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NUCLEAR ROCKET OPERATIONS

SACRAMENTO PLANT

REPORT NO. RP-QR-0008
TO
SPACE NUCLEAR PROPULSION OFFICE - CLEVELAND EXTENSION

PHOEBUS-2 QUARTERLY REPORT (U)
FOR THE PERIOD OF
1 MARCH 1967 THROUGH 31 MAY 1967

JUNE 1967

CONTRACT SNPC-35

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**AEROJET
GENERAL**

MASTER

REPORT NO. RP-QR-0008

PHOEBUS-2 QUARTERLY REPORT (U)

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1 MARCH 1967 THROUGH 31 MAY 1967

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REPORT NO. RP-QR-0008

PHOEBUS-2 QUARTERLY REPORT (U)
FOR THE PERIOD OF
1 MARCH 1967 THROUGH 31 MARCH 1967

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ABSTRACT

This report describes work performed on Contract SNPC-35 during the period 1 March through 31 May 1967. Activities in connection with Tasks H, I, J, K, L, M, N, and Q are discussed. A summary of work performed by task begins on Page 1.

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I. SUMMARY

A. TASK H - SPECIAL TEST EQUIPMENT

Testing was resumed on Test Stand H4B on 15 March 1967. During the tests, a failure in the P_c 2B measurement system initiated a fail-safe shutdown. Loss of the P_c 2B signal caused the coolant flow to remain at the initial rate of 50 lb/sec.

A failure analysis was conducted, and preventive measures were included in the system to eliminate problems.

The test stand was prepared for fuel-film-cooled Nozzle Test Assembly S/N 880002, which was received and installed.

Galling of the thrust-chamber oxidizer valve occurred on 31 May 1967.

B. TASK J - DESIGN

Steady-state thermal analysis was completed for thermocouple pass-through instrumentation in the convergent section of the convectively cooled nozzle jacket.

Design changes in the thermocouple boss and nozzle assembly were completed.

Redesign was completed for the addition of a third coolant circuit on the film-cooled nozzle.

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C. TASK K - FABRICATION

Fabrication of Nozzles S/N 880601, 880603, and 880604 was completed, and Nozzle S/N 880603 was delivered to NRDS; fabrication of Nozzle S/N 880605 was continued.

Braze patches to monitor temperatures during chemical and cold-flow testing were deposited on Nozzles S/N 880600, 880601, and 880603.

The Miller-Peaslee brazing specimens were sent to ORNL for irradiation. The results were submitted to Aerojet for analysis.

Build-up of film-cooled Nozzle Test Assembly S/N 880002 was initiated and completed; and the assembly was delivered to Test Area H4B.

D. TASK L - RELIABILITY AND QUALITY ASSURANCE

Specification AGC 90180, governing the procedure and acceptance levels for X-ray inspection of nozzle coolant channels and torus welds, was released.

The design of special tooling for ultrasonic inspection of Nozzles S/N 880604 and 880605 was initiated.

Ultrasonic standards were fabricated, and laboratory tests were conducted for inspection standards.

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E. TASK M - TESTING

The third test in the series conducted on Test Stand H4B resulted in transverse cracking of nine coolant channels in the nozzle convergent section. The fifth test had the previously mentioned fail-safe shutdown due to a failure in P_c 2B measurement. Hardware was extensively damaged. Report RP-TR-0012, Phoebus-2 Test Failure Report, delineates causes and corrective actions.

F. TASK Q - MISCELLANEOUS SUPPORT EQUIPMENT

Design and fabrication of a nozzle throat plug and nozzle inverting stand were completed, and the hardware was delivered to the Nevada Test Site.

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II. DETAILED DISCUSSION

A. TASK H - SPECIAL TEST EQUIPMENT (CPFF)

1. Work Performed This Quarter

Testing of Phoebus-2 Nozzle Assembly S/N 880001 was resumed on 15 March 1967, when a test of 2.9-sec duration was conducted. Test-stand control systems performed as predicted and controlled the test systems within the parameters necessary to meet test objectives. The burn pond, pressurization system, and all other support systems performed as predicted.

Subsequently, during Test Run No. 1.2-15-NNN-005 (see Report RP-TR-0012, Phoebus-2 Test Failure Report), a failure in the P_c 2B measurement circuit to the analog programmer initiated a fail-safe shutdown. This malfunction circuit monitors chamber pressure, which must reach 100 psi in 1.75 sec or signal a shutdown. Although combustion in the nozzle was causing chamber pressure to rise normally, loss of the P_c 2B signal to the programmer caused the coolant flow to remain at the initial 50 lb/sec until shutdown occurred. The failure of the coolant flow to increase as chamber pressure increased resulted in damage to the test hardware.

The failure in the P_c 2B circuitry was attributed to a loose patch cord connecting the data-acquisition-amplifier output and the programmer input. The patch cord is believed to have been inadvertently disengaged during last-minute patching and unpatching on the same high-level board, even though these actions did not involve the P_c 2B channel.

The program for determining modes of failure of the convectively cooled nozzle was re-evaluated, and additional fail-safe shutdown modes were determined to be necessary. A series of analog-computer simulation runs were accomplished to (1) investigate the start-transient revisions necessary

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to accommodate a higher flow rate in the nozzle prechill system; (2) consider conditions existing during a variety of malfunction modes in the start-transient, steady-state, and shutdown portions of typical tests of convectively cooled nozzles; and (3) consider conditions created by the malfunction of test-facility systems.

