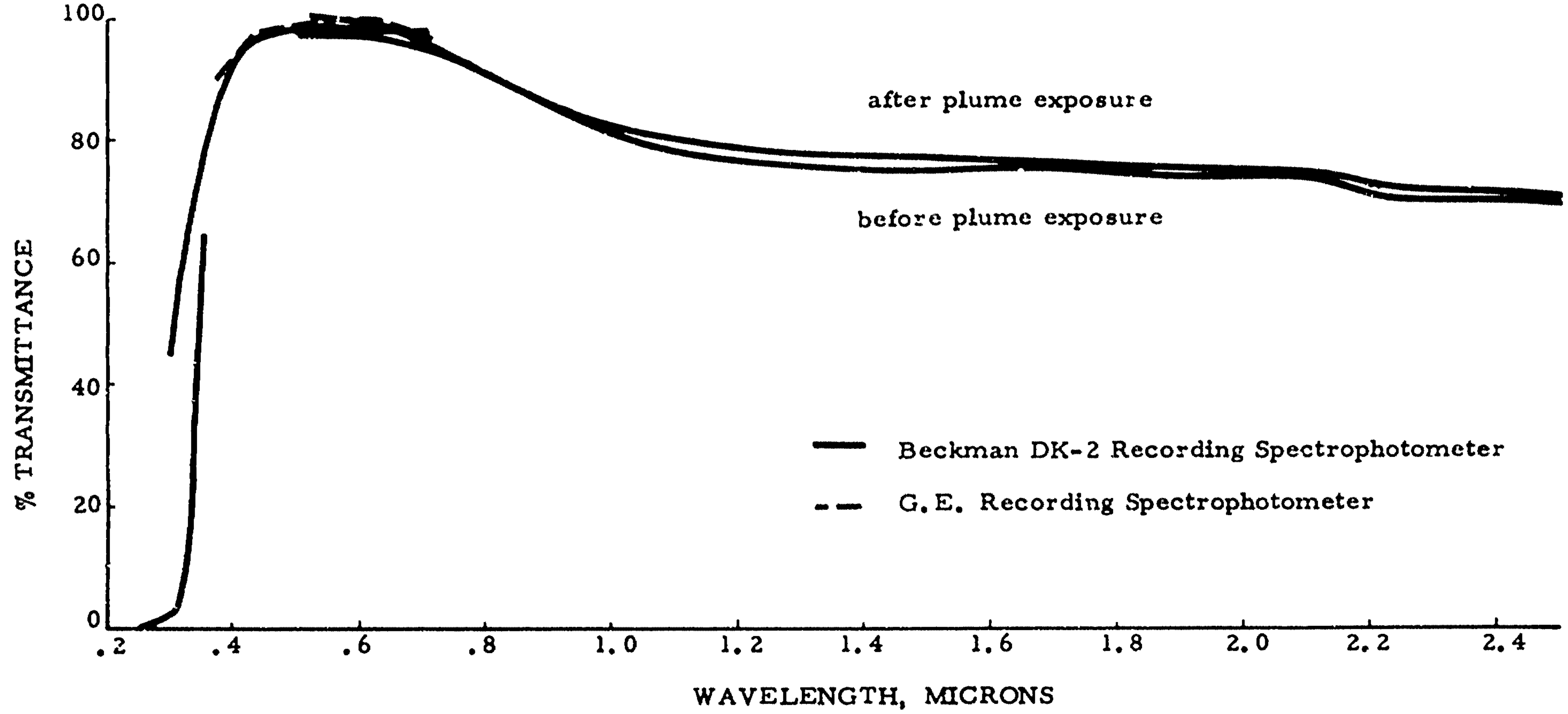

Figure 23. Spectral Transmittance of Optical Coupon No. 8

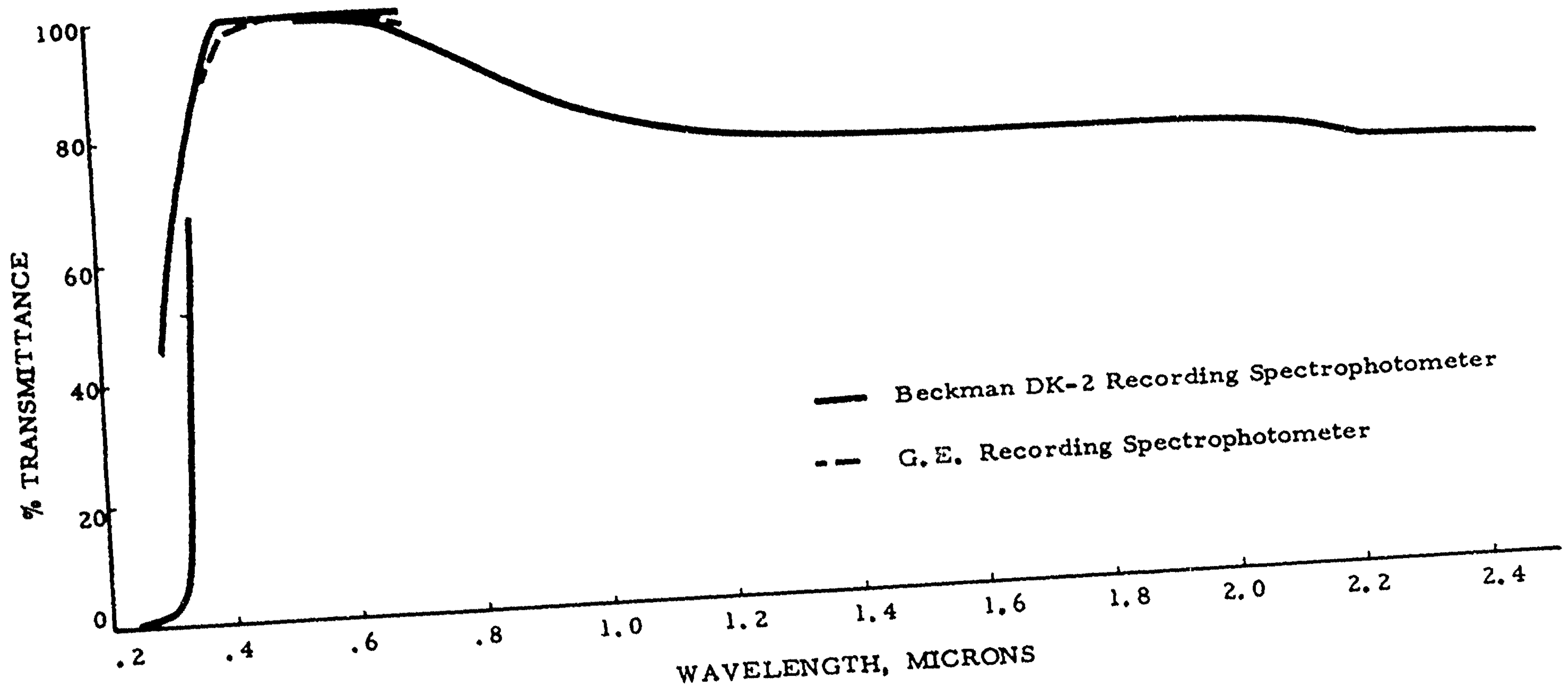

Figure 24. Spectral Transmittance of Optical Coupon No. 9

should be pointed out that the application of contaminants on the laboratory specimens were more severe than what would have been experienced during actual ACR firings, especially with regard to uniformity. Discussion with the Air Force Materials Laboratory (AFML) concerning the reason for the increase in transmittance of the ammonia-coated coupons suggested that ammonia residue acted as an antireflection coating.

The comparison of the pretest and posttest measurements of the solar cells loacted at the 5-foot test position revealed, in some cases, an increase and in others a decrease in solar cell output (reference Table II). AFAPL personnel, responsible for the pretest and posttest measurements of the solar cells, have stated in their report that the percentage differences between the preexposure and postexposure short-circuit current values were primarily attributed to radiometric measurement inaccuracies. In view of the phenomenon that occurred regarding the increase in transmittance of the ammonia-coated optical coupon, identical tests were conducted with solar cells. The results of the hydrazine experiment revealed