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REON

ROCKET ENGINE OPERATIONS - NUCLEAR

REPORT NO. RN-DR-0010

NOZZLE - MOUNTED CAMERA SYSTEM

NERVA PROGRAM
CONTRACT SNP-1
JUNE 1964

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ABSTRACT

This report has been prepared to define the environmental conditions, performance requirements, and operational requirements for visual examination of the reactor core during NRX-A1 Cold Flow Tests. The discussion includes the methods selected, tests performed, equipment purchased, and the problems of nozzle and camera housing design to obtain the coverage required.

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SECTION I
INTRODUCTION

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I. INTRODUCTION

A. HISTORICAL BACKGROUND

The Kiwi-B4A test performed by IASL on 30 November 1962 demonstrated the necessity of reviewing the downstream (or aft) end of the core during gas flow. It was determined in March 1963 that a motion picture camera should be utilized for this observation. To accommodate the camera, a Rocketdyne RN-2 nozzle was reworked with two ports, one for camera and one for light, located at the same radial position parallel to the thrust axis with the camera port aft of the light port. The tubes intersected by the ports were blocked off.

The camera used for the IASL test was a Milliken DBM5A, operated at 200 frames per second, using a 16-mm lens. For lighting, a Sylvania "Sun Gun" was modified to meet the physical restraints of the system. The success of the Kiwi camera coverage provided the information required in this test.

The results of the camera coverage and the information obtained caused SNPO-C to direct REON on 1 June 1963 to propose similar coverage for the NRX-A1 tests planned for NRDS.

The IASL system was reviewed and design requirements for the NRX-A1 nozzle were developed.

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SECTION II
PRELIMINARY DESIGN

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II. PRELIMINARY DESIGN

A. SELECTION OF CAMERAS

Based on the success of the LASL cameras, and because of its physical size, it was decided to again use a Milliken DBM5A camera for the basic design effort. The position of the lens mount on the motion picture camera was important in port diameter selection, when the intent of using TV camera was added to the design.

The original test performed by LASL did not provide for any method of visual examination during the test. Based on analysis of the Kiwi test film, it was determined that the use of a TV camera for viewing the core would be of value under flow conditions.

Since the use of TV for viewing a vibrating object was an unknown value from an instrumentation stand-point, tests were conducted at Cohu Electronics to determine the effect of the standard vertical scan rate on vibrational modes. These tests showed that, at frequencies from 28 to 32 and from 58 to 62 cycles per second, there were well defined stroboscopic effects. At 30 and 60 cycles per second, there was no apparent motion on the TV monitor because of the 30 frame/sec initial scan rate.

B. SELECTION OF LIGHTING

Three methods of lighting the core face were considered:

1. A single light port located forward (nearer the core), and in the same radial position as the camera port. The use of this position required one light of high intensity, approximately 650-watts output, nominal. The parabolic reflector for this light required a beam angle of approximately 75° to cover the core adequately.

2. Two light ports, one located as above, and the other rotated 90° radially from the first port.

This method decreased the light output per lamp requirement. The area to be illuminated by each lamp was also decreased.

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3. Two light ports located at the same station, but 45° radially on either side of the camera port.

This method of lighting provided a cross lighting resulting in excellent textural detail of the core, and was considered to be the best approach if other design conditions did not make it impractical.

C. SELECTION OF CAMERA PORT POSITIONING

These camera port positioning methods were considered:

One port for the TV camera and one port for the motion picture camera. This individual camera port approach led to the use of four ports in the nozzle, when combined with the light position requirements in II,B,2 above.

The alternate camera port approach used one port for both TV and motion picture camera. This single port approach could be utilized with any lighting method discussed in II,B above.

D. SELECTION OF PORT DESIGN

The port design considerations were:

The use of small ports, with the tubes intersecting the ports being blocked. This is the method used by LASL.

The use of a manifolded port. This method was preferable for these reasons:

A larger diameter port could be used

The asymmetric flow caused by blocked tubes was eliminated

The manifold design was complete because of the Hot-Bleed Port nozzle environment.