Preparations for testing of the film cooled nozzle were initiated during the week of 21 April 1967. Included in these activities was the separation of the instrumentation functions to isolate the data systems from the control systems. The separation was completed during the week ending 12 May, with analog programmer parts received on 10 May.

Fuel-film-cooled Nozzle Test Assembly S/N 880002 was received and installed in Test Stand H4B on 8 May. Coolant inlet lines were fabricated and installed along with brackets for installation of the Photocon high-frequency transducers, which were also installed and calibrated. Fabrication of the flow-control-valve mechanical stops was completed, and a satisfactory leak check of the propellant line was conducted.

Test preparations were proceeding toward an anticipated test date of 8 June. However, on 31 May, galling of the 6-in. thrust-chamber oxidizer valve (TCOV) jeopardized the 8 June test date. The valve was removed and disassembled, and inspection revealed that the galling had occurred between the valve plug and the plug guide, resulting in the valve failing to close on demand. The impact of this problem on the test schedule cannot be determined until the valve manufacturer (Hammel-Dahl) can be contacted.

2. Work Planned for Next Quarter

Hammel-Dahl will be contacted to determine the status of AGC Purchase Order 808177, dated 14 February 1967, which includes a replacement plug-guide assembly to fit the TCOV.

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The other two flow-control valves will be removed from the test stand and inspected for a similar condition.

B. TASK I - REPORTS (CPFF)

1. Work Performed This Quarter

Program-highlight TWX reports were prepared and transmitted weekly to SNPO-C (RP-TWX-0101 through RP-TWX-0113).

Ten copies each of the Financial Management Reports, NASA Form 533, for the CPFF portion of the contract were submitted to SNPO-C during March, April, and May.

Monthly Reports RP-MR-0017 (for the period 1 March through 31 March 1967, and including RP-TM-0013, Design Report, Phoebus-2 Development Nozzle, as an appendix) and RP-MR-0018 (for the period 1 April through 30 April 1967, and including RP-TM-0014, Design Report, Coaxial Injector, as an appendix) were submitted to SNPO-C, with distribution being made as directed by the SNPO-C Technical Director.

Quarterly Report RP-QR-0007, for the period 1 December 1966 through 28 February 1967, was submitted to SNPO-C, with distribution being made as directed by the SNPO-C Technical Director.

2. Work Planned for the Next Quarter

Reports required by the work statement, as well as other reports required by the contract or requested by SNPO-C, will be submitted.

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C. TASK J - DESIGN

1. Work Performed in April

a. Film-Cooled Nozzle

Redesign of the film-cooled nozzle was completed. A third film-coolant circuit was added, and the existing two circuits were enlarged to reduce pressure drop.

b. Convectively Cooled Nozzle

A steady-state thermal analysis was performed for two design configurations of a thermocouple pass-through instrumentation-boss assembly in the convergent section of the nozzle jacket. One design concept incorporates a countersunk installation in the jacket. The other is a flush-welded configuration. Emphasis was given to the flush-welded installation in the analysis. Mathematical models were analyzed with the 278B IBM Program and were run as two-dimensional steady-state conduction problems.

One case indicated the cooling effects of natural convection and radiation to the atmosphere (the external film coefficient assumed was $15 \text{ Btu/ft}^2\text{-hr-}^\circ\text{R}$). Cases also were analyzed by considering the forced convection over the thermocouple boss assembly provided by a jet of ambient nitrogen. Maximum and minimum convective film coefficients (as suggested by LASL) of 500 and $100 \text{ Btu/ft}^2\text{-hr-}^\circ\text{R}$, respectively, were assumed. A factor of 1.25 was used, applied to the nominal nuclear heating rates.

Results of the analysis indicate that, with natural convection, observed temperatures would be marginal. The minimum film coefficient ($100 \text{ Btu/ft}^2\text{-hr-}^\circ\text{R}$) provides adequate cooling throughout the assembly. The maximum value ($500 \text{ Btu/ft}^2\text{-hr-}^\circ\text{R}$) reduces the extremity of the

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thermocouple to almost ambient temperature. A nitrogen flow rate equivalent to the convection film coefficient values specified should provide adequate cooling to the boss assembly. The two configurations, countersunk and flush-mounted, had no significant effect on thermal profiles.

Design was initiated and completed for the flush-mounted thermocouple boss.

A design change was initiated, completed, and released for the addition of six flush-mounted thermocouple bosses on Nozzle S/N 880605.

2. Work Planned for Next Quarter

Work performed under this task has been completed.

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D. TASK K - FABRICATION

1. Work Performed This Quarter

a. Convectively Cooled Nozzle

(1) Nozzle S/N 880601

The following operations were completed: final machining of the core support flange, drilling and counterboring of the 144 bolt holes in the main flange, low-pressure proof and leak checking, titration testing, back flushing, flushing, flowing for K_w values, dehydration, X-ray of the coolant channels and main torus, polishing of the 144 bolt-hole counterbores, installation of accelerometer mounts, inspection of interface control dimensions, final cleaning, and the addition of temperature-indicating braze patches on coolant channels. The nozzle was completed on 5 May 1967.

(2) Nozzle S/N 880603

The following operations were completed: dehydration, low-pressure helium leak checking, final X-ray, polishing of the 144 bolt-hole counterbores, inspection of interface control dimensions, final cleaning, packaging, and delivery to NRDS. Braze patches were added to the nozzle at NRDS by a Phoebus certified welder.