a very slight degradation of solar cell output by about 2 to 3%. The ammonia-coated solar cell revealed an increase in power output by 4%. Based on the results of these laboratory tests, it is possible that the Air Force Aero Propulsion Laboratory (AFAPL) data are real to a certain degree.

The comparison of the optical pretest and posttest measurements for the 9-foot test position revealed no difference in transmittance value (reference Figures 25 through 32). The possible explanation for this could be the reduction in the concentration of ammonia by a factor of 4 within the ACR plume at a distance of 9 feet downstream of the rocket engine nozzle exit under vacuum conditions.

The comparison of the solar cell pretest and posttest measurements (reference Table III) for the 9-foot test position revealed, in most cases, a very slight decrease in solar cell output varying from -.03 to -1.4%. Coupon 23 showed a 4% increase in power output. The protected reference

TABLE II. COMPARISON OF SHORT-CIRCUIT-CURRENT DATA ON SOLAR CELLS EXPOSED AT THE 5-FOOT TEST POSITION

CELL NO.	PREEXPOSURE SCC	POSTEXPOSURE SCC	% DIFF.
1	131.0	131.2	+.037
2	136.0	137.5	+1.0
5	137.6	138.0	+.04
20	138.0	135.0	-2.2
17	122.0	127.0	+4.0
*4	132.0	130.0	-1.5
*19	135.5	135.6	.01

* CHAMBER CONTROL CELLS. THESE CELLS WERE NOT EXPOSED TO THE PLUME.