E. SELECTION OF FILM

All previous motion picture films of reactors during cold flow were made on black and white film, and good clear pictures were obtained. It is believed, however, that identification of small particles in the flow stream would be made

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easier by using color film. The analysis of the formation of liquid air or flame would be observable by use of color film. Bright spots observable on black and white film would be minimized by the use of color film.

Reversal color film, which has three light sensitive emulsions instead of one, is capable of differentiating color intensity and brightness of a subject. The combination of these qualities reproduces the light reflected by the subject surface and the flow characteristics of a given test flow better than does black and white film. These same qualities add to the apparent depth relationship (3 dimensional) of the subject, due to variations in hue and brightness. Color film, because of the characteristics of the emulsions, reproduces the subject more accurately than black and white. (Ref. American Cinematographer Manual, Joseph V. Mascell: Amer. Soc. of Cinematographers, October 1960.)

F. TIME-BASE ANALYSIS OF PICTURES

A time-base for analysis of the motion pictures taken during a run is a requirement. The standard method of preparing this is a camera-contained system which superimposes timing marks on the edge of the film while the camera is operating. These marks are then compared to start time by visual analysis of the film strip. A method that would give both time and operating sequence (that is, Item 1, start of flow, and the seconds (5.010) on a given step, and Item 2, 5 lb/sec for 3.25 seconds on the film for first viewing) was desirable.

When IASL analyzed the film after the Kiwi-B4 cold-flow test, it became apparent that a correlation of "time after start of run," "actual time," or the "specific event" (flow rate and fluid), and the "duration of that event," was required. The method selected by REON was a time and event pulse generation system, as suggested by the camera manufacturer (D. B. Milliken Co., Arcadia, California).

The timing and event pulse system was designed and developed by the Solid Rocket Plant of Aerojet. The equipment design and function requirements are covered completely in Equipment Specification TDI-010B of Test Division Instrumentation, Solid Rocket Plant. The display on the film used in the camera is a dot for time and a long bar for event (see Figure 1). These marks appear on both edges of the film in the sprocket area. The simultaneous appearance of these marks, time

(text continued on p. 12)

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Figure 1
Time and Event Marks

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or event, is required to actuate a logic circuit on a specially designed photocopier system. This causes the numbers that appear on the top of each frame to change. The event number is on the upper left side of each frame, and the time display is on the upper right side of each frame, (see Figure 2). This display of digital information will be on all film that is viewed during projection.

The time and event pulse generation system will be completed early in Contract Year 1964; however, preliminary testing of the system to the movie camera can be performed with existing equipment.

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SECTION III
FINAL DESIGN SELECTION

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III. FINAL DESIGN SELECTION

A. PORT SEALING

Port design and quantity were selected on a basis of the hot-bleed port design, flow path for the propellant, and the best relative position.

The prime requirement for bleed-port design was that the hydrogen flow should be symmetrical through the system; this was met by the hot-bleed port. This design provided additional benefits in the size of the port (6-in.-dia), the existence of nozzle tube bundles that were planned for porting, and the minimum design time required to utilize multiple port nozzle for the camera study of the core.

Selection of a design for closing the hot-bleed port, (one that would provide the maximum opening diameter and the minimum leak paths around the ports), was the second consideration in port selection. NASA-WOO, through Marshall Space Flight Center, provided a design, and this design in connection with a design used by LASL, was used as a basis for analysis. The developed configuration allowed only one leak path from the interior of the nozzle, and provided 5-in. of unrestricted view, (see Figure 3).

In addition, the design allowed direct mounting to the nozzle of the equipment housings, and the nozzle portions of the ports were identical.

B. PORT POSITIONING

The positions of the ports were selected on the basis of the best obtainable flow pattern, ease of fabrication, optimum lighting position, and best camera coverage, including the three-dimensional effect apparent in the LASL Kiwi-B⁴ Cold Flow motion pictures.

The camera port was located as far downstream on the convergent section of the nozzle as practical, approximately 20 in. from the core support flange (Figure 4). The port was located radially opposite the instrumentation boom to minimize the interference with instrumentation wires and supports.