(3) Nozzle S/N 880604

The following operations were completed: installation of main and bolt-coolant torus assemblies, fitting of bolt-coolant line to assembly, installation of main torus inlet, final machining of core support flange, drilling and counterboring of 144 bolt holes, low-pressure proof and leak checking, repair of leaks, machining of neutron counter pads, installation

of accelerometer mounts, high-pressure proof and leak testing, back flushing, flowing for K_w valves, titration, individual tube flow, X-ray of coolant channels, low-pressure helium leak check, polishing of 144 counterbores, and inspection of interface control dimensions. The final MRB was held with the local SNPO-C representative, and the nozzle was accepted on 5 May 1967.

The nozzle is being stored at AGC pending availability of ultrasonic inspection tooling.

(4) Nozzle S/N 880605

The following operations were completed: Coolant-channel grooves were alloyed, and installation of the coolant channels was stopped by direction of SNPO-C on 17 March 1967, to comply with a forthcoming contract modification incorporating a thermocouple pass-through. Go-ahead was given on 3 April 1967 for design and fabrication of thermocouple modification. The tooling requisition was released, and the tool was fabricated for drilling of the pass-through hole in the nozzle jacket. The thermocouple bosses were fabricated as a parallel operation. The six pass-through holes were drilled in the nozzle jacket, channel lay-up was completed, and brazing was initiated.

b. Film-Cooled Nozzle

S/N 880608 - Redesign of the film-cooled nozzle, which included opening the orifice sizes in the two existing coolant circuits and adding a third coolant circuit upstream of the convergent section radius, was completed. Two inlets were added to the throat coolant circuit for increased flow. The nozzle was penetrant-inspected and cleaned prior to assembly in the film-cooled-nozzle test assembly.

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(1) Adapter

S/N 880699 - Adapter was back-flushed and cleaned prior to assembly in the film-cooled-nozzle test assembly.

(2) Coaxial Injector

S/N 884133 - Injector was back-flushed and cleaned prior to assembly in the film-cooled-nozzle test assembly.

(3) Film-Cooled TCA

Film-cooled-nozzle test assembly was built up by using the support (S/N 880673), adapter (S/N 880699), coaxial injector (S/N 884133), and film-cooled nozzle (S/N 880608). The test assembly was proof- and leaked-tested and delivered to the test area.

c. Brazing

Braze patches to monitor temperatures during chemical firing were deposited on the coolant tubes in Nozzles S/N 880600 and 880601. Braze patches to monitor temperatures during cold-flow testing were deposited on the coolant tubes in Nozzle S/N 880603 at NRDS. All patches were placed on the tube crowns by using the oxy-hydrogen flame generator (water welder). The braze patches were approximately 1/8 in. in diameter and 0.030 in. thick. After brazing, the patches were dressed down and scribe cross marks were made on the patches for ease in detecting melting.

Coolant-tube braze patches (using Nicro alloy, melting point 1742°F) were deposited on Nozzle S/N 880600 in the following locations:

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Prior to Test No. 1

<u>Tube No.</u>	<u>No. of Patches</u>	<u>Location</u>
187	1	2 in. downstream of throat
	1	2 in. upstream of throat
	1	5-1/2 in. upstream of throat
213	1	2 in. upstream of throat
240	1	2 in. upstream of throat
266	1	2 in. upstream of throat
294	1	2 in. upstream of throat

Prior to Test No. 2

189	1	5-1/2 in. upstream of throat
263	1	5-1/2 in. upstream of throat

Prior to Test No. 3

(No patches added prior to this test.)

Prior to Test No. 4

<u>Tube No.</u>	<u>No. of Patches</u>	<u>Location</u>
197	6	2, 5, 8, 12, 16, and 20 in. upstream of throat
240	7	2, 5, 8, 12, 16, 18, and 20 in. upstream of throat
284	6	2, 5, 8, 12, 16, and 20 in. upstream of throat

Coolant tubes on Nozzle S/N 880601 had 68 braze patches deposited, utilizing 13 alloys with temperature ranges from 410 to 1913°F. Figure 1 shows patch locations on the tubes and identifies the alloys used, their respective temperature ranges, and the alloy compositions.

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ALLOY NO.	NAME	COMPOSITION	TEMP. RANGE
1	ELECTROD 157	SN-AG (PROPERITORY)	410 - 425°F
2	ASTM B 3260T	15N-1.5 AG-97.5 Pb	580 - 588
3	EUTECROD 155	95 SN-5 AG	710 - 725
4	ALLOY X	SN-CU-AG	850
5	ALLOY Y	SN-CU-AG	990
6	INCUSIL 15	AG-CU-In	1165 - 1300
7	INCUSIL 10	63 AG-27 CU-10 In	1265 - 1345
8	CWSIL (BT)	72 AG-28 CU	1435
9	PALCUSIL 5	AG-CU PD	1480 - 1490
10	SILCORO 60	60 AU-20 CU-20 AG	1535 - 1553
11	NICORO 80	82 AU-16 CU-2Ni	1670 - 1697
12	NICORO	82 AU-18 Ni	1742
13	PALNICORO 70	70 AU-8 Pd-22 Ni	1846 - 1913

Figure 1 - Alloy Locations for Nozzle S/N 880601

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Coolant tubes on Nozzle S/N 880603 had 12 braze patches deposited on three coolant tubes in the divergent section of the nozzle. In addition, three thermocouple lead wires were attached to the aft coolant-tube section of the nozzle as shown in Figure 2. These patches were applied by an AGC welder using the water-welder torch.

d. Materials

Miller-Peaslee shear specimens made at Aerojet were sent to ORNL for irradiation testing. The samples were irradiated at 50°C to a dose of 9×10^{19} nvt thermal and 5×10^{18} nvt fast; then single specimens were tested by ORNL at -320°F, room temperature, and 750°F along with single control (unirradiated) specimens. The data for ultimate shear strength are shown in Table 1.