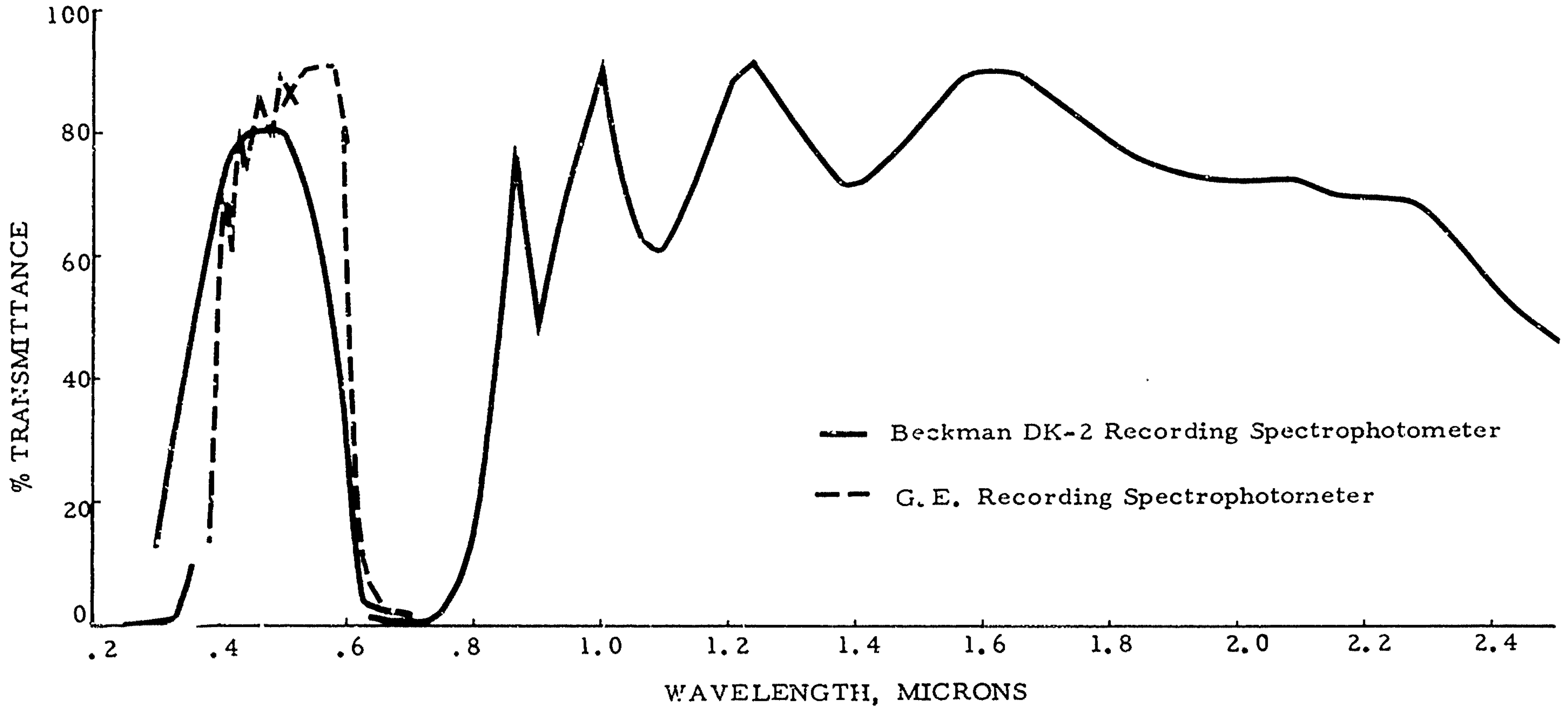

Figure 25. Spectral Transmittance of Optical Coupon No. 5

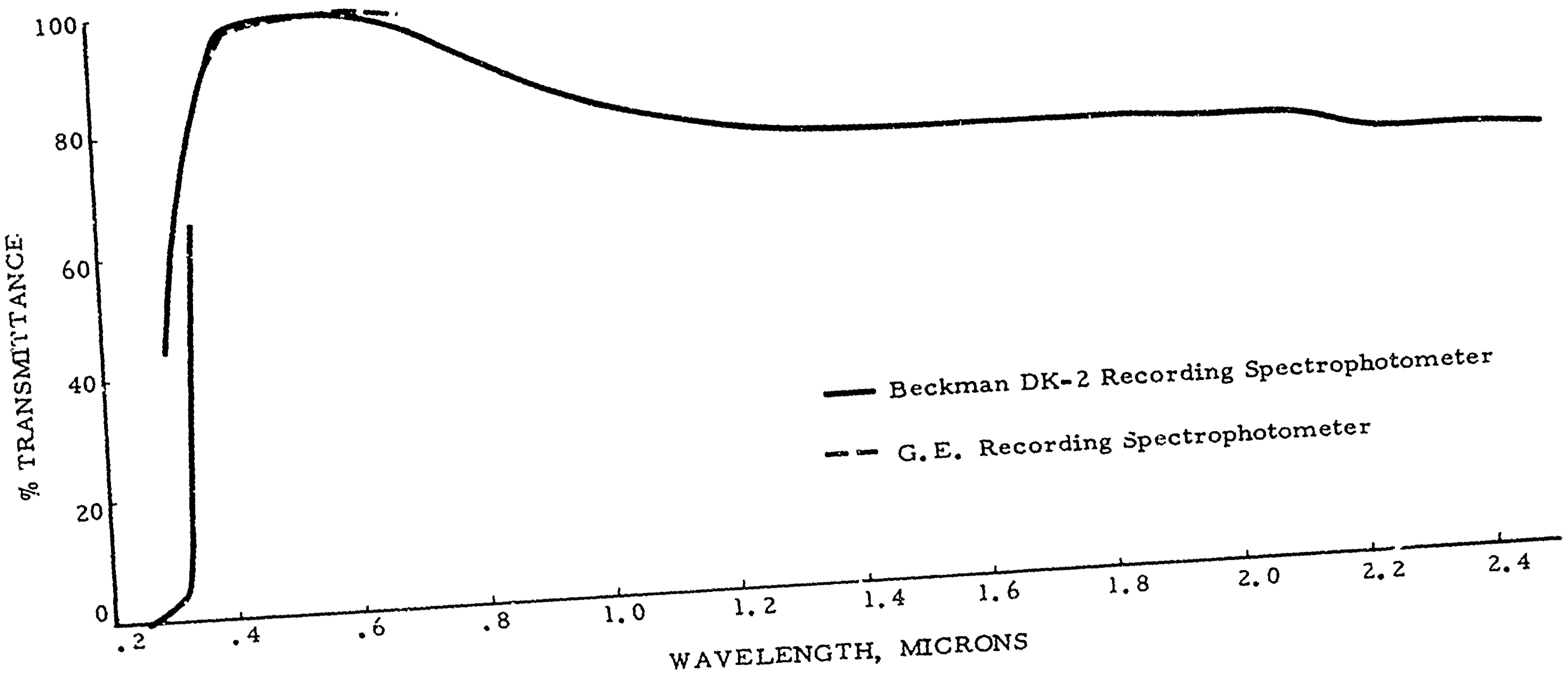

Figure 26. Spectral Transmittance of Optical Coupon No. 10