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The light ports were located as described in II,B,3, as near as possible to the nozzle/pressure vessel flange (see Figure 5).

The overall design layout is shown on Figure 6.

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Figure 3

Camera View Port Design

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298650-29
PART NO. 704596 S/N 11
ENGR: A. CLAYTON
DRAWN: N DOZIER

Figure 4

Location of Camera Port

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298650-29
PART NO 704595 S/N 11
ENGR: A CLAYTON
DRAWN 11 DOZIER

Figure 5
Location of Light Port

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Figure 6
Overall Design Layout

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SECTION IV
SPECIFICATIONS FOR EQUIPMENT

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IV. SPECIFICATIONS FOR EQUIPMENT

A. MOTION PICTURE CAMERA

Acceleration	+ 25 g on three principal axes
Temperature	0 to 135 ^o F
Vibration	10 g peak load from 5 to 3000 cps
Pressure	10-35 psia
Atmosphere	Air, nitrogen, helium
Weight	15 lb or less
Power	115 volt 60 cycle AC
Film Capacity	400 ft
Frame Rate	64, 128, 200, 400 (operating, 200) frames/second
Shutter Speed	1/1000 sec (72 ^o shutter sector)
Size	10 x 5 x 8 in.
Lens Mount	"C" mount, offset from the centerline of the camera
Current Consumption	3.0 amperes AC maximum

B. TV CAMERA

Acceleration	$\pm$ 25 g on three principal axes
Temperature	0 to 135 ^o F
Vibration	Meet MIL-E-5272C Procedure XIV
Pressure	10 to 35 psia
Atmosphere	Air, nitrogen, helium
Power	Supplied by TV camera control unit
Weight	5 lb
Size	3.5 x 3 x 9 in.
Lens	"C" mount, 16-mm

C. LAMP & LAMP HOUSING

There are no established specifications for lamps that met the conditions of IV,A and B, above, and the physical design restraints accompanying the mounting on a nozzle. Therefore, the lamp housing design selected had to damp the vibration

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that would be transmitted to the lamp filament. The lamp housing mounting needed to be designed and attached in such a manner as to have the lowest possible g load transmitted to the lamp filament. The entire assembly (lamp, lamp housing, and mounting base) had to damp dynamic responses. The lamp filament had to be of the rugged type listed for heavy duty use by the vendor.

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SECTION V
REQUIREMENTS FOR PERFORMANCE

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V. REQUIREMENTS FOR PERFORMANCE

The television system had to be instrumentation quality, and completely automatic in operation. The TV and motion picture cameras and lights were required to be designed for independent operation of any portion of the system.

The port closures (quartz lenses) were designed to seal the nozzle and to withstand the pressures specified for the NRX-A1 test. The camera port closure consists of two quartz windows to allow purge flow between them to eliminate frosting and liquid air formation during low temperature runs.

The light housing was designed to mount directly to the nozzle and to utilize one lens. The light housing was designed to include purging and cooling of the lamps by a flow of nitrogen, and/or helium, purge gas.

The lens system for the movie cameras had to meet the standard requirements for 16-mm film; with capability of viewing at least 3 in. of the core face on the camera side of the core centerline, and 3 in. of the wall 180° from the camera location. The TV and motion picture camera lenses had to be selected so that approximately the same core surface area was viewed by both.

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SECTION VI
TESTING FOR DESIGN

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VI. TESTING FOR DESIGN

A. CAMERA TESTING

The purpose of the tests performed 29 July and 2 August 63 was to determine the required light level, the type of film to be used, and overall operational characteristics of TV camera, motion picture camera, and lighting equipment. A full-scale mockup of the Aerojet nozzle was fabricated for this analysis prior to the selection of equipment and final design. Motion picture film from these tests are filed at Aerojet Azusa Photo Lab, File Nos. 29064 and 29076.

1. Motion Picture Camera

A Milliken DBM5A Motion Picture Camera was used for the film and camera studies. See Figures 7 and 8. A 12.5-mm f 1.9 Wollensak, "C" mount lens was used. The 200 frame-per-second (fps) operating rate was used for all light and film tests performed. Two types of film were used for the testing: Ektachrome ERB with an ASA rating of 125, and Tri-X Reversal film with an ASA tungsten rating of 200.