Although the data indicate no apparent damage at -320°F or at room temperature, the effect at 750°F is readily apparent from the large degradation in strength. The tests were conducted so that stress (load) and strain measurements were obtained, and, although they cannot be expressed in absolute units, the total strain and the areas under the stress-strain curves decreased for each alloy at all test temperatures after irradiation, and with increased severity as the test temperature was increased to 750°F.

The structural joints in the nozzle operate at cryogenic temperatures, and, based on these limited data, the maximum strength degradation is small. Even at room temperature, the maximum strength loss is less than 4%. Analyzing the results to extreme (that is, pooling the percent changes for all three alloys) reveals the following standard-deviation estimates (with $n - 1 = 2$):

<u>Temp, °F</u>	<u>One Standard Deviation, %</u>
-320	10.5
Room	3.4

Utilizing three standard deviations at -320°F, a maximum degradation of 31.5% is predicted, which provides possible minimum shear strengths as follows:

<u>Alloy</u>	<u>Approximate Minimum Ultimate Shear Strength at -320°F, ksi</u>
Nioro	54.0
Palniro-7	48.0
Nicoro 80	36.0

The maximum shear stress calculated on the structural joint is about 6000 psi.

2. Work Planned for the Next Quarter

a. Convectively Cooled Nozzle

S/N 880601 - Build up into TCA and deliver to test area for chemical simulation testing.

S/N 880604 - Complete the ultrasonic inspection (added work scope) when tooling is available.

S/N 880605 - Complete fabrication and deliver nozzle.

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1	TEMPERATURE RANGE	580/588 ⁰ F	(ASTM B 326 OT)
2	TEMPERATURE RANGE	1165/1300 ⁰ F	(INCUSIL 15)
3	TEMPERATURE RANGE	1670/1697 ⁰ F	(NICORO 80)

NOTE: JUNCTION OF THERMOCOUPLE BRAZED WITH BT ALLOY.
TACKS APPROX. 1/2-IN. SPACING USING NO. 1.

Figure 2 - Braze-Patch Installation on Nozzle S/N 880603
at NRDS

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TABLE 1

MILLER-PEASLEE SHEAR SPECIMEN;
RADIATION* DAMAGE OF HASTELLOY X

BRAZE ALLOY: NIORO

<u>Condition</u>	<u>Temp, °F</u>	<u>Ultimate Shear Strength, ksi</u>	<u>% Change From Unirradiated Strength</u>
Unirradiated	-320	82.8	--
Unirradiated	Room	68.0	--
Unirradiated	750	53.4	--
Irradiated	-320	79.9	-3.5
Irradiated	Room	65.4	-3.8
Irradiated	750	37.5	-29.8

BRAZE ALLOY: PALNIRO-7

Unirradiated	-320	74.8	--
Unirradiated	Room	62.8	--
Unirradiated	750	53.8	--
Irradiated	-320	81.2	+8.5
Irradiated	Room	62.4	-0.6
Irradiated	750	39.9	-25.8

BRAZE ALLOY: NICORO 80

Unirradiated	-320	56.4	--
Unirradiated	Room	56.5	--
Unirradiated	750	34.9	--
Irradiated	-320	63.2	+12.1
Irradiated	Room	54.9	-2.8
Irradiated	750	12.6	-62.1

*Dose: 9×10^{19} nvt thermal and 5×10^{18} nvt fast at 50°C.

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E. TASK L - RELIABILITY AND QUALITY ASSURANCE

1. Work Performed This Quarter

a. Radiographic Inspection

(U) Final X-ray inspection of Nozzle S/N 880603 was completed for absence of foreign material in the coolant channels, and the nozzle was accepted.

(U) Specification AGC 90180, governing procedures and acceptance levels for X-ray inspection of nozzle coolant channels and torus closure welds, was released. This specification was essentially the same procedure used previously. After publication of AGC 90180, Nozzle S/N 880601 was X-rayed and accepted.

(U) Nozzle S/N 880604 was X-rayed in accordance with AGC 90180 after being hydrostatically tested, and the nozzle was accepted.

(U) Surveillance of shop and receiving-inspection X-ray procedures was maintained. The last torus X-rays received from the vendor showed full compliance with the specified procedure and indicated that earlier X-ray problems had been corrected.

b. Ultrasonic Inspection

(C) New ultrasonic reference standards were fabricated by using a 9-in. section (taken from a flat tube sample 24 in. long) and an 8-in. section (taken from the contoured hydrostatic-test sample). These were made by using the EDM method to cut slots in the Hastelloy X material. Slot dimensions were: 1/4 and 1/2 in. in length, approximately 0.010 in. in width, and at depths of 0.020, 0.040, 0.070, and 0.100 in. Laboratory tests are being

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conducted to determine the feasibility of using these references for inspection of nozzle-tube braze quality.