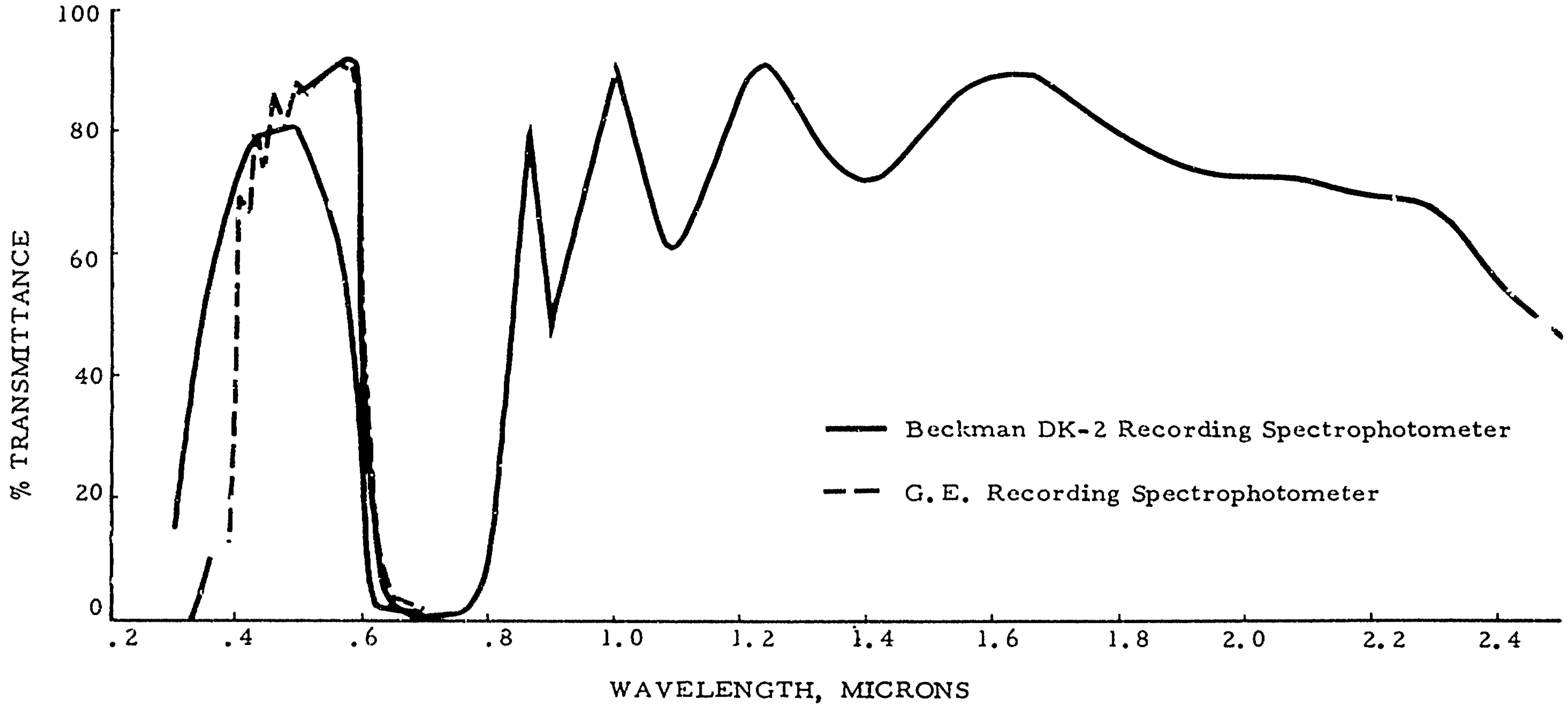

Figure 27. Spectral Transmittance of Optical Coupon No. 11

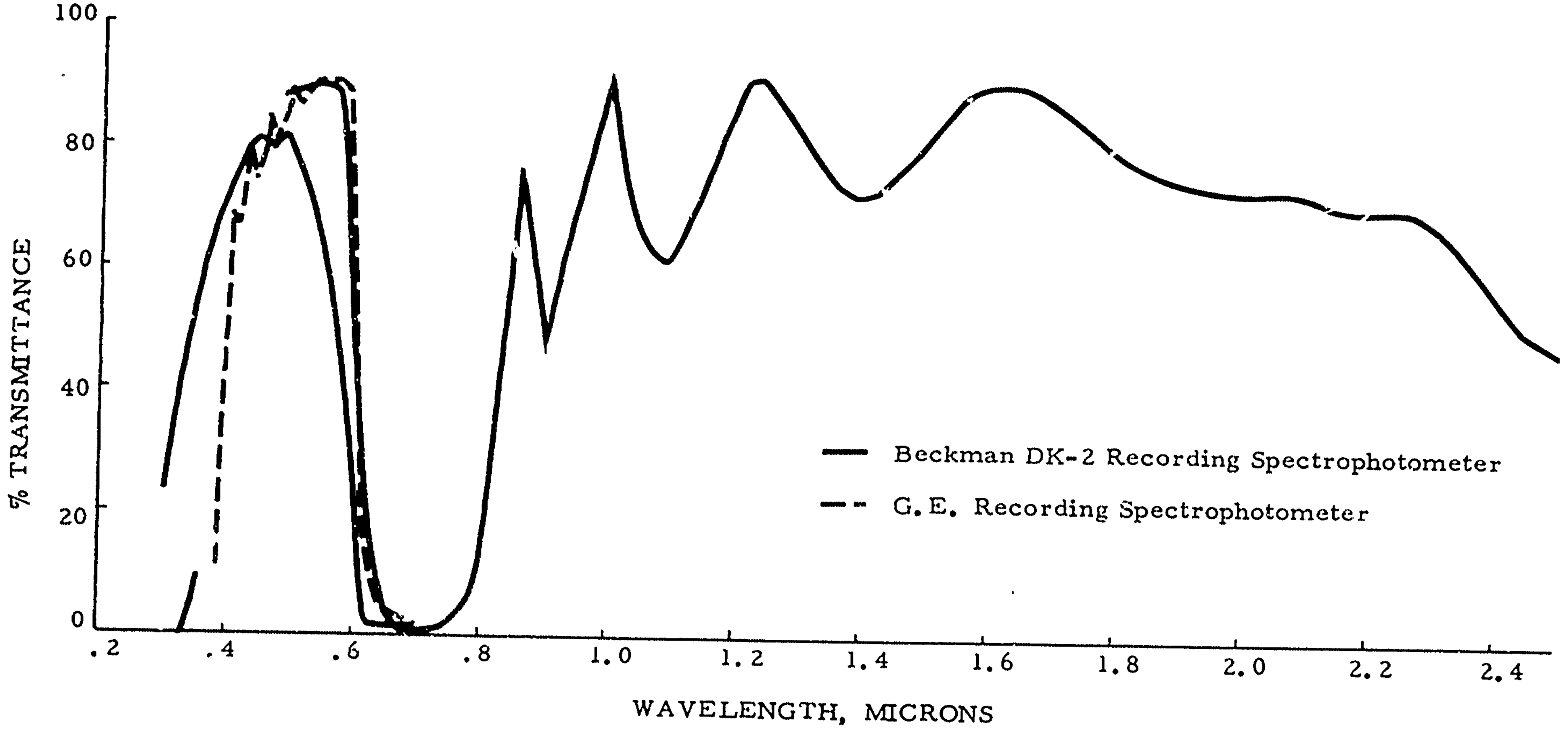

Figure 28. Spectral Transmittance of Optical Coupon No. 12