These tests were used to analyze the variation in camera speed at a nominal speed of 200 fps, and to compare color to black and white. The time impulse marks (at 60 cps) were compared with the number of frames within 60 impulses giving less than 1% frame-rate deviation after acceleration. Comparison of color to black-and-white film was not done by mathematical means, but was based on observable detail and f-stop setting comparison. Stops were set at f 2.8, 4, and 5.6 in all cases. The limit of f 5.6 approached the exposure limitation of the films at the operating conditions. Clarity and detail of the color film was superior to that of the black and white.

A visual analysis of these films demonstrated the requirement for a high quality lens with a focal length of less than 12.5 mm for the motion picture camera. The field of view was approximately 3 in. on the camera side of the core centerline, and 3 in. of chamber wall at the point opposite the camera. Based on these photographs and the design layouts, it was determined that a 9 or 10-mm focusable lens should be used with the motion picture camera.

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Figure 7

Movie Camera Position Side View

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Figure 8

Movie Camera Position End View

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2. TV Camera

A Kintel 2011 series TV camera with a 1/2-in. (12.5-mm) f 1.4 lens, a 1995 TV camera control unit, and a General Electric TV monitor were used for the television system study (see Figure 9). The purpose of the study was to determine the quality and resolution of picture, the field of view of the TV camera with the selected lens, and the ability of the camera and control unit to adjust automatically to changes in light level.

The picture resolution was of good quality (see Figure 10). The field of view covered a larger area than the motion picture camera lens (see Figures 11, 12, and 13). Using these comparisons the 1/2-in. (12.5 mm) f 1.4 lens was selected for the TV system. The response time required for the TV system to adjust from daylight to artificial light and to changes in artificial light intensity was barely discernible with the eye.

B. LIGHT TESTING

The lights used for these tests were 300-watt photofloods (see Figure 8). The light intensity on the subject was approximately 50% of the total illumination available because of losses attributable to the cone angle of 115° . * Using this study as the design requirement for light intensity, a 150-watt flood light with a cone angle of 60° was selected as the basic lighting requirement.

These tests demonstrated the necessity of aiming and directing the light on the subject to be observed. The design of the lighting system was established to meet the following requirements:

1. Loss of available light intensity not to exceed 10%.
2. The light to be as close as practical to inner wall of the nozzle.
3. The number of quartz windows in the light assembly to be one, to minimize the loss of light due to reflection and refraction from the quartz surfaces.
4. The light system to be capable of overdriving to approximately 300 watts at each light.
5. The light housing to mount directly to the nozzle.

*GE, Incandescent Lamps Physical and Performance Data, No. 602-1102.2, Incandescent Data, July 1962.

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6. The housing assembly to be capable of positioning to give maximum uniformity of lighting on the subject surface (Figure 14) without introducing reflections.

It was also indicated by these tests that the use of spot lights (cone angle of 30°) might be preferable.

(text continued on p. 42)

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Figure 9

TV Camera Test

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Figure 10

Monitor Picture of TV Camera Test

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Figure 11

Movie Camera Position and Field
With 12.5-mm Lens
Perpendicular to Convergent Section of Nozzle

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Figure 12

Movie Camera Optimum Position and Field
With 12.5-mm Lens

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Figure 13

TV Camera Optimum Position and Field
12.5-mm, f 1.9 Lens

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C. QUARTZ LENS TESTING

The purpose of these tests was to determine the thickness requirements for quartz used at the cryogenic and ambient temperatures and pressures specified in the NRX-A1 Test Plan.

1. Preliminary Data

Preliminary investigation yielded information about design requirements. The thickness of quartz is a function of the unsupported area exposed to pressure and the method of holding (clamping) the quartz (Figure 15). This figure uses an overdesign factor of 7. The overdesign factor selected for NRX-A1 was 1.5 (Figure 16), is for four specific exposed area conditions, and is based on properties of infra-red optical materials suitable for high temperature applications (Table 1).