(C) One problem encountered in the ultrasonic inspection of Nozzle S/N 880603 was accurate counting of the grooves to provide the circumferential location of each groove on the recorder strip chart. To facilitate this procedure, it is planned to modify the existing roll ring used for this inspection to incorporate a limit switch that will be actuated at each ten-groove interval to send a signal to the recorder to mark these points. This modification will permit accurate location of the grooves and will assist in data plotting.

(C) A Model 621 S.F. Visicorder has been obtained for use in place of the Mark II Brush recorder. The Visicorder can record the full range of signal amplitudes received from the reflectoscope. The Brush recorder does not have this capability.

(U) The design of special tooling was initiated for ultrasonic inspection of Nozzles S/N 880604 and 880605.

c. Fabrication

(U) The following integrated manufacturing and inspection planning was approved and released for fabrication:

P/N 1113392-1	Flange, Throat Plug
P/N 1118300-9	Nozzle, Nuclear Rocket Engine; Flange Weld
P/N 1118300-9	Nozzle, Nuclear Rocket Engine; Machining, S/N 880604
P/N T-1016587	Protective Plug
P/N 1118781-19	Frame Plate
P/N 1118780-1	Support, Throat Plug

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P/N 1118300-9	Nozzle; Nuclear Rocket Engine, Hydrotest Instruction for Nozzle S/N 880604
P/N AS1149-32	Restrictor for Nozzle S/N 880601
P/N AS1149-32	Restrictor for Nozzle S/N 880604
P/N SN7750-3227	Washer
P/N 1114830-23	Nozzle, Nuclear Rocket Engine; Braze Patches, S/N 880600
P/N 1115344	Tube Assy, Metal; K _w for Nozzle S/N 880604
P/N 1118781-1	Frame Support Throat Plug
P/N 1118784-1	Throat Plug Assy
P/N 1115202-9	Leg-Adapter
P/N 1118774-1	Seal and Closure Assembly Throat Plug
P/N 1115342-1	Boss, Thermocouple-Adapter
P/N 1115034-9	Nozzle Assembly, Test - Convectively Cooled
P/N 1115456-9	Line, Coolant - Nozzle Inlet
P/N 1115311-9	Injector Assembly
P/N 1118781-11	Plate, Frame
P/N 1117091-9	Back Flush of Adapter
P/N 1114830-49	Nozzle, Nuclear Rocket Engine; Braze Patch Installation
P/N 1115486-9	Adapter, Nozzle to injector
P/N NAS 1351C8H-36	CAP Screws
P/N 1115858-19	Nozzle, Assembly Test - Film Cooled
P/N 1115485-1	Venturi Meter, Tube
P/N HTI 2-1101/B	Hydrotest Instruction for P/N 1115344-9 Bolt Coolant Line
P/N HTI 2-1067/B	Hydrotest Instruction for P/N 1115858-19 Nozzle Assembly Test, film cooled
P/N 1115321-19	Injector Assembly, Coaxial
P/N AR 100118/B	Omniseal Assembly
P/N 1115344-7	Tube Assembly, Metal-Adapter
P/N 1115344-9	Tube Assembly, Metal
P/N 1118784-1	Seal Closure Assembly Throat Plug

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P/N 1117833-9	Leg, Adapter
P/N 1134067-1	Boss, Thermocouple
P/N 1114175-19	Strainer Element, Propellant
P/N 1114175-9	Strainer Element, Propellant
P/N 1115034-9	Nozzle Assembly, Test - Convectively Cooled
P/N 1134129-1	Plug, Machine Thread - Nozzle Film Cooled
P/N AS4099-06016H	Bolt, 12 point Cres
P/N AS4099-12070H	Bolt, 12 point Cres
P/N 1115487-5	Bolt, Machined - Double Hex Head
P/N NAS 1351C8H36	Screw, Cap Socket Head
P/N MS 20002C8	Washer, Countersunk
P/N MS 20002C12	Washer, Countersunk
P/N 1010108	Gasket, "K" Seal
P/N 1118772-1	Closure, Forward Throat Plug
P/N 1118300-29	Nozzle; Nuclear Rocket Engine; S/N 880605
P/N 1118300-29	Nozzle, Nuclear Rocket Engine; S/N 880603, for Hydrotest
P/N 1118706-1	Stud, Mounting Detector
P/N 1118797-1	Cover, Protective Mounting Stud
P/N 1114830-29	Nozzle, Nuclear Rocket Engine; Cleaning for S/N 880601

The narrative end-item report on Nozzle S/N 880603, P/N 1118300-9/E, was completed. Material Review Board action was completed on Nozzles S/N 880600, S/N 880603, and S/N 880604.

Proposed plan was submitted to Pyromet Company (P. O. 203629) for manufacturing and inspection of pass-through holes for Nozzle P/N 1118300-29/G, S/N 880605; and the supplier was requested to prepare and submit manufacturing and inspection planning for AGC approval.

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Pyromet accepted revised manufacturing and inspection planning from AGC.

The drill fixture, T-1019265, was approved for the six pass-through holes. The holes were drilled and verified to meet Phoebus-2 quality-engineering requirements.