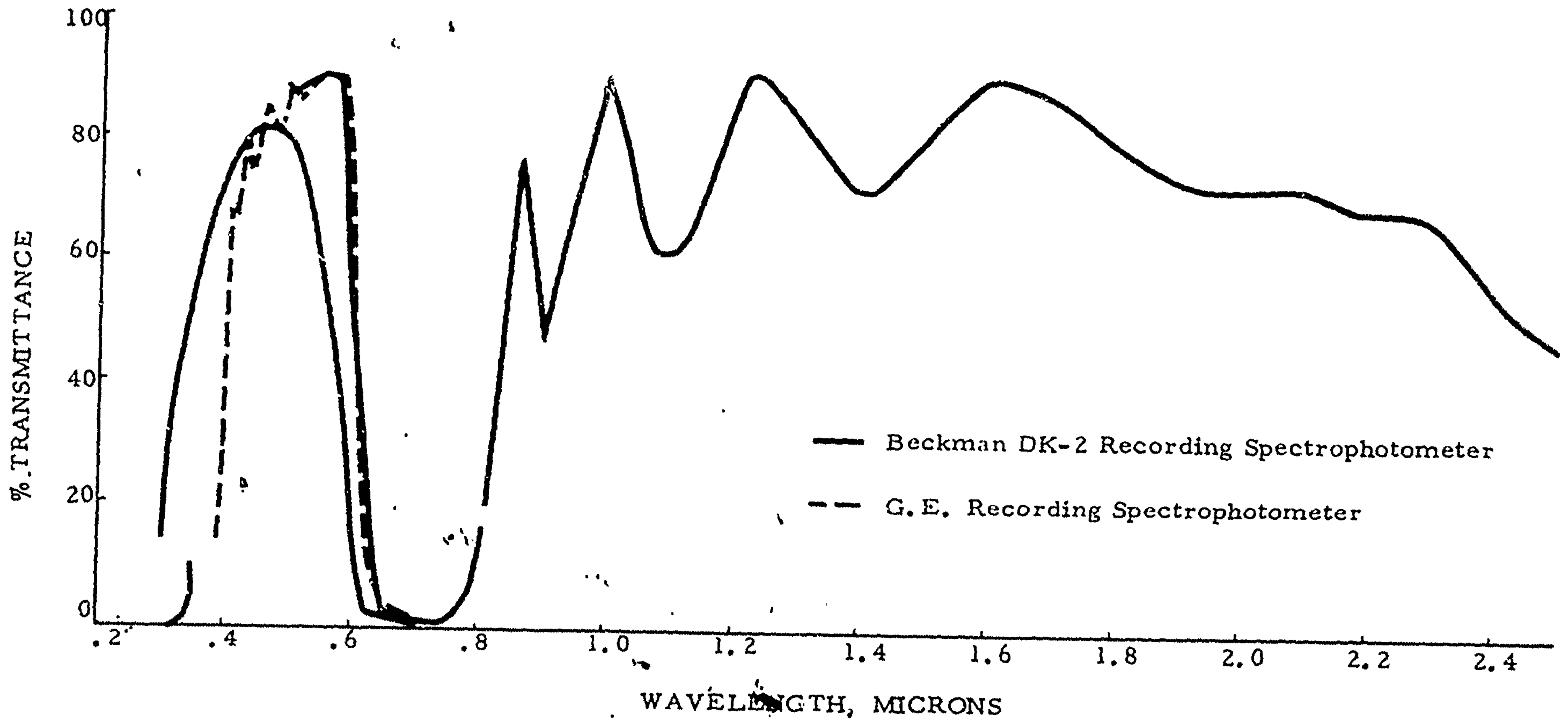

Figure 29. Spectral Transmittance of Optical Coupon No. 13

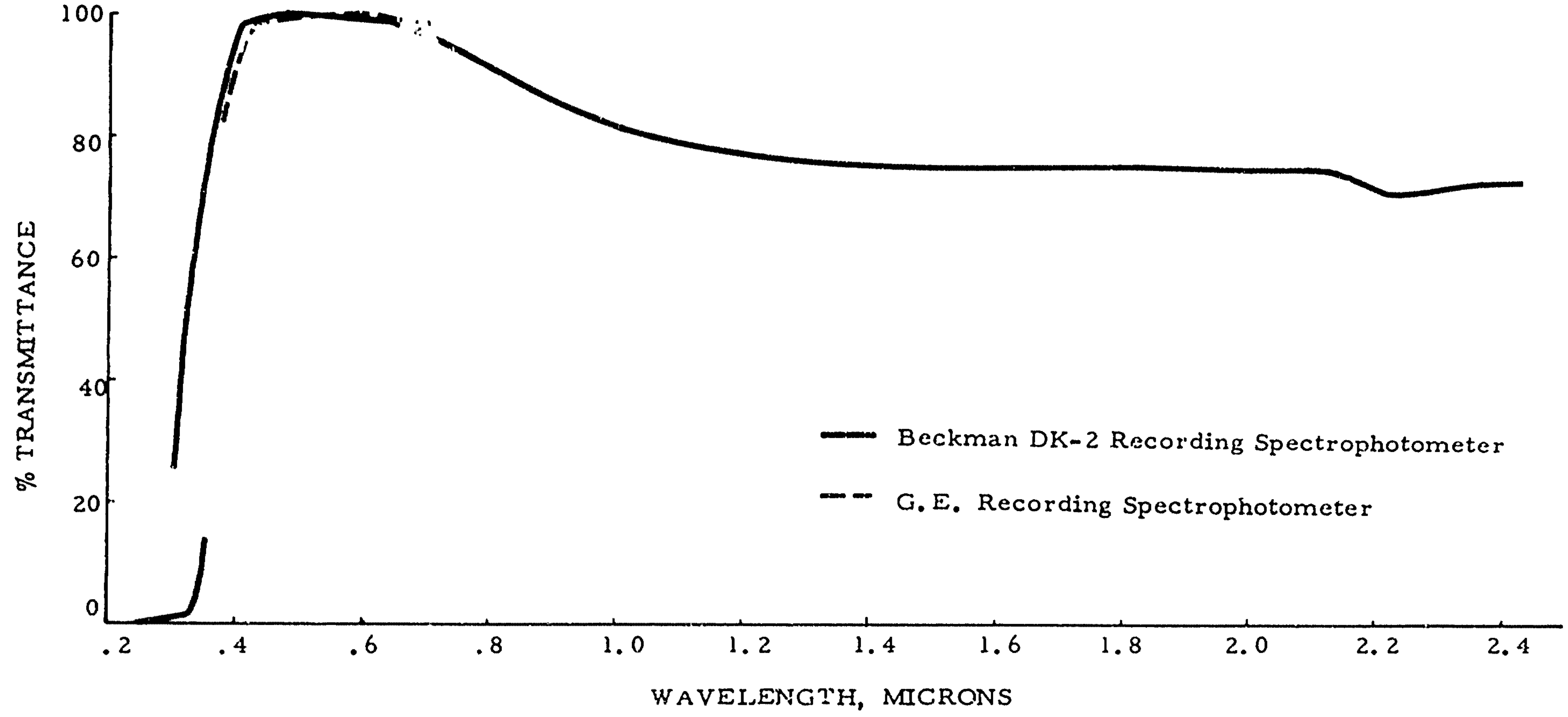

Figure 30. Spectral Transmittance of Optical Coupon No. 16

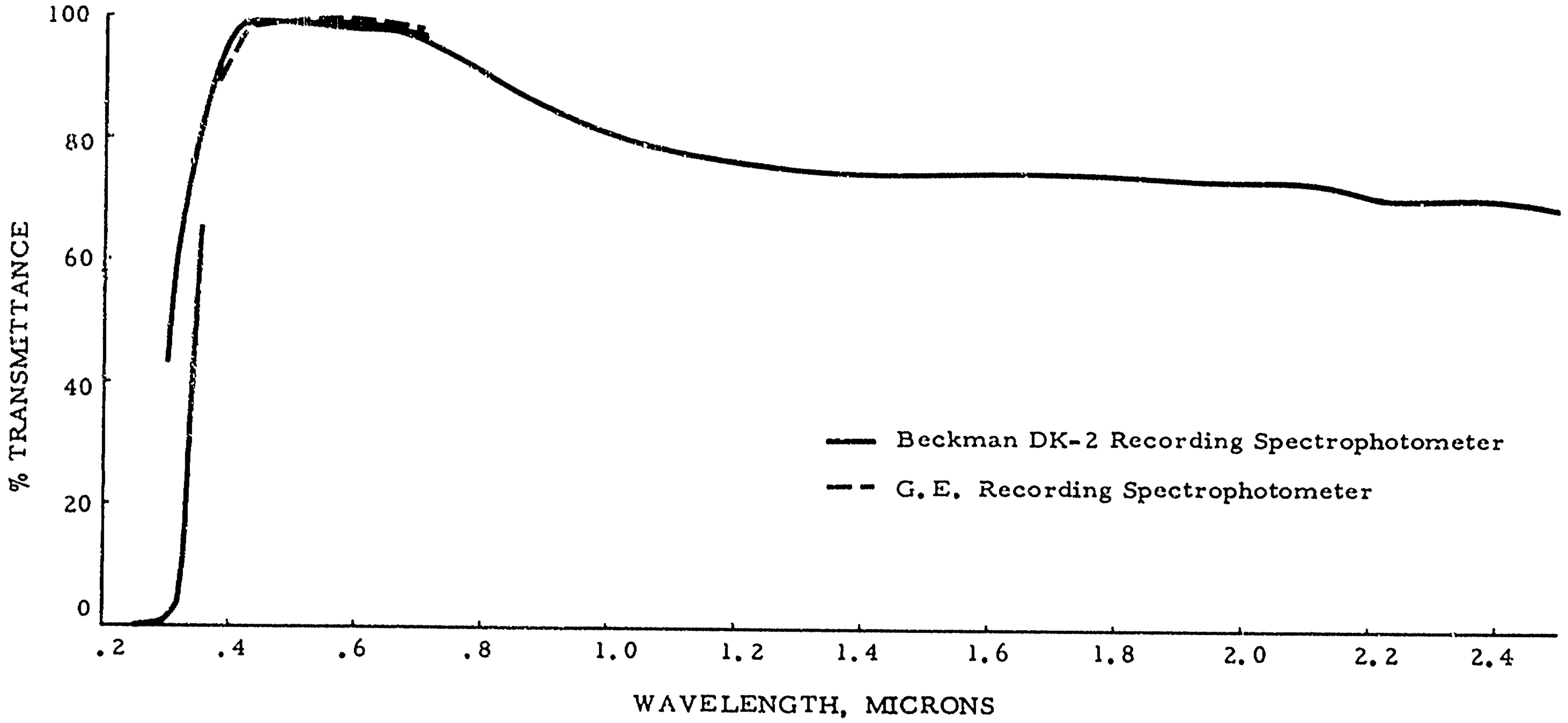

Figure 31. Spectral Transmittance of Optical Coupon No. 17

TABLE III. COMPARISON OF SHORT-CIRCUIT-CURRENT DATA ON SOLAR CELLS EXPOSED AT THE 9-FOOT TEST POSITION

CELL NO.	REEXPOSURE SCC	POSTEXPOSURE	% DIFF.
6	131.0	130.0	-.07
7	134.6	134.2	-.03
8	130.0	130.0	0
22	136.0	134.0	-1.4
23	122.0	127.0	+4.0
*9	132.0	131.0	-.07
*25	131.4	131.2	-.01

* CHAMBER CONTROL CELLS. THESE CELLS WERE NOT EXPOSED TO THE PLUME.