Testing was required due to the lack of information concerning low and cryogenic temperature applications and thermal shock values.

2. Quartz Window Burst Tests

Fused quartz windows, designed for the view-ports installed in NRX-A nozzles S/N 0000010 and S/N 0000011, were burst-tested during September 1963. The windows were discs of General Electric fused quartz, type 101, and were 5.3-in.-dia., and 0.38-in. thick.

The purpose of the test was to determine the burst-pressure range of the windows at the temperature of liquid nitrogen and at room temperature. This pressure range was then to be correlated with the nozzle pressures and temperatures anticipated for the NRX-A cold-flow program.

Five windows were delivered to the Aerojet-Azusa Proving Ground for testing. They were installed in a test fixture that clamped the quartz between two flat gaskets 4.3-in.-ID, which allowed pressurant and/or coolant to be introduced above the quartz. A c-c thermocouple measured the temperature at a point 0.25 in. above the glass, and pressure was sensed through a fitting that was separate from the pressurizing line. Fill and bleed ports were provided for the LN₂ coolant.

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Figure 14

Light Position and Field
Beam Centerline Describes Relocation Capability

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Figure 15

Maximum Pressure vs Ratio of Thickness to Diameter
For Clamped and Unclamped Circular Plates

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Figure 16
Overdesign Factors
Based on Properties of
Suitable Infra-Red Optical Materials

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Optical Properties									
Transmittance				Refractive Index		Emissivity (total)		Cubic	
Thickness	%	At μ Values	Value	At μ Value	Value	At $^{\circ}\text{C}$			
Fused Mgo	3/16-in.	85	2-2.5	1.7226	1.014	0.60	400	isometric crystal	
		85	4.5-3.6	1.6853	3.033	0.51	600		
		86	3.5-4.3	1.624	5.35				
96% Silica Glass	2 mm at room temperature	90-91	1.3-3.1	1.449	1.0				
		75	3.4	1.443	1.5				
		10	3.6	1.437	2.0	-	-	-	
				1.428	2.5				
				1.417	3.0				
				1.405	3.5				
Thermal Properties									
Thermal Conductivity									
cal/(cm ²)(sec)($^{\circ}\text{C}$)									
Specific Heat			Value	At $^{\circ}\text{C}$	Melting Point		Expansion Coef.		
Fused Mgo	0.276 g cal/g over range 20-800 $^{\circ}\text{C}$		0.1	0	2790 $^{\circ}\text{C}$		139 x 10 ⁻⁷ $^{\circ}\text{C}$ ave.		
			0.048	300			over range C-1000 $^{\circ}\text{C}$		
			0.014	1300					
			min.	1500					
			0.02	1800					
96% Silica Glass	-	-	-	-	-	-	-	-	
Mechanical Properties									
Density				Young's Modulus					
Units	Value	At	Hardness	Comp. Strength	Mod. of Rupture	Units	Value	At Temp	
Fused Mgo	g/ml	3.5761	25 $^{\circ}\text{C}$	5.5-6 Mohs	112,000 psi	20,000 psi	dynes/cm ²	2.51 x 10 ¹²	
96% Silicon Glass	g/cc	2.18	-	-	-	-	lb/in ²	9.6 x 10 ⁴	25 $^{\circ}\text{C}$
								10.64 x 10 ⁶	
Physical Properties									
Chemical and Weather Resistance									
Fused Mgo	Slowly soluble in aqueous acids resists aqueous and caustic alkali fused alkali alkaline vapor anhydrous HF					Plates and windows, about 1 in. dia.			
96% Silica Glass									

Table 1

Properties of IR Optical Materials
Suitable For High-Temperature Application
Optical Properties

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One window was cracked during installation. Burst pressures and temperatures of the other four discs were

<u>Window</u>	<u>Temp. °F</u>	<u>Pressure, psig</u>
S/N 1	-111°	295
2	-	-
3	92	232
4	97	307
5	-285	210

The lowest burst pressure observed, which was also at the lowest temperature, gave an adequate margin of safety above the pressures anticipated during NRX-A testing.