The throat plug assembly, P/N 1118784-1/B, was tested and accepted. Material Review Board action was completed, and the plug was sent to NRDS.

d. Nozzle Design

The following drawings were reviewed and approved:

1114157B	Strainer Element
1114830J	Nozzle, Nuclear Rocket Engine
1115034C	Nozzle Assembly, Test - Convectively Cooled
1115344A	Tube Assembly, Metal
1115485NC	Venturi Meter, Tube
1115858D	Nozzle, Assembly Test - Film Cooled
1116478A	Test Assembly, Convectively Cooled Nozzle
1118300H	Nozzle, Nuclear Rocket Engine
1118772A	Closure, Forward Throat Plug
1118780B	Support, Throat Plug
1118781C	Frame, Support, Throat Plug
1118784C	Throat Plug Assembly
1134061NC	Torus - Nozzle, Uncooled
1134062NC	Nozzle, Fuel Film Cooled
1134129NC	Plug - Machine Thread - Nozzle, Film Cooled
1134274NC	Shim
1134067NC	Boss, Thermocouple

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The Modes of Failure Analysis, Fuel Film Cooled Nozzle was updated to reflect the revised design, Drawing No. 1134062.

The Modes of Failure Analysis, Phoebus-2 Nozzle Chemical Testing was updated to reflect the corrective action taken after the incident reported in RP-TR-0012, dated April 1967.

The critical experiment review of the fuel-film-cooled nozzle was held on 26 May.

e. Procurement

Source surveillance was maintained on all active vendors. Source acceptance of the following components was completed:

1115382-39B - Torus Assembly - S/N 880008
1114180-17C - Seal, Static Metals - 16 each,
S/N 880472 through 880477
1118770-1, -3, -5, - Seal - 1 in.
1118578-1 through -53 - Shim, Plated - 438 sets
1118579-1 - Coolant Channel, Plated - 355 each
1118579-3 - Coolant Channel, Plated - 10 each
1118579-5 - Coolant Channel, Plated - 12 each

2. Work Planned for the Next Quarter

Design and fabrication of S/N 880604 and S/N 880605 will be completed, and ultrasonic inspection will be initiated.

Quality-control review and follow-up for fabrication and the inspection planning of work to be performed at AGC and vendor facilities will be continued.

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F. TASK M - TESTING

1. Work Performed This Quarter

On 28 February, Nozzle S/N 880600 was tested in a chemical simulation firing at a mixture ratio of 4.9 and a chamber pressure of 650 psia. The test was terminated on schedule after 2.6 sec. Visual observation after the firing revealed oxide films on most tube surfaces. Some tube surfaces (through the 3 to 6 o'clock positions) exhibited a darker discoloration in the convergent section. This nozzle incorporated braze-alloy patches as temperature indicators.

A second firing of 2.8-sec duration at a mixture ratio of 5.0 and a pressure of 705 psia was accomplished on 15 March. Visual observation revealed no change from the first firing except for further discoloration of the tubes and a more pronounced darkening of about ten tubes in the 4 to 5 o'clock position (about 20 to 24 in. from the forward flange in the convergent section). Another darker area (about ten tubes in width and in a similar axial location) was also evident at about the 7 o'clock position. Other small, dark areas were noted on one or two tubes. The appearance of the tubes was considered generally excellent.

The third firing was conducted for 16 sec on 17 March at a mixture ratio of 5.5 and a chamber pressure of 685 psia. The nozzle was visually examined, and, though further darkening of the tubes was evident in the convergent section, its appearance was satisfactory. However, leak testing indicated leakage in several areas. Closer examination revealed transverse cracking in nine tubes in the convergent section. A detailed examination revealed cracks at the following locations:

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<u>Tube No.</u>	<u>Nozzle Section</u>	<u>Axial Distance from Forward Flange, in.</u>	<u>Approx. No. of Cracks</u>	<u>Circumferential Location of Cracks</u>
177	Convergent	20 to 22	}	Left side of tube crown looking forward to injector
177	Convergent	32		
195	Convergent	20 to 22	}	Right side of tube crowns looking forward to injector
196	Convergent	21 to 23		
197	Convergent	20 to 21		
199	Convergent	20 to 24		
199	Convergent	30		
200	Convergent	20 to 23		
201	Convergent	21 to 24		
201	Convergent	32		
202	Convergent	21 to 23		
203	Convergent	23 to 24-1/2		
279	Convergent	20 to 22	20	Left side of tube crown. No indications by dye-penetrant inspection

The following additional observations were also made:

- a. All tubes between No. 195 and 203 were cracked on the right side of the tube crowns.
- b. Tube No. 177 was cracked on the left side (opposite side of eight tubes noted above).
- c. All cracks had originated off the center of the tube crowns, although some had been propagated to the crown, especially in the

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areas closer to the throat (tubes 199 and 201 at 30 and 32 in. from the forward flange, or 7 to 9 in. upstream of the throat). The sketch below indicates typical tube crack locations (with crack widths exaggerated):

d. Initial investigation revealed a very slight stepped or rippled condition along the tube surface that was cracked. Closer examination showed this condition to be the result of a slight lifting of the mating crack edges, as sketched below.

e. Crack lengths varied from $1/32$ to $3/16$ -in. Spacing between cracks ranged from $1/8$ to $1/4$ in.

f. The cracked side of each tube that cracked was noticeably darker than the uncracked side.

g. Tube cracking occurred in areas that exhibited darkening in the first two firings but did not occur in every dark area.

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h. There was no evident correlation of cracking with the number of manual tube-to-tube braze repairs, braze-alloy runoff, or braze fillet size. The manual tube-to-tube braze repairs, which were numerous in the primary area of tube cracking (tubes 195 to 203), were moderately extensive and similar to about five other areas in the convergent section. Likewise, the braze-alloy runoff was heavy in this area but was similar to that in five other areas around the circumference of the convergent section. Figure 3 shows tubes 175 through 250 and the location of tube-to-tube braze repairs, braze-alloy runoff, and the axial length of tube cracking. Although tubes 201, 202, and 203 cracked, they contained no braze runoff and had no manual tube-to-tube braze repairs; the cracks were no more extensive than those of tubes 199 and 200, which had extensive manual repair.

i. The braze runoff on tubes 196, 197, and 200 appeared to have remelted. The scribe mark on tube 187 revealed no evidence of melting.

Surface visual examination indicated: (1) a localized hot area (due to injector variation) and (2) possible gas impingement (due to swirling). The hot area would have significantly increased thermal-expansion stresses, and the effect would have been added to that of the apparently higher-than-anticipated temperatures observed in the firing (as evidenced by the 1740°F braze patch melting to a point 12 in. forward of the throat).

The relatively insignificant tube rippling that occurred may have been due to the following:

a. High thermal stresses may have promoted prompt cyclic failure, with limited time for significant wrinkling.

b. The cracked area may have reached temperatures of 2200°F or more and may have exhibited an oxidation embrittlement effect or a hot-short brittle failure (sometimes associated with Hastelloy X) as a result of slight compressive bending or upsetting while at that temperature.

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c. Failure stresses may have occurred in tension in the cooldown cycle and hence could be expected to exhibit lower ductility than at the operating temperature. The thinness of the section would preclude an accurate visual assessment of the amount of reduction or thinning that occurred.

d. A combination of all the above items may have occurred.

It was concluded that braze alloying with Hastelloy X did not contribute significantly to cracking because: (1) cracking occurred in tubes without braze runoff; (2) cracking occurred in tubes without manual braze repairs; (3) cracking occurred in tubes with both low and high fillets; and (4) cracking originated on one side of the crown rather than at the tube-wall and braze-fillet interface.

The coaxial injector with baffle (P/N 1115321-19, S/N 884134) was installed in place of the multiorifice injector. Injector substitution was accomplished without removing the test assembly from the stand. Appropriate fuel and nozzle coolant-valve sequence changes were made because of the larger injector propellant manifold volumes.

The fourth test was conducted on 29 March. A combustion-stability-monitor (CSM) shutdown occurred at 1.90 sec. Posttest data analysis indicated combustion to be stable, and no hardware damage was incurred.

The following test data were obtained:

	<u>Actual FS₂</u>
Duration	1.9 sec
P _c	465 psia (546 psia max)
MR	8.8
$\dot{W}_c$	221 lb/sec

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The 1740°F braze alloys installed on the nozzle coolant tubes were melted 2 to 5 in. above the throat.

Data analysis from this test indicated that combustion was stable and that the shutdown input to the CSM was due to the ringing of the Taber transducer at its natural frequency. The amplitude setting for the CSM was increased from 100 psi, peak-to-peak, to 150 psi.

Also, a second CSM was installed on the accelerometer at the nozzle inlet torus. The setting for this CSM was: frequency, greater than 1000 cps; amplitude, greater than 75 g; duration, greater than 0.030 sec.

The fifth test was conducted on 31 March. At $FS_1 + 1.81$ sec, shutdown occurred because of a thrust-chamber pressure-switch (TCPS) malfunction. The TCPS was installed to ensure ignition and was set at 100 ± 10 psig. An MTCPS timer was set at $FS_1 + 1.75 \pm 0.05$ sec. Thus, if $P_c 2$ did not achieve 100 psig before expiration of the timer, a malfunction shutdown occurred.

Posttest checks indicated that the $P_c 2$ signal was not being fed to the computer controller. Since the nozzle coolant flow ramp from the initial 50-lb/sec preflow is taken from the rise in chamber pressure, the coolant flow did not increase above 50 lb/sec. A loose patch panel connection was found to have caused the loss of the $P_c 2$ signal. Continuity checks made up to 2 hr before the test indicated that the connection was sound.

Posttest hardware inspection revealed that the nozzle tubes were eroded from approximately 4 in. below the throat to the core support flange. Approximately 20 adapter coolant tubes were eroded through by the molten metal from the nozzle tubes within a 9-in. band from the core support flange. The coaxial injector baffle was heat-marked but was not damaged.

External hardware inspection revealed that the bellows section of the coolant dump line was eroded through in several places because

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of the combustion gases entering the dump line. The adapter leg and dump line were heat-marked at the dump-line interface.

Data analysis indicates that the bulk of the nozzle-tube damage occurred approximately 0.050 to 0.200 sec after FS_2 . The P_{fJ} -CSM shutdown was also signaled 0.030 sec after the TCPS was tripped, approximately the same as occurred in the fourth test. The high-frequency EOS transducer in P_{fJ} was ringing more than was noticed in the fourth test. Accelerometer data were approximately the same as for other tests in the series.

The following test data were obtained:

	<u>FS_2</u>
P_c	450 psia (494 psia max)
MR	7.4
$\dot{W}_c$	60 lb/sec

A meeting of the board of inquiry for the Phoebus-2 nozzle incident review was held 13 through 14 April with SNPO-W, SNPO-C, and LASL personnel to investigate Test 1.2-15-NNN-005.

Report RP-TR-0012, Phoebus-2 Test Failure Report, Test 1.2-15-NNN-005, was issued.

The test sequence for the film-cooled-nozzle test series has been established, and analog model analysis has been conducted to define values for valve sequencing and fail-safe shutdown mode settings.

The test request for film-cooled-nozzle test series 1.2-09-NNJ was issued.

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The report on modes of failure analysis has been revised and published. This report is an integrated effort involving project-engineering, reliability-and-quality-assurance, and test-operations personnel and reflects the current concept for Phoebus chemical testing.

The final meeting of the board of inquiry for the Phoebus-2 nozzle incident review was held on 26 May. Representatives from SNPO-W and SNPO-C were present with AGC personnel from Phoebus Engineering, NRO Reliability and Quality Assurance, and Test Operations. The following documents were presented and discussed:

- a. Test Failure Report RP-TR-0012.
- b. Updated Test Procedures - These test procedures reflect corrective actions to be implemented for film-cooled-nozzle tests and convectively-cooled-nozzle tests.
- c. Revised modes of failure analysis - Phoebus-2 chemical testing.
- d. Control System Design Report 0830:110, Analog Model Analysis.

A critical experiment review for the film-cooled-nozzle test series was held in conjunction with the incident review.

2. Work Planned Next Quarter

Coaxial injection will be tested on the film-cooled-nozzle test assembly to verify its suitability for testing of the Phoebus-2 convectively cooled nozzle.

The Phoebus-2 convectively cooled nozzle, S/N 880601, will be proof-tested.

Tests will be conducted to determine the operational limits of the Phoebus-2 convectively cooled nozzle.

G. TASK N - REPORTS (CPIF)

1. Work Performed This Quarter

Program-highlight TWX reports were prepared and transmitted weekly to SNPO-C (RP-TWX 0101 through 0113).

Ten copies each of the Financial Management Reports, NASA Form 533, for the CPIF portion of the contract were submitted to SNPO-C during March, April, and May.

Biweekly PERT reports were submitted to SNPO-C during this quarter.

Quarterly Report RP-QR-0007 (for the period 1 December 1966 through 28 February 1967) was submitted to SNPO-C, with distribution made as directed by the SNPO-C Technical Director.

Monthly Report RP-MR-0017 (for the period 1 March through 31 March 1967, and including RP-TM-0013, Design Report, Phoebus-2 Development Nozzle, as an appendix) was submitted to SNPO-C, with distribution made as directed by the SNPO-C Technical Director.

Monthly Report RP-MR-0018 (for the period 1 April through 30 April 1967, and including RP-TM-0014, Design Report, Coaxial Injector, as an appendix) was submitted to SNPO-C, with distribution made as directed by the SNPO-C Technical Director.

2. Work Planned for the Next Quarter

Reports required by the work statement, as well as other reports required by the contract or requested by SNPO-C, will be submitted.

H. TASK Q - MISCELLANEOUS SUPPORT EQUIPMENT

1. Work Accomplished During This Quarter

a. Inverting-Stand Assembly, 1018510

Fabrication of the nozzle inverting tool was completed (Figure 4). The tool was assembled with the center of gravity determined for the nozzle and the rotating assembly. The sliding trunnion arms were locked in the balanced position.

A spreader bar (Figure 5) was designed and fabricated to facilitate installation of the cage halves. With the spreader bar, a single hoist could be used to install the cage halves, whereas a fork lift was previously required to assist the hoist in lateral positioning because of sling interference with the nozzle torus.

The inverting-stand assembly was delivered to NRDS.

b. Nozzle-Throat-Plug Assembly, 1118784-1

Fabrication of the nozzle throat plug was completed. Initial testing was conducted in a simulated nozzle throat with the plug unrestrained by the support structure. The plug was inserted, actuated, and pressurized with water to 50 psig. Leakage developed at the bond between the aft cone of the plug and the rubber seal. The first leak was repaired locally by injecting a bonding material into the leak path. Another leak then developed, and the 20-durometer seal was replaced with one of 40-durometer rubber.

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Figure 4 - Nozzle and Cage in Inverting Stand

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Figure 5 - Spreader Bar for Installation of Cage Halves

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The harder seal was successfully tested to 50 psig. The previous leakage was attributed to excessive shear stress at the bond due to deflection of the plug when unrestrained.

Subsequent tests were conducted with a prototype nozzle that was part of a chemical-simulation-test assembly (Figures 6 and 7).

The test assembly was filled with water and pressurized to 297 psig, at which time the test was terminated because of a leak in the bond area. The leak was repaired and the assembly was again set up for testing. During the water fill operation and while the support preload was removed, the assembly was inadvertently subjected to the line pressure of 50 to 90 psig, which resulted in a leak at the aft-cone-to-seal bond. The decision was made to proceed with the test with the known leak path and to rely on the support-column preload to seal the leak path. The assembly was pressurized to 250 psig before leakage occurred at the known leak path. The test was considered successful and the series was terminated. The plug was removed, cleaned, repaired, and delivered to the Nevada Test Site.

2. Work Planned for the Next Quarter

Liaison will be maintained during initial use of the plug at the Nevada test site.

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Figure 6 - Nozzle Throat Plug Being Installed

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Figure 7 - Test Assembly with Throat Plug Installed

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