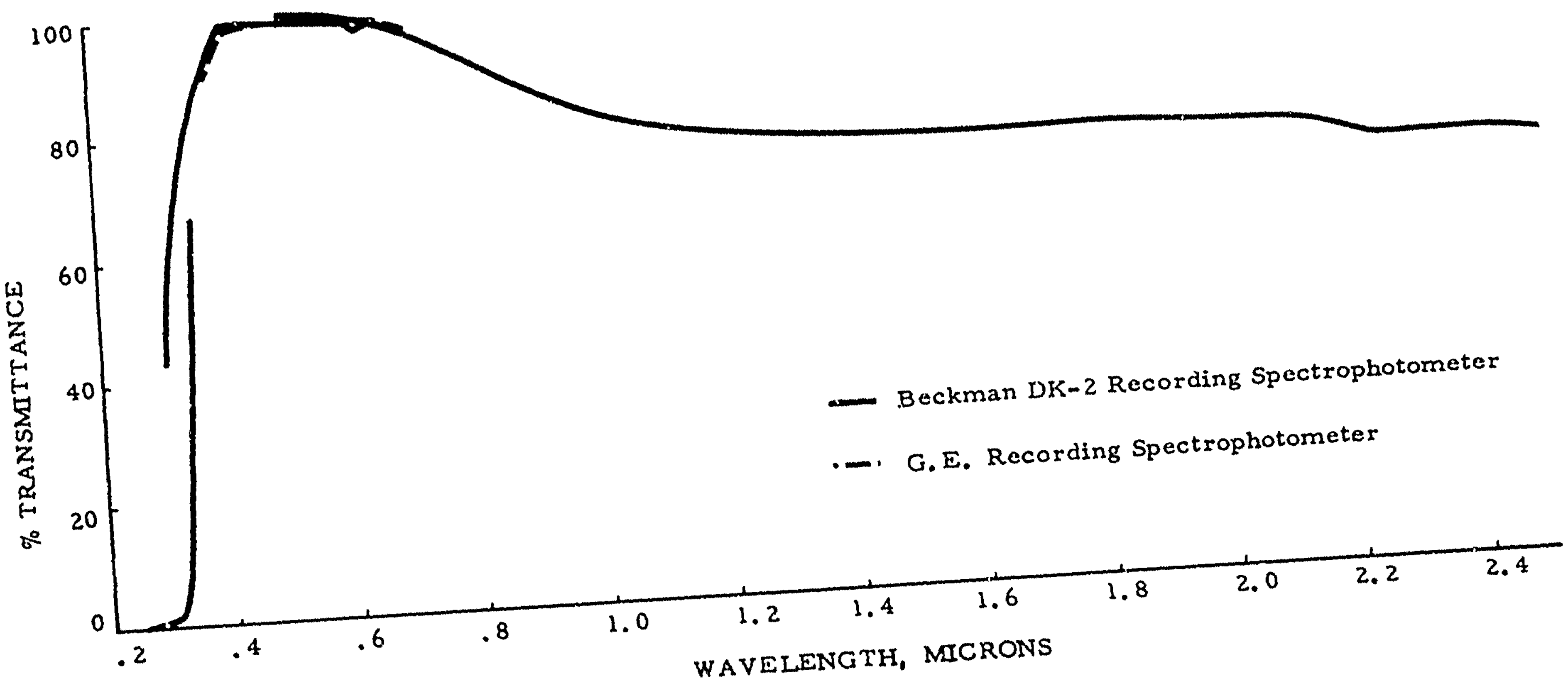

Figure 32. Spectral Transmittance of Optical Coupon No. 18

cells 9 and 25 revealed a slight change of -.01 and -.07, respectively. It is possible that these test values are a combination of radiometric inaccuracies. and to a small degree, ACR plume contamination.

SECTION VII

CONTAMINATION COUPON AND TEST RESULTS

The purpose of the contamination coupon was to collect ACR exhaust contaminants and attempt to identify the type and quantities of the contaminants using the collimetric analysis method. The size and shape of the contamination coupon was identical to the optical coupons. The coupon was secured to the main test specimen module by the use of a retainer ring and was positioned on the centerline of the ACR engine for both the 5- and 9-foot test positions. Upon completion of testing, the contamination coupon was removed from the main test specimen module under a gaseous nitrogen atmosphere and placed in a special container to minimize atmospheric contamination during shipment to the laboratory for analysis. Due to the low contamination level experienced during this effort, it was not possible to identify the contaminants, i. e., hydrazine and ammonia, below the level of . 1 microgram, which was the lower limit of the Color-Ametric analysis method.

SECTION VIII

CONCLUSIONS

Based on the test results derived from this effort, the monopropellant ACR plume is relatively clean.

Monopropellant ACR plume impingement on thermal-control coatings revealed a minor change in absorptance value, however, no change in emittance value. The change in the initial ratio of α_s/ϵ of these coupons indicates that the ACR plume effects on the Transtage thermal paint are insignificant.

Direct monopropellant ACR plume impingement on optics and solar cells did not have any serious effects on the operational characteristics of this equipment at either the 5- or 9-foot distance downstream of the rocket engine nozzle exit.

The results of this program indicate that the operation of the Transtage ACR roll engines will not present a problem of contamination of onboard Transtage space-borne equipment.

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13. ABSTRACT

This report presents the results of the Monopropellant Attitude Control Rocket (ACR) exhaust contamination investigation. The purpose of this effort was to determine ACR engine plume effects on vehicle space-borne equipment, i.e., thermal control paint, solar cells and optics. Plume impingement tests were conducted at an altitude of 400,000 feet, using a 25-lb-thrust monopropellant attitude-control rocket engine. The propellant was hydrazine (N_2H_4) and the ignition source was Shell 405 catalyst. A series of 200 firings were conducted at each test position at an engine pulse width of 200 milliseconds. The analysis of the test data revealed that the monopropellant ACR exhaust plume had little or no effect on the operating characteristics of the space-borne equipment involved in the test program. Furthermore, the monopropellant exhaust plume concerning contamination is relatively clean compared to a bipropellant ACR plume using N_2O_4/A-50 and/or N_2O_4/MMH. This comparison is based on past bipropellant plume contamination test results. ( )

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Monopropellant ACR engine exhaust contamination						
Space-borne equipment						