Results of quartz window burst tests 11-14-63, are given below:

<u>Part No.</u>	<u>Type</u>	<u>Burst Pressure psig</u>	<u>Temperature °F</u>	<u>Thickness in.</u>
093128-3	106	340 to 338	-	0.380
093527-1	101	450 to 443	77 room	0.505
093527-3	106	360 to 352	77 room	0.505
093528-3	106	200 to 240	-318 LN ₂	0.381
093527-1	101	250 to 239	-318 LN ₂	0.507
093130-1	106	295	room	0.382
093527-3	106	205	room	0.505

Pressure rise to burst averaged about 3 seconds.

Burst pressure readings were taken on a gage about 6 ft from the test fixture. Accurate pressure and temperature readings were recorded on an oscillograph, with the thermocouple about 1/4-in. above the glass, and the pressure transducer about 6-in. from the fixture.

3. Effects of Temperature and Clamping Methods

The data spread and the apparent decrease in strength at cryogenic temperatures caused the checking of temperature effects and clamping

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methods. The vendor indicated that clamping techniques have a more detrimental effect than cryogenic temperatures. The effect of clamping is thoroughly discussed in Chapter 15, Glass Engineering Handbook, Errol Shand, McGraw-Hill Publishing Co.

The information in C.2 above was used as a basis for the final quartz test. This test was conducted to determine the effects of cryogenic cycling followed by pressurizing. The 5-in. exposed diameter was shock-chilled to -318°F with liquid nitrogen, warmed to room temperature, then pressurized to 190 psig at room temperature. This sequence was performed 10 times. The lens successfully passed the temperature shock and pressure test, establishing the importance of installation procedures and the reliability of .500-in.-thick quartz with an exposed diameter of 5-in.

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SECTION VII

ADOPTED DESIGN, CAMERA HOUSINGS

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VII. ADOPTED DESIGN, CAMERA HOUSINGS

The purpose of the housing was to provide a purgeable container for the cameras and to contain the support structure required for the cameras mounting.

A. SUPPORT BRACKETS

The reason for the cameras support bracket is to furnish a stable platform for mounting the cameras. The platform allows a minimum of 2° of lateral movement about the center line between the two cameras. The support bracket allows vertical positioning of the cameras so that the optical center line of the camera lenses is 10° aft of the center line of the port. The port center line is 45° to the thrust axis, therefore the optical center line will be 35° to the thrust axis.

The camera mounting bracket will provide for a ± 1 -in. movement related to the nozzle and along the centerline between the cameras. In this manner the length of lenses on the cameras may be changed to give the specific type of coverage desired.

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SECTION VIII

PORT CLOSURE MATERIAL

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VIII. PORT CLOSURE MATERIAL

Quartz was selected as the basic material for the port closure material in the nozzle, since it met the necessary requirements: to transmit light, be durable at cryogenic temperatures, and withstand pressure loads at ambient and cryogenic temperatures. The type was selected on the basis of the effect of impurities and bubbles contained.

Type 106 fused quartz was selected for the clear-camera view-port lens because the average transmission properties are 99.1% in the visible light regions, at 400 to 700 millimicrons. Since the impurities and bubble sizes were minimum, the view of the core was not restricted.

Type 101 fused quartz was selected for the lamp housing closure because the average transmission properties are 99.7% in the visible light region. The bubbles and impurities do not affect the photographic or TV camera, and the cost is approximately half that of Type 106.

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SECTION IX
FINAL DESIGN

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IX. FINAL DESIGN

A. LAMP HOUSINGS

The lamp housing bases were designed with a 15° angle to the flange, as shown on Figure 17, to permit positioning of the light for optimum coverage of the core face with the rotation of the light moving the center of the beam as shown on Figure 14.

A ColorTran, LEX 38, lamp housing was selected for use in conjunction with a PAR 38, 150 watt, flood or spot light. The complete lighting system includes a power convertor that overdrives the lamp to approximately 300 watts each, 500 feet of power supply cable, and two lamp housing assemblies, in accordance with Figure 18. The power supply cable provides power to both lights and the camera motion picture.

The lamp housing was designed in such a manner that it would accept either the PAR 38's listed above or the DXK, General Electric lamp, with minor modification. The DXK is a 650 watt, quartz-halide lamp. The selection of the lamp and positioning of the lamp housing bases is based on test film strips of the actual NRX-A1 test conditions.

The TV camera is used for preliminary positioning of the lamp housing bases. Viewing of a black subject will cause the lamp "hot-spot" cone to be very evident on both TV camera and motion picture film (especially black and white). The use of a black subject is the standard method of showing light "hot-spot" configuration.

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Figure 17

Lamp Housing Base

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Figure 17

Lamp Housing Assembly

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B. LENSES SELECTED FOR CAMERAS

The lens as finally selected for use with the motion picture camera was a Rank-Taylor-Hobson 9-mm, f 2.0, with coverage as shown in Figure 18. The core coverage obtained by tilting the camera toward the exit plane of the nozzle is much greater. See Figure 19. An Angeniux 10-mm, f 1.9 lens was selected as an alternate, with a coverage as described in Figures 20 and 21.

The above lens selection was based on the exposure of 400-ft of test film, using the lenses as specified in Table 2.

Based on these tests, the depth of field and the illumination were optimum at f 4.0 and focal distance of approximately 14 inches.

The film is filed at Aerojet Azusa Photo Lab as No. 29399.

The lens selected for the TV camera has a 700-line TV resolution and 12.5 mm, f 1.9. The lens coverage is described by Figures 22 and 13.

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Lighting - 150 watt, PAR 38, Flood Light, CC6 Filament

Frame Rate - 200 fps

Shutter Angle - 72°

Lens - Rank-Raylor-Hobson 9 mm focusable, f 2.0

	f	Focal Distance in.	Light Meter Reading		
			Edges	Center	Rear
1	2.5	24	16	64	32
2	2.5	22	16	64	32
3	2.5	20	16	64	32
4	2.5	18	16	64	32
5	2.5	16	16	64	32
6	2.5	14	16	64	32
7	2.5	12	16	64	32
8	2.5	10	16	64	32
9	2.5	9	16	64	32
10	3	9	16	64	32
11	3	14	16	64	32

Lens Angenieux Retrofucus 10 mm, f 1.8

	f	Focal Distance in.	Light Meter Reading		
			Edges	Center	Rear
12	1.8	fixed	16	64	32
13	2.8	fixed	16	64	32
14	4.0	fixed	16	64	32
15	5.6	fixed	16	64	32
16	8.0	fixed	16	64	32
17	11.0	fixed	16	64	32
18	16.0	fixed	16	64	32

Lighting - 150 watt, PAR 38, Spot Light, CC6 Filament

Frame Rate - 200 fps

Shutter Angle - 72°

Lens - Angenieux Retrofocus 10 mm, f 1.8

	f	Focal Distance in.	Light Meter Reading		
			Edges	Center	Rear
19	16.0	fixed	32	125	64
20	11.0	fixed	32	125	64
21	8.0	fixed	32	125	64
22	5.6	fixed	32	125	64
23	4.0	fixed	32	125	64
24	2.8	fixed	32	125	64
25	1.8	fixed	32	125	64

Lens - Rank-Taylor-Hobson 9 mm focusable, f 2.0

	f	Focal Distance in.	Light Meter Reading		
			Edges	Center	Rear
26	3.5	24	32	125	64
27	3.5	22	32	125	64
28	3.5	20	32	125	64
29	3.5	18	32	125	64
30	3.5	16	32	125	64
31	3.5	14	32	125	64
32	3.5	12	32	125	64
33	3.5	10	32	125	64
34	3.5	9	32	125	64
35	2.5	9	32	125	64
36	4.5	9	32	125	64

Table 2

Camera Lens Tests

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Figure 18

Movie Camera Position and Field
With 9-mm Lens

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Figure 19

Movie Camera Optimum Position and Field
With 9-mm Lens

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Figure 20

Movie Camera Position and Field
With 10-mm Lens

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Figure 21

Movie Camera Optimum Position and Field
With 10-mm Lens

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Figure 22

TV Camera Position and Field